United States Government Accountability Office

Report to Congressional Committees

April 2021

HIGH-PERFORMANCE COMPUTING

NNSA Could Improve Program Management Processes for System Acquisitions

GAO-21-194

GAO@100 Highlights

Highlights of GAO-21-194, a report to congressional committees

April 2021

HIGH-PERFORMANCE COMPUTING

NNSA Could Improve Program Management Processes for System Acquisitions

Why GAO Did This Study

NNSA is responsible for maintaining the nation's nuclear stockpile. To analyze the performance, safety, and reliability of nuclear weapons, it acquires high-performance computing (HPC) systems to conduct simulations. The latest system, El Capitan, is expected to be fully deployed by March 2024.

The committee report accompanying the Energy and Water Development and Related Agencies Appropriations Act, 2019, includes a provision for GAO to review NNSA's management of its Advanced Simulation and Computing program. This report examines, among other things, (1) the extent to which NNSA's AOA process for the El Capitan acquisition met best practices and followed agency policy and guidance and (2) the extent to which NNSA is implementing selected acquisition best practices in carrying out the El Capitan acquisition program. GAO reviewed documents and interviewed NNSA officials and laboratory representatives involved in carrying out the AOA and acquisition processes.

What GAO Recommends

GAO recommends that NNSA (1) ensure that future HPC acquisition programs follow AOA best practices, where possible, and justify and document any deviations consistent with policy; (2) ensure that an independent entity conducts future AOA processes; and (3) update and maintain acquisition program documents to include El Capitan requirements for the ongoing acquisition. NNSA generally concurred with these recommendations.

View GAO-21-194. For more information, contact Allison Bawden at (202) 512-3841 or bawdena@gao.gov or Kevin Walsh at (202) 512-8151 or walshk@gao.gov.

What GAO Found

The National Nuclear Security Administration's (NNSA) analysis of alternatives (AOA) process for its $600 million El Capitan HPC acquisition did not fully follow agency policy that states that AOA processes should be consistent with GAO best practices, where possible, and any deviations must be justified and documented. According to GAO best practices, a reliable AOA process should meet four characteristics: it should be comprehensive, well documented, unbiased, and credible. As seen in the table, the AOA process for El Capitan partially met one of these characteristics and minimally met the other three. NNSA did not justify or document the deviations from these best practices, as required by NNSA policy. GAO also found that the AOA process was conducted by the contractor that manages the El Capitan acquisition program, contrary to agency policy and guidance stating that AOAs should be conducted by an independent entity. Without following AOA best practices where possible; justifying and documenting any deviations; and ensuring AOA processes are conducted by an independent entity, as required, NNSA cannot be assured of a reliable assessment of options for meeting critical mission needs.

Extent to Which the National Nuclear Security Administration (NNSA) Met the Characteristics of a Reliable Analysis of Alternatives (AOA) Process

AOA characteristic	GAO assessment	Example of deviation
Comprehensive	Partially met	Cost estimates are incomplete and did not follow best practices.
Well documented	Minimally met	The alternatives' descriptions are not detailed enough for a robust analysis.
Unbiased	Minimally met	NNSA had a predetermined solution, acquiring an HPC system, before performing the AOA process.
Credible	Minimally met	The selection criteria appear to have been written for the preferred alternative.

Source: GAO analysis of NNSA information. | GAO-21-194

GAO found that, in the second year of the El Capitan acquisition program's 5-year acquisition life cycle, NNSA has fully implemented selected key practices related to program monitoring and control. However, NNSA has only partially implemented key practices related to requirements management. Specifically, El Capitan program officials did not update and maintain acquisition program documents to include current requirements. NNSA officials stated that once the program developed its program plan early in the program's life cycle, they did not require the program to update and maintain that program plan. However, NNSA's own program management policy requires programs to update program documents throughout the duration of the program. Without updating and maintaining El Capitan program documents to include current requirements, NNSA officials may be limited in their ability to ensure that all mission requirements are met.

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Abbreviations

AOA	analysis of alternatives
ASC	Advanced Simulation and Computing
CEPE	National Nuclear Security Administration Office of Cost Estimating and Program Evaluation
CMMI®	Capability Maturity Model Integration®
CMMI®-ACQ	Capability Maturity Model Integration® for Acquisition
DOE	Department of Energy
ExaFLOPS	one quintillion floating point operations per second
FLOPS	floating point operations per second
HPC	high-performance computing
LCCE	life cycle cost estimate
Livermore	Lawrence Livermore National Laboratory
Los Alamos	Los Alamos National Laboratory
NA-MB	National Nuclear Security Administration Office of Management and Budget
NAP	National Nuclear Security Administration Policy
NNSA	National Nuclear Security Administration
Sandia	Sandia National Laboratories
TFLOPS	teraFLOPS, or 1 trillion floating point operations per second
TiB	tebibyte

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April 29, 2021

The Honorable Dianne Feinstein
Chair
The Honorable John Kennedy
Ranking Member
Subcommittee on Energy and Water Development
Committee on Appropriations
United States Senate

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

Since 1992, the United States has observed a moratorium on nuclear explosive testing, based on the national security assessment that it does not need to conduct such testing to ensure the safety, security, and effectiveness of the nuclear weapons it maintains. As a result, the Department of Energy's (DOE) National Nuclear Security Administration (NNSA), through its Stockpile Stewardship Program, maintains and modernizes the nuclear stockpile without relying on nuclear testing.[1]

NNSA's Advanced Simulation and Computing (ASC) program is an essential element of the Stockpile Stewardship Program.[2] It develops

[1]The Stockpile Stewardship Program was established in 1995 and includes a series of what DOE initially called "campaigns," which DOE defined as technically challenging, multiyear, multifunctional efforts to develop and maintain the critical capabilities needed to continue assessing the safety and reliability of the nuclear stockpile into the foreseeable future without underground testing. See GAO, *Nuclear Weapons: Preliminary Results of Review of Campaigns to Provide Scientific Support for the Stockpile Stewardship Program*, GAO-05-636R (Washington, D.C.: Apr. 29, 2005). More recently, NNSA has organized its Stockpile Stewardship work around science, technology, and engineering programs, each of which may have several campaign-like initiatives. See Department of Energy, National Nuclear Security Administration, *Fiscal Year 2020 Stockpile Stewardship and Management Plan* (Washington, D.C.: July 2019).

[2]The ASC program was established in 1996 as the Accelerated Strategic Computing Initiative, which officially ended in fiscal year 2004 and became the Advanced Simulation and Computing program in fiscal year 2005.

modeling and simulation capabilities and deploys high-performance computing (HPC) platforms to analyze and predict the performance, safety, and reliability of nuclear weapons and to help certify their functionality in the absence of nuclear testing.[3] Since its establishment in 1996, NNSA's ASC program has developed and deployed some of the world's most powerful computers, according to the TOP500 list.[4]

Three contractor-managed and -operated national laboratories, which NNSA oversees, develop the computing, modeling, and simulation tools for the ASC program: Los Alamos National Laboratory (Los Alamos) in New Mexico; Sandia National Laboratories (Sandia) in New Mexico and California; and Lawrence Livermore National Laboratory (Livermore) in California. NNSA works with these labs to manage the acquisition of the HPC systems on which the tools run. As part of this process, the labs help develop requirements for modeling and simulation capabilities; conduct an analysis of alternatives (AOA) process for each acquisition, which is intended to identify the best way to meet those requirements; and manage contracts with vendors to supply HPC capabilities.

NNSA's latest HPC system acquisition is named El Capitan and is required by the statement of work associated with the contract for its acquisition to provide a greater-than-10-fold increase in computational performance, as measured by the peak operational speed, over the current highest-performing ASC HPC system—Sierra. El Capitan will be the ASC program's first exascale computing system. As such, it is part of

[3]High-performance computing generally is the use of aggregated computing power to achieve much higher performance than that of typical desktop computers or workstations to solve large problems in science, engineering, or business. The performance of a computer is a function of characteristics such as response time, throughput, and execution time.

[4]The TOP500 list is a project started in 1993 to rank the most powerful computing systems around the world. The rankings are based on system performance against the LINPACK benchmark. The performance information is self-reported, and the authors of the list attempt to verify the information but cannot guarantee its accuracy. The LINPACK benchmark is used to measure the actual performance of a computing system by running a system of linear equations on the system. This allows uniformity in reporting performance across all systems. However, no single benchmark or method of measuring system performance can provide the overall performance of a system.

DOE's Exascale Computing Initiative[5] that seeks to meet NNSA's goal of achieving an exascale HPC system by the early 2020s to support its nuclear weapons stockpile and nonproliferation activities as included in its strategic vision.[6] According to an NNSA document, the need to assess the performance of current and future weapons systems against the growing capabilities of adversaries to use advanced defensive systems requires computing capabilities that will exceed those provided by nonexascale computing systems. NNSA's HPC systems will be used to simulate nuclear weapons designs that may differ from the weapons designs that were historically tested due to changes such as design modifications or aging effects, according to an NNSA document.

The House committee report accompanying the Energy and Water Development and Related Agencies Appropriations Act, 2019, includes a provision for us to review NNSA's management of the ASC program to evaluate NNSA's process for setting requirements and evaluating alternatives and to identify the estimated costs of NNSA's future systems compared with previous acquisitions.[7] Our objectives were to examine (1) how the cost of NNSA's El Capitan acquisition program will compare with the costs of previous HPC acquisition programs, (2) the extent to which NNSA's AOA process for the El Capitan acquisition program met best practices and followed agency policy and guidance, and (3) the extent to which NNSA is implementing selected acquisition best practices in carrying out the El Capitan acquisition program.

