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August 2023

NUCLEAR WEAPONS

Program Management Improvements Would Benefit U.S. Efforts to Build New Experimental Capabilities

GAO-23-105714

GAO Highlights

Highlights of GAO-23-105714, a report to the Committee on Armed Services, House of Representatives

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Program Management Improvements Would Benefit U.S. Efforts to Build New Experimental Capabilities

Why GAO Did This Study

NNSA is responsible for ensuring the performance, safety, and reliability of the nation's nuclear stockpile without nuclear explosive testing. Subcritical experiments are used to support NNSA's assessments. NNSA conducts these experiments at the U1a underground facility at the Nevada National Security Site. This allows NNSA to obtain experimental data on plutonium and high explosives together without a nuclear explosion—hence, the experiments remain subcritical.

In 2014, NNSA identified the need for new data from these experiments and established the ECSE program to provide such data.

House Report 117-118, accompanying a bill for the National Defense Authorization Act for Fiscal Year 2022, included a provision for GAO to review the ECSE program. GAO's report (1) describes the objective of the program and (2) examines the risks that NNSA has identified to completing the program and the extent to which NNSA has used appropriate program management processes to manage these risks.

To address both objectives, GAO reviewed program documentation, interviewed NNSA and contractor officials, and conducted site visits.

What GAO Recommends

GAO is recommending that NNSA ensure adoption of additional management processes to improve risk management of the Zeus ECSE program elements. NNSA concurred with GAO's recommendation and plans to implement it by September 2025.

View GAO-23-105714. For more information, contact Allison Bawden at (202) 512-3841 or BawdenA@gao.gov or Karen Howard at (202) 512-6888 or HowardK@gao.gov.

What GAO Found

The National Nuclear Security Administration's (NNSA) objective for the Enhanced Capabilities for Subcritical Experiments (ECSE) program is to improve NNSA's ability to assess the performance, safety, and reliability of nuclear weapons without nuclear explosive testing. To do so, NNSA plans to make new measurements of plutonium during subcritical experiments by building

- an instrument named Scorpius to produce a series of x-ray images of the plutonium and
- an instrument named Zeus to measure the rate of the nuclear chain reaction.

As of March 2023, NNSA estimated that constructing both instruments and related infrastructure upgrades in the U1a facility will cost about $2.5 billion to $2.6 billion. NNSA requires both instruments by 2030 to inform plans for modernizing the nuclear weapons stockpile.

Images of a Subcritical Experiment Vessel and the U1a Underground Experimental Facility

Sources: Lawrence Livermore National Laboratory and Nevada National Security Site. | GAO-23-105714

NNSA has identified risks to the ECSE program and has appropriately managed risks to build Scorpius. Specifically, NNSA identified risks to the ECSE program in four categories: integration of efforts, safety, economic conditions, and technology development. GAO found that NNSA applied appropriate processes to manage these risks for Scorpius and associated infrastructure, such as using a technical change control board to integrate the efforts to design and build Scorpius and the associated infrastructure upgrades.

NNSA used less rigorous processes to manage risks for Zeus and its associated infrastructure, resulting in a 2-year delay and increased cost. Specifically, the lack of processes to integrate the instrument and infrastructure, such as a technical change control review board, resulted in the need for additional mining at U1a to accommodate instrument design changes. While NNSA used less rigorous management processes typical of research and development programs, such as Zeus, NNSA's program management requirements provide flexibility to use additional processes to appropriately address risks. As of May 2023, NNSA began implementing more rigorous processes to manage Zeus' infrastructure, but NNSA has not yet adopted more rigorous processes to manage risks for the Zeus instrument, in particular related to technology development and integration. By implementing additional risk management processes, NNSA may prevent further delays to Zeus and the associated infrastructure and ensure that it obtains necessary data for stockpile modernization.

Contents

Abbreviations

ASD	Advanced Sources and Detectors
DARHT	Dual Axis Radiographic Hydrodynamic Test
DOE	Department of Energy
ECSE	Enhanced Capabilities for Subcritical Experiments
Livermore	Lawrence Livermore National Laboratory
Los Alamos	Los Alamos National Laboratory
NDSE	Neutron Diagnosed Subcritical Experiments
NNSA	National Nuclear Security Administration
Sandia	Sandia National Laboratories
UCEP	U1a Complex Enhancements Project
ZTBFI	Zeus Test Bed Facilities Improvement

U.S. GOVERNMENT ACCOUNTABILITY OFFICE

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

Since 1992, the U.S. has observed a unilateral moratorium on nuclear explosive testing while continuing to maintain and modernize the nuclear stockpile.[1] Ensuring the stockpile's performance, safety, and reliability is the responsibility of the National Nuclear Security Administration (NNSA)—a separately organized agency within the Department of Energy (DOE). As a result, NNSA, through its Stockpile Stewardship Program, maintains and modernizes the nuclear stockpile, without relying on nuclear explosive testing, by regularly assessing each type of weapon through a network of experimental facilities and complex computer models.

Subcritical experiments play a crucial role in NNSA's weapon assessments because they allow NNSA to study plutonium by compressing it with high explosives—the same process that occurs in a nuclear weapon—but in a way that falls short of conducting a nuclear explosive test.[2] NNSA conducts subcritical experiments approximately 1,000 feet underground at its U1a facility of the Nevada National Security Site. Weapon designers and physicists from Los Alamos National Laboratory (Los Alamos) and Lawrence Livermore National Laboratory (Livermore) design these subcritical experiments and incorporate the data into the nuclear weapon computer models that are used to assess the stockpile.

In recent years, weapon design changes from programs to modernize and extend the life of warheads and bombs in the stockpile, as well as the

[1]A nuclear explosive test is the detonation of a nuclear weapon in a controlled environment, such as underground, to check its operation and measure its capabilities.

[2]Most nuclear weapons in the U.S. stockpile use two stages. The first stage, known as the primary, consists of a pit made of plutonium surrounded by high explosives. Detonation of the high explosives creates an implosion that compresses the plutonium and starts the chain of fission nuclear reactions. Subcritical experiments study the compression of plutonium in implosion, as well as flat (planar) configurations.

aging of weapon components, have increased uncertainties in NNSA's computer models. The models were originally developed using the data from historical U.S. nuclear tests, and the historical data do not fully reflect the changes in the stockpile. In 2014, NNSA and the laboratories identified gaps in their understanding of nuclear weapons physics that, if filled with new experimental data, would help address these uncertainties. In response, NNSA established the Enhanced Capabilities for Subcritical Experiments (ECSE) program—a joint collaboration among the Nevada National Security Site, Los Alamos, Livermore, and Sandia National Laboratories (Sandia), managed and overseen by NNSA. In 2016, the JASON Defense Advisory Group reviewed the mission need for ECSE, noted the same gaps in experimental data, and confirmed the need to fill those gaps by improving the ability to carry out and study subcritical experiments.[3] Through ECSE, NNSA plans to expand the infrastructure of the U1a facility and construct two new scientific instruments, named Scorpius and Zeus, which NNSA will use to obtain the needed experimental data.[4] NNSA plans to complete these instruments by fiscal year 2030. As of March 2023, NNSA estimated that the combined efforts under ECSE would cost approximately $2.5 billion to $2.6 billion.

House Report 117-118, accompanying a bill for the National Defense Authorization Act for Fiscal Year 2022, includes a provision for GAO to review NNSA's ECSE program.[5] Our report (1) describes the objective of the ECSE program and (2) examines the risks that NNSA has identified to completing the ECSE program and the extent to which NNSA has employed appropriate program management processes to manage these risks.

