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Report to the Committee on Armed Services, House of Representatives

May 2022

# NUCLEAR SECURITY ENTERPRISE

# NNSA Could Enhance Its Evaluation of Manufacturing-Related R&D Performance

GAO-22-104506

GAO Highlights

Highlights of GAO-22-104506, a report to the Committee on Armed Services, House of Representatives

May 2022

# NUCLEAR SECURITY ENTERPRISE

## NNSA Could Enhance Its Evaluation of Manufacturing-Related R&D Performance

## Why GAO Did This Study

NNSA is in the midst of a major effort to modernize its nuclear weapons and supporting infrastructure. As part of this effort, NNSA and its sites in the nuclear security enterprise support a variety of R&D projects. These projects explore new manufacturing methods or alternatives to manufacturing processes that may be inefficient, unsafe, or obsolete.

The House report accompanying the Fiscal Year 2021 National Defense Authorization Act included a provision for GAO to review NNSA's manufacturing-related R&D programs. This report (1) describes the manufacturing-related R&D projects underway at NNSA sites and (2) assesses the extent to which NNSA's management of its manufacturing-related R&D projects follow leading practices. GAO analyzed relevant NNSA documents and data, assessed NNSA's management of its manufacturing-related R&D projects against leading practices for managing a federal R&D portfolio, and interviewed knowledgeable officials.

## What GAO Recommends

GAO is making two recommendations to NNSA: (1) fully develop and document its process for evaluating R&D portfolio performance for its AMD program and (2) develop measures for assessing progress on long-term R&D goals and priorities for its AMD program. NNSA agreed with the recommendations and described plans to address them.

View GAO-22-104506. For more information, contact Allison B. Bawden at (202) 512-3841 or BawdenA@gao.gov.

## What GAO Found

In fiscal year 2021, National Nuclear Security Administration (NNSA) sites had underway almost 600 research and development (R&D) projects related to manufacturing and spent about $300 million on these efforts. These R&D projects focused on developing innovative manufacturing techniques, such as additive manufacturing, and pursuing alternatives to replace obsolete materials and processes. Four different programs funded these projects. NNSA conducted 133 manufacturing-related R&D projects through its Advanced Manufacturing Development (AMD) program. Contractors that manage and operate NNSA's sites supported 441 additional manufacturing-related R&D projects through the Laboratory-Directed R&D, Plant-Directed R&D, and Site-Directed R&D programs, which are referred to collectively as "directed R&D programs."

NNSA's management of R&D projects funded under its AMD program generally followed leading practices for managing a federal R&D portfolio (see table below). Specifically, GAO found that NNSA fully or substantially followed five out of six leading practices and partially followed the remaining one. For example, consistent with these leading practices, NNSA developed R&D goals and priorities, coordinated with stakeholders to develop the R&D project portfolio, and tracked these projects using a portfolio-wide system.

**Extent to Which NNSA's Advanced Manufacturing Development (AMD) Program Followed Leading Practices for Managing Federal Research and Development (R&D)**

| Leading practice | Extent followed |
|---|---|
| Develop and align short- and long-term R&D goals and priorities | ● |
| Develop an R&D portfolio by prioritizing and selecting projects that align | ● |
| Identify and coordinate with stakeholders to develop the R&D portfolio | ● |
| Ensure that the R&D portfolio can adapt to changing goals and priorities | ● |
| Use a portfolio-wide system to track the progress of R&D | ● |
| Evaluate the performance of the R&D portfolio | ◒ |

Legend:

● = **Fully or substantially followed** —NNSA took actions that addressed most or all aspects of the key questions GAO examined for the practice.
◒ = **Partially followed** —NNSA took actions that addressed some, but not most, aspects of the key questions GAO examined for the practice.

Source: GAO analysis of National Nuclear Security Administration (NNSA) documents and interviews with NNSA officials. | GAO-22-104506

However, NNSA has not fully developed and documented a process for evaluating the performance of AMD's R&D portfolio as a whole. As a result, NNSA may be using inconsistent measures across individual projects to evaluate performance. Moreover, in evaluating the portfolio's performance, officials did not measure progress on long-term R&D goals and priorities. This could limit the agency's ability to determine the extent to which the portfolio provides value in the long term.

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## Abbreviations

| | |
|---|---|
| AMD | Advanced Manufacturing Development |
| DOE | Department of Energy |
| LDRD | Laboratory-Directed Research and Development |
| M&O | management and operating |
| MRL | Manufacturing Readiness Level |
| NNSA | National Nuclear Security Administration |
| OETM | Office of Engineering and Technology Maturation |
| PDRD | Plant-Directed Research and Development |
| R&D | research and development |
| SDRD | Site-Directed Research and Development |
| TRL | Technology Readiness Level |

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May 20, 2022

The Honorable Adam Smith
Chairman
The Honorable Mike Rogers
Ranking Member
Committee on Armed Services
House of Representatives

The National Nuclear Security Administration (NNSA)—a separately organized agency within the Department of Energy (DOE)—is responsible for maintaining and modernizing the U.S. nuclear weapons stockpile and the supporting infrastructure on which weapons research and production programs depend. To fulfill these responsibilities, NNSA oversees eight laboratory and production sites—collectively known as the nuclear security enterprise[1]—that are managed and operated by private contractors. NNSA is unique in the federal government in that it produces a significant number of materials and components rather than procuring them, and it relies on management and operating (M&O) contractors to conduct this production work at government-owned facilities.[2]

[1]NNSA's nuclear security enterprise comprises a network of eight government-owned, contractor-operated research laboratories and nuclear weapons production facilities that provide the research, development, testing, and production capabilities needed to maintain and modernize our nation's nuclear weapons stockpile and related infrastructure. These eight sites are the Kansas City National Security Campus in Missouri; the Lawrence Livermore National Laboratory in California; the Los Alamos National Laboratory in New Mexico; the Nevada National Security Site, formerly known as the Nevada Test Site, in Nevada and other locations; the Sandia National Laboratories in New Mexico and other locations; the Pantex Plant in Texas; the Y-12 National Security Complex in Tennessee; and NNSA operations at DOE's Savannah River Site in South Carolina. We collectively refer to these eight sites as "laboratory and production sites."

[2]M&O contracts are agreements under which the government contracts on its behalf for the operation, maintenance, or support of government-owned or government-controlled research, development, special production, or testing establishments wholly or principally devoted to one or more of the major programs of the contracting agency. 48 C.F.R. § 17.601.

NNSA is undertaking a major effort to modernize the nation's nuclear weapons stockpile and its supporting infrastructure.[3] To achieve this effort, NNSA and its M&O contractors at nuclear security enterprise sites support a variety of research and development (R&D) projects designed to explore new manufacturing methods, as well as alternatives to legacy manufacturing processes that may be inefficient, unsafe, or obsolete.[4] NNSA and the M&O contractors at its nuclear security enterprise sites conduct manufacturing-related R&D projects through four main programs: (1) the Advanced Manufacturing Development (AMD) program, (2) Laboratory-Directed R&D (LDRD) programs at each laboratory, (3) Plant-Directed R&D (PDRD) programs at each plant, and (4) the Site-Directed R&D (SDRD) program at the Nevada National Security Site. In this report, we refer to the LDRD, PDRD, and SDRD programs collectively as "directed R&D programs." Unlike the AMD program, which NNSA manages, the three directed R&D programs are managed by M&O contractors, consistent with statute.[5]

House Report 116-442, accompanying the National Defense Authorization Act for Fiscal Year 2021, included a provision that we review NNSA's directed R&D programs and their relationship to NNSA's AMD program.[6] This report (1) describes the manufacturing-related R&D projects underway at NNSA laboratory and production sites and (2) examines the extent to which NNSA's management of its manufacturing-

[3]NNSA is conducting five programs to modernize nuclear weapons, and the Department of Defense's 2018 *Nuclear Posture Review* called for NNSA to consider additional programs to refurbish or build new weapons over the next 2 decades. NNSA is also managing numerous, multi-billion-dollar construction projects to modernize the infrastructure it uses to produce components and materials needed for its weapon programs. See Department of Defense, *Nuclear Posture Review* (Washington, D.C.: February 2018).

[4]According to NNSA's Fiscal Year 2020 Stockpile Stewardship and Management Plan, the agency's increased focus on modernization required restarting production operations that have been dormant for decades and increasing overall production rates of many components. We have previously reported that NNSA has encountered difficulties in restarting technical manufacturing processes after long periods of inactivity. See National Nuclear Security Administration, *Fiscal Year 2020 Stockpile Stewardship and Management Plan* (Washington, D.C.: July 2019); and GAO, *Nuclear Weapons: NNSA Should Further Develop Cost, Schedule, and Risk Information for the W87-1 Warhead Program*, GAO-20-703 (Washington, D.C.: Sept. 9, 2020).

[5]50 U.S.C. §§ 2791- 91a.

[6]H.R. Rep. No. 116-442, at 307 (2020) (accompanying William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021, Pub. L. No. 116-283, 134 Stat. 3388).

related R&D programs follows leading practices for managing federal R&D.

To describe the manufacturing-related R&D projects underway at NNSA sites, we reviewed and analyzed project data and documents for NNSA's AMD and M&O contractors' directed R&D programs. Specifically, we analyzed the data to determine the total number of fiscal year 2021 manufacturing-related R&D projects; the total costs associated with those projects; and any trends in the data, including the different categories of research supported by current projects. We took steps to assess the reliability of these data and found them to be sufficiently reliable for the purposes of our reporting objectives. Specifically, we assessed the reliability of the AMD and directed R&D projects' data by (1) performing electronic testing (i.e., looking for obvious errors, missing data, and applying logic tests), (2) reviewing existing information about the data and the systems that produced them, and (3) interviewing agency officials knowledgeable about the data.

We also selected eight nongeneralizable projects out of 574 total manufacturing-related projects from the laboratory and production sites with the greatest number of projects to use as illustrative examples in our report. We selected the projects based on factors such as project costs or research topics. We requested further documentation (e.g., project fact sheets) and interviewed NNSA officials about those projects to better understand the manufacturing-related R&D projects underway at NNSA sites.[7]

To determine the extent to which NNSA's management of its manufacturing-related R&D programs follows leading practices, we first identified leading practices for managing federal R&D based on our prior work. Specifically, we reviewed leading practices from our prior work, the work papers and literature sources used to develop these practices, and

[7]Findings from these projects cannot be generalized to those we did not select and review.

additional relevant GAO reports.[8] We also conducted an additional literature review covering material published from 2017 through 2021 to ensure that we had identified any relevant literature since the practices were first developed. We validated the leading practices with internal subject-matter experts, as well as relevant NNSA officials.

We developed interview questions designed to assess the extent to which NNSA's management of its manufacturing-related R&D programs followed these practices and then interviewed knowledgeable NNSA officials. Specifically, we interviewed AMD program officials from NNSA headquarters and selected NNSA field offices.[9] We also interviewed NNSA officials from its Office of Production Modernization to understand the perspective of one of the AMD program's key stakeholders.[10] Finally, we interviewed NNSA officials with knowledge of and experience with the directed R&D programs—from headquarters and selected NNSA field offices—to better understand how NNSA conducts oversight of these programs.[11]

To assess the extent to which NNSA is following leading practices, two GAO analysts independently assessed the evidence regarding NNSA's

[8]In our prior work, we identified leading practices for managing a federal R&D portfolio by reviewing relevant literature, consulting GAO stakeholders with expertise in federal R&D, and validating the practices with agency officials. See GAO, *Aviation Research: FAA Could Improve How It Develops Its Portfolio and Reports Its Activities*, GAO-17-372 (Washington, D.C.: Apr. 24, 2017). We modified the language of the practices identified and adapted them for the purposes of this report. We also incorporated supporting language from additional relevant GAO reports, such as GAO, *Defense Science and Technology: Adopting Best Practices Can Improve Innovation Investments and Management*, GAO-17-499 (Washington, D.C.: June 29, 2017).