To address our first objective, we reviewed cost and budget documents for the ASC HPC acquisition programs, comparing the cost and budget for El Capitan against the cost and budget for previous HPC acquisition programs. We also interviewed NNSA officials and laboratory representatives about the costs of the acquisition programs.

[5]As part of the 2015 interagency National Strategic Computing Initiative, DOE's Office of Science and NNSA partner on the Exascale Computing Initiative to develop exascale systems with applications to address next-generation science, engineering, and data problems. An exascale computing system is one that is capable of at least a quintillion (or billion billion) floating point operations per second (FLOPS), or one exaFLOPS.

[6]National Nuclear Security Administration, *Strategic Vision: Strengthening Our Nation through Nuclear Security* (Washington, D.C.: December 2018).

[7]H. Rep. No. 115-697 at 111 (2018) (accompanying Pub. L. No. 115-244, 132 Stat. 2898 (2018)).

To address our second objective, we reviewed the AOA documentation for the El Capitan acquisition program[8] against GAO's best practices for an AOA process.[9] These practices are grouped into four characteristics that identify a reliable AOA process—that is, a process that is comprehensive, well documented, unbiased, and credible.[10] To determine the extent to which NNSA's AOA process met each of the four characteristics, we assigned a rating of "not met," "minimally met," "partially met," "substantially met," or "fully met" for each best practice associated with a characteristic.[11] We then combined the ratings for the best practices to determine the extent to which the AOA process met each of the four characteristics, assigning an overall rating of not met, minimally met, partially met, substantially met, or fully met.

We also reviewed DOE's and NNSA's Office of Defense Programs program management and AOA policy and guidance, which provide a management framework for the El Capitan acquisition program, and interviewed NNSA officials and laboratory representatives to determine

[8]Lawrence Livermore National Laboratory, *Mission Need Package (CD-0) for ASC El Capitan System Acquisition Project* (Livermore, CA: November 2017); and *Draft Conceptual Baseline/Execution Readiness Package (CD-1/3a) for the NNSA ASC El Capitan Advanced Technology System Procurement* (Livermore, CA: January 2018).

[9]For this report, we used the best practices for an AOA process as identified in GAO, *Amphibious Combat Vehicle: Some Acquisition Activities Demonstrate Best Practices; Attainment of Amphibious Capability to Be Determined,* GAO-16-22 (Washington, D.C.: Oct. 28, 2015). Subsequent to our review, these best practices were updated in GAO, *Cost Estimating and Assessment Guide,* GAO-20-195G (Washington, D.C.: March 2020). The differences between the two versions are minor and did not impact the results of our review.

[10]A comprehensive AOA process is one that ensures that the mission need is defined in a way to allow for a robust set of alternatives, that all analyzed alternatives have been considered, and that each alternative is analyzed thoroughly over the program's entire life cycle. A well-documented AOA process is one that is thoroughly described in a single document, including all source data, clearly detailed methodologies, calculations and results, and where the selection criteria are explained. An unbiased AOA process is one that does not have a predisposition toward one alternative over another and is based on traceable and verifiable information. A credible AOA process is one that thoroughly discusses the limitations of the analysis resulting from the uncertainty that surrounds both the data and the assumptions for each alternative.

[11]The ratings were assigned as follows: not met—provided no evidence that satisfies any of the best practice or characteristic; minimally met—provided evidence that satisfies a small portion of the best practice or characteristic; partially met—provided evidence that satisfies about half of the best practice or characteristic; substantially met—provided evidence that satisfies a large portion of the best practice or characteristic; and fully met—provided complete evidence that satisfies the best practice or characteristic.

the extent to which the AOA process for the El Capitan acquisition program followed applicable agency policy and guidance.[12] These interviews were conducted with officials from NNSA's Office of Advanced Simulation and Computing and Institutional Research and Development Programs under NNSA's Office of Defense Programs, which is the program office for the El Capitan acquisition program; NNSA's Office of Management and Budget, which is responsible for leading NNSA-initiated AOA processes; and NNSA's Office of Cost Estimating and Program Evaluation, which provides independent analyses, including cost estimating, alternatives assessment, and program performance evaluation for NNSA. More detail about our review of the El Capitan AOA process can be found in appendix II.

For our third objective, we reviewed the Software Engineering Institute's Capability Maturity Model Integration® for Acquisition (CMMI®-ACQ) and selected two areas—program monitoring and control and requirements management—that represented information technology acquisition areas of particular importance to the El Capitan acquisition program.[13] Next, using our professional judgment, we selected the best practices related to those two areas that were most applicable to the El Capitan acquisition program when factoring in that the acquisition is in early stages. We reviewed the extent to which NNSA is implementing the selected best practices applicable to early stage acquisitions by reviewing El Capitan acquisition program documents, such as its risk registers, conceptual baseline document, and acquisition plan, and assessed the documents against the best practices. Based on this analysis, we assessed each practice area as "implemented," "partially implemented," or "not implemented."[14] We also interviewed officials from NNSA and

[12]Department of Energy, *Program and Project Management for the Acquisition of Capital Assets,* DOE Order 413.3B (Change 5) (Washington, D.C.: April 2018); Department of Energy, Office of Defense Programs, *DP Program Execution Instruction: NA-10 Program Management Tools and Processes,* (Washington, D.C.: Rev. 1, October 2015, and Rev. 2, June 2019); Department of Energy, *Defense Programs Analysis of Alternatives Guidance* (Washington, D.C.: January 2017); and *Business Operating Procedure 03.07: Analysis of Alternatives* (Washington, D.C.: March 2016).

[13]Software Engineering Institute, *Capability Maturity Model Integration® for Acquisition (CMMI®-ACQ)*, Version 1.3 (Pittsburgh, PA: November 2010).

[14]The assessments were assigned as follows: implemented—NNSA provided complete evidence that showed it fully satisfied the practice area; partially implemented—NNSA provided evidence that showed it partially satisfied the practice area; or not implemented—NNSA did not provide evidence that showed it satisfied any of the practice area.

representatives from Livermore involved in the El Capitan acquisition program.

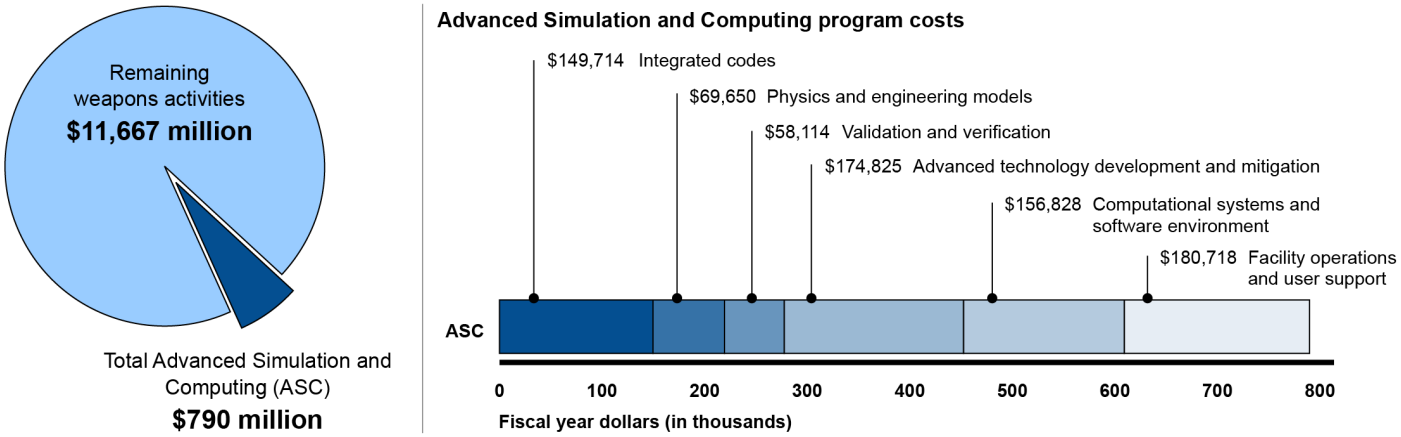
We conducted this performance audit from March 2019 to April 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

NNSA's HPC System Acquisitions

In 1993, DOE established the Stockpile Stewardship Program to improve the science and technology for assessing an aging nuclear weapons stockpile without underground nuclear testing. NNSA's ASC program, an integral part of this program, develops simulation capabilities to predict the performance, safety, and reliability of nuclear weapons and to help certify their functionality. As part of this effort, NNSA's national labs—Los Alamos, Sandia, and Livermore—acquire HPC systems to support the software used for running simulations. NNSA leverages each HPC as a shared resource among the three labs, regardless of the location of the HPC system. For fiscal year 2020, funding for the ASC program constituted about 6 percent of NNSA's total funding for weapons activities. According to an NNSA official, funding for all ASC HPC system acquisitions comes from the Computational Systems and Software Environment portion of the ASC program's overall costs (see fig. 1).

Figure 1: Advanced Simulation and Computing Program Budget for Fiscal Year 2020



Source: National Nuclear Security Administration. | GAO-21-194

Since 1996, NNSA has acquired 13 major HPC systems to support its simulation efforts and is in the process of acquiring two more—Crossroads and El Capitan. Generally, the computational performance of NNSA's HPC systems has increased over time. However, NNSA plans for a very significant increase in computational performance with its El Capitan system acquisition program.[15] For example, the statement of work requires El Capitan's peak operational speed—one key performance measure—to be more than 10 times that of the most recent system currently in use—Sierra. Additionally, the statement of work requires El Capitan's memory capacity to increase by more than six times that of Sierra. Table 1 identifies NNSA's major HPC system acquisitions for the ASC program.