To address the first objective, we reviewed key documentation from NNSA—including classified documentation—about the scientific motivation for the ECSE program. This documentation included the ECSE mission need statement, the Scorpius project's analysis of alternatives,

[3]The JASON's mission is to contribute to national security and public benefit by working on problems of importance to the U.S. government. The group is organized and supported by the MITRE Corporation—a not-for-profit research and development organization.

[4]Throughout this report, we refer to these scientific instruments as the Scorpius instrument and the Zeus instrument. Both instruments require associated infrastructure improvements at the Nevada National Security Site's U1a facility. The name Zeus is an acronym for Z-pinch Experimental Underground System (ZEUS), but we will refer to it as "Zeus" throughout this report.

[5]H.R. Rep. No. 117-118, pt. 1, at 337 (accompanying H.R. 4350, a bill for the National Defense Authorization Act for Fiscal Year 2022).

and ECSE program key performance parameters. We interviewed NNSA officials for the ECSE program, the subcritical experiments program, and certain warhead modernization programs. We also interviewed scientists, weapon designers, and program staff at the contractor-managed and -operated national laboratories—Los Alamos, Livermore, Sandia—and the Nevada National Security Site and conducted a site visit to each of the four sites. Finally, we reviewed relevant JASON reports and interviewed a scientist from JASON who had reviewed the ECSE program mission need and technical requirements.

To address the second objective, we reviewed documentation from NNSA about the risks and associated program management processes for ECSE. This documentation included project and program plans for each element of the ECSE program. We also reviewed supplemental documentation, including risk management plans, risk registers, and information on new technologies. We interviewed NNSA program officials, as well as ECSE program staff from Los Alamos, Livermore, Sandia, and the Nevada National Security Site.

From our review of documentation and interviews, we developed a list of high-level risks—those risks with the highest probability of occurrence and most significant consequences—that NNSA had identified for each element of the ECSE program. We grouped these risks into four broad categories: economic conditions, integration of efforts, safety, and technology development. One analyst performed the initial grouping of these risks, and a second analyst reviewed the groupings. For each of these risk categories, we identified program management processes that NNSA employed to manage risks, as well as the overall risk management processes that NNSA used and compared the processes with NNSA's program management requirements.

We conducted this performance audit from January 2022 to August 2023 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives. We are separately issuing a classified annex to this report that provides additional details on how

ECSE supports the weapon modernization programs.[6] The annex will be available upon request to those with the appropriate clearance and a validated need to know.

Background

Subcritical Experiments

Subcritical experiments are an integral part of Stockpile Stewardship. To date, the U.S. has conducted 33 subcritical experiments since 1997. These experiments are carefully designed so that the plutonium never reaches the point where a nuclear explosion would occur—thus, the experiments remain subcritical.[7] Because subcritical experiments do not produce a nuclear explosion, they do not conflict with the U.S moratorium on nuclear testing. However, subcritical experiments do involve plutonium—a radioactive material. To contain the radioactive material after detonation and protect human health and the environment, NNSA conducts each subcritical experiment underground and in a steel confinement vessel. (See fig. 1.) After executing the subcritical experiment, NNSA encapsulates the confinement vessel in concrete at the U1a facility—a process known as entombment.

Figure 1: Images of a Subcritical Assembly in a Steel Confinement Vessel (left) and a View of an Underground Tunnel at the U1a facility Used to Conduct Subcritical Experiments (right)

Sources: Lawrence Livermore National Laboratory and Nevada National Security Site. | GAO-23-105714

NNSA's Office of Experimental Sciences within the Office of Research, Development, Test, and Evaluation is responsible for overseeing subcritical experiment planning and execution. Los Alamos and Livermore

[6]GAO, *Classified Annex for GAO-23-105714: Applications of New Experimental Capabilities to Stockpile Modernization Programs and Plutonium Science*, GAO-23-106738C (Washington, D.C.: August 2023).

[7]A nuclear chain reaction that produces a nuclear explosion is referred to as a supercritical reaction.

are responsible for identifying experiments to prioritize based on the research needs of Stockpile Stewardship and modernization programs. Sandia provides diagnostic support to the subcritical experiments. For its part, the Nevada National Security Site is responsible for maintaining and operating the U1a facility, including exercising mining capabilities and conducting nuclear safety analyses. The Office of Experimental Sciences also coordinates with the Plutonium Program Office for the production of plutonium components needed for the experiments.

The Subcritical Experiments Council—comprised of representatives from Los Alamos, Livermore, Sandia, and the Nevada National Security Site—develops and provides NNSA with a recommended schedule of experiments to support Stockpile Stewardship. Typically, an experiment, or series of experiments, is placed on the Council's schedule between 5 and 10 years before the execution date. Approximately 3 years before execution, a baseline plan with defined requirements must be established. The Council meets every 6 months to adjust the schedule, as needed, based on changing priorities. As of May 2023, the subcritical experiments schedule includes planned experiments through 2032, including experiments that are intended to rely on ECSE.

NNSA Program Management Requirements

The ECSE program is part of the Office of Experimental Sciences within the Office of Research, Development, Test, and Evaluation in NNSA's Office of Defense Programs. The *Defense Programs Program Execution* Instruction provides methods for conducting program management and establishes program management categories and execution requirements for those categories, among other things.[8] Defense Programs uses four program management categories, in order of increasing rigor: Standard Management, Enhanced Management B, Enhanced Management A, and Capital Acquisition Management.

The *Defense Programs Program Execution Instruction* establishes criteria to determine the category in which a program should be designated:

- Standard Management includes weapon surveillance, technology maturation, science, and engineering programs. This category utilizes a tailored approach to program management implementation. A tailored approach means that the program manager can exercise

[8]Department of Energy, National Nuclear Security Administration, *Defense Programs Program Execution Instruction, Rev. 3* (Washington D.C.: September 2021).

professional judgment to determine the degree of controls, verification, and documentation needed to meet requirements.

- Enhanced Management B applies to programs that use a tailored approach but have been designated as requiring additional rigor for reasons including schedule or cost commitments; complexity and risk associated with the activity; or the need for inter-site integration.
- Enhanced Management A applies to programs that require certain congressional reporting. NNSA uses this category for weapon modernization programs, including life extension programs.
- Capital Acquisition Management applies to projects designated as capital asset acquisition projects.[9] For the Capital Acquisition Management category, the *Defense Programs Program Execution Instruction* refers to DOE Order 413.3B, which provides additional requirements and guidance for capital asset acquisition projects.[10] According to DOE Order 413.3B, the management processes apply to all capital asset acquisition projects with a total project cost greater than $50 million. However, according to the order, NNSA may also apply these processes to nuclear first-of-a-kind projects under that threshold.

For each management category, the *Defense Programs Program Execution Instruction* identifies minimum requirements for executing programs, including requirements for risk management. The *Defense Programs Program Execution Instruction* directs managers to use a risk management process to identify, assess, and systematically manage risks. This process includes ensuring that managers address risks to minimize negative impacts on cost, performance, and schedule and to ensure that risks factor into program planning and decision-making. How a risk management process is implemented, including the extent that it is documented, varies depending on (1) the level of management rigor employed and, particularly for programs using a tailoring approach, (2) the judgment of the program manager.

[9]NNSA defines a capital asset as land, structures, equipment, and intellectual property that are used by the federal government and that have an estimated useful life of 2 years or more.

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

ECSE Program Elements

The ECSE program consists of four main elements (see fig. 2).