[9]In order to obtain the perspective of NNSA field office officials, we interviewed officials from two NNSA field offices with the greatest number of AMD R&D projects. NNSA's field offices are responsible for overseeing M&O contractors' site operations.

[10]AMD program officials identified NNSA's Office of Production Modernization and the Office of Stockpile Management as their main customers. We spoke with officials from the Office of Production Modernization who oversee activities related to two of AMD's priority projects in order to understand the extent to which AMD program officials coordinate with key stakeholders. Findings from interviews with these stakeholders cannot be generalized to those we did not interview.

[11]We selected two field offices for the LDRD/SDRD and PDRD programs, respectively—four field offices in total—and interviewed officials from these offices. We selected the two field offices with the greatest number of LDRD/SDRD manufacturing-related R&D projects and two field offices with the greatest number of PDRD manufacturing-related R&D projects.

management of its AMD program using a three-point scale and came to an agreement on all ratings.[12] We also reviewed agency documents and external reviews of the programs, as well as relevant NNSA policies and directives for the AMD and directed R&D programs. However, we did not assess NNSA's management of the directed R&D programs against the leading practices for federal R&D management because, as consistent with statute, NNSA does not directly manage those programs. We include an overview of NNSA's activities to oversee the contractors' directed R&D programs in appendix I.

We conducted this performance audit from October 2020 to May 2022, in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

# Background

## NNSA Offices Responsible for Manufacturing-Related R&D Activities

NNSA's manufacturing-related R&D activities primarily fall under the Office of Defense Programs.[13] Within the Office of Defense Programs, the mission of the Office of Engineering and Technology Maturation (OETM) is to support NNSA's nuclear stockpile and enterprise modernization efforts by developing innovative solutions to reduce program costs and schedules and improve effectiveness across the nuclear weapon life cycle.[14] OETM manages NNSA's AMD program and oversees the contractor-managed PDRD programs across NNSA's weapons production plants. In addition, NNSA's Office of Advanced Simulation, Computing, and Institutional R&D programs oversees the contractor-managed LDRD programs across NNSA's laboratories and the SDRD

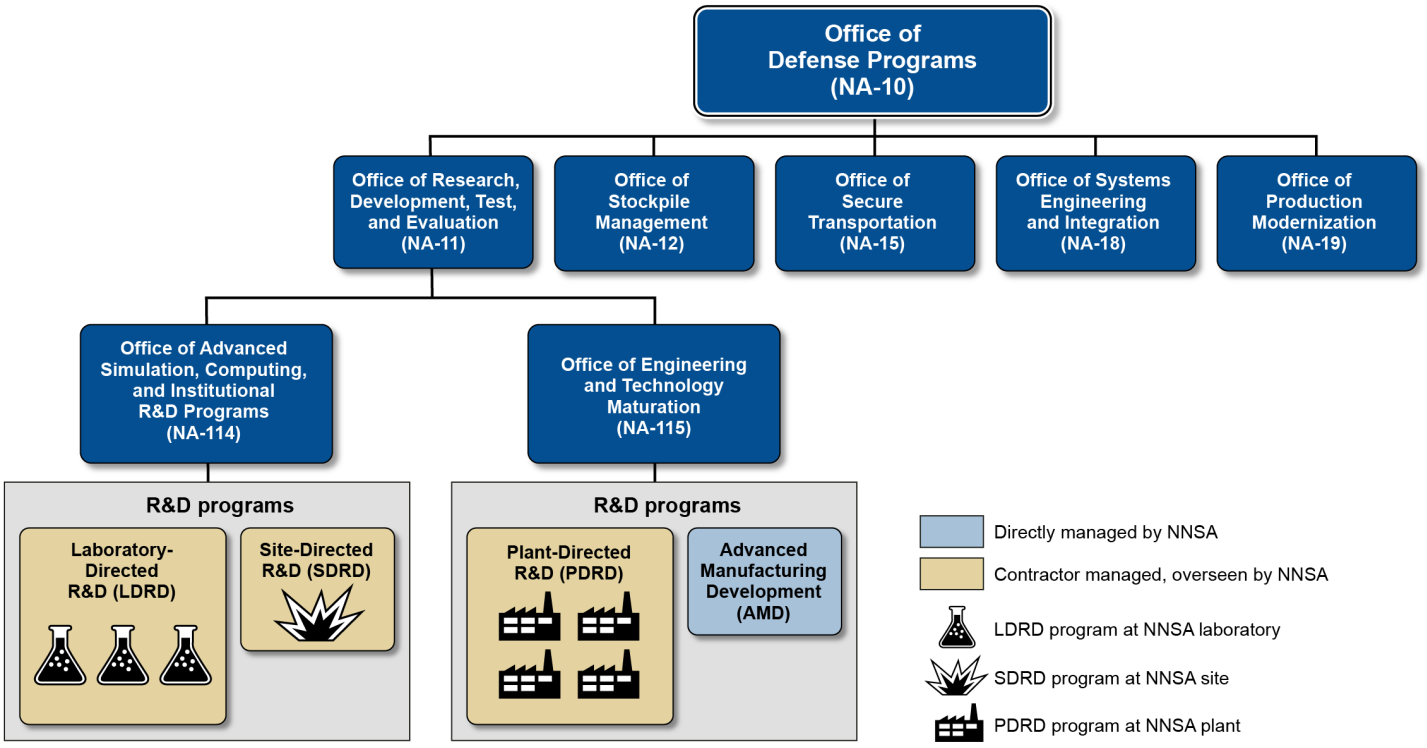
[12]The three-point scale is (1) fully or substantially followed—NNSA took actions that addressed most or all aspects of the key questions GAO examined for the practice; (2) partially followed—NNSA took actions that addressed some, but not most, aspects of the key questions GAO examined for the practice; and (3) not followed—NNSA took no actions that addressed the aspects of the key questions GAO examined relevant to the practice.

[13]The Office of Defense Programs is also known as NA-10.

[14]OETM is also known as NA-115.

program at the Nevada National Security Site.[15] According to NNSA officials, the AMD and directed R&D programs constitute the main programs for NNSA's manufacturing-related R&D activities.[16] Figure 1 shows the main offices under NNSA's Office of Defense Programs and the offices primarily responsible for managing and overseeing NNSA's manufacturing-related R&D activities.

**Figure 1: National Nuclear Security Administration (NNSA) Offices Responsible for Managing and Overseeing Manufacturing-Related Research and Development (R&D) Programs**




Source: GAO presentation of NNSA information. | GAO-22-104506

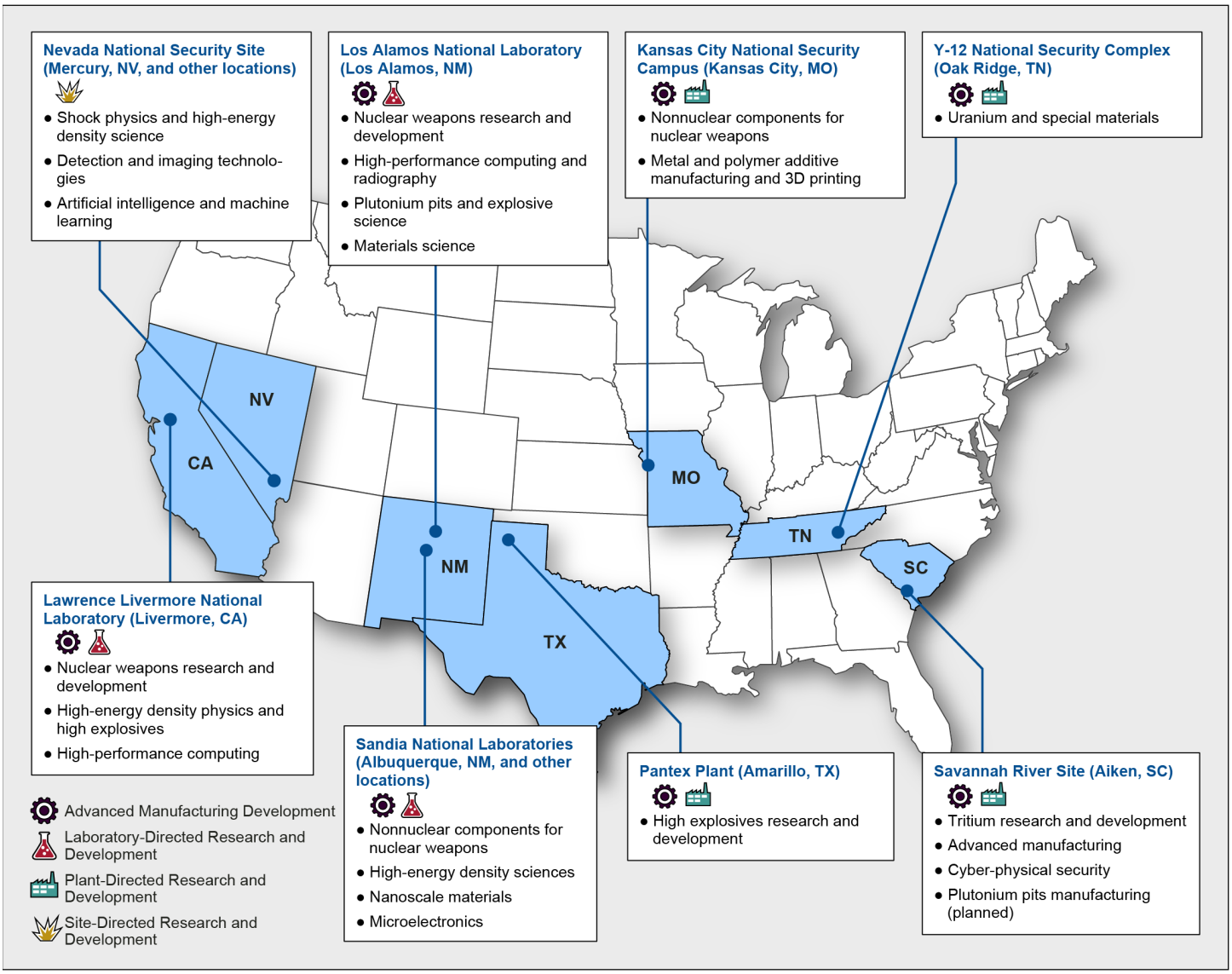
[15]The Office of Advanced Simulation, Computing, and Institutional R&D programs is also known as NA-114.

[16]Research conducted under the directed R&D programs is not limited to manufacturing-related R&D activities; for example, research conducted under the SDRD program at the Nevada National Security Site may contribute to high-energy density physics applications rather than manufacturing. However, this review focuses only on manufacturing-related R&D activities.

NNSA has seven field offices that are co-located at the agency's eight sites and are responsible for overseeing NNSA's M&O contractors, including ensuring compliance with federal contracts.[17] The sites that constitute the nuclear security enterprise each have specific capabilities and responsibilities with respect to stockpile sustainment and modernization. As shown in figure 2, NNSA's R&D programs that conduct manufacturing-related activities operate across the enterprise.

[17]NNSA's field offices are the Kansas City Field Office in Missouri, the Livermore Field Office in California, the Los Alamos Field Office in New Mexico, the NNSA Production Office in Tennessee and Texas, the Nevada Field Office, the Sandia Field Office in New Mexico, and the Savannah River Field Office in South Carolina.