[15]There are many ways to measure computational performance, such as the speed at which a system calculates floating point operations per second, known as FLOPS, or the speed at which a system can run graphics-intensive applications. Performance also depends on a number of other factors, such as the amount and speed of memory, network performance, and how well the computer codes utilize the system hardware.

Table 1: NNSA's Major High-Performance Computing System Acquisitions for the Advanced Simulation and Computing Program

System name	Theoretical peak operational speed (TFLOPS)[a]	Memory capacity (TiB)[b]	Years of operation	National laboratory where the system was, is, or will be located
Red	3	1.2	1996-2005	Sandia
Blue Mountain	3	1.5	1998-2004	Los Alamos
Blue Pacific	4	1.5	1998-2004	Lawrence Livermore
White	12	6	2000-2004	Lawrence Livermore
Q	20	~16	2002-2008	Los Alamos
Red Storm	41; 284 (upgraded)	~76	2005-2012	Sandia
Purple	93	50	2005-2010	Lawrence Livermore
Blue Gene/L	367; 596 (upgraded)	32; 48 (upgraded)	2005-2012	Lawrence Livermore
Roadrunner	1,380	104	2009-2013	Los Alamos
Cielo	1,374	286	2011-2016	Los Alamos
Sequoia	20,132	1,536	2012-2020	Lawrence Livermore
Trinity	41,780	2,070	2016-2022[c]	Los Alamos
Sierra	125,712	1,320	2018-2023[c]	Lawrence Livermore
Crossroads[d]	TBA[e]	TBA[e]	2022-2027	Los Alamos
El Capitan[d]	>1,500,000	TBA[e]	2023-2029	Lawrence Livermore

Source: National Nuclear Security Administration (NNSA). | GAO-21-194

[a]A TFLOPS or teraFLOP per second is a unit of computing speed equal to one trillion (10^{12}) floating point operations per second (FLOPS).

[b]A tebibyte (TiB) is a unit of digital information storage that equals 2^{40} bytes (1,099,511,627,776 bytes).

[c]According to Advanced Simulation and Computing program officials, Trinity's and Sierra's operations will likely be extended by a year beyond their planned years of operation, in order to overlap a few months with the incoming Crossroads and El Capitan systems.

[d]NNSA is currently acquiring the system, so the peak operational speed, memory capacity, and years of operation are either anticipated or cannot be disclosed at this time.

[e]To be announced (TBA).

DOE's Policy and Guidance Relevant for the El Capitan Acquisition

According to agency officials and laboratory representatives, beginning with the Sequoia acquisition program, ASC HPC acquisition programs have followed a tailored version of DOE Order 413.3B. This order has provided guidance for the acquisition of capital assets[16] that meet performance, cost and schedule, and other project requirements since

[16]According to DOE, capital assets are land, structures, equipment, and intellectual property with an estimated useful life of two or more years.

2010.[17] According to ASC program documentation, this tailored process was adapted in accordance with NNSA's Office of Defense Programs Program Execution Instruction, which was first issued in 2015.[18] According to the Program Execution Instruction, AOA processes must be performed in accordance with DOE's Business Operating Procedure 03.07 and its Defense Programs AOA policy, which incorporates Defense Programs AOA guidance.[19]

To further document this tailored approach, in February 2018—after the January 2018 completion of the draft of the report documenting El Capitan's AOA process—the Director of DOE's Office of Acquisition Management issued a memo stating that the El Capitan acquisition program is not a capital asset project and, therefore, is not required to follow DOE Order 413.3B. However, the memo also documented agreement between the Director of the ASC program and the Director of the Office of Acquisition Management that the El Capitan acquisition program should continue to follow the best practices outlined in the order, which requires conducting an AOA process. It further recommends that the El Capitan acquisition program follow relevant Acquisition Management and Defense Programs' program management policies and guidance.

According to Defense Programs guidance, the AOA process is a key first step in the acquisition process intended to assess alternative solutions for addressing a validated mission need. The process involves comparing the operational effectiveness, costs, and risks of a number of potential alternatives to ensure the best alternative is selected. According to Defense Programs guidance, AOA processes should be performed on all projects and programs with a cost of $10 million or greater. Additionally, agency policy requires that AOA processes be consistent with GAO best practices for the AOA process, where possible, and that any deviations must be justified and documented. Table 2 provides relevant policy, guidance, and best practices for the ASC programs' AOA processes, which includes the El Capitan acquisition program's AOA process.

[17]Department of Energy, *Program and Project Management for the Acquisition of Capital Assets,* DOE Order 413.3B (Change 5) (Washington, D.C.: November 2010).

[18]Department of Energy, Office of Defense Programs, *DP Program Execution Instruction: NA-10 Program Management Tools and Processes, Rev. 1.*

[19]Department of Energy, *Business Operating Procedure 03.07* and Department of Energy, Defense Programs, *Analysis of Alternatives Guidance.*

Table 2: Analysis of Alternatives Policy, Guidance, and Best Practices for the Advanced Simulation and Computing High-Performance Computing System Acquisition Programs

Guidance, policy, or best practices document	Description
Department of Energy (DOE), *Program and Project Management for the Acquisition of Capital Assets,* DOE Order 413.3B (Change 5) (Washington, D.C.: November 2010)	Provides DOE organizations with program and project management direction for the acquisition of capital assets, with the goal of delivering projects within performance baselines and meeting cost, schedule, and mission requirements. It is relevant to all capital asset projects that cost more than $50 million. Capital assets are land, structures, equipment, and intellectual property with an estimated useful life of 2 years or more.
DOE, Office of Defense Programs, *DP Program Execution Instruction: NA-10 Program Management Tools and Processes* (Washington, D.C.: Rev. 1., October 2015, and Rev. 2, June 2019)	Implements NNSA Policy 413.2 (NAP-413.2), Program Management Policy, specifically for programs managed and overseen by NNSA's Office of Defense Programs, and provides program execution methods for conducting program management within the Office of Defense Programs. It includes policies regarding the conduct of an analysis of alternatives (AOA) process, including that it must be performed in accordance with DOE Business Operating Procedure 03.07 and Defense Programs AOA policy. In addition, the Program Execution Instruction requires that the program office conduct an AOA process independent of the contractor organization responsible for managing the construction of or constructing the capital asset project.
DOE, *Business Operating Procedure 03.07: Analysis of Alternatives* (Washington, D.C.: March 2016)	Describes how to perform an AOA process to inform the selection of an alternative during an acquisition process, including that the process must be consistent with GAO best practices, where possible, and that deviations must be documented and justified when these best practices cannot be followed. In addition, it requires that an AOA process must be conducted independent of the contractor organization responsible for managing or executing the project or program.
DOE, *NNSA, Defense Programs: Analysis of Alternatives Guidance* (Washington, D.C.: January 2017)	Provides guidance for NNSA's Office of Defense Programs for conducting AOA processes, including that they should be conducted in accordance with GAO best practices, where possible, and that any of the GAO practices that are not applicable should be documented. It also states that the AOA analysis must be independent from any party that will benefit from the execution of the program, which, in most cases for Defense Programs, would exclude the management and operating contractors for the sites where the alternatives are considered.
GAO, *Amphibious Combat Vehicle: Some Acquisition Activities Demonstrate Best Practices; Attainment of Amphibious Capability to be Determined,* GAO-16-22 (Washington, D.C.: Oct. 28, 2015), app. 1[a]	A GAO report that includes an earlier version of GAO best practices for an AOA process.
GAO, *Cost Estimating and Assessment Guide,* GAO-20-195G (Washington, D.C.: March 2020)[a]	A GAO guide that includes updated GAO best practices for an AOA process.

Sources: DOE, National Nuclear Security Administration (NNSA), and GAO. | GAO-21-194

[a]For this report, we used the best practices for an AOA process as identified in GAO-16-22. Subsequent to our review, these best practices were updated in GAO-20-195G. The differences between the two versions are minor and did not impact the results of our review.

Two offices within NNSA that provide support and assistance with AOA processes are the Office of Cost Estimating and Program Evaluation (CEPE) and the Office of Management and Budget (NA-MB). Both offices are independent of NNSA programs such as ASC. CEPE is responsible for establishing policies and procedures for AOAs and provides the NNSA Administrator with independent analyses, including cost estimates, reviews of AOA processes, and program performance evaluation. NA-MB was appointed in 2019 as the lead for conducting NNSA-initiated AOA processes. Agency officials told us that CEPE provides independent reviews of AOA processes performed by other organizations within NNSA, while NA-MB conducts AOA processes for major capital acquisitions and advises on AOA and AOA-like processes.

Status of the El Capitan Acquisition

According to NNSA officials, due to the agency's need for HPC systems, such as El Capitan, with capabilities that are typically not yet commercially available, they must navigate uncertainty in the acquisition process. Because of this uncertainty, NNSA officials defer decisions on certain requirements until later in the acquisition process and, thus, use a late-binding decision approach. Agency officials also stated that this approach allows NNSA and the vendor to better understand complex requirements before firm commitments are made.

The El Capitan acquisition is early in its life cycle. NNSA's prime contractor (Lawrence Livermore National Security, LLC), which is responsible for managing and operating Livermore, awarded two subcontracts for El Capitan.