Figure 2: Program Elements of the Enhanced Capabilities for Subcritical Experiments Program

Scorpius project		Zeus project	
Instrument	**Infrastructure**	**Instrument**	**Infrastructure**
• Advanced Sources and Detectors (ASD) to build Scorpius instrument • **Estimated cost:** $1.8 billion • **Estimated completion:** fiscal year 2030	• U1a Complex Enhancements Project (UCEP) • **Estimated cost:** $610 million • **Estimated completion:** fiscal year 2027	• Neutron Diagnosed Subcritical Experiment (NDSE) to build Zeus instrument • **Estimated cost:** $70.1 million • **Estimated completion:** fiscal year 2025	• Zeus Test Bed Facilities Improvement (ZTBFI) project • **Estimated cost:** $49.5 million to $125.5 million • **Estimated completion:** fiscal year 2026

Source: GAO analysis of National Nuclear Security Administration documentation. | GAO-23-105714

- **Scorpius instrument.** A capital asset acquisition project, named the Advanced Sources and Detectors (ASD) project, will design and build the Scorpius instrument under the requirements of DOE Order 413.3B. As of March 2023, NNSA had approved a cost baseline for this project of $1.8 billion, with expected completion in fiscal year 2030.[11]
- **Scorpius infrastructure.** A capital asset acquisition project, named the U1a Complex Enhancements Project (UCEP), will provide the infrastructure upgrades necessary to house the Scorpius instrument at U1a under the requirements of DOE Order 413.3B. Activities include mining additional tunnels, constructing new diagnostic and control rooms, installing safety equipment, and providing power supplies. As of March 2023, NNSA had approved a cost baseline for this project of $610 million, with expected completion in fiscal year 2027.[12]
- **Zeus instrument.** A subprogram, named the Neutron Diagnosed Subcritical Experiments (NDSE), will design and build the Zeus

[11]A cost baseline is a budget that has been developed from the cost estimate that is time phased, supports the technical baseline, and is traceable to the work breakdown structure. DOE evaluates project performance against this cost baseline. All capital asset acquisition projects must develop a baseline cost as part of their project management process.

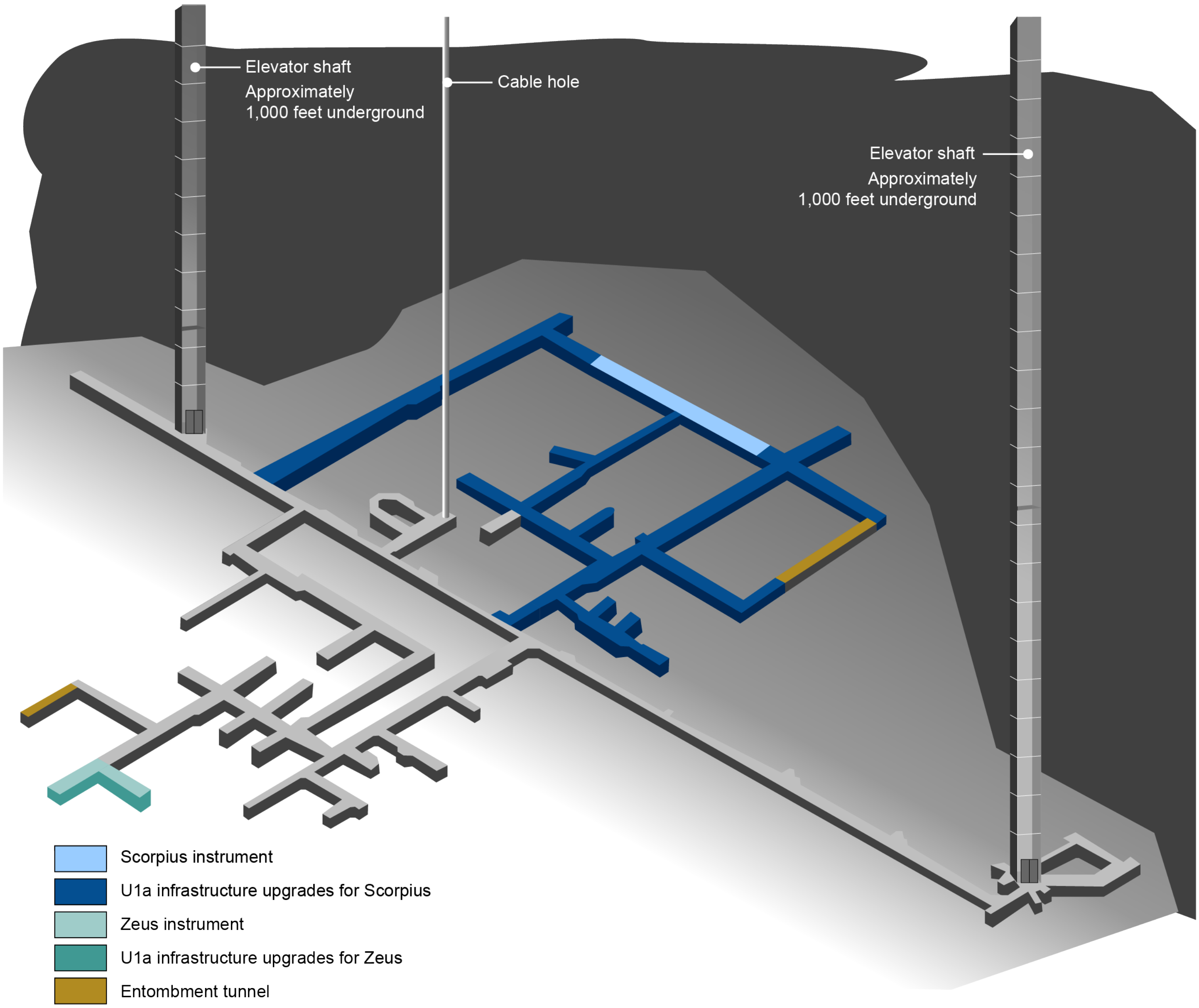
[12]This cost baseline includes two subprojects, one of which was completed in June 2022 for $50 million and another for which NNSA approved a cost baseline of $560 million in June 2022.

instrument. NNSA manages the Zeus instrument using its Standard Management processes. As of May 2023, NNSA estimated that this effort will cost $70.1 million and be completed in fiscal year 2025.

- **Zeus infrastructure.** NNSA initially managed the U1a infrastructure upgrades necessary to house the Zeus instrument, along with the effort to design and build the instrument, as a single ECSE subprogram using its Standard Management processes. NNSA has begun transitioning the infrastructure upgrades to a separate capital asset acquisition project under DOE Order 413.3B. The new project, named the Zeus Test Bed Facilities Improvement (ZTBFI) project, will also include additional mining activities. NNSA issued an official memorandum in May 2023 informing Congress of these plans. However, the transition is not expected to be complete until fiscal year 2024, in part because NNSA had to include the project as a specific line item in its budget justification for congressional authorization. As of March 2023, NNSA estimated that this effort will cost between $49.5 million and $125.5 million and be completed in fiscal year 2026.

Figure 3 shows the planned location of the ECSE program elements at the U1a facility.

Figure 3: Elements of the Enhanced Capabilities for Subcritical Experiments Program at the Underground U1a Facility, Nevada National Security Site, as of June 2023



Source: GAO analysis of National Nuclear Security Administration documentation. | GAO-23-105714

NNSA's Ability to Improve Its Assessments of Weapons without Nuclear Testing Relies on the ECSE Program to Develop New Instruments

NNSA's objective for the ECSE program is to improve its ability to assess weapons without nuclear explosive testing. To achieve this objective, NNSA requires new measurements of plutonium from subcritical experiments. According to NNSA, data from these new measurements can help NNSA reduce uncertainties in the weapon computer models it uses to assess the stockpile. NNSA plans to build two new scientific instruments to make these measurements.