**Figure 2: National Nuclear Security Administration's (NNSA) Laboratory and Production Sites**




Sources: GAO presentation of NNSA information; Map Resources (map). | GAO-22-104506

## NNSA's AMD Program

NNSA established the AMD program in 2015 in response to congressional direction to enhance NNSA's secure manufacturing

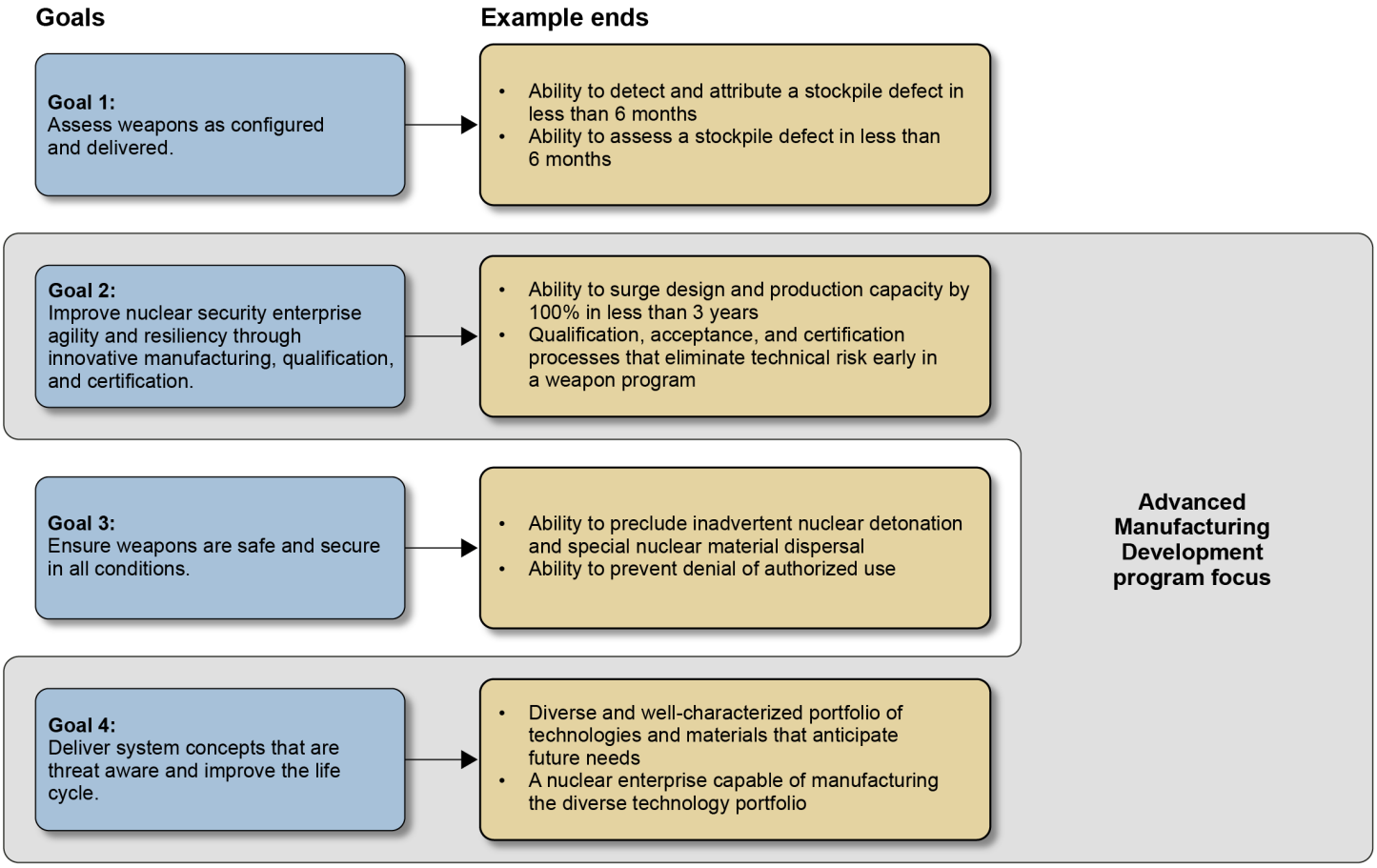
capabilities.[18] According to AMD's Strategic Plan, the program is part of NNSA's broader Defense Programs Technology Maturation program and supports R&D in a broad suite of next-generation, or advanced, manufacturing processes for nuclear weapons tooling, fixtures, and components.[19] R&D projects under the AMD program are conducted at all but one of the sites in the nuclear security enterprise (these activities are not conducted at the Nevada National Security Site). According to AMD program officials we interviewed, AMD investments are guided by the strategic goals developed by OETM, with particular emphasis on goals 2 and 4, as outlined in figure 3 below. In its Strategic Plan, OETM outlines the broad work it will undertake to achieve strategic goals, and "ends," or specific nuclear security enterprise capabilities that are required to address national security challenges.[20] Figure 3 below also provides examples of several OETM ends.

[18]The Consolidated and Further Continuing Appropriations Act, 2015, provided the first funding for the AMD program. The explanatory statement accompanying the act directed NNSA to develop, demonstrate, and utilize advanced technologies that are needed to enhance NNSA's secure manufacturing capabilities and to ensure timely support for the production of nuclear weapons and other critical national security components. Pub. L. No. 113-235, Div. D, tit. III, §301(d); 160 CONG. REC. H9307, H9703, H9714 (daily ed. Dec. 11, 2014) (statement of Rep. Rogers).

[19]Advanced manufacturing is a family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting-edge materials and emerging capabilities enabled by the physical and biological sciences, for example, nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products and especially the manufacture of new products emerging from new advanced technologies. See also National Nuclear Security Administration, *Advanced Manufacturing Development Strategic Plan* (Washington, D.C.: Feb. 24, 2020). Additive manufacturing, or 3-D printing, has specifically been used to produce tools and fixtures at NNSA sites in ways that cut production costs while improving performance. Tooling may include, for example, drill parts, while fixtures hold material in place for inspection and cutting into a desired shape and size through a controlled material removal process.

[20]OETM also developed several potential indicators of success toward achieving the strategic goals and ends outlined in the agency's 2020-2050 Strategic Plan. National Nuclear Security Administration, *Office of Engineering and Technology Maturation 2020-2050 Strategic Plan* (Washington, D.C.: Apr. 14, 2021).

**Figure 3: National Nuclear Security Administration's (NNSA) Office of Engineering and Technology Maturation Strategic Goals and Example Ends**




Sources: GAO analysis of Office of Engineering and Technology Maturation 2020-2050 Strategic Plan and interviews with NNSA officials. | GAO-22-104506

Note: According to the Office of Engineering and Technology Maturation Strategic Plan, the office contributes to the entire nuclear weapon life cycle, in every phase, from early research and development of stockpile and enterprise capabilities prior to the start of a major acquisition program, through that weapon's or capability's life, until it is time to dispose of a weapon. "Ends" are specific nuclear security enterprise capabilities that are required to address national security challenges.

The AMD Strategic Plan also outlines broad objectives to guide investment decisions and help focus NNSA's advanced manufacturing R&D priorities across the nuclear security enterprise, as outlined in table 1 below.

**Table 1: National Nuclear Security Administration's Advanced Manufacturing Development (AMD) Strategic Plan Program Objectives**

| Program objectives | Description |
|---|---|
| Explore new and innovative manufacturing technologies | Invest in a balanced portfolio of exploratory projects with focuses on component production and deployment to understand the tangible benefits of these alternative manufacturing technologies. |
| Reduce the time to deploy advanced manufacturing technologies | Reduce the time to identify design options during a life extension, as well as the time to develop multiweapon concepts and deploy new manufacturing methods. |
| Develop efficient and cost-effective manufacturing technologies | Develop technologies and processes that create efficiencies and cost savings, such as by decreasing factory downtime and increasing component throughput, utilizing a smaller factory footprint, or reducing the time to create final parts. |
| Adopt improved, risk-based manufacturing qualification methods | Reduce time lines and effort associated with qualification of components, using novel advanced manufacturing methods and technologies, such as process-based qualification and in-parallel qualification. |
| Secure material and component supply chains | Explore newly proposed methods and materials to assure the long-term health of the supply chain, including the machines used to do the work; the materials or feedstocks themselves; and, in some cases, the constituents that make up those materials. |
| Continuously improve processes | Incorporate small and incremental improvements into ongoing manufacturing processes to increase their efficiency and effectiveness. |

Source: GAO analysis of AMD Strategic Plan. | GAO-22-104506

## Directed R&D Programs

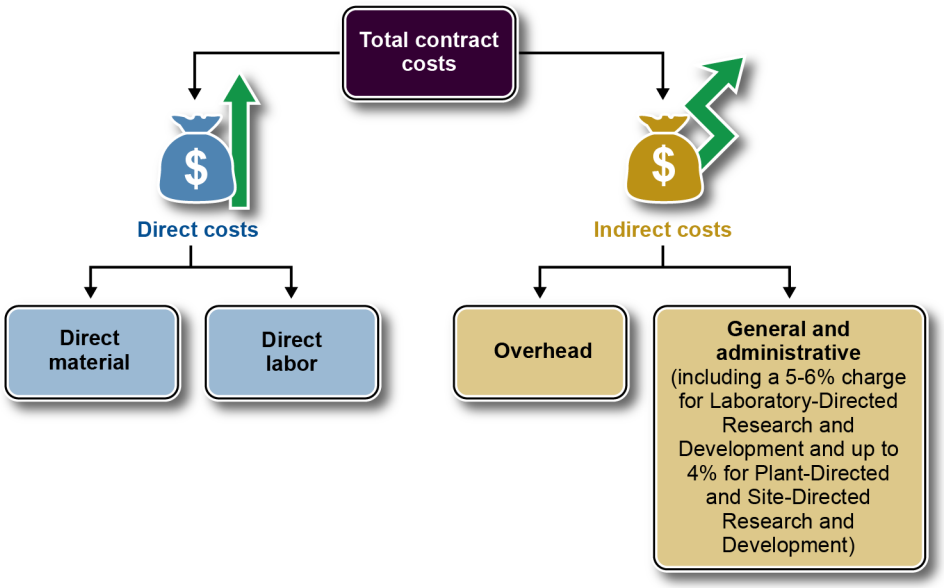
Directed R&D programs are managed by M&O contractors at the various laboratory and production sites within the nuclear security enterprise.[21] To foster scientific excellence, M&O contractors use a portion of their annual budgets to conduct self-initiated R&D projects selected at the discretion of the site's director. According to NNSA officials we interviewed, directed R&D programs operate from the bottom up, whereby M&O contractors establish their own priorities, with guidance from NNSA to ensure that specific projects help address the agency's mission-related needs. NNSA's sites pay for directed R&D programs by including an indirect charge, up to statutory limits, against their direct costs.[22] Statutory limits require that LDRD funding comprise between 5 and 6 percent of NNSA laboratories' budgets. These limits also establish that PDRD and SDRD

[21]Although M&O contractors manage their directed R&D programs, both NNSA headquarters and field office officials provide oversight of these programs.

[22]M&O contractors classify costs as either direct or indirect. Direct costs are assigned to the benefitting program or programs. Indirect costs—costs that cannot be assigned to a particular program, such as costs for administration and site support—are to be accumulated, or grouped, into indirect cost pools. The final program cost is the sum of the total direct costs plus the indirect costs assigned or attributed to the program.

funding may comprise up to 4 percent of production sites' budgets. (See fig. 4.)