- The first subcontract was awarded to Cray Incorporated in April 2019 and is for research and development. It has a ceiling of $105 million. NNSA and the Office of Science have agreed to share the costs of this subcontract. NNSA expects to pay for about 50 percent of this subcontract's costs through Livermore, with the Office of Science paying for the remaining costs through Oak Ridge National Laboratory.
- The second subcontract was awarded to Cray Incorporated in July 2019 and is for building the El Capitan system. It has a ceiling of $523 million.[20] Under this subcontract, the vendor is building three pilot systems—each with increasing similarity to El Capitan's final system

[20]While the combined ceilings of these two subcontracts total $628 million, NNSA believes DOE will not spend up to the ceiling amount but rather will spend approximately $559 million procuring El Capitan.

design. NNSA will use the three pilot systems to develop system software, tools, and NNSA weapons applications for El Capitan.

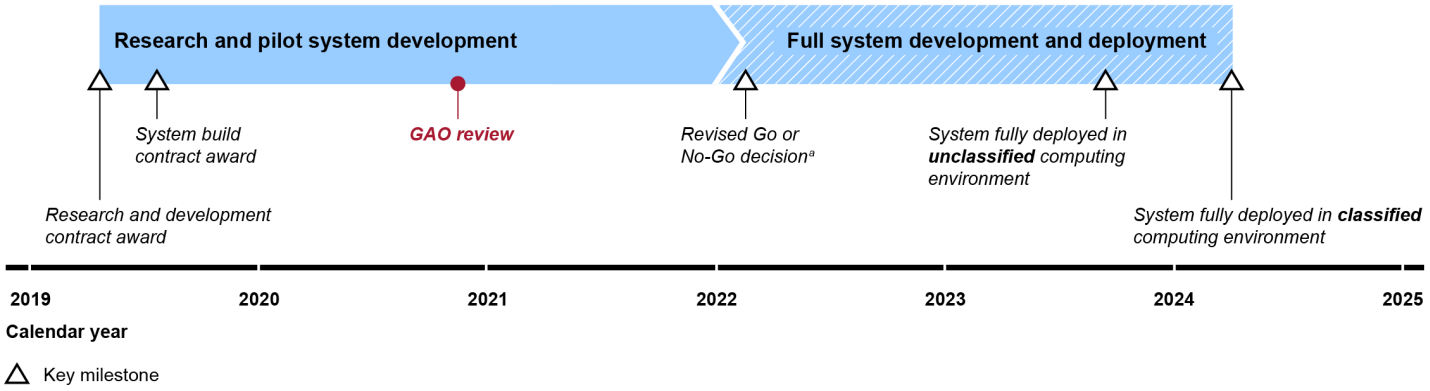
According to NNSA officials, in early 2022 they plan to evaluate available information and pilot results related to El Capitan and will either (1) decide that the vendor is able to deliver an HPC system that meets enough of its target performance requirements and then give the vendor approval to continue with the full build of the new system to meet the final performance requirements or (2) decide that the vendor will not be able to meet enough of the target performance requirements and then terminate the vendor's contract. The decision is referred to as the Go or No-Go decision.

NNSA officials decided to defer certain decisions related to the system design until after the second subcontract was awarded, in order to accommodate technology enhancements that were expected to emerge following the award. Accordingly, following the second award, NNSA officials began negotiating on a late-binding decision related to the design of the system. During this time, agency officials deferred the delivery of program management milestones until after the conclusion of negotiations. In August 2020, NNSA officials told us that they had concluded negotiations with the vendor on this late-binding decision and had modified the subcontract on July 29, 2020. The modification is intended to enable significantly higher performance for El Capitan with no increase to the cost, according to NNSA officials. Agency officials had initially planned to make their Go or No-Go decision by December 2020; however, due to additional time needed to negotiate on the late-binding decision, officials moved the decision to February 2022.

These two subcontracts establish 105 research and development and system build tasks (referred to as milestones) to be delivered from 2019 to 2023. As of August 2020, NNSA had paid $11.3 million to the El Capitan vendor for completing 10 milestones.

If NNSA decides to give the vendor approval to build the full system, the agency plans to fully deploy the El Captain system in the unclassified environment by September 2023 and in the classified environment by March 2024. See figure 2 for an overview of the El Capitan program's time line and key milestones. The AOA process was completed prior to the award of the first subcontract.

Figure 2: El Capitan Program Time Line and Key Milestones, as of November 2020



Source: GAO analysis of National Nuclear Security Administration documentation. | GAO-21-194

[a]The Go or No-Go decision is a key El Capitan program decision, where NNSA officials decide either that (1) the vendor will be able to deliver El Capitan and meet NNSA's requirements and is approved to continue the full system build; or (2) the vendor will not be able to meet enough of NNSA's requirements, and NNSA will then terminate the vendor's contract. Agency officials had initially planned to make their Go or No-Go decision by December 2020; however, due to additional time needed to negotiate on certain aspects of the system's design, officials moved the decision to February 2022.

The El Capitan Acquisition Program Will Cost Significantly More than Previous HPC System Acquisition Programs Due to a Planned Large Increase in Computer Performance and Capacity

According to NNSA's fiscal year 2021 congressional budget request, the El Capitan acquisition program is expected to cost $600 million, more than the three previous HPC system acquisition programs combined. According to NNSA officials and contractor representatives, this significant increase in cost is due primarily to the need for significantly greater computational performance than is currently available. El Capitan is required to be at least 10 times faster than Sierra and to provide more than 6 times the memory capacity. This increase in performance is expected to lead to a significant decrease in computational times for weapon simulations. For example, NNSA estimates that running a full, high-fidelity system simulation of a weapon takes 259 days on Sierra but will only take 16 to 32 days on El Capitan. Table 3 shows how the cost and performance of El Capitan compare with those of the previous three ASC HPC systems.

Table 3: Cost and Performance of NNSA's Four Latest High-Performance Computing (HPC) Systems

HPC system	System cost ($ in millions)[a]	Theoretical peak operational speed (TFLOPS)[b]	Cost per TFLOPS of operational speed ($/TFLOPS)	Memory capacity (TiB)[c]	Power consumption (megawatts)[d]
Trinity	187	41,780	4,476	2,070	7.6
Sierra	171	125,712	1,320	1,320	7.4
Crossroads[e]	115	TBA[f]	TBA[f]	TBA[f]	15
El Capitan[e]	600	>1,500,000	<400	TBA[f]	29.3

Source: National Nuclear Security Administration (NNSA) and TOP500. | GAO-21-194

[a]Total system cost is derived from NNSA's fiscal year 2021 congressional budget request, adjusted to remove site preparation costs.

[b]A TFLOPS, or teraFLOP per second, is a unit of computing speed equal to one trillion (10^{12}) floating point operations per second (FLOPS).

[c]A tebibyte (TiB) is a unit of digital information storage that equals 2^{40} bytes, or 1,099,511,627,776 bytes.

[d]According to an NNSA official, power consumption values for Trinity and Sierra were measured when the systems were run against a benchmark of linear equations to determine system performance. Power consumption values for Crossroads and El Capitan are anticipated values, as the systems are not yet operational. For context, 1 megawatt is the amount of energy produced by 10 automobile engines.

[e]NNSA is currently acquiring the system, so the peak operational speed, memory capacity, and power consumption are either anticipated or cannot be disclosed at this time.

[f]To be announced (TBA).

According to NNSA officials and laboratory representatives, NNSA has a greater operational need for computer simulation than it has computational and capacity capabilities. Because of capacity limitations, according to agency officials and laboratory representatives, weapons designers sometimes compromise on the fidelity of simulations to shorten computational time, resulting in greater uncertainty in simulation results. For example, there is greater uncertainty that a weapon and its components will perform as predicted by the simulation. According to an NNSA document, the need for computational resources is expected to grow as the stockpile moves farther away from the weapons that were actually tested, due to changes such as design modifications or aging effects. Additionally, as adversaries increasingly develop advanced defensive systems, which threaten the ability of U.S. weapons to perform as intended, NNSA anticipates computational needs to exceed even those that may be provided by early exascale systems such as El Capitan. According to an NNSA document, El Capitan is expected to help, but not completely address, the gap between NNSA's computational capabilities and its requirements.

NNSA's AOA Process for the El Capitan Acquisition Program Did Not Fully Meet Best Practices or Follow Agency Policy and Guidance

NNSA's AOA process for the El Capitan acquisition program did not fully meet GAO best practices or follow agency policy and guidance. Agency policy requires that AOA processes be consistent with GAO best practices where possible and, while agency policy allows for deviations from GAO's best practices when they cannot be followed, it also requires that deviations be justified and documented. However, the AOA process did not fully meet GAO's best practices for an AOA process, and NNSA did not justify or document deviations from these best practices. Additionally, the AOA process was not performed by an independent entity, as required by agency policy and guidance.

El Capitan's AOA Process Did Not Fully Meet GAO's Best Practices and Did Not Justify or Document Deviations from These Best Practices, as Required by Agency Policy

According to agency policy, AOA processes must be consistent with GAO best practices, where possible, and document and justify any deviations. GAO has identified 22 best practices for an AOA process. These best practices are grouped into four characteristics that identify a high-quality, reliable AOA process. The characteristics are that the analysis be comprehensive, well documented, unbiased, and credible. Appendix II lists the best practices, as well as their corresponding characteristics. As part of the AOA process, life cycle cost estimates should be developed for each alternative to enable the AOA team to understand the full cost of each alternative and compare the costs when determining the preferred alternative.

Our review found that the AOA process for the El Capitan acquisition program did not fully follow GAO best practices and that deviations were not documented or justified. We found that the El Capitan acquisition program partially met the characteristic of a comprehensive AOA process and minimally met the characteristics of a well-documented, unbiased, and credible AOA process.[21] Table 4 summarizes our assessment of the AOA process for El Capitan's acquisition program against the characteristics in GAO best practices. Appendix II provides more detailed information about NNSA's AOA process and our review.