NNSA Requires Improved Measurements of Plutonium to Continue Assessing Nuclear Weapons

According to ECSE program documentation, NNSA has identified a need for new measurements of plutonium from subcritical experiments to improve its ability to assess weapons without nuclear explosive testing. Specifically, NNSA identified two types of measurements needed when the plutonium reaches high pressure and density, during the late stages of implosion:

- radiographic measurements in the form of multiple, quick succession x-ray images to study how the imploding subcritical assembly changes in time; and
- measurements of the rate of the fission chain reaction in plutonium to study the nuclear properties of the subcritical assembly, which change as the plutonium becomes more compact.[13]

NNSA and the national laboratories have stated in ECSE program and supporting documentation that incorporating new experimental data from these measurements is essential to lowering uncertainties in computer models, which will allow them to make timely and necessary stockpile assessments. In particular, in DOE's fiscal year 2023 budget justification, NNSA stated that it requires data from ECSE to complete assessments of

[13]A nuclear chain reaction occurs when neutrons from a fission, or splitting, of one nucleus produce additional fissions in nearby nuclei. Thus, each fission has a multiplicative effect of producing additional fissions (e.g., one fission yields two additional fissions, which yield four more, etc.). The rate of this multiplication for a given assembly of nuclear material is called reactivity.

the ongoing W87-1 Modification Program.[14] In addition, NNSA reported in its ECSE program requirements document that the new data are necessary to assess elements of weapon modernization designs, such as the use of existing or newly manufactured pits or the replacement of conventional high explosives with insensitive high explosives to reduce the risk of accidental detonation.[15] Furthermore, the Federal Program Manager for the Subcritical Experiments Program noted that NNSA plans to use data from ECSE to help assess the effects of plutonium aging on weapon performance.

To provide data in time to inform stockpile modernization plans, NNSA requires the ability to make both types of measurements by 2030, according to NNSA's subcritical experiment schedule. Specifically, NNSA plans to begin subcritical experiments that measure the rate of the fission chain reaction in fiscal year 2026 to obtain the timely and necessary data by 2030. Similarly, the subcritical experiments schedule identifies the need to begin making radiographic measurements of subcritical experiments in 2030. For more information on NNSA's intended plans to use ECSE to support stockpile modernization programs and plutonium science, see the separately reported classified annex to this report.[16]

[14]The W87-1 Modification Program is one of NNSA's multibillion- dollar warhead modernization programs. The program will replace aging W78 warheads used on intercontinental ballistic missiles. See GAO, *Nuclear Weapons: NNSA Has Taken Steps to Prepare to Restart a Program to Replace the W78 Warhead Capability,* GAO-19-84 (Washington, D.C.: November 2018); and *Nuclear Weapons: NNSA Should Further Develop Cost, Schedule, and Risk Information for the W87-1 Warhead Program,* GAO-20-703 (Washington, D.C.: September 2020).

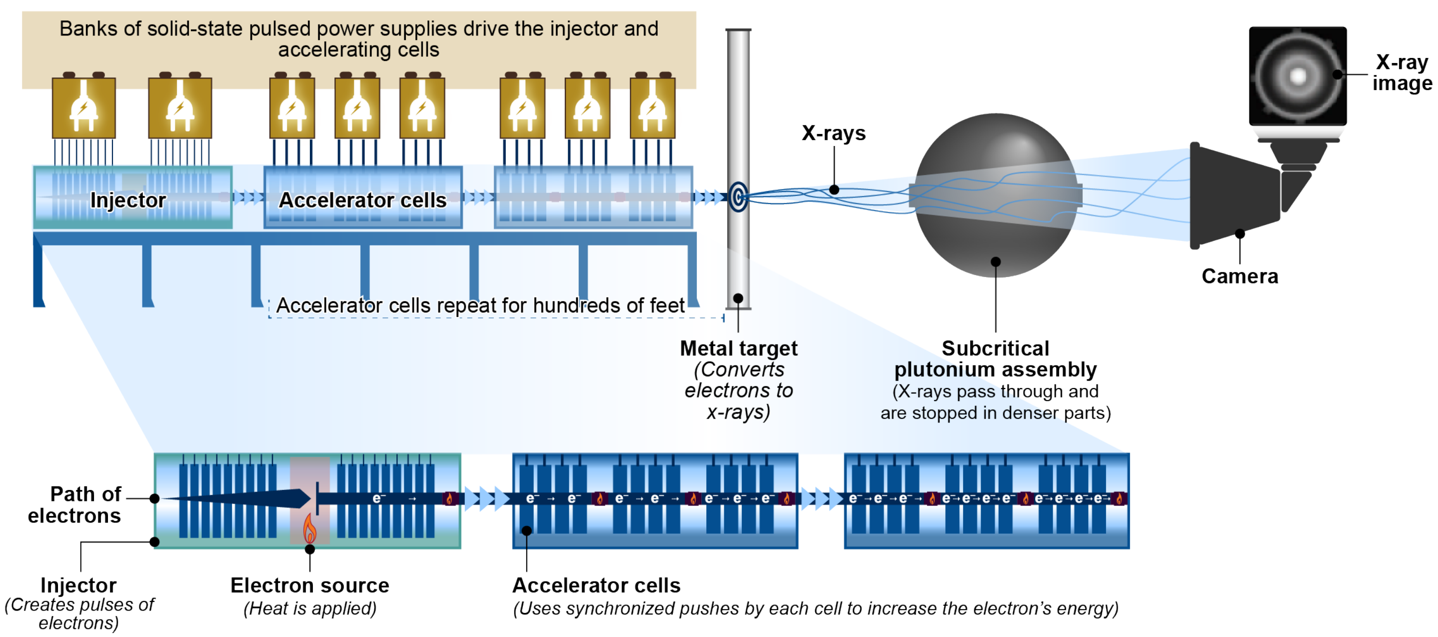
[15]Insensitive high explosives consist of a material known as triaminotrinitrobenzene (TATB), which is less susceptible to accidental detonation; less violent upon accidental ignition; and, therefore, safer to handle than conventional high explosives, which use cyclotetramethylene tetranitramine (HMX). See GAO, *Nuclear Weapons: Additional Actions Could Help Improve Management of Activities Involving Explosive Materials*, GAO-19-449 (Washington, D.C.: June 2019). For information about NNSA's pit manufacturing program, see GAO, *Nuclear Weapons: NNSA Does Not Have a Comprehensive Schedule or Cost Estimate for Pit Production Capability,* GAO-23-104661 (Washington, D.C.: January 2023).

[16]GAO-23-106738C.

NNSA Requires New Scientific Instruments and Updated Infrastructure to Make These Measurements

NNSA plans to build two new scientific instruments, named Scorpius and Zeus, and update infrastructure to U1a to make the radiographic and chain reaction rate measurements. NNSA plans to build the Scorpius instrument—a type of linear induction accelerator—to make the radiographic measurements underground in the U1a facility.[17] NNSA designed Scorpius to produce high-energy pulses of electrons and convert them to x-rays. According to NNSA's plan, Scorpius will direct the x-rays onto the subcritical assembly. A camera will detect the x-rays that pass through the subcritical assembly and produce an image—similar to the process used to create a medical x-ray image. (See fig. 4.) Scorpius is designed to produce four x-ray pulses in quick succession to create a series of images that show how the subcritical assembly changes in time.

Figure 4: Schematic of the Scorpius Linear Induction Accelerator Instrument Developed under the Enhanced Capabilities for Subcritical Experiments Program



Source: GAO analysis of National Nuclear Security Administration documentation. | GAO-23-105714

[17] A linear induction accelerator uses coordinated electromagnetic fields to accelerate particles to very high energies.

Technologies in Scorpius

According to the National Nuclear Security Administration (NNSA), the Scorpius linear induction accelerator will incorporate several new technologies designed to produce four quality x-ray images.