**Figure 4: Direct and Indirect Costs Charged by the National Nuclear Security Administration's Management and Operating Contractors**




Source: GAO presentation of a Defense Systems Management College graphic. | GAO-22-104506

According to the 2019 NNSA LDRD and SDRD Strategic Framework, the individual strategic plans of the laboratories and site are to align with priorities set by DOE, NNSA, and key relevant national strategy guidance documents, such as the 2018 Nuclear Posture Review, which establish U.S. nuclear weapons policies, missions, capabilities, and forces. The LDRD program, among other objectives, strives to ensure scientific and technical vitality at DOE laboratories while meeting current and future national security missions.[23] DOE Order 413.2C provides that LDRD

[23]The National Defense Authorization Act for Fiscal Year 1991 authorized the contractor-operated laboratories that receive funding for national security programs to use a percentage of laboratory funds to perform laboratory-directed R&D of a creative and innovative nature to maintain the vitality of the laboratories' defense-related scientific disciplines. Pub. L. No. 101-510 Div. C, tit. XXXI, §3132, 104 Stat. 1485, 1832 (1990) (codified as amended at 50 U.S.C. § 2791). In 1992, DOE formalized its laboratories' self-initiated R&D programs by establishing the LDRD program, under which directors of contractor-operated laboratories may allocate funding to scientists to conduct worthy independent research.

projects must typically be limited to a maximum performance period of 36 months and will normally include one or more of the following:

- advanced study of hypotheses, concepts, or innovative approaches to scientific or technical problems;
- experiments and analyses directed toward “proof of principle” or early determination of the utility of new scientific ideas, technical concepts, or devices; and
- conception and preliminary technical analyses of experimental facilities or devices.[24]

Although DOE Order 413.2C does not explicitly cover the SDRD program, NNSA also applies the objectives outlined in the order to the SDRD program, as described in the NNSA LDRD and SDRD Strategic Framework. In addition, NNSA’s Office of Advanced Simulation, Computing and Institutional R&D Programs oversees both the LDRD and SDRD programs and applies these objectives to both programs.

The PDRD program is to support innovative or high-risk design and manufacturing concepts and technologies with potentially high payoff for the nuclear weapons complex.[25] According to PDRD program guidance, the objective of PDRD is to select projects that benefit NNSA’s mission and support the development and maturation of technologies. As described in the program guidance, PDRD funds may be used to

- fund conceptual or preliminary designs of technology applications that have high potential for payoff for their mission applications;
- fund capital expenditures for acquisition of general-purpose equipment, only if the equipment is required for the PDRD projects; and
- train, recruit, or retain essential personnel in critical engineering and manufacturing disciplines.

Table 2 describes the program objectives for the directed R&D programs.

[24]Department of Energy, *Laboratory Directed Research and Development*, DOE 413.2C (Washington, D.C.: Aug. 2, 2018).

[25]National Defense Authorization Act for Fiscal Year 2001, Pub. L. No. 106-398, Div. C., tit. XXX, §3156, 114 Stat. 1654, 1654A–467.

**Table 2: Directed Research and Development (R&D) Programs' Key Objectives**

| Laboratory and Site-Directed R&D Programs' (LDRD/SDRD) key objectives[a] | Plant-Directed R&D Programs' (PDRD) key objectives[b] |
|---|---|
| • Maintain the scientific and technical vitality of the laboratories<br>• Enhance the laboratories' ability to address current and future DOE/NNSA missions<br>• Foster creativity and stimulate exploration of forefront areas of science and technology<br>• Serve as a proving ground for new concepts in research and development<br>• Support high-risk, potentially high-value R&D | • Replace obsolete or aging design and manufacturing technologies<br>• Develop innovative, agile manufacturing techniques and processes<br>• Train, recruit, or retain essential personnel in critical engineering and manufacturing disciplines |

Sources: Department of Energy (DOE) Order 413.2C, and National Nuclear Security Administration (NNSA) guidance. | GAO-22-104506

[a]DOE Order 413.2C. While the order technically only applies to the LDRD program, NNSA officials told us that they also apply its objectives to the SDRD program.

[b]PDRD program guidance.

## Maturity and Life Cycle of R&D Projects

NNSA officials described their manufacturing-related R&D projects underway in fiscal year 2021 as falling into two main categories:

- **Basic research.** Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts.
- **Applied research.** Applied research is directed primarily toward a specific practical aim or objective.

NNSA officials we interviewed told us that the research they conduct in these two categories may be similar but could be used for different applications. For example, researchers could simulate a high-performance computing function that a laboratory has designed, and they could conduct simulations for basic or applied functions.

Technology Readiness Levels (TRL) or Manufacturing Readiness Levels (MRL) are common measures and vocabulary for assessing and discussing maturity and risk for technologies or manufacturing capabilities, respectively. TRLs fall on a 9-point scale, starting with paper studies of a basic concept and ending with a technology that has proven itself in operation. MRLs fall on a 10-point scale, starting with the identification and study of basic manufacturing shortfalls and opportunities, and ending with full-rate production. TRLs and MRLs are distinct, and both enable consistent comparison of maturity between different types of technologies or manufacturing capabilities.

NNSA's manufacturing-related R&D programs all aim to support projects that are considered early stage in technology maturation or manufacturing capabilities. According to the AMD Strategic Plan, the AMD program oversees the maturation of technologies prior to the start of a warhead program, as well as ongoing technology development through TRL 5 and manufacturing readiness through MRL 4. According to the federal program manager for LDRD and SDRD, these directed R&D programs are meant to support projects up to the "pilot stage of development," as set in statute, though there is no specific TRL or MRL cap documented.[26] While NNSA officials said the PDRD program also does not have an official cap on what TRL or MRL stage projects should fall under, they told us that, in practice, the directed R&D programs all aim to mostly support projects up to TRL or MRL 6.[27] See figure 5.

[26]42 U.S.C. § 5817a. This provision applies to the LDRD program but, as noted above, NNSA applies LDRD requirements to the SDRD program as well.

[27]According to NNSA officials, the Fiscal Year 2022 PDRD Program Guidance is being revised to state that projects ideally should focus on early stage R&D, up through and including TRL/MRL 4. Proposed projects that matured beyond these readiness levels would require NNSA headquarters or field office approval.

**Figure 5: Definitions of Technology Readiness Levels (TRL) and Manufacturing Readiness Levels (MRL)**

| National Nuclear Security Administration manufacturing-related research and development projects | | | | |
|---|---|---|---|---|
| | **TRL 1:** | Basic principles observed and reported | **MRL 1:** | Basic manufacturing implications identified |
| | **TRL 2:** | Technology concept and/or applications formulated | **MRL 2:** | Manufacturing concepts identified |
| | **TRL 3:** | Analytical and experimental critical function and/or characteristic proof of concept | **MRL 3:** | Manufacturing proof of concept developed |
| | **TRL 4:** | Component and/or system validation in laboratory environment | **MRL 4:** | Capability to produce the technology in a laboratory environment |
| | **TRL 5:** | Component or system validation in a relevant environment | **MRL 5:** | Capability to produce prototype components in a production-relevant environment |
| | **TRL 6:** | Engineering/pilot-scale, similar (prototypical) system validation in relevant environment | **MRL 6:** | Capability to produce a prototype system or subsystem in a production-relevant environment |
| | **TRL 7:** | Full-scale, similar (prototypical) system demonstrated in relevant environment | **MRL 7:** | Capability to produce systems, subsystems, or components in a production-representative environment |
| | **TRL 8:** | Actual system completed and qualified through test and demonstration | **MRL 8:** | Pilot line capability demonstrated; ready to begin low-rate initial production |
| | **TRL 9:** | Actual system proven through successful mission operations | **MRL 9:** | Low rate production demonstrated; capability in place to begin full rate production |
| | | | **MRL 10:** | Full rate production demonstrated and lean production practices in place |

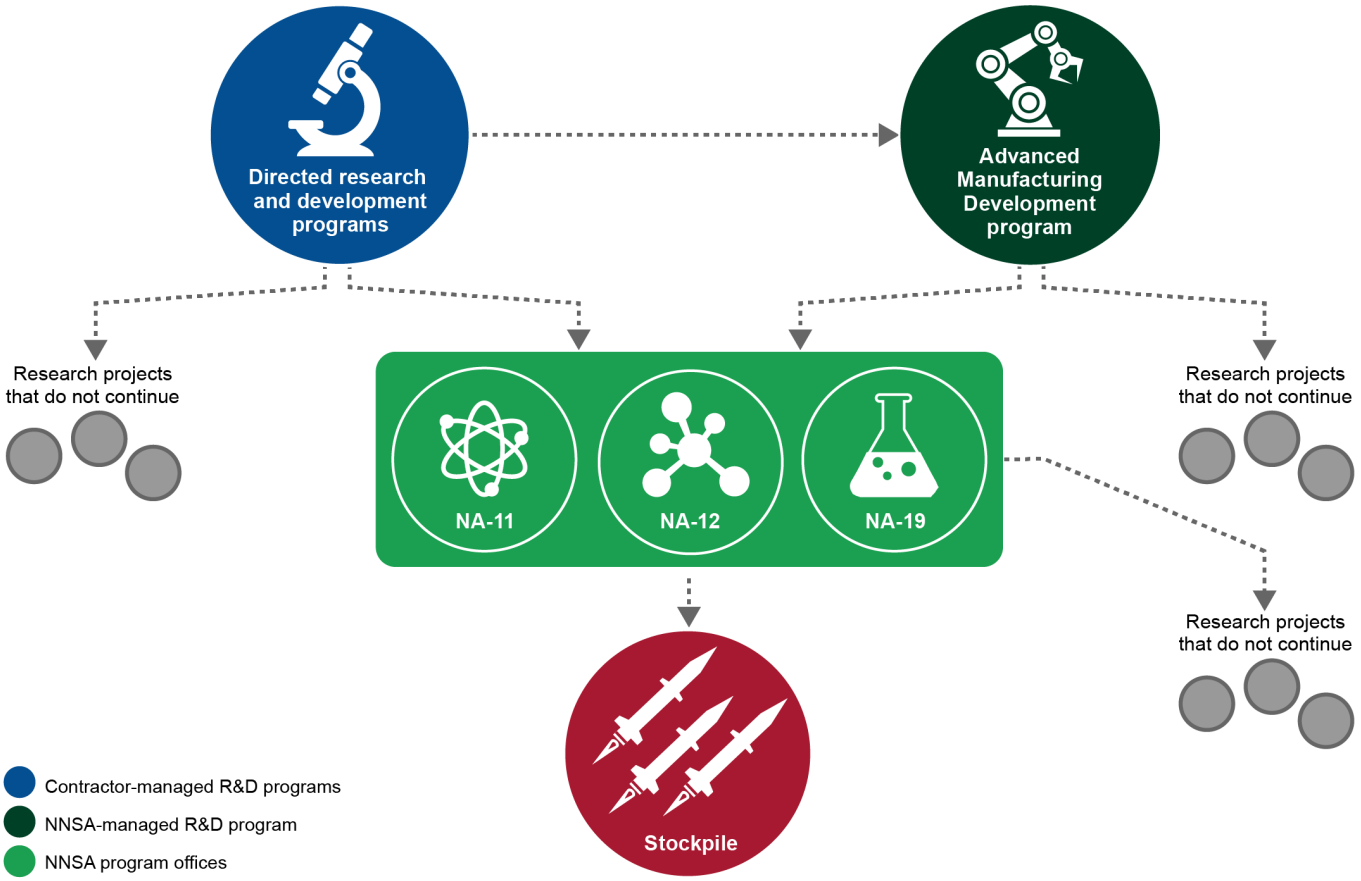
Sources: National Nuclear Security Administration and GAO, *Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects*, GAO-20-48G (Washington, D.C.: January 2020). | GAO-22-104506

There are several potential pathways for research projects—or for the technology developed during a research project—to mature and transition to another NNSA program or office (and eventually to the stockpile) once the project has run its course in the AMD or directed R&D programs. The AMD Fiscal Year 2021 Implementation Plan, for example, lists several offices that coordinate with AMD on potentially transferring more mature technologies for further development, including the Office of Production Modernization (NA-19); the Office of Research, Development, Test, and Evaluation (NA-11); and the Office of Stockpile Management (NA-12).