[21]A well-documented AOA process is one that is thoroughly described in a single document, including all source data; clearly detailed methodologies, calculations, and results; and where the selection criteria are explained. An unbiased AOA process is one that does not have a predisposition toward one alternative over another and is based on traceable and verifiable information. A credible AOA process is one that thoroughly discusses the limitations of the analysis resulting from the uncertainty that surrounds both the data and the assumptions for each alternative.

Table 4: GAO's Review of the National Nuclear Security Administration's (NNSA) Analysis of Alternatives (AOA) Process for the El Capitan Acquisition Program[a]

AOA characteristic	GAO assessment[b]	Examples of how the AOA process did not meet best practices associated with each characteristic[c]
Comprehensive	Partially met	• Functional requirements are not specifically tied to mission needs.[d] • There are no details about the qualitative and operational factors used to determine the alternatives' viability or details about the assessment, only the conclusions.[e] • The life cycle cost estimates for the alternatives are not complete. For example, they do not account for inflation and are not expressed in present value terms, as best practices recommend. Additionally, NNSA did not follow best practices when developing the alternatives' cost estimates to ensure accurate cost estimates and a good comparison of alternatives.
Well documented	Minimally met	• The descriptions of the alternatives are not detailed enough to allow for a robust analysis of each alternative's viability, cost, benefit, or effectiveness. • While some risks are mentioned in the document for some of the alternatives, they are limited; there are no risks mentioned for some alternatives, including the preferred alternative; and there are no risk mitigation strategies presented. • Assumptions and constraints are included only for the preferred alternative.
Unbiased	Minimally met	• The AOA team included members from NNSA's three national laboratories but only included technical personnel. No participants had project or program management or cost estimating backgrounds. • The selection criteria were not weighted, and no AOA process plan was developed. • NNSA had already decided to procure and deploy a new high-performance computing (HPC) system (i.e., an exascale system, now referred to as El Capitan), before performing its AOA.
Credible	Minimally met	• While NNSA defined selection criteria and a baseline alternative, the selection criteria appear to have been written for the preferred alternative, to procure and deploy an HPC system, rather than neutrally. Further, the baseline alternative is not well documented or used to provide a basis of comparison among alternatives. • No risk or uncertainty analysis was performed, and the budget range was derived from vendor request for information responses. • While the AOA document was reviewed by contractor representatives from Lawrence Livermore National Laboratory, it was not signed by NNSA officials, and there is no evidence that an independent review outside of the chain of command was performed.

Source: GAO analysis of NNSA information. | GAO-21-194

[a]For this report, we used the best practices for an AOA process as identified in GAO, Amphibious Combat Vehicle: Some Acquisition Activities Demonstrate Best Practices; Attainment of Amphibious Capability to Be Determined, GAO-16-22 (Washington, D.C.: Oct. 28, 2015). Subsequent to our review, these best practices were updated in GAO, Cost Estimating and Assessment Guide, GAO-20-195G (Washington, D.C.: March 2020). The differences between the two versions are minor and did not impact the results of our review.

[b]The ratings were assigned as follows: not met—provided no evidence that satisfies any of the best practice or characteristic; minimally met—provided evidence that satisfies a small portion of the best practice or characteristic; partially met—provided evidence that satisfies about half of the best practice or characteristic; substantially met—provided evidence that satisfies a large portion of the

best practice or characteristic; and fully met—provided complete evidence that satisfies the best practice or characteristic.

[c]GAO best practices and their associated characteristics are included in appendix II.

[d]Functional requirements define the functionalities, capabilities, and activities that a system must be able to perform, and they specify the overall behavior of the system to be developed. They are the general parameters that the selected alternative must have in order to address the mission need.

[e]The five alternatives included in the AOA are (1) no action, (2) employ a cloud-based solution, (3) upgrade deployments of existing production systems, (4) procure and deploy a commodity technology system, and (5) procure and deploy a high-performance computing system. A commodity technology system is one that is readily available in the commercial market.

NNSA officials from the ASC program and laboratory representatives identified several reasons why they did not fully follow agency policy requiring that an AOA process be consistent with GAO best practices, where possible, and that any deviations be documented and justified. They said they were not required to perform an AOA process because the Office of Acquisition Management issued a waiver that exempted the El Capitan program from complying with DOE policy and guidance related to AOA processes. However, they also told us that DOE's Office of Acquisition Management advised them to follow NNSA Offices of Acquisition Management and Defense Programs policy and guidance. In fact, while the waiver does exempt the El Capitan program from complying with DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets,* it goes on to say that the Director of the Office of Acquisition Management recommends that the program develop and maintain a proper acquisition and management plan in accordance with NNSA Offices of Acquisition Management and Defense Programs program management policy and guidance.[22] The Defense Programs policy and guidance require program offices to perform an AOA process for capital asset acquisition projects and programs.

Agency officials and laboratory representatives also said that they did not see a need to perform a full AOA process because they believed that the acquisition of a new exascale HPC system was the only viable alternative to meet NNSA's mission needs and provide a solution that was economical and met security requirements. Additionally, they said that they knew that the other alternatives presented in the AOA documentation were not viable because they continually talk with vendors and do market research.

[22] Department of Energy, *Program and Project Management for the Acquisition of Capital Assets,* DOE Order 413.3B (Change 5).

Because agency officials and laboratory representatives believed they were not required to perform an AOA process and because they had a predetermined solution, they considered the AOA a pro forma activity and did not fully follow agency policy and guidance. As a result, the AOA process for El Capitan acquisition program did not fully follow GAO best practices and, therefore, does not demonstrate that the alternatives were appropriately analyzed to determine that the acquisition of an exascale HPC system was the best alternative.

Additionally, while agency policy allows the program to deviate from GAO best practices, the deviations in the El Capitan AOA process were not justified or documented, as agency policy requires. According to NNSA AOA policy, when GAO best practices cannot be followed, deviations must be justified and documented in the study plan and the final report. However, NNSA did not justify and document deviations from GAO best practices. Therefore, the AOA team did not demonstrate that the deviations were appropriate for the El Capitan acquisition program.

According to GAO best practices for an AOA process, the AOA process compares the operational effectiveness, costs, and risks of the alternatives and helps ensure that the best alternative that satisfies the mission need is chosen. We have applied these best practices for the AOA process to many different types of acquisitions, including weapons systems, buildings, and information technology systems, and we have found that they are important to evaluate options for meeting mission needs. Without taking steps to ensure that the ASC program follows GAO best practices for its AOA processes, where possible, and justifies and documents any deviations, the ASC program cannot be assured that the AOA processes are high-quality and reliable and that the chosen alternatives meet mission needs and are the best solutions available at the time to support the modeling and simulation of nuclear weapons, in the absence of nuclear testing.

El Capitan's AOA Process Did Not Follow Agency Policy and Guidance Related to Independence

GAO best practices require an independent review of the AOA process, and DOE and Defense Programs policy requires that AOA processes be conducted independent of the contractor organization responsible for managing or executing the project or program. Further, the Defense Programs AOA guidance states that the analysis must be independent from any party that will benefit from the execution of the program,

meaning that, in most cases, the contractors managing and operating the site where the alternatives are considered should be excluded.[23]

El Capitan's AOA process was performed by representatives from Livermore with, according to NNSA officials and laboratory representatives, input from representatives of the other two labs that are part of the ASC program, Los Alamos and Sandia. Livermore is not independent because it is the contractor managing and executing the acquisition of the El Capitan system, and it manages and operates the site where El Capitan will be installed.

According to CEPE officials and NNSA policy, the program office leads the AOA process as the chair of the committee providing guidance to the AOA team. NA-MB has the responsibility to support the program office by conducting the AOA process, including developing the study plan in coordination with the program office, managing all AOA teams, and performing the cost, schedule, and risk analyses. However, NNSA officials noted that, if NA-MB cannot perform the AOA process, for example, due to resource limitations, there are independent resources available to help design and conduct an AOA process. For example, the process can be outsourced to an independent federally funded research and development center or other independent contractor. Additionally, NA-MB officials told us that program offices can consult with them concerning AOA and AOA-like analyses. Finally, CEPE can perform independent cost estimates, and CEPE officials told us that they can be consulted on the AOA process, provide independent reviews, and suggest improvements to the process. However, NNSA did not make use of these resources.

According to an NNSA official, instead of having an independent entity perform the AOA process, NNSA took other steps to ensure independence. Specifically, NNSA had two independent reviewers from

[23]In addition to requiring that an AOA process be consistent with GAO best practices, agency policy and guidance require that an independent entity perform the AOA process. According to DOE 413.3B, the AOA process must be performed independent of the contractor organization responsible for the construction of or constructing the capital asset project. Additionally, Business Operating Procedure 03.07 requires that the AOA process be conducted independent of the contractor organization responsible for managing or executing the project or program. Finally, according to the *Defense Programs Analysis of Alternatives Guidance*, the AOA process must be independent from any party that will benefit from the execution of the program. In most cases for Defense Programs, this would exclude the management and operating contractors for the sites where the alternatives are considered, according to the guidance.

HPC programs outside of NNSA perform an independent cost review.[24] However, this independent cost review was not part of the AOA process. It was performed after the AOA process was completed and was intended to review the costs provided in the vendor proposals for the preferred alternative.

According to the Defense Programs Program Execution Instruction, the AOA must be conducted independent of the contractor organization responsible for managing the construction of or constructing a capital asset project. Additionally, according to Defense Programs guidance, the analysis must be independent from any party that will benefit from the execution of the program in order to avoid conflicts of interest. According to CEPE officials, these requirements are in place to avoid conflicts of interest and potential bias. By ensuring that the ASC program's AOA processes are performed by an independent entity, the agency can reduce the risk of conflicts of interest and potential biases that may lead to decisions that are not in the agency's best interests.