First, Scorpius will be the first instrument to use a push-pull design for its injector to produce four consecutive pulses of electrons. In this design, the electrons are to be accelerated between two electrodes: one that is negatively charged and one that is positively charged. Each electrode voltage is generated by 21 individual cells that collectively produce the necessary voltage on each electrode (0.85 megavolts). As negatively charged particles, the electrons will be pushed away from the negative electrode and pulled toward the positively charged one.

The push-pull design reduces the necessary voltage on each electrode by half, which is required to be compatible with the size constraints at the U1a facility. This design requires NNSA and the laboratories to develop improved technologies related to the injector cells, power transmission, and vacuum system, among others.

In addition, Scorpius will be the first linear induction accelerator to use exclusively solid-state pulsed power supplies. Each cell in the injector and accelerator must receive a carefully timed pulse of electrical energy to accelerate the electron beam. Other accelerators use banks of capacitors to supply this power. However, these banks cannot be recharged in time to provide the four consecutive pulses of Scorpius.

By contrast, solid-state pulsed power supplies use a series of circuit boards with solid-state (nonmechanical) switches to produce multiple pulses without needing to completely discharge and recharge the supplies, according to scientists from the Lawrence Livermore National Laboratory. These solid-state supplies are designed to allow Scorpius to produce four pulses with consistent energy and duration.

Source: NNSA. | GAO-23-105714

Pending construction of Scorpius, NNSA relies on equipment with more limited capabilities. NNSA has an existing accelerator at U1a, named Cygnus, to make radiographic measurements, but Cygnus does not have enough energy to take images of late-stage implosions. NNSA currently makes radiographic measurements of late-stage implosions using surrogate materials at its Dual Axis Radiographic Hydrodynamic Test (DARHT) facility at Los Alamos. Due to safety concerns, NNSA cannot use plutonium at DARHT, which is aboveground; the surrogate materials mimic, but do not perfectly replicate, certain properties of plutonium. According to Los Alamos and Livermore scientists, the use of surrogates limits their ability to answer stockpile questions. Scorpius aims to improve on Cygnus and DARHT by providing a high-energy accelerator that can measure late-stage implosions using plutonium.

Scorpius will use two new technologies never incorporated on a linear induction accelerator before: (1) a four-pulse, push-pull injector to generate the electron pulses and (2) solid-state power supplies for the injector and accelerating cells. According to scientists from Sandia, Los Alamos, and Livermore, these new technologies allow them to produce the required four electron pulses with better control over their formation and timing, which results in better x-ray images.

As mentioned above, in addition to building Scorpius, NNSA plans to upgrade the U1a infrastructure to support the new accelerator. These infrastructure upgrades include mining new tunnels in U1a. NNSA also plans to install new utilities to supply power and chilled water for Scorpius.

Principles of Zeus

According to the National Nuclear Security Administration (NNSA) the Zeus instrument aims to measure the nuclear reactivity in subcritical experiments. When a neutron strikes an assembly of plutonium, it can initiate a nuclear chain reaction based on the properties of the assembly, such as the geometry (e.g., sphere or flat sheet) and the density of the plutonium. The rate of the chain reaction is a nuclear property of the plutonium assembly that depends, in part, on these physical properties.

The rate of the chain reaction can be characterized as supercritical—when the rate increases exponentially; critical—when the rate remains constant; or subcritical—when the rate declines exponentially.

However, in addition to characterizing the rate into those three categories, an actual quantitative measurement of the rate of the chain reaction, even a subcritical chain reaction, can help weapon scientists design and assess nuclear primaries. The Zeus instrument is intended to make a quantitative measurement of the chain reaction rate in subcritical assemblies.

During the chain reaction, each fissioning nucleus emits gamma radiation, which, for nuclear explosive tests, NNSA could detect to measure the rate of the chain reaction. The Zeus system simulates that process by bombarding the subcritical assembly with many additional neutrons to increase the number of fissions and gamma rays.

Since the plutonium assembly is subcritical, the increased neutrons will not produce a nuclear explosion but, according to NNSA documentation, should produce a gamma ray signal that allows NNSA to measure the rate of the chain reaction in the subcritical assembly.

Source: NNSA. | GAO-23-105714

To make the chain reaction measurement, NNSA plans to build the Zeus instrument—a type of dense plasma focus. A dense plasma focus is a device that uses electrical energy to heat a gas—in the case of Zeus, hydrogen gas using the isotopes deuterium and tritium.[18] With enough energy, this gas will form an ionized plasma and initiate a fusion reaction.[19] When two of the hydrogen nuclei fuse together, they will produce a neutron that the Zeus system will use to study subcritical assemblies. According to NNSA's plan, Zeus is designed to direct the neutrons it produces onto the subcritical assembly. As the pulse of neutrons causes the plutonium to fission, a separate wall of detectors, approximately 9 square meters in size, are to measure the energy coming from those fissions and determines the rate of the fission chain reaction.[20]

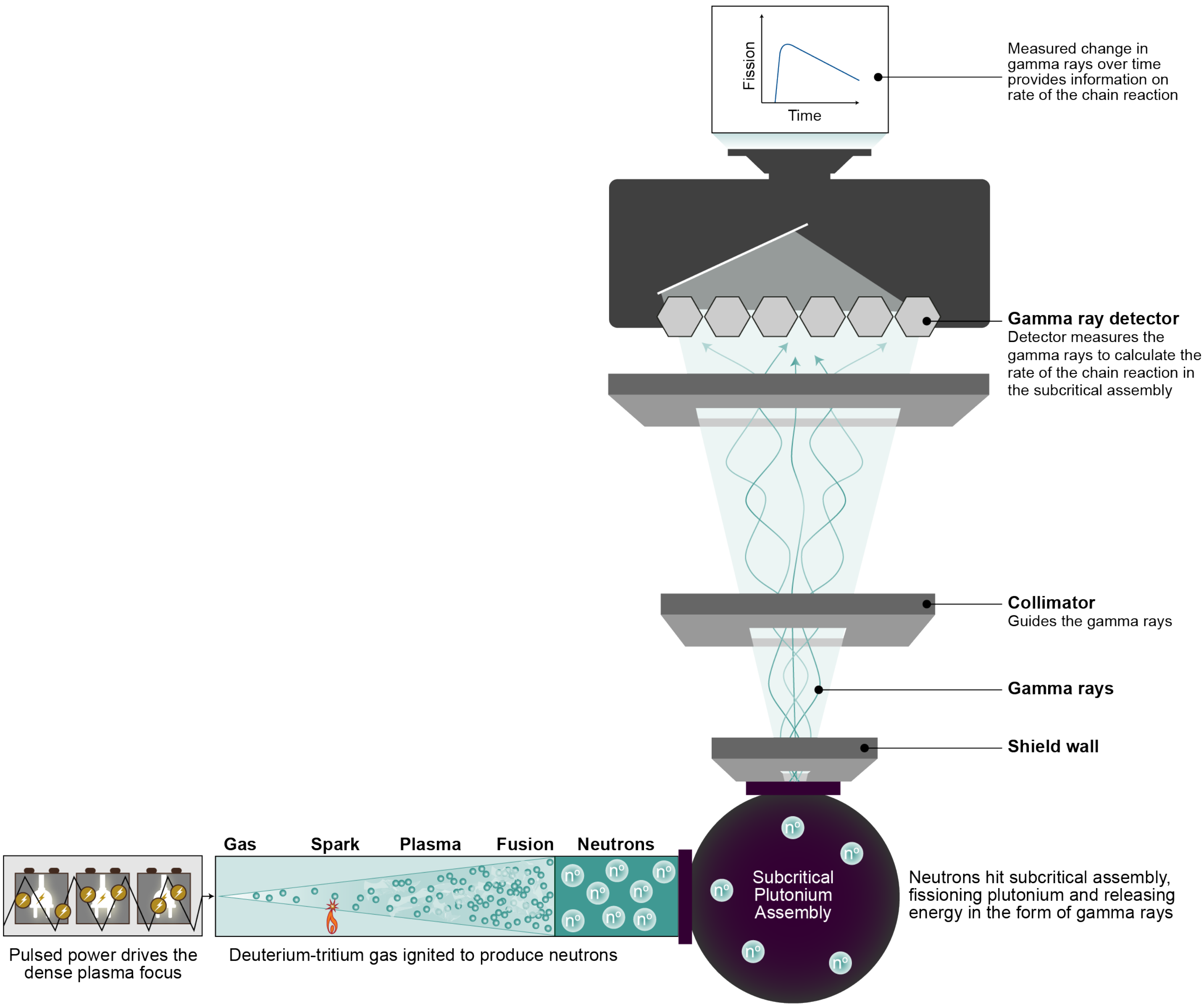
NNSA has developed dense plasma focus instruments before, but Zeus would be the first application of this technology to measure plutonium implosions. To successfully measure the chain reaction during the implosion process, the laboratories must demonstrate the ability to carefully control the timing and duration of the neutron pulse. In addition, NNSA must use a detector wall with enough area and separation from the subcritical experiment to detect and measure the energy signal from the fissioning plutonium. (See fig. 5.)