Projects that originated in AMD may transition to NA-11, NA-12, or NA-19 and then transition to the stockpile, according to NNSA officials. For example, NNSA officials we interviewed in NA-19 told us that a project—that uses a furnace to melt metal into a direct shape for weapons components—recently transitioned from AMD to their office because the project had reached a higher level of technology maturation than AMD oversees. However, some projects may never leave AMD, if the technology is not found to be viable, NNSA officials said.

Projects in the directed R&D programs can also transition to the AMD program or to other offices within NNSA (such as NA-11, NA-12, or NA-19), once the research and technology has matured to a point where those other offices can better develop or prepare the technology for use in the stockpile. See figure 6 for an illustration of potential pathways for the maturation of R&D projects' technology through the different NNSA programs and offices.

**Figure 6: Potential Pathways for Technology Maturation for Contractor-Managed and National Nuclear Security Administration (NNSA)-Managed Manufacturing-Related Research and Development (R&D) Projects**




Source: GAO presentation of NNSA information. | GAO-22-104506

Note: NA-11 is the Office of Research, Development, Test, and Evaluation; NA-12 is the Office of Stockpile Management; and NA-19 is the Office of Production Modernization.

## NNSA and Its M&O Contractors Spent Almost $300 Million on Almost 600 Manufacturing-Related R&D Projects in Fiscal Year 2021

NNSA and the agency's M&O contractors at the eight nuclear security enterprise sites conducted or oversaw a total of almost 600 manufacturing-related R&D projects under the AMD and directed R&D programs active during fiscal year 2021. Together, NNSA and its contractors spent almost $300 million on projects associated with these manufacturing-related R&D programs in fiscal year 2021. (See table 3.)

**Table 3: National Nuclear Security Administration (NNSA) and Contractor-Managed Manufacturing-Related Research and Development (R&D) Projects and Costs by Program, Fiscal Year 2021**

| Program | Number of manufacturing-related projects | Total costs (dollars in thousands) | Average cost per project (dollars in thousands) |
|---|---|---|---|
| Advanced Manufacturing Development | 133 | 96,731 | 727 |
| Directed R&D programs | 441 | 175,761 | 399 |
| **Total** | **574** | **272,492** | |

Source: GAO analysis of NNSA data | GAO-22-104506

## NNSA Spent Almost $100 Million on 133 R&D Projects through Its AMD Program

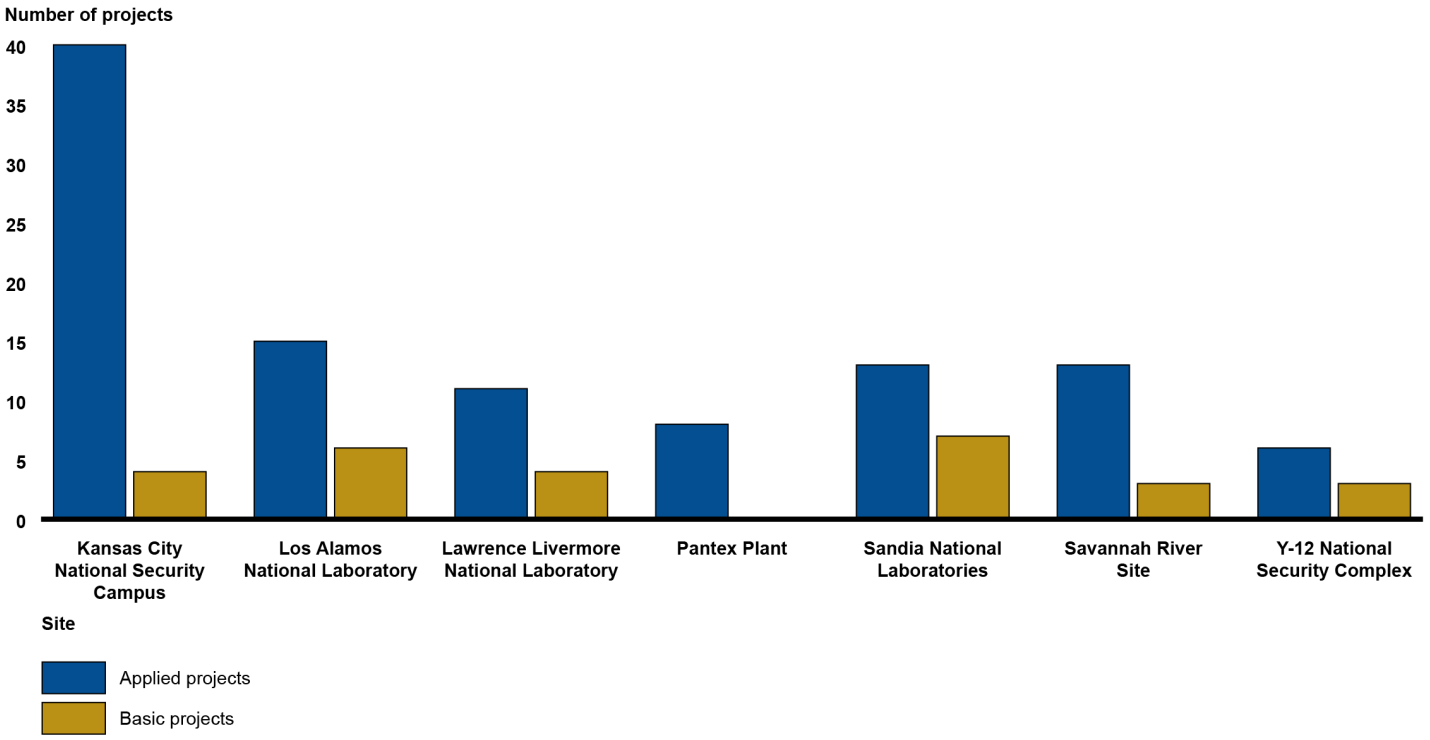
In fiscal year 2021, NNSA's AMD program conducted 133 manufacturing-related R&D projects.[28] The AMD program spent almost $100 million on these projects, with the average cost per project at about $727,000. The cost of a single AMD project ranged from $5,000 to about $6 million in fiscal year 2021.

Manufacturing-related R&D projects funded under the AMD program were conducted at seven of NNSA's eight sites, with the largest number of projects (44) conducted at the Kansas City National Security Campus.[29] The vast majority of AMD projects (106, or 80 percent) were applied research projects, while a smaller number of projects (27, or 20 percent) were categorized as basic research (see fig. 7).

[28]AMD program officials also identified two projects conducted at the Pacific Northwest National Laboratory (PNNL), which cost a total of about $500,000. However, because PNNL is a DOE Office of Science laboratory, we did not include these two projects or their costs in our total here.

[29]The Nevada National Security Site was the only NNSA site that did not have projects underway under the AMD program in fiscal year 2021.

**Figure 7: Number and Type of Advanced Manufacturing Development Research and Development (R&D) Projects by Site, Fiscal Year 2021**




Source: GAO analysis of National Nuclear Security Administration data. | GAO-22-104506

The AMD program organizes projects under eight major technical efforts.[30] In fiscal year 2021, AMD's Additive Manufacturing Coordination Team had the largest number of projects (43), while the Material Obsolescence category had the highest dollar amount for its projects (approximately $27 million total), as shown in table 4.

[30]The eight major technical efforts are Additive Manufacturing Coordination Team, Advanced Engineering Materials, Digital Manufacturing and Diagnostics, Improved Production Capability Development, Manufacturing Process Integration, Material Obsolescence, Novel Production Capability Development, and Program Management and Integration. For a description of the types of research involved in each major technical effort, see table 4.

**Table 4: Number of Advanced Manufacturing Development Research and Development (R&D) Projects and Costs by Major Technical Effort, Fiscal Year 2021**

| Major technical effort | Major technical effort description | Number of manufacturing-related projects | Costs, fiscal year 2021 (dollars in thousands) |
|---|---|---|---|
| Additive Manufacturing Coordination Team | Capitalize on three-dimensional printing of polymers and metals for stockpile applications designed to shorten production schedules and design cycles and may ultimately lead to lower life-cycle costs. | 43 | 23,113 |
| Advanced Engineering Materials | Invest in strategic material selection, development, and characterization for current and future stockpile programs. | 4 | 1,016 |
| Digital Manufacturing and Diagnostics | Employ digital manufacturing, which enables faster and more efficient qualification and deployment of production-ready manufacturing processes. | 22 | 9,552 |
| Improved Production Capability Development | Improve existing technologies and processes to decrease production costs, improve agility and throughput, and decrease production time and waste. | 18 | 8,790 |
| Manufacturing Process Integration | Facilitate introduction of new manufacturing techniques into production lines. | 1 | 748 |
| Material Obsolescence | Pursue alternatives for replacing obsolete or hazardous materials and aging production processes. | 22 | 26,830 |
| Novel Production Capability Development | Pursue novel, transformational technical, and manufacturing options that anticipate and directly address enterprise production challenges. | 21 | 25,451 |
| Program Management and Integration | Activities related to project management of the Advanced Manufacturing Development portfolio, including budget support, travel and attendance at meetings and events, and ancillary activities. | 2 | 1,231 |
| **Total** | | **133** | **96,731** |

Source: GAO analysis of National Nuclear Security Administration data. | GAO-22-104506

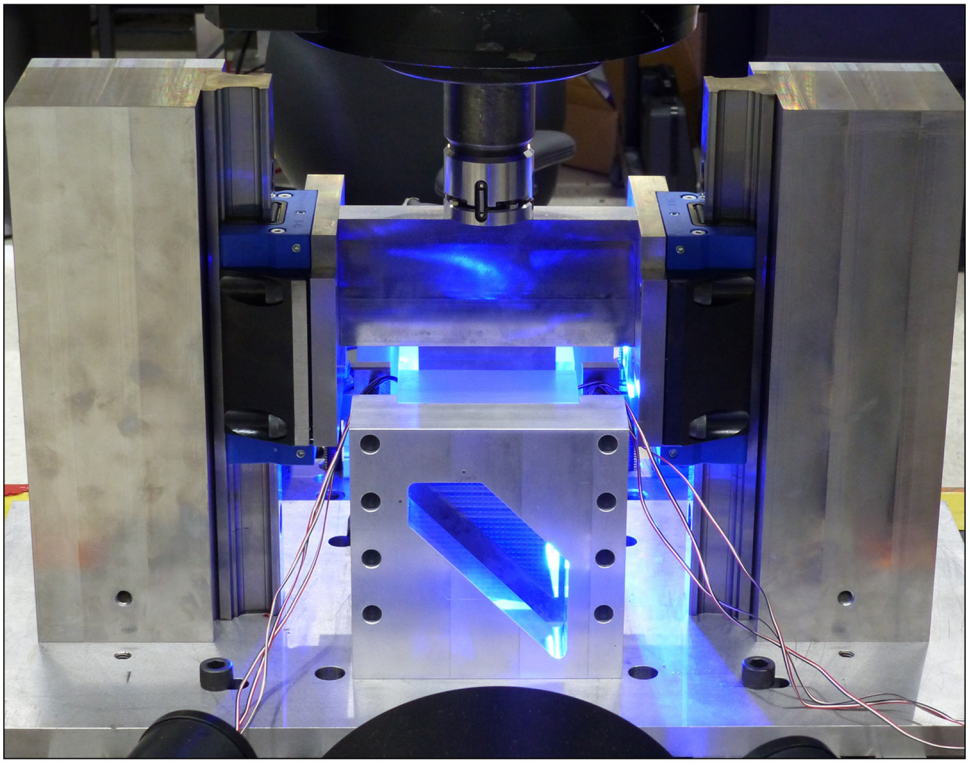
Note: Advanced Manufacturing Development officials said projects typically last longer than 1 fiscal year, but the costs shown here are only for fiscal year 2021. The total costs of those projects over their life cycle would be higher.