NNSA Is Fully Implementing Selected Acquisition Best Practices for Program Monitoring but Not for Requirements Management

According to the Software Engineering Institute, effective program management of an information technology acquisition involves, among other key practice areas, (1) program monitoring and control and (2) requirements management. We found that, in the second year of the El Capitan acquisition program's 5-year acquisition life cycle, NNSA has fully implemented selected key practices related to program monitoring and control. However, NNSA has only partially implemented key practices related to requirements management.

NNSA Has Fully Implemented Selected Key Practices Related to Program Monitoring and Control

According to the Software Engineering Institute's CMMI®, program monitoring and control includes 11 key practices intended to enable an agency to monitor and, where necessary, correct a program's progress according to its plan.[25] Of the 11, we selected five key practices that represent foundational information technology acquisition practices of particular importance and were applicable to the El Capitan program,

[24]One reviewer was from the Department of Defense's HPC Modernization Program and the other from Lawrence Berkeley National Laboratory.

[25]Software Engineering Institute, Capability Maturity Model Integration® for Acquisition, Version 1.3 (Pittsburgh, PA: November 2010).

which is in the second year of a 5-year plan to acquire and deploy the program. Effective and early implementation of the five key practices we selected enable the agency to determine progress against the program plan in order to identify and mitigate deviations from the plan. These five key practices are

- monitor program progress related to actual cost, schedule, and scope relative to the program plan;
- monitor risks against the program plan;
- monitor stakeholder involvement;
- review and communicate program performance to stakeholders; and
- review program results at milestones.

We found that NNSA has fully implemented the five selected practices related to program monitoring and control.[26] Table 5 summarizes our assessment of NNSA's implementation of the selected monitoring and control key practices.

Table 5: GAO's Assessment of the National Nuclear Security Administration's (NNSA) Implementation of Five Selected Program Monitoring and Control Key Practices for the El Capitan Program

Key practice	GAO assessment	GAO analysis
Monitor program progress related to actual cost, schedule, and scope relative to the program plan.	Implemented	NNSA officials and Lawrence Livermore National Laboratory (Livermore) representatives monitored the 10 (of 105 total) research and development and system build milestones that had been completed as of August 2020 through a monthly process by which the officials review the actual start and finish dates for each of the milestones, as well as the vendor's progress toward completion of milestones. Once the vendor completed a milestone, NNSA officials and Livermore representatives evaluated the vendor's work to determine if it was acceptable. If acceptable, laboratory representatives paid the vendor. In September 2020, NNSA officials and Livermore representatives stated that they are working with the vendor on updating the program milestones to accommodate the July 29, 2020, contract modification.
Monitor risks against the program plan.	Implemented	NNSA officials and Livermore representatives monitored a registry of program risks monthly. The registry included important information, such as mitigation plans, risk owners, and dates by which program officials should begin implementing the mitigation plans. In addition, officials communicated program risk statuses with stakeholders monthly.

[26]Although we initiated our review by selecting eight key practices for program monitoring and control, we determined that three related to taking corrective actions were not applicable to the El Capitan program since, as of September 2020, NNSA officials reported that the program had not experienced any significant deviations from the plan that warranted any corrective actions.

Key practice	GAO assessment	GAO analysis
Monitor stakeholder involvement.	Implemented	The El Capitan program used a council of stakeholders, referred to as the Center of Excellence Management Council, to involve its stakeholders. This council included various working groups of expert laboratory and vendor staff from NNSA's three national laboratories: Livermore, Los Alamos National Laboratory, and Sandia National Laboratories. Each of these laboratories will need to run simulations on El Capitan. NNSA officials and laboratory representatives tracked and periodically reviewed the activities of the working groups to ensure that stakeholders remained involved with the program.
Review and communicate program performance to stakeholders.	Implemented	Livermore representatives prepared monthly program performance reports to communicate to stakeholders and Department of Energy (DOE) officials the program's current cost, schedule, progress in completing milestones, and key risks. According to the El Capitan program baseline document, DOE and laboratory management officials are to use these reports to enable them to review and provide oversight to the program.
Review program results at milestones.	Implemented	NNSA officials and Livermore representatives reviewed each milestone's deliverables at completion to ensure the results met the program's planned objectives and performance expectations. As of August 2020, the laboratory officials had paid the El Capitan vendor $11.3 million for completing 10 of the 105 milestones.

Source: GAO analysis of NNSA and El Capitan program documentation. | GAO-21-194

Note: These key practices are specified in Software Engineering Institute, Capability Maturity Model Integration® for Acquisition, Version 1.3 (Pittsburgh, PA: November 2010).

Moving forward, as NNSA officials oversee the completion of the remaining 95 milestones over the program's remaining 3 years, it will be important that they continue to monitor cost, schedule, and scope progress relative to the program plan; monitor risks against the program plan; monitor stakeholder involvement; review and communicate program performance to stakeholders; and review program results at milestones so that they can identify and mitigate any deviations from the plan.

NNSA Has Fully Implemented Two Key Practices Related to Requirements Management and Has Partially Implemented Three

According to the CMMI®-ACQ, requirements management includes five key practices that help an agency manage changes to the requirements throughout a program's life cycle. These practices ensure continuous alignment of the program's high-level mission and operational requirements all the way down to the lower-level functional and technical requirements to ensure the delivered system will meet its original goals and meet the needs of its end users. These five key practices are:

- Establish an understanding of requirements with program stakeholders;
- Obtain commitment to requirements from program stakeholders;
- Manage changes to requirements throughout the life cycle;
- Maintain a clear and discernable association between high-level mission and operational requirements and the lower-level functional

and technical requirements (referred to as bidirectional traceability) among program documents, which is typically achieved by using a requirements traceability matrix or automated requirements management system; and

- Ensure program plans remain aligned to requirements, including when program requirements change over time.

We found that NNSA has fully implemented the first two of the five practices for requirements management and partially implemented the remaining three practices. Table 6 summarizes our assessment of NNSA's implementation of requirements management key practices.

Table 6: GAO's Assessment of the National Nuclear Security Administration's (NNSA) Implementation of Requirements Management Key Practices for the El Capitan Program

Practice	GAO assessment	GAO analysis
Establish an understanding of requirements with program stakeholders.	Implemented	NNSA established an understanding of El Capitan's requirements with the program's stakeholders. Specifically, in January 2018, NNSA officials, and representatives from three national laboratories overseen by NNSA, finalized a program plan that established El Capitan's six mission requirements. Subsequently, in March 2019, NNSA officials, including the program's stakeholders, finalized and documented El Capitan's seven high-level functional requirements in the vendor's contract. From the seven high-level functional requirements, the vendor identified and defined 468 lower-level functional requirements.
Obtain commitment to requirements from program stakeholders.	Implemented	NNSA ensured it obtained commitment to the program requirements from stakeholders. Specifically, stakeholders from Lawrence Livermore National Laboratory, with assistance from experts from the other two NNSA national laboratories, developed and agreed to the requirements that were included in the El Capitan vendor's scope of work.
Manage changes to requirements throughout the life cycle.	Partially Implemented	The program appears to manage changes to the 468 lower-level functional requirements. Specifically, the El Capitan vendor uses an automated requirements management system that tracks changes to these requirements. However, while NNSA officials first established high-level functional requirements in April 2018, and the vendor further refined the high-level functional requirements in March 2019, NNSA did not update its program documents with these refined requirements. For example, one of NNSA's original high-level functional requirements required the vendor to deliver a system with 1,300 petaFLOPS[a] of computing speed, and the vendor refined this requirement and planned to deliver a system with an even greater computing speed. However, NNSA did not update its program documents to reflect this refinement to the original functional requirements.

Practice	GAO assessment	GAO analysis
Maintain a clear and discernable association between high-level mission and operational requirements and lower-level functional and technical requirements (referred to as bidirectional traceability).	Partially Implemented	Although NNSA established six mission and seven high-level functional requirements, NNSA did not establish a clear linkage between these two sets of requirements in El Capitan's program documents. For example, El Capitan's program documents do not demonstrate which mission requirements drive the functional requirement on software speed nor do program documents describe how the functional requirement for 1,300 petaFLOPS links to at least one mission requirement. However, the El Capitan vendor's automated requirements management system maintains bidirectional traceability among the three tiers into which the 468 lower-level functional requirements are divided.
Ensure program plans remain aligned to requirements, including when program requirements change over time.	Partially Implemented	NNSA officials documented some of the high-level program requirements within the El Capitan program plan, but they did not ensure that they updated the program plan once they further refined their requirements. Specifically, when the El Captain program plan was established in January 2018, it included the six mission requirements, but when the seven high-level functional requirements were established and subsequently refined, the program plan was not updated to include either the high-level functional requirements or to demonstrate the relationship between the mission requirements and the high-level functional requirements.

Source: GAO analysis of NNSA and El Capitan program documentation. | GAO-21-194

Note: These key practices are specified in Software Engineering Institute, Capability Maturity Model Integration® for Acquisition, Version 1.3 (Pittsburgh, PA: November 2010).

[a]A petaFLOPS is a unit of computing speed equal to one quadrillion (10^{15}) floating point operations per second (FLOPS).

With regard to the three partially implemented requirement management practices—pertaining to managing changes, maintaining traceability, and ensuring that program plans remain aligned to requirements—NNSA officials stated that once the program developed its program plan early in the program's life cycle, they did not require the program to update and maintain that program plan. However, NNSA's own program management policy requires NNSA to update program documents, such as program plans, throughout the duration of the program.