[18]Isotopes are variations of a given chemical element with the same number of protons but different numbers of neutrons. Most hydrogen consists of one proton and zero neutrons. Deuterium contains one proton and one neutron. Tritium has one proton and two neutrons.

[19]An ionized plasma is a state of matter where the electrons have enough energy that they separate from the nucleus. Fusion is a nuclear reaction where two nuclei fuse together to form a heavier nucleus, releasing energy in the process.

[20]NNSA will measure the energy from the fission to determine the rate of the chain reaction by detecting prompt gamma rays. These gamma rays are particles of light that are released when the nucleus fissions.

Figure 5: Schematic of the Zeus Dense Plasma Focus Instrument Developed under the Enhanced Capabilities for Subcritical Experiments Program



Source: GAO analysis of National Nuclear Security Administration documentation. | GAO-23-105714

As mentioned above, in addition to building Zeus, NNSA plans to upgrade the U1a infrastructure to support the instrument. These infrastructure upgrades include additional mining to house the Zeus system and constructing radiation shielding walls.

NNSA Has Identified Multiple Risks but Has Not Implemented Appropriate Risk-Management Processes for All ECSE Program Elements

NNSA has identified multiple risks across ECSE program elements—Scorpius, Zeus, and associated infrastructure—but has not implemented appropriate processes to manage these risks for all elements. The risks are similar across the elements and are associated with integration of efforts, safety, economic conditions, and technology development. NNSA has used less rigorous processes to manage these risks for Zeus than it has for Scorpius, contributing to delays and cost increases for Zeus and its associated infrastructure.

NNSA Has Identified Similar Risks across ECSE Program Elements

Officials managing Scorpius, Zeus, and their associated infrastructure program elements have identified similar risks. Our analysis indicates that these risks fall into four broad categories:

- **Integration of efforts:** NNSA identified risks related to the integration of efforts across program elements to design and build the Scorpius and Zeus instruments and the parallel program elements to construct their associated infrastructure. For example, NNSA identified that not defining and coordinating requirements between the design of the Scorpius instrument and the construction of its associated infrastructure could lead to missed requirements, schedule delays, and increased costs. Similarly, NNSA noted that not finalizing the instrument design for Zeus in time could delay construction of the associated infrastructure.
- **Safety:** NNSA identified safety risks regarding the construction and operation of the Scorpius and Zeus instruments and their associated infrastructure. For example, Scorpius officials identified risks related to possible accidents during its construction and the potential need to provide additional stabilization to the tunnels during construction. Zeus officials identified potential risks to human health related to the use of tritium in the Zeus instrument underground at U1a due to limited ventilation. Tritium, a radioactive isotope, poses a health hazard if inhaled. Both Scorpius and Zeus officials also noted risks related to completing required safety analyses in time to move the projects forward.

- **Economic conditions:** For both Scorpius and Zeus, NNSA identified risks related to economic conditions, such as having personnel available to support the design, procurement, construction, and safety analysis work due to limited staffing and difficulty recruiting additional staff. Further, for the Scorpius instrument, NNSA identified numerous risks due to the procurement of specialized parts with limited supplier options, as well as with general global economic uncertainty caused by inflation.
- **Technology development:** NNSA identified risks to developing critical, new technologies for both the Scorpius and Zeus instruments in time to meet the overall projects' goals. As mentioned above, both instruments include technologies that need additional development to meet the ECSE program requirements. For example, Scorpius officials identified several technologies related to the injector and solid-state pulsed power systems that require development. Similarly, Zeus officials identified the need to develop technology to use tritium, which, as noted above, is essential to the neutron production of the Zeus instrument.

NNSA Used Appropriate Processes to Manage Risks for Scorpius but Used Less Rigorous Processes for Zeus, Adding to Delays and Cost

NNSA used appropriate processes to manage risks for Scorpius, but it has used less rigorous risk management processes for Zeus, resulting in delays and increased cost. The use of less rigorous risk management processes for Zeus, such as the lack of a single federal project director and the lack of a change control board, led to the unsuccessful management of an integration risk for Zeus. Specifically, in February 2022, NNSA determined that, because of design changes to the Zeus instrument, the preexisting tunnel planned to house the instrument was too narrow to fit it. Without processes to manage the integration risks between instrument and infrastructure, NNSA did not identify problems with the tunnel when they changed the instrument design. According to NNSA documentation, Zeus will now be delayed by approximately 2 years and face a significant cost increase for redesigning and drilling additional tunnels.[21] The delay in Zeus has resulted in a nearly 3-year delay to NNSA's planned subcritical experiments to measure the rate of the fission chain reaction, according to the agency's subcritical experiments schedule.

While the risk management processes selected for managing Zeus were consistent with the minimum requirements outlined in the *Defense*

[21]According to NNSA documentation, the total cost estimate for the Zeus infrastructure upgrades at U1a increased from $17.2 million to a range of $49.5 million to $125.5 million.

Programs Program Execution Instruction, the processes selected have not appropriately addressed the risks for Zeus program elements. Under the *Defense Programs Program Execution Instruction* and DOE Order 413.3B, NNSA could have adopted more rigorous management processes, given the complexity and integration needs of Zeus.[22] However, unlike for the Scorpius program elements, the agency did not tailor the Zeus program elements to include additional risk management processes.

Our analysis indicates that for NNSA's overall risk management approach, as well as to manage integration and technology risks, NNSA used less rigorous processes to manage Zeus compared with Scorpius, which contributed to the delays and cost increases for Zeus. In contrast, NNSA has used substantially similar processes to manage economic condition and safety risks for both Scorpius and Zeus.