About half of all the projects that the AMD program funded in fiscal year 2021 were considered to be cross-site projects. NNSA officials said these cross-site projects are collaborative efforts, where different sites look at different aspects or components within a project. For example, in fiscal year 2021, AMD supported a collaborative project at six sites focused on additively manufacturing metal lattices for use in the stockpile (see fig. 8). According to NNSA officials, these additively manufactured metal lattices help improve the warhead life cycle by having low weight and being comparatively easy to manufacture. The funding levels for these projects

at the different sites ranged from about $300,000 to over $1 million for fiscal year 2021.

**Figure 8: Testing the Strength of Additively Manufactured Metals at Lawrence Livermore National Laboratory**

This machine measures the strength of additively manufactured metal lattices and shows that a significant percentage of the weight can be removed from the lattice and maintain strength requirements.



Source: National Nuclear Security Administration. | GAO-22-104506

## M&O Contractors Spent $176 Million on 441 Projects through Directed R&D Programs

In fiscal year 2021, M&O contractors at NNSA sites spent about $176 million on 441 manufacturing-related directed R&D projects (277 LDRD projects, 160 PDRD projects, and four SDRD projects). The LDRD programs constituted the largest share (or about 75 percent) of manufacturing-related directed R&D costs among the 441 projects conducted across NNSA sites, spending about $131 million in fiscal year 2021. (See table 5.) The cost of a single directed R&D project ranged from $4,000 to about $4 million in fiscal year 2021.

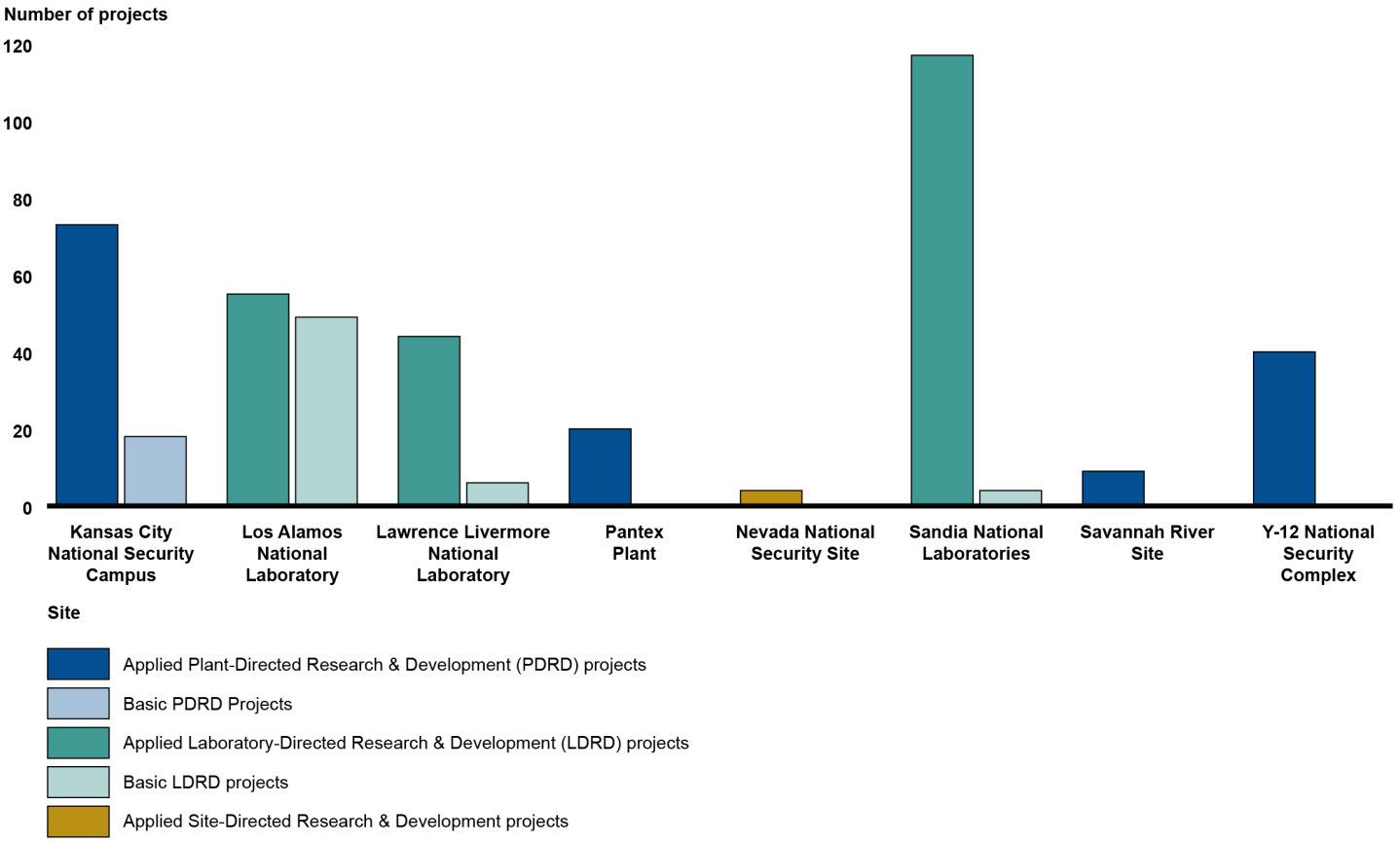
**Table 5: Number of Manufacturing-Related Contractor-Directed Research and Development (R&D) Projects and Costs by Program, Fiscal Year 2021**

| Program | Number of manufacturing-related projects | Total costs (dollars in thousands) | Average cost per project (dollars in thousands) |
|---|---|---|---|
| Laboratory-Directed R&D Programs | 277 | 130,957 | 473 |
| Plant-Directed R&D Programs | 160 | 44,125 | 276 |
| Site-Directed R&D Program | 4 | 679 | 170 |
| **Total** | **441** | **175,761** | |

Source: GAO analysis of National Nuclear Security Administration data. | GAO-22-104506

Directed R&D projects were conducted across the nuclear security enterprise but were concentrated at Sandia National Laboratories, Los Alamos National Laboratory, and the Kansas City National Security Campus. Specifically, the largest number of manufacturing-related LDRD projects (121) conducted across NNSA's sites were at the Sandia National Laboratories. By comparison, a little over half of the manufacturing-related PDRD projects (91) in fiscal year 2021 were conducted at the Kansas City National Security Campus. Of the four SDRD projects, one was located at the Nevada location; two were located at the Los Alamos, New Mexico, location; and one was located at the Santa Barbara, California, location for the Nevada National Security Site, according to NNSA officials. Most of the manufacturing-related LDRD and SDRD projects (220, or about 78 percent) involved applied, rather than basic, research; and almost all of the PDRD projects involved applied research. (See fig. 9.)

**Figure 9: Number and Type of Manufacturing-Related Contractor-Directed Research and Development (R&D) Projects by Site, Fiscal Year 2021**




Source: GAO analysis of National Nuclear Security Administration data. | GAO-22-104506

NNSA officials identified five categories to characterize the manufacturing-related research conducted under the contractors' directed R&D programs. In fiscal year 2021, Manufacturing Processes had the largest number of projects (117) across the directed R&D programs, while Material Properties had the highest dollar amount for its projects ($51 million). (See table 6.)

**Table 6: Number of Contractor-Directed Research and Development (R&D) Projects and Costs by Manufacturing-Related Category, Fiscal Year 2021**

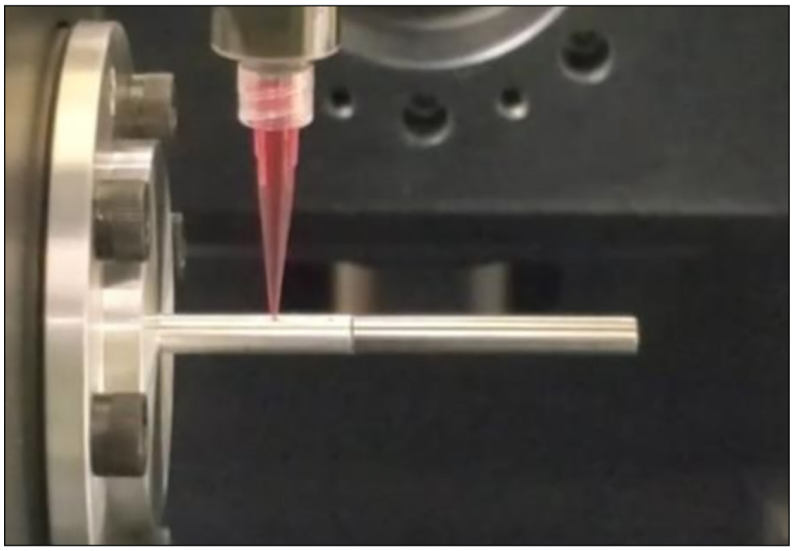
| Manufacturing category | Manufacturing category description | Number of projects | Costs, fiscal year 2021 (dollars in thousands) |
|---|---|---|---|
| Feedstock Materials | Explore new types of feedstock materials needed to address mission-critical applications, as well as innovative ways to design and develop feedstocks used to produce advanced components or parts tailored to specific national security needs. | 72 | 23,594 |
| Material Properties | Model, predict, and optimize a material's properties, including its morphology, structure, or performance across various environments and at different scales. | 96 | 51,095 |
| Diagnostic Techniques | Explore new diagnostic and characterization techniques that enable researchers to assess the quality, performance, and reliability of manufactured parts, components, and systems in various mission-critical environments. | 113 | 35,960 |
| Manufacturing Processes | Develop new manufacturing processes and understand the underlying science of those processes to enable safe production of mission-critical materials, increase production yield, and optimize the purity and performance of materials. | 117 | 44,458 |
| Lifecycle Performance | Enhance the ability to simulate and predict life cycle performance of components, parts, and systems produced using new manufacturing processes. | 42 | 20,600 |
| **Total** | | **440** | **175,707** |

Source: GAO analysis of National Nuclear Security Administration (NNSA) data. | GAO-22-104506

Note: NNSA officials identified one project costing $53,000 as applying to more than one category, so we have excluded that project from the totals here. Directed R&D projects typically last about 3 years, but the costs shown here are only for fiscal year 2021. The total costs of those projects over their life cycle would be higher.

As an example of an LDRD project, one of the projects supported by the Sandia National Laboratories in the Material Properties category focused on developing limited-rechargeable, high-energy-density lithium batteries for national security assets (see fig. 10 below). This project would allow NNSA to replace single-use lithium batteries and overcome qualification challenges associated with those batteries. The technology developed from this project could also be used in new applications where high-energy density and limited-recharging would be required. According to NNSA officials, this project, if successful, would help NNSA meet its national security missions that require specialized batteries with high power, extremely long shelf lives (measured in decades), and limited cycles for testing purposes. The fiscal year 2021 costs for this project were about $4 million.

**Figure 10: Limited-Rechargeable, High-Energy Density Lithium Battery Research and Development at Sandia National Laboratories**



Source: National Nuclear Security Administration. | GAO-22-104506

While the AMD program uses the eight major technical efforts to categorize its data, the directed R&D programs do not use these categories. According to NNSA officials we interviewed, there is not a clear, direct link between the categories used for the AMD program and those identified by the directed R&D programs. However, an NNSA official said that these differences do not impede the programs' ability to collaborate or to transition projects between programs as they mature.