Without updating and maintaining acquisition program documents to include current El Capitan requirements and clearly documenting the relationship between El Capitan's mission requirements and functional requirements, NNSA officials may be limited in their ability to ensure that all mission requirements are met in the final system.

Conclusions

For over two decades, the ASC program has played a key role in supporting NNSA's Stockpile Stewardship Program by developing modeling and simulation capabilities and deploying HPC systems to analyze and predict the performance, safety, and reliability of nuclear weapons and help certify their functionality in the absence of nuclear testing. To support the Stockpile Stewardship Program, the ASC program has developed some of the world's most powerful computers. The most

recent computing system acquisition, El Capitan, is estimated to cost $600 million—more than NNSA's three predecessor systems combined. Because of the importance and cost, it is imperative that NNSA follow best practices for HPC acquisition wherever practicable.

The ASC program conducted the El Capitan AOA process largely as a pro forma activity to meet management requirements because officials believed the only viable alternative was the acquisition of an HPC system. In doing so, they did not follow agency policy and guidance that state that AOA processes should be consistent with GAO best practices where possible and, if these practices cannot be followed, deviations must be justified and documented. In the future, the ASC program is likely to acquire additional HPC systems to meet the need to assess the performance of current and future weapons systems against the growing capabilities of adversaries to use advanced defensive systems. Without taking steps to ensure that the ASC program follows GAO best practices for its AOA processes, where possible, and justifies and documents any deviations, the ASC program cannot be assured that the AOA processes are high quality and reliable and that the chosen alternatives meet mission needs and are the best solutions to support the modeling and simulation of nuclear weapons in the absence of nuclear testing.

In addition, El Capitan's AOA process was conducted by Livermore, the contractor managing and executing the El Capitan system, as well as managing and operating the site where the system will be installed. This runs counter to Defense Programs policy and guidance that AOAs must be conducted independently of the contracting organization responsible for managing or executing the program, and of any party that will benefit from the execution of the program, to avoid conflicts of interest and potential bias. By ensuring that ASC HPC acquisition programs' AOA processes are performed by an independent entity, the agency can reduce the risk of conflicts of interest and potential biases that may lead to decisions that are not in the agency's best interest.

In carrying out the El Capitan acquisition program, NNSA has fully implemented all five selected key practices related to program monitoring and control. However, NNSA has only partially implemented key practices related to managing changes, maintaining traceability, and ensuring that program plans remain aligned to requirements. Until NNSA officials update and maintain program documents to include current El Capitan requirements and clearly document the relationship between El Capitan's mission requirements and functional requirements, agency officials may

be limited in their ability to ensure that all mission requirements are met in the final system.

Recommendations for Executive Action

We are making the following three recommendations to NNSA:

- The Administrator of NNSA should take steps to ensure that, for future HPC acquisitions, the ASC program follows GAO best practices for AOA processes, where possible, and justifies and documents any deviations, as required by agency policy. (Recommendation 1)
- The Administrator of NNSA should ensure that the ASC program's future AOA processes are performed by an entity independent of the contractor organization managing and executing the program. (Recommendation 2)
- The Administrator of NNSA should update and maintain its acquisition program documents to include current El Capitan requirements and clearly document the relationship between El Capitan's mission and functional requirements. (Recommendation 3)

Agency Comments

We provided a draft of this report to NNSA for review and comment. NNSA generally concurred with all three of our recommendations and provided technical comments, which we incorporated as appropriate. However, the agency's response to our second recommendation does not meet the intent of the recommendation. NNSA said that, for capital asset projects, future AOA processes would be conducted by an independent entity. However, according to agency officials, NNSA has not classified its ASC HPC system acquisitions as capital asset projects. This includes the El Capitan acquisition, which is the most expensive NNSA HPC acquisition to date. Further, future HPC acquisitions are unlikely to be classified as capital asset projects because NNSA views them primarily as research and development efforts. We continue to believe that the ASC program should follow agency policy requiring that AOA processes be conducted by an entity independent of the contractor organization responsible for managing or executing the program, whether or not the AOA is for a capital asset project. Doing so will reduce the risk of conflicts of interest and potential bias that may lead to decisions that are not in the agency's best interests. It will also enhance the credibility of NNSA's HPC acquisitions, especially in light of the increasing costs of obtaining higher levels of computing performance. A failure to have future AOA processes conducted by an independent entity may erode the confidence of senior decision makers and congressional committees in NNSA's efforts to achieve ever higher levels of HPC performance.

We are sending copies of this report to the appropriate congressional committees, the Secretary of Energy, and the Acting Administrator of NNSA. 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 Kevin Walsh at (202) 512-6151 or walshk@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made significant contributions to this report are listed in appendix IV.

Allison Bawden
Director, Natural Resources and Environment

Kevin Walsh
Director, Information Technology and Cybersecurity

Appendix I: Objectives, Scope, and Methodology

The House committee report accompanying the Energy and Water Development and Related Agencies Appropriations Act, 2019, includes a provision for us to review the National Nuclear Security Administration's (NNSA) management of the Advanced Simulation and Computing (ASC) program to evaluate NNSA's process for setting requirements and evaluating alternatives and to identify the estimated costs of NNSA's future systems compared with previous acquisition programs.[1] Our objectives were to examine (1) how the cost of NNSA's El Capitan acquisition program will compare with the costs of previous high-performance computing (HPC) system acquisition programs, (2) the extent to which NNSA's analysis of alternatives (AOA) process for the El Capitan acquisition program met best practices and followed agency policy and guidance, and (3) the extent to which NNSA is implementing selected acquisition best practices in carrying out the El Capitan acquisition program.

To address our first objective, we reviewed cost and budget documents for ASC HPC acquisition programs, comparing the cost and budget for El Capitan against the cost and budget for previous HPC acquisition programs. We also interviewed NNSA officials and laboratory representatives about the costs of the acquisition programs.

To address our second objective, we reviewed the AOA documentation for the El Capitan acquisition program[2] against GAO's best practices for an AOA process.[3] These practices are grouped into four characteristics that identify a reliable AOA process—that is, a process that is

[1]H. Rep. No. 115-697 at 111 (2018) (accompanying Pub. L. No. 115-244, 132 Stat. 2898 (2018)).

[2]Lawrence Livermore National Laboratory, *Mission Need Package (CD-0) for ASC El Capitan System Acquisition Project* (Livermore, CA: November 2017); and *Draft Conceptual Baseline/Execution Readiness Package (CD-1/3a) for the NNSA ASC El Capitan Advanced Technology System Procurement* (Livermore, CA: January 2018).

[3]For this report, we used the best practices for an AOA process as identified in GAO, *Amphibious Combat Vehicle: Some Acquisition Activities Demonstrate Best Practices; Attainment of Amphibious Capability to Be Determined,* GAO-16-22 (Washington, D.C.: Oct. 28, 2015). Subsequent to our review, these best practices were updated in GAO, *Cost Estimating and Assessment Guide,* GAO-20-195G (Washington, D.C.: March 2020). There are minor differences, the primary one being that some of the best practices have been moved among the characteristics, and did not impact the results of our review.

comprehensive, well documented, unbiased, and credible.[4] To determine the extent to which NNSA's AOA process met each of the four characteristics, we assigned a rating of not met, minimally met, partially met, substantially met, or fully met for each best practice associated with a characteristic.[5] We then combined the ratings for the best practices to determine the extent to which the AOA process met each of the four characteristics, assigning an overall rating of not met, minimally met, partially met, substantially met, or fully met.

We also reviewed the Department of Energy's (DOE) and NNSA's Office of Defense Programs program management and AOA policy and guidance, which provide a management framework for the El Capitan acquisition program, and interviewed NNSA officials and laboratory representatives to determine the extent to which the AOA process for the El Capitan acquisition program followed applicable agency policy and guidance.[6] These interviews were conducted with officials from NNSA's Office of Advanced Simulation and Computing and Institutional Research and Development Programs under NNSA's Office of Defense Programs, which is the program office for the El Capitan acquisition program; NNSA's Office of Management and Budget, which is responsible for leading NNSA-initiated AOA processes; and NNSA's Office of Cost

[4]A comprehensive AOA process is one that ensures that the mission need is defined in a way to allow for a robust set of alternatives, that all analyzed alternatives have been considered, and that each alternative is analyzed thoroughly over the program's entire life cycle. A well-documented AOA process is one that is thoroughly described in a single document, including all source data; clearly detailed methodologies, calculations, and results; and where the selection criteria are explained. An unbiased AOA process is one that does not have a predisposition toward one alternative over another and is based on traceable and verifiable information. A credible AOA process is one that thoroughly discusses the limitations of the analysis resulting from the uncertainty that surrounds both the data and the assumptions for each alternative.

[5]The ratings were assigned as follows: not met—provided no evidence that satisfies any of the best practice or characteristic; minimally met—provided evidence that satisfies a small portion of the best practice or characteristic; partially met—provided evidence that satisfies about half of the best practice or characteristic; substantially met—provided evidence that satisfies a large portion of the best practice or characteristic; and fully met—provided complete evidence that satisfies the best practice or characteristic.

[6]Department of Energy, *Program and Project Management for the Acquisition of Capital Assets,* DOE Order 413.3B (Change 5) (Washington, D.C.: April 2018); Department of Energy, Office of Defense Programs, *DP Program Execution Instruction: NA-10 Program Management Tools and Processes Rev. 1* (Washington, D.C.: Rev. 1, October 2015, and Rev. 2, June 2019); Department of Energy, *Defense Programs Analysis of Alternatives Guidance* (Washington, D.C.: January 2017); and *Business Operating Procedure 03.07: Analysis of Alternatives* (Washington, D.C.: March 2016).