- **Overall risk management**
  - Scorpius. To manage risks for Scorpius and the associated infrastructure, NNSA developed documented risk management plans and risk registers. The plans defined the processes for identifying, handling, and monitoring risks, as well as the roles and responsibilities for people who managed the risks. NNSA used the risk registers to identify and track risks, as well as to estimate their likelihood and the consequences of their realization.
  - Zeus. To manage risks for Zeus and the associated infrastructure, NNSA developed a risk register but not a risk management plan. Without a documented risk management plan, NNSA did not define the processes for identifying, handling, and monitoring risks or the roles and responsibilities for managing risks. The absence of a documented risk management plan increases the likelihood that NNSA may not identify all risks or track their mitigation to completion.
- **Integration of efforts**
  - Scorpius. NNSA established processes to manage risks related to the integration of efforts across the instrument and infrastructure program elements, including assigning a single project director to oversee both the Scorpius instrument and infrastructure upgrades to U1a; an integrated project team consisting of federal and

[22]Department of Energy, National Nuclear Security Administration, *Defense Programs Program Execution Instruction, Rev. 3.*

contractor representatives working on both program elements; a memorandum of agreement outlining the respective responsibilities for the contractors of the national laboratories and the Nevada National Security Site; and a technical change control board to manage technical design changes. The contractors involved said that these efforts have helped NNSA coordinate design and construction activities across the projects. For example, the technical change control board considers any design changes to the Scorpius instrument and the associated infrastructure and whether changes to one might affect the other. According to NNSA officials and laboratory representatives, having a single body consider changes helps reduce the risk that the changes will have unintended adverse effects on the program.

    - Zeus. NNSA did not establish processes to manage risks related to the integration of efforts across the instrument and infrastructure program elements. For example, NNSA did not designate a single federal project director to manage Zeus and the associated U1a upgrades nor a technical change control board to approve design changes of the Zeus instrument that might affect the design of associated U1a infrastructure upgrades. Without such processes, there is an increased risk that the designs for the Zeus instrument and its associated U1a infrastructure will not be well integrated or coordinated. As mentioned above, NNSA already realized this risk in one way when the lack of such processes led to the unsuccessful management of integration risks for Zeus, resulting in a 2-year delay and significant increased costs for designing and drilling additional tunnels in U1a.

- **Safety**
    - Scorpius. NNSA developed a safety strategy to identify and mitigate safety risks related to the Scorpius instrument and associated infrastructure upgrades. This strategy includes developing a documented safety analysis that details controls to address each identified safety risk.
    - Zeus. NNSA used the same processes to manage safety risks for the Zeus instrument and its associated infrastructure upgrades as it used for Scorpius.

- **Economic conditions**
    - Scorpius. NNSA employed a procurement strategy to obtain specialized components with long delivery time frames for the Scorpius instrument and to reduce risks from economic

conditions, such as limited availability or price fluctuation. For components that it could not obtain through this strategy, NNSA provided adjusted risk assessments and cost estimates in the wake of COVID-19 supply chain issues and inflation.

- Zeus. According to NNSA officials, they adjusted its risk assessments and cost estimates in the wake of COVID-19 supply chain issues and inflation. Similar to Scorpius, NNSA employed a procurement strategy to obtain specialized components with long delivery time frames for Zeus and its associated infrastructure.

- **Technology development**
  - Scorpius. NNSA conducted technology readiness assessments to evaluate the maturity of new technologies in the Scorpius instrument. NNSA conducted these assessments using independent experts apart from the contractors developing the instrument. The program also developed a technology maturation plan to identify steps to mature certain technologies in time to meet project goals and milestones.
  - Zeus. NNSA did not conduct independent technology readiness assessments to assess the maturity of new technologies in the Zeus instrument. Instead, the federal program manager relied on assessments of maturity from the contractors developing the technologies.[23] This approach increases the risk that NNSA may not have accurate information about the maturity of these new technologies that NNSA needs to ensure that Zeus meets the program goals and timeline.

In general, NNSA has used more rigorous processes to manage Scorpius due to NNSA's initial expected cost and scope of Scorpius, which met the criteria for the use of its most stringent category of program management—Capital Acquisition Management, under DOE Order 413.3B.[24] Some of the processes used to manage Scorpius and the associated infrastructure, such as designating a federal project director and employing independent technology readiness assessments, are

[23]For comprehensive technical readiness assessments, members of the assessment team should be subject matter experts who are independent of the program to avoid conscious or subconscious bias or the perception thereof. 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.: Jan. 7, 2020) [Reissued with revisions on Feb. 11, 2020].

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

required for capital asset acquisition projects. However, NNSA also adopted additional discretionary processes to manage risks, such as the memorandum of agreement, that are not requirements for Capital Acquisition Management. According to NNSA officials and contractor representatives, these additional management processes are used to enhance risk management between the program elements to build the Scorpius instrument and the associated infrastructure.

NNSA has achieved several improvements and positive outcomes since tailoring its management approach and adopting the current risk management processes for Scorpius that we observed during our review. Prior to 2019, NNSA's efforts to build the Scorpius instrument and its associated U1a upgrades experienced challenges because of insufficient project management, according to a report by the DOE Office of Inspector General that primarily focused on U1a infrastructure upgrades.[25] According to NNSA officials, measures like the memorandum of agreement and the technical change control board have helped address past issues and mitigate integration risks that could lead to delays or cost overruns. In addition, NNSA officials said that all critical, new technologies for the Scorpius instrument have reached the necessary maturity and are on schedule. Further, despite increases to the preliminary cost estimates, NNSA's September 2022 independent cost estimate review found that the program's estimate followed best practices related to the analysis of risk, which resulted in a credible cost estimate.[26]

NNSA officials said that they did not apply the same rigorous processes for Zeus and the associated infrastructure because that work started as a

[25]According to the DOE Office of Inspector General, project management weaknesses occurred, in part, because of the Nevada National Security Site management and operating contractor's lack of experienced staff initially assigned to the project, poor project performance, and earned value management system certification issues. Department of Energy, Office of Inspector General, *U1A Complex Enhancements Project*, Audit: DOE-OIG-23-09 (Washington, D.C.: Nov. 22, 2022).

[26]GAO, *Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Program Costs*, GAO-20-195G (Washington, D.C.: Mar. 12, 2020); and *Schedule Assessment Guide: Best Practices for Project* Schedules, GAO-16-89G (Washington, D.C.: Dec. 22, 2015). The Independent Cost Estimate team found that NNSA's estimate was consistent with GAO best practices for cost estimating and that the Scorpius project will cost $1.8 billion, with completion in February 2030. It also found that NNSA was meeting seven of eight applicable best practices for project schedules. The cost estimate for the project increased from a preliminary range of $500 million-$1.1 billion established in 2019 to a baseline cost estimate of $1.8 billion in 2022. The preliminary cost estimate was generated prior to the COVID-19 pandemic, and all construction costs have since increased.

research and development program. According to the *Defense Programs Program Execution Instruction*, research and development programs are typically only required to follow the less rigorous program management requirements for the Standard Management category of programs.[27] As noted above, however, NNSA can use a tailored approach when implementing Standard Management requirements. This gives managers the flexibility to select the program management processes to use, including risk management processes, with sufficient rigor to ensure that program requirements are met.

In January 2023, the Nevada National Security Site contractor completed a causal analysis that identified factors that contributed to the delays to Zeus.[28] The analysis found that the program's management approach was insufficient to address programmatic risks. As of May 2023, NNSA officials told us that they were beginning to implement more rigorous management processes for Zeus to address programmatic risks, in particular for the associated infrastructure upgrades. Specifically, NNSA officials said that they were transitioning management of the infrastructure upgrades from Standard Management to a capital asset acquisition project under DOE Order 413.3B. NNSA has already begun this transition by including the new Zeus infrastructure project in the integrated project team and technical change control board previously established to manage the construction of the Scorpius instrument and its infrastructure upgrades. However, the transition is not expected to be complete until fiscal year 2024, in part because NNSA had to include the project as a specific line item in its budget for congressional authorization.[29]

Unlike the Zeus infrastructure, NNSA will continue to manage the design and building of the Zeus instrument using its Standard Management processes but plans to establish additional processes to manage the risks related to integrating the instrument with its associated infrastructure upgrades, according to NNSA officials and Los Alamos, Livermore, and the Nevada National Security Site representatives. However, as of May

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[27]Department of Energy, National Nuclear Security Administration, *Defense Programs Program Execution Instruction, Rev. 3.*

[28]The Nevada National Security Site is managed under a management and operating contract with Mission Support and Test Services, LLC. Contractor personnel prepared the causal analysis to identify the cause of the delays to Zeus and possible preventative actions.