## NNSA's Management of Its AMD Program Generally Followed Leading Practices, but NNSA Has Not Fully Developed a Performance Evaluation Process or Measures

NNSA's management of its AMD program fully or substantially followed five of six leading practices for managing federal R&D portfolios, according to our analysis of NNSA documents and information provided during our interviews with agency officials. The AMD program's collection of manufacturing-related R&D projects has the characteristics of an R&D portfolio; therefore, we applied the leading practices for managing a federal R&D portfolio to NNSA's management of the AMD program as a

whole.[31] However, NNSA has not fully developed and documented its process and measures for evaluating the performance of its manufacturing-related R&D portfolio under the AMD program.[32] Table 7 provides a summary of our analysis of the extent to which NNSA's management of its AMD program follows these leading practices.

**Table 7: Extent to Which the National Nuclear Security Administration's (NNSA) Management of Its Advanced Manufacturing Development Program Followed Leading Practices for Managing a Federal Research and Development (R&D) Portfolio**

| Leading practice | Extent followed |
|---|---|
| Develop both short-term and long-term R&D goals and priorities that align with organizational missions, needs, or strategies. | ● |
| Develop an R&D portfolio by prioritizing and selecting projects that align with short-term and long-term R&D goals and priorities. | ● |
| Identify and coordinate with stakeholders to obtain their input in developing the R&D portfolio. | ● |
| Ensure that the R&D portfolio can adapt to changing goals and priorities. | ● |
| Use a portfolio-wide system to track the progress of R&D projects to support performance monitoring. | ● |
| Evaluate the performance of the R&D portfolio to ensure that the research provides value. | ◒ |

Legend:

● = **Fully or substantially followed**—NNSA took actions that addressed most or all aspects of the key questions GAO examined for the practice.

◒ = **Partially followed**—NNSA took actions that addressed some, but not most, aspects of the key questions GAO examined for the practice.

○ = **Not followed**—NNSA took no actions that addressed the aspects of the key questions GAO examined for the practice.

Source: GAO analysis of NNSA documents and interviews with NNSA officials. | GAO-22-104506

[31]In our prior work, we referred to NNSA's Weapons Activities portfolio as a collection of projects, programs, subsidiary portfolios, and operations managed as a group to achieve strategic objectives. See GAO, *Nuclear Security Enterprise: NNSA Should Use Portfolio Management Leading Practices to Support Modernization Efforts*, GAO-21-398 (Washington, D.C.: June 9, 2021). In this context, the AMD program contributes to the Weapons Activities portfolio. However, for the purposes of this report, we are using the term "portfolio" to refer to a collection of R&D projects managed as a group to achieve strategic objectives.

[32]We did not assess the management of directed R&D programs against leading practices for managing a federal R&D portfolio because NNSA does not directly manage these programs, consistent with statute. Instead, NNSA conducts a variety of activities to oversee the directed R&D programs managed by its M&O contractors. For the purposes of this report, we are defining "management" as conducting or supervising day-to-day operations and activities, including making operational decisions and policies. We define "oversight" as the actions taken to review and monitor an organization and its policies, plans, programs, and projects to ensure that they are achieving expected results, represent good value for money, and comply with applicable laws and regulations. For examples of NNSA's oversight of the directed R&D programs, see app. I.

More specifically, our analysis of NNSA's management of its AMD program found that NNSA fully or substantially followed five leading practices for managing a federal R&D portfolio:

- **Develop short-term and long-term R&D goals, as well as priorities that align with organizational missions, needs, or strategies.** We found that NNSA has substantially followed this leading practice because AMD program officials developed short- and long-term R&D goals that aligned with organizational strategies. As previously discussed, AMD program officials stated that their R&D projects are mainly tied to two goals identified in NNSA's OETM Strategic Plan.[33] According to AMD program officials we interviewed, the OETM goals and ends were identified by taking into account customer input and priorities, such as from the Office of Production Modernization and the Office of Stockpile Management. In addition, according to AMD program officials and agency documentation, the AMD program has also developed short-term and long-term targets in its Strategic Plan that outline how the program plans to meet broader organizational missions and needs, including addressing the OETM goals.[34] Although AMD program officials indicated that the current targets are out of date, they also told us that they expect to update the targets by the end of fiscal year 2022.
- **Develop an R&D portfolio by prioritizing and selecting projects that align with short-term and long-term R&D goals and priorities.** We found that NNSA has substantially followed this leading practice because, according to AMD program officials, they follow an iterative process to prioritize and select projects that align with the sites' and headquarters' priorities.[35]
    - First, according to AMD program officials we interviewed, they disseminate the OETM goals and ends, the AMD Strategic Plan, and information about anticipated funding levels and priorities from NNSA's Offices of Stockpile Management and Production Modernization to the sites to ensure that site contractors are

[33]National Nuclear Security Administration, *Office of Engineering and Technology Maturation 2020-2050 Strategic Plan.*

[34]National Nuclear Security Administration, *Advanced Manufacturing Development Strategic Plan.*

[35]According to officials, the general process for prioritizing and selecting projects within the Weapons Technology and Manufacturing Maturation Team is outlined in its team plan. However, AMD program officials described the additional steps they take to set priorities and select projects.

aware of and can align proposed projects with R&D goals and priorities.

- Next, according to documentation we reviewed and AMD program officials we interviewed, sites compile their lists of current and proposed projects during an annual data call, explicitly tying projects to the goals and ends and ranking them based on their funding priorities.
- AMD program officials in headquarters then hold a series of monthly and ad hoc meetings with the sites to understand their priorities.
- Finally, according to AMD program officials, they develop a preliminary project list to send to the sites for comment.

Officials told us that project selections are determined by both top-down, higher-level inputs at NNSA headquarters as well as bottom-up, subject-matter expertise at the sites. Officials also document the linkage between individual AMD R&D projects and potential customers for each project—who help to determine priorities—in their information system. According to officials, customer priorities mostly encompass short-term needs related to modernizing production and producing components for the currently planned stockpile. Several of the targets in the AMD Strategic Plan focus on advancing specific projects or technologies taking into account these customer priorities.

- **Identify and coordinate with stakeholders to obtain their input in developing the R&D portfolio.** We found that NNSA has substantially followed this leading practice because AMD program officials coordinate regularly with potential technology end-users, the individual sites, and other stakeholders in developing the R&D portfolio, according to documentation we reviewed and AMD program officials we interviewed. For example:
  - The AMD program manager meets regularly with program managers from NNSA's Office of Production Modernization to discuss technology priorities. Specifically, officials we interviewed from the Office of Production Modernization told us they

coordinated extensively with AMD program officials on priority projects, such as Special Materials or Direct Cast.[36]

- The AMD program manager holds monthly calls with each AMD site program manager, and officials coordinate on project prioritization and selection.
- The AMD program manager maintains a working relationship with other stakeholders, such as the Weapon Technology and Manufacturing Maturation Program managers and the Office of Program Integration.
- AMD program officials participate in Technology Realization Teams for priority projects, along with other key stakeholders. These teams enhance collaboration between all relevant NNSA stakeholders who are required to develop, advance, and deploy a technology into stockpile sustainment and modernization programs, including identifying obstacles and encouraging NNSA's program offices to champion technologies for deployment.[37] Key roles and responsibilities for the teams are defined in charter documents, where OETM officials provide concurrence.

- **Ensure that the R&D portfolio can adapt to changing goals and priorities.** We found that NNSA has substantially followed this leading practice because AMD program officials told us that they are able to

[36]According to AMD program officials we interviewed, certain materials currently deployed in various weapon systems have significant health and safety issues and will not be used in next-generation weapon designs. However, these materials play a critical role in the function of those systems. The Special Materials project aims to develop approaches to manufacture replacement materials for application in future weapon systems and ultimately select and demonstrate a method at full scale. Direct Casting technology uses a furnace to melt and shape-cast depleted uranium alloy components specifically, creating an alternative production method that could replace or augment the existing process for such manufacturing. These components have some of the highest costs, lowest material yields, and longest lead times of any components in the nuclear stockpile. The Direct Cast project successfully transitioned from the AMD program to the Office of Production Modernization for further maturation of the technology. For further discussion of direct casting technology, see GAO, *Nuclear Weapons: NNSA Plans to Modernize Critical Depleted Uranium Capabilities and Improve Program Management*, GAO-21-16 (Washington, D.C.: Oct. 15, 2020).

[37]The key purpose of a Technology Readiness Team is to ensure the maturation of a technology from TRL 3 and MRL 1 to at least TRL 5 and MRL 3 or to show the lack of feasibility for advancement. The likelihood of a technology being inserted into a modernization or sustainment program is also increased by establishing and maintaining contact with subject-matter experts involved in all aspects of maturing a technology early in the development.

cut proposed projects from their project list, adjust the budget for projects, and reprioritize budgets to change the portfolio as priorities change. For example:

- AMD program officials we interviewed told us that they decided not to provide funding for 18 low-priority projects in fiscal year 2021.
- Officials told us that they can modify the project list depending on priorities to provide more funds for projects that could benefit from additional support. For example, according to officials and data we reviewed, the amount allotted for the Special Materials priority project was increased at one site by approximately $1.2 million during fiscal year 2021, after it was determined that additional funding for an engineering test, training, and prototype demonstration would help accelerate this priority project.
- Officials told us that they can reprioritize funds based on other circumstances, such as challenges in hiring staff with particular expertise.

According to officials, priorities change depending on the needs of the AMD program's customers—such as the Office of Stockpile Management and the Office of Production Modernization.[38] In addition, according to officials, some of the program budget is kept in reserve at the beginning of a fiscal year to be flexible and responsive to any stakeholder needs that arise between annual portfolio planning cycles.

- **Use a portfolio-wide system to track the progress of R&D projects to support performance monitoring.** We found that NNSA has substantially followed this leading practice because AMD program officials use the Technology Maturation Integrated Information System to track R&D projects and support performance monitoring, according to officials and data we reviewed. In addition to serving as a portfolio planning tool, this database serves as a repository for tracking project information. Data captured in the database include project funding levels, TRL/MRL, project scope, a description of risks and benefits, and other data points.

We found that NNSA's management of its AMD program only partially followed the remaining leading practice—**evaluate the performance of**

[38]As previously stated, customer priorities mostly encompass short-term needs related to modernizing production and producing components for the currently planned stockpile.

**the R&D portfolio to ensure that the research provides value**—for two main reasons:

- **NNSA has not fully developed and documented its process for evaluating the performance of the AMD R&D portfolio.** Leading practices we identified state that agencies should evaluate the performance of an R&D portfolio as a whole to ensure that the research provides value.[39] In addition, NNSA's directive on program management requires that programs establish and document requirements for technical and programmatic performance management.[40] NNSA has established and documented some aspects of its performance evaluation process for the AMD program, but its process for evaluating the performance of the entire AMD R&D portfolio is more informal and ad hoc. Specifically, the AMD program's Implementation Plan documents some aspects of the process for evaluating R&D projects via reporting requirements, such as standard templates for monthly site reports and program reviews, monthly teleconferences, and individual telephone calls with the officials and contractors at NNSA nuclear security enterprise sites.

  However, the Implementation Plan does not specify the measures used to evaluate performance beyond the milestones for key priority projects, and it does not specify how officials should evaluate performance across the entire portfolio. AMD program officials told us they are developing an AMD-wide end-of-year summary report, but this report would largely compile existing end-of-year documentation to provide a snapshot of information for a given fiscal year. AMD program officials we interviewed also said that they track progress of the portfolio through TRL and MRL metrics and project transition to other offices for further maturation, but they have not fully developed and documented the process for evaluating portfolio-wide performance. Without fully developing and documenting a process for evaluating R&D portfolio performance, NNSA may be relying on inconsistent measures across individual projects to evaluate performance, which could hinder NNSA's ability to evaluate performance across the entire R&D portfolio.

[39]We previously reported that organizations should consider the performance of the R&D portfolio as a whole against the organization's broader strategy and goals. GAO-17-372.

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

- **NNSA does not measure progress on long-term R&D goals and priorities for the AMD program.** Leading practices we identified state that agencies should evaluate the performance of an R&D portfolio to ensure that the research provides value. We have also previously reported that program performance assessments should include long-term and short-term goals with corresponding performance measures to assess progress on meeting these goals.[41] NNSA officials told us that they assess progress on short-term R&D goals and priorities.[42] According to officials, short-term needs are well known and defined, and typically higher priority than long-term needs.

  Conversely, NNSA does not assess progress on long-term R&D goals and priorities to evaluate portfolio performance. The AMD Strategic Plan identifies long-term targets that represent how AMD intends to achieve OETM goals.[43] However, officials we interviewed stated that long-term AMD program targets are broader, vaguer, and harder to

[41]GAO, *VA Could Improve Management by Establishing Performance Measures and Fully Assessing Risks*, GAO-16-393 (Washington, D.C.: Apr. 28, 2016). See also GAO, *Program Evaluation: Strategies to Facilitate Agencies' Use of Evaluation in Program Management and Policy Making*, GAO-13-570 (Washington, D.C.: June 26, 2013); *Performance Measurement and Evaluation: Definitions and Relationships*, GAO-11-646SP (Washington, D.C.: May 2011); and *Managing for Results: Enhancing Agency Use of Performance Information for Management Decision Making*, GAO-05-927 (Washington, D.C.: Sept. 9, 2005).

[42]For example, officials said they have established several measures for assessing progress on short-term goals and priorities. Specifically, officials told us that they first look at individual project performance to evaluate the performance of the entire portfolio, with particular emphasis on TRL/MRL and a project's ability to successfully transition to another program for further maturation. In fact, several short-term targets outlined in the AMD Strategic Plan focus on specific projects reaching a desired TRL/MRL. Officials review individual projects throughout the year, and site contractors report on project progress through monthly site reports. Officials also assign milestones and grading criteria to specific priority projects that they review and adjust those criteria quarterly based on changing priorities and funding constraints.

[43]Although the AMD Strategic Plan differentiates between mid-term (5 to 10 years) and long-term (10 to 20 years) targets, we distinguish both of these from AMD's near-term targets for the purposes of this report.

measure performance against compared to short-term targets.[44] For example, one of the AMD program's long-term targets is increasing connectivity across the nuclear security enterprise to rapidly share manufacturing feedback with designers. Officials told us that having cross-site collaborative projects could be a possible measure for this target and that progress could be measured in other ways, but they currently do not have specific measures for doing so. By contrast, NNSA officials overseeing the LDRD/SDRD programs have developed and implemented qualitative as well as quantitative measures to assess the long-term performance of those programs' R&D portfolio.[45] Without establishing measures to assess progress toward meeting long-term R&D goals and priorities, NNSA may be unable to determine the extent to which the AMD R&D portfolio will provide its intended value over time and whether the long-term goals and priorities are feasible.

## Conclusions

NNSA's efforts to modernize the nation's nuclear weapons stockpile and supporting infrastructure require manufacturing-related R&D efforts to explore new manufacturing methods, as well as alternatives to legacy manufacturing processes. Toward that end, NNSA and its contractors

[44]Our prior work has found that choosing performance measures that identify how well each organizational level is achieving its goals poses an especially difficult challenge for federal managers of research programs, for whom the link between federal efforts and desired outcomes is often difficult to establish and may not be apparent for years. Nonetheless, producing qualitative or quantitative performance measures for agency goals and objectives allows managers to assess progress and, if necessary, make changes. Managers may use qualitative measures, such as milestones, in circumstances where objectives cannot be defined by quantitative measures. See GAO, *Department of Energy: Improved Performance Planning Could Strengthen Technology Transfer*, GAO-21-202 (Washington, D.C.: Feb. 1, 2021).

[45]In fiscal year 2017, DOE's Advanced Scientific Computing Advisory Committee conducted a review of LDRD programs across the national laboratories and recommended that officials should document and highlight the longer-term (greater than 5 years) impact of LDRD as a national asset. In response, LDRD/SDRD officials developed long-term measures to assess the impacts of LDRD on the three main program objectives, with the goal of ensuring that LDRD investments are not optimized for short-term gains at the expense of future capabilities. For example, quantitative measures include the number of LDRD-related patents leading to a license over a period of years, retention of staff with early career LDRD involvement over time, the number of researchers admitted to external professional societies, and the number of projects resulting in prestigious R&D 100 Awards, among others. Qualitative measures include LDRD long-term success stories for projects that had a transformative influence on a field of science and long-term impacts on staff recruitment, among others. For context, LDRD's short-term (annual) performance indicators include the number of related peer-reviewed publications, intellectual property disclosures, patents issues, copyrights, postdoctoral support provided and conversions, and R&D awards received.

have spent hundreds of millions of dollars in recent years on manufacturing-related R&D projects, including projects in its AMD program. We found that NNSA's management of its AMD program fully or substantially followed five of six leading practices for managing a federal R&D portfolio. However, NNSA only partially followed the leading practice of evaluating the performance of the R&D portfolio to ensure that the research provides value. By fully developing and documenting its process for evaluating the performance of the entire AMD R&D portfolio and by developing measures for assessing progress on long-term R&D goals and priorities, the AMD program could better ensure that its manufacturing-related research meets NNSA's nuclear weapon stockpile modernization needs.

## Recommendations for Executive Action

We are making the following two recommendations to NNSA:

The Deputy Administrator for the National Nuclear Security Administration's Office of Defense Programs should fully develop and document the process for evaluating the performance of the AMD R&D portfolio. (Recommendation 1)

The Deputy Administrator for the National Nuclear Security Administration's Office of Defense Programs should develop measures for assessing progress on long-term R&D goals and priorities for the AMD program. (Recommendation 2)

## Agency Comments

We provided a draft of this report to NNSA for comment. In its comments, reproduced in appendix II, NNSA agreed with our recommendations and described plans to address them. NNSA also provided technical comments, which we incorporated as appropriate.

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

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

Allison Bawden
Director, Natural Resources and Environment

# Appendix I: National Nuclear Security Administration (NNSA) Activities to Conduct Oversight over the Directed Research and Development (R&D) Programs

We did not assess management of directed R&D programs against leading practices for managing federal R&D because NNSA does not manage these programs directly. Rather, these programs are managed by NNSA's management and operating (M&O) contractors at the eight sites comprising the nuclear security enterprise. However, according to NNSA officials and agency documentation we reviewed, NNSA conducts a variety of activities to oversee the M&O contractors' directed R&D programs, including sharing strategic planning, guidance documents, and directives; overseeing R&D project prioritization and selection; ensuring regular coordination with stakeholders; and monitoring R&D project progress and assessing the performance of the directed R&D portfolio. These activities are summarized below.

**Sharing strategic planning, guidance documents, and directives.** According to NNSA officials, NNSA provides guidance to site contractors through strategic plans; program guidance documents; and directives such as Department of Energy (DOE) Order 413.2C, *Laboratory Directed Research and Development*. The purpose of the guidance is to help ensure that site goals and priorities are in line with NNSA's requirements and mission. In addition, according to officials and documentation we reviewed, site contractors document their R&D goals and priorities in program plans or other strategy documents that NNSA field offices review. Officials we interviewed from select field offices responsible for overseeing Laboratory-Directed Research and Development (LDRD) programs told us that they are able to attend meetings with site contractors while the program plan (including goals and priorities in the plan) is being developed. Moreover, according to officials, each site's Annual Strategic Plan is also reviewed by NNSA programmatic offices and approved by NNSA field offices. LDRD officials we interviewed at NNSA headquarters specifically told us that they work with the NNSA field offices to oversee the contractors' development of R&D goals and priorities.

**Overseeing R&D project prioritization and selection.** According to NNSA officials, NNSA field offices review every project proposed by site contractors for mission relevance, regulatory compliance, and alignment with program-specific guidance. For each proposal, the principal investigators will also select NNSA or DOE organizations that the project supports in terms of programmatic goals, and the NNSA field office reviews this information, according to officials we interviewed from NNSA headquarters and select field offices. NNSA field offices provide concurrence on the final list of projects annually, so each project receives concurrence at initiation, as well as annually thereafter. NNSA officials

explained that they can request modifications to a project proposal or even reject projects if, for example, a business case for the project no longer exists. In addition, according to LDRD program officials from select field offices, changes are usually made annually to investment areas when identifying gaps or emerging needs.

**Ensuring regular coordination with stakeholders.** Site contractors coordinate with NNSA's Office of Stockpile Management, the Office of Production Modernization, or other stakeholders directly, and NNSA headquarters and field office officials regularly coordinate with site contractors. For example, according to officials we interviewed, they hold monthly calls with site contractors to discuss R&D portfolio planning and to monitor progress. NNSA officials overseeing each of the directed R&D programs also take specific steps to facilitate coordination among stakeholders. For example, according to officials overseeing the sites' LDRD and Site-Directed Research and Development (SDRD) programs, they use a working group to facilitate coordination and information sharing across the different site contractors and with NNSA officials. In addition, the LDRD and SDRD programs operate a web page to share best practices and lessons learned across the programs, including practices that may facilitate portfolio planning. Plant-Directed Research and Development (PDRD) program officials also stated that they facilitate communication between the plants and any other stakeholders when asked to do so.[1]

**Monitoring R&D project progress and assessing the performance of the directed R&D portfolio.** According to NNSA officials we interviewed, they rely on the contractors' internal review processes to assess project and portfolio performance; however, they also take steps to monitor progress and review performance. For example, according to officials, field offices monitor progress of a select sample of priority projects. For the sites' LDRD/SDRD programs specifically, officials we interviewed explained that field office officials have access to all of the systems that the site contractors use to monitor and track projects.[2] Moreover, NNSA

[1]For example, according to officials, officials from the Office of Production Modernization may reach out to headquarters officials to request information on a project, and headquarters officials will share that information.

[2]NNSA's Office of the Chief Financial Officer also has a reporting system that is used to produce an annual report for Congress on directed R&D expenditures, but NNSA officials do not use this system for performance monitoring. The system collects project and financial information on individual directed R&D projects, collects site-wide funding data, and provides standard reports.

officials and contractor representatives developed long-term qualitative and quantitative metrics to assess long-term performance across the LDRD/SDRD R&D portfolios. Officials also review portfolio performance when site contractors report to NNSA annually during program reviews. PDRD program officials we interviewed emphasized the annual reports produced by the plants, which contain a list of every PDRD project at the plants with key information. PDRD officials we interviewed from select field offices explained that field office officials receive information from the plants regarding any challenges they are facing that could require intervention from the NNSA field office or headquarters. Finally, NNSA field offices also review overall contractor performance annually.

# Appendix II: Comments from the Department of Energy

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

May 9, 2022

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 Security Enterprise: NNSA Could Enhance Its Evaluation of Manufacturing-Related R&D Performance" (GAO-22-104506). The Department of Energy's National Nuclear Security Administration (NNSA) appreciates GAO's recognition and validation of the Advanced Manufacturing Development (AMD) program's implementation of leading practices in managing their federal research and development (R&D) portfolio. NNSA agrees with the GAO's recommendations to further enhance those practices by more fully developing and documenting the process for evaluating the performance of the AMD R&D portfolio, and by developing measures to assess progress on long-term R&D goals and priorities for the AMD program. The estimated date for completing these actions is September 30, 2023.

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 (202) 836-3327.

Sincerely,

Jill Hruby

# Appendix III: GAO Contact and Staff Acknowledgments

## GAO Contact

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

## Staff Acknowledgments

In addition to the contact named above, Jason Holliday (Assistant Director), Jessica Lewis (Analyst-in-Charge), Antoinette Capaccio, John Delicath, Cindy Gilbert, Elizabeth Luke, Dustin Milne, Shylene Mata, Dan C. Royer, and Tind Shepper Ryen made key contributions to this report.