[29]As noted previously, NNSA informed Congress in May 2023 that it plans to transition the Zeus infrastructure program element to a capital asset acquisition project under DOE Order 413.3B.

2023, plans for these additional processes were not completed, and these processes were not yet in place. Without them, NNSA may still not be sufficiently addressing these integration risks.

Further, as of May 2023, NNSA has not established a plan for implementing independent technology readiness assessments to evaluate the maturity of new technologies for the Zeus instrument. Instead, Nevada National Security Site and Los Alamos representatives said that they will continue to evaluate whether the Zeus instrument is ready for use in U1a in time to meet program goals, using their own assessment processes. Planning for and implementing independent assessments, however, would allow NNSA program managers greater assurance that they have accurate information about the maturity of, and remaining technical challenges associated with, the technologies that NNSA needs to ensure that Zeus meets the program goals and timeline.

To meet ECSE program requirements and ensure timely assessment of the performance, safety, and reliability of nuclear weapons, NNSA must obtain data from Zeus by 2030. Using improved processes to manage integration and technology risks, as well as a robust risk management plan, may help prevent further delays to Zeus and the associated infrastructure. Further delays could jeopardize NNSA's ability to obtain these data, which could place significant limitations on NNSA's ability to continue assessing the nuclear weapons stockpile.

Conclusions

Subcritical experiments play a crucial role in NNSA's assessments of the performance, safety, and reliability of the U.S. nuclear stockpile. To address uncertainties in NNSA's computer models that it uses to assess the stockpile, NNSA plans to design and build two new instruments—Scorpius and Zeus—under the ECSE program, to make measurements of plutonium during the late stages of implosion in subcritical experiments. NNSA has made progress in designing and building the Scorpius instrument and constructing the associated infrastructure upgrades at U1a that, when completed, would allow NNSA and the national laboratories to obtain necessary radiographic measurements of subcritical experiments. NNSA, however, has not appropriately managed risks while designing and building the Zeus instrument and constructing the associated infrastructure upgrades to ensure that Zeus will meet requirements to make measurements of the rate of the chain reaction in subcritical experiments. Accordingly, NNSA has experienced delays and cost increases. By implementing more rigorous processes to manage integration and technology risks, as well as a robust and documented risk management plan, NNSA may prevent further delays to Zeus and the associated infrastructure.

Recommendation for Executive Action

The Assistant Deputy Administrator of the Office of Research, Development, Test, and Evaluation should ensure that program management processes are adopted to appropriately address risks to designing and building the Zeus instrument and constructing the associated U1a infrastructure upgrades. In particular, these processes should include documented risk management plans that define the process for identifying, handling, and monitoring risks, as well as the roles and responsibilities for managing risks; processes to manage risks related to the integration of efforts across the instrument and infrastructure program elements, such as a technical change control board to manage design changes to the Zeus instrument; and processes to independently assess the maturity of new technologies needed for the instrument to meet program goals and timelines. (Recommendation 1)

Agency Comments

We provided a draft of this report to NNSA for its review and comment. In its comments, reproduced in Appendix I, NNSA concurred with our recommendation, stating that it acknowledges the need for additional processes to manage Zeus and plans to implement more rigorous processes. 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 NNSA Administrator, 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 Allison Bawden at (202) 512-3841 or bawdena@gao.gov or Karen L. Howard at (202) 512-6888 or howardk@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 major contributions to this report are listed in appendix II.

Allison Bawden
Director, Natural Resources and Environment

Karen L. Howard, PhD
Acting Chief Scientist and Director, Science, Technology Assessment, and Analytics

Appendix I: Comments from the National Nuclear Security Administration

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

August 16, 2023

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: Program Management Improvements Would Benefit U.S. Efforts to Build New Experimental Capabilities* (GAO-23-105714). The Department of Energy's National Nuclear Security Administration (DOE/NNSA) appreciates GAO's recognition that the Scorpius testbed, including both the Advanced Sources and Detectors project and the U1a Complex Enhancement Project, is being managed with the appropriate level of rigor, as the Scorpius testbed constitutes over 90 percent of the total estimated cost of the Enhanced Capabilities for Subcritical Experiments Program.

With regard to the Zeus test, we acknowledge that additional processes are necessary beyond the application of the Standard Management program management category in the area of risk management. NNSA converted the Zeus Test Bed Facilities Improvement (ZTBFI) project into a 413.3B capital acquisition project via the fiscal year 2024 President's Budget, which will significantly enhance the rigor of our risk management practices and include documented risk management plans. We are also formalizing the interfaces between the Zeus instrument and ZTBFI through a series of Interface Control Documents while proceeding with experimental demonstrations of Zeus. The Zeus demonstrations will establish that the technology in Zeus' instruments is mature and ready for deployment.

We agree with the auditors' recommendation to further enhance Zeus program management processes and will focus our efforts on enhancement opportunities where actions that address the recommendation are not currently underway. The enclosed Management Decision outlines the specific actions planned and taken to address GAO's 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, please contact Dean Childs, Director, Audits and Internal Affairs, at (202) 836-3327.

Sincerely,

Jill H

Jill Hruby

Enclosure

NATIONAL NUCLEAR SECURITY ADMINISTRATION
Management Decision

"Nuclear Weapons: Program Management Improvements Would Benefit U.S. Efforts to Build New Experimental Capabilities" (GAO-23-105714)

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

Recommendation 1: Ensure that program management processes are adopted to appropriately address risks to designing and building the Zeus instrument and constructing the associated U1a infrastructure upgrades. In particular, these processes should include documented risk management plans that define the process for identifying, handling, and monitoring risks as well as the roles and responsibilities for managing risks; processes to manage risks related to the integration of efforts across the instrument and infrastructure program elements, such as a technical change control board to manage design changes to the Zeus instrument; and processes to independently assess the maturity of new technologies needed for the instrument to meet program goals and timelines.

Management Response: Concur. We acknowledge that additional processes are necessary beyond the application of the Standard Management program management category in the area of risk management. NNSA converted the Zeus Test Bed Facilities Improvement (ZTBFI) project into a DOE O. 413.3B capital acquisition project via the fiscal year 2024 President's Budget which will significantly enhance the rigor of our risk management practices and include documented risk management plans. We are also formalizing the interfaces between the Zeus instrument and ZTBFI through a series of Interface Control Documents while proceeding with experimental demonstrations of Zeus. The Zeus demonstrations will establish that the technology in Zeus' instruments is mature and ready for deployment. Additional process enhancements will take into consideration risks related to the coordination of efforts across several different program elements, among other issues, and a change control board will actively manage the development of Interface Control Documents for the Zeus instrument. The estimated date for completing this action is September 30, 2025.

Appendix II: GAO Contacts and Staff Acknowledgments

GAO Contacts

Allison Bawden, (202) 512-3841, bawdena@gao.gov or Karen L. Howard, PhD at (202) 512-6888 or howardk@gao.gov.

Staff Acknowledgments

In addition to the contacts named above, Brian M. Friedman (Assistant Director), R. Scott Fletcher, PhD (Assistant Director), William Bauder, PhD (Analyst in Charge), Colleen Berny, Antoinette Capaccio, Penney Harwell Caramia, John W. Hocker, Cynthia Norris, Steven Putansu, and Sara Sullivan made key contributions to this report.

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