Estimating and Program Evaluation, which provides independent analyses, including cost estimating, alternatives assessment, and program performance evaluation for NNSA. More detail about our review of the El Capitan AOA process can be found in appendix II.

For our third objective, we reviewed the Software Engineering Institute's Capability Maturity Model Integration® for Acquisition (CMMI®-ACQ) to identify best practices associated with managing an information technology acquisition.[7] We then selected two areas that, in our professional judgment, represented foundational information technology acquisition areas of particular importance applicable to the El Capitan program, which is early in its acquisition life cycle—program monitoring and control, and requirements management. Program monitoring and control includes 11 key practices, and requirements management includes five key practices. From these 16 practices, we selected 13 nonoverlapping best practices that represented foundational information technology acquisition practices. Of the 13 selected best practices across the two areas, eight relate to program monitoring and control:

- Monitor program progress related to actual cost, schedule, and scope relative to the program plan.
- Monitor risks against the program plan.
- Monitor stakeholder involvement.
- Review and communicate program performance to stakeholders.
- Review program results at milestones.
- Determine necessary corrective actions.
- Take corrective actions.
- Manage corrective actions to closure.

The remaining five of the 13 selected best practices relate to requirements management:

- Establish an understanding of requirements with program stakeholders.
- Obtain commitment to requirements from program stakeholders.
- Manage changes to requirements throughout the life cycle.

[7]Software Engineering Institute, Capability Maturity Model Integration® for Acquisition, Version 1.3 (Pittsburgh, PA: November 2010).

- Maintain a clear and discernable association between high-level mission and operational requirements and lower-level functional and technical requirements (referred to as bidirectional traceability).
- Ensure program plans remain aligned to requirements, including when program requirements change over time.

We obtained and analyzed El Capitan program documentation, such as the risk registers; the conceptual baseline document; the acquisition and program plan, contracts, and modifications; monthly status reports; center of excellence management council artifacts; ASC executive oversight artifacts; and the vendor scope of work.

We assessed the El Capitan program documentation against the 13 selected practices to determine the extent to which the agency had implemented them. We then assessed each best practice as

- implemented—NNSA provided complete evidence that showed it fully satisfied the practice area;
- partially implemented—NNSA provided evidence that showed it partially satisfied the practice area; or
- not implemented—NNSA did not provide evidence that showed it satisfied any of the practice area.

Although we initiated our review with eight key practices for program monitoring and control, we determined that three related to taking corrective actions were not applicable to the El Capitan program since, as of September 2020, NNSA officials reported that it had not experienced any significant deviations from the plan that warranted any corrective actions. These three practice areas considered not applicable to the El Capitan program are to (1) determine necessary corrective actions, (2) take corrective actions, and (3) manage corrective actions to closure.

Additionally, we conducted a site visit at Lawrence Livermore National Laboratory (Livermore) to understand the mission requirements behind the El Capitan program and Livermore's efforts to acquire, install, and integrate an exascale computer into its facility. We also observed the El Capitan vendor's demonstration of its automated requirements management system used to manage software development requirements for the El Capitan program. Lastly, we interviewed officials from NNSA and representatives from Livermore on their efforts to implement the selected information technology acquisition best practices.

We conducted this performance audit from March 2019 to April 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: GAO Review of the National Nuclear Security Administration's (NNSA) Analysis of Alternatives (AOA) Process for El Capitan

The Lawrence Livermore National Laboratory (Livermore) documented five alternatives for achieving exascale high-performance computing (HPC) capabilities in the *Draft Conceptual Baseline/Execution Readiness Package* in January 2018,[1] which documented the El Capitan AOA process.[2]

The alternatives considered in the El Capitan AOA process included:

1. No action; provide no further system acquisitions
2. Employ a cloud-based solution
3. Upgrade deployments of existing production systems (for example, Sierra)
4. Procure and deploy a commodity technology system
5. Procure and deploy an HPC system

However, according to NNSA officials and laboratory representatives, and our review of the AOA process, they had determined that option 5, to procure and deploy an HPC system, would be the selected alternative prior to performing the AOA analysis. While the selected alternative was to procure and deploy an HPC system, the AOA process did not define the precise architecture of the system (e.g., node, network bandwidth, memory capacity, power consumption, floor space, etc.).

According to Livermore's written responses, NNSA took the approach of using the competitive procurement process to further define the exascale HPC system, now called El Capitan, to be procured. This included reviewing research on exascale computing by issuing a request for information and holding meetings with vendors. Based on this information, NNSA issued a request for proposals that provided guidance to the vendors on how to bid viable, cost-effective solutions that would

[1]High-performance computing generally is the use of aggregated computing power to achieve much higher performance than that of typical desktop computers or workstations to solve large problems in science, engineering, or business. The performance of a computer is a function of characteristics such as response time, throughput, and execution time. An exascale computing system is an HPC system that is capable of at least a quintillion (or billion billion) floating point operations per second (FLOPS), or one exaFLOPS.

[2]Lawrence Livermore National Laboratory, *Draft Conceptual Baseline/Execution Readiness Package (CD-1/3a) for the NNSA ASC El Capitan Advanced Technology System Procurement* (Livermore, CA: January 2018).

meet NNSA mission requirements. Livermore evaluated the vendor proposals to select the best-value alternative.

We reviewed NNSA's El Capitan AOA process against GAO's 22 best practices for an AOA process. The results of our review are shown in table 7.

Table 7: Review of the National Nuclear Security Administration's (NNSA) Analysis of Alternatives (AOA) Process Against GAO Best Practices[a]

Best practice	GAO assessment[b]	Summary of assessment and effects
I. Initialize the AOA process		
1. Define mission need: *The customer defines the mission need without a predetermined solution.*	Partially met	Lawrence Livermore National Laboratory (Livermore) defined the mission need. However, there was a predetermined solution when the mission statement was written. According to agency officials and laboratory representatives, they believed that the preferred alternative, to procure and deploy a high-performance computing (HPC) system, was the only viable alternative. *Effect of not conforming to the practice: Allowing mission needs to be defined in solution-specific terms creates a potential bias and could invalidate the analysis.*
2. Define functional requirements: *The customer defines functional requirements based on the mission need without a predetermined solution. These functional requirements are realistic, organized, clear, prioritized, and traceable.*	Minimally met	The AOA document includes some functional requirements, but they are not traceable to the mission need. For example, the document includes a requirement for a throughput increase of 8- to 16-fold over the newest operating Advanced Simulation and Computing HPC system, Sierra, on a suite of weapons performance calculations. This requirement appears to relate to the mission need of acquiring enhanced simulation capabilities. However, the document does not indicate that this requirement is intended to meet that need. *Effect of not conforming to the practice: Setting functional requirements to a standard other than the mission need allows bias because the functional requirements might then reflect arbitrary measures. Additionally, functional requirements that are not tied to mission need make it challenging for decision makers to assess which capability gaps will be met for each alternative.*
3. Develop AOA time frame: *The customer provides the team conducting the analysis enough time to perform a robust and complete analysis.*	Not met	Livermore did not develop a time frame for conducting the analysis. According to agency officials and laboratory representatives, they do not know how long it took to perform the AOA process because they did not develop a schedule. They told us that they completed the AOA process documented in the initial AOA document very quickly because they had a predetermined solution in mind and did not believe they needed to carefully analyze the other alternatives. *Effect of not conforming to the practice: Recommending an alternative without adequate time to perform the analysis is a contributing factor to high dollar acquisitions that have overrun both costs and schedules while falling short of expected performance.*

Best practice	GAO assessment[b]	Summary of assessment and effects
4. Establish AOA team: *A diverse AOA team is established to develop the AOA, with members with a variety of necessary skill sets, specific knowledge, and abilities to successfully execute the study.*	Partially met	The AOA team included members from Livermore, Sandia National Laboratories, and Los Alamos National Laboratory. Livermore representatives told us that the team was composed of technical experts and did not include members with project management or cost estimating backgrounds. According to agency officials and laboratory representatives, they did not include program management or cost estimating experts because they believed the preferred solution, to procure and deploy an HPC system, was the only viable solution. *Effect of not conforming to the practice: Without the appropriate expertise on the team, errors in the results and gaps in the analysis may occur, causing the AOA's completion to be delayed until more subject matter experts are identified and assigned to work as part of the AOA process.*
5. Define selection criteria: *The AOA team or decision maker defines selection criteria based on the mission need, independent of a particular solution.*	Partially met	The selection criteria were written based on the predetermined solution and were not used to evaluate all of the alternatives. For example, the criteria list repeatedly refers to what is needed from an HPC system. *Effect of not conforming to the practice: If selection criteria are not established prior to the analysis in the AOA process based on the documented mission need and independent of a particular solution, bias can enter the AOA process and prevent the decision makers from forming an impartial and credible decision.*
6. Weight selection criteria: *The AOA team or decision maker decides on the weighting of the selection criteria to reflect the relative importance of each criterion prior to the beginning of the AOA process.*	Not met	The selection criteria were not weighted, and there is no documented justification. *Effect of not conforming to the practice: An unjustified weighting method can oversimplify the results and lead to an uninformed and biased decision.*
7. Develop AOA process plan: *The AOA team creates a process plan, including proposed methodologies for identifying, analyzing, and selecting alternatives prior to the beginning of the AOA process.*	Not met	According to agency officials and laboratory representatives, no AOA process plan was created. *Effect of not conforming to the practice: If methodologies for the remaining phases of the AOA study are not established and documented up front, the risk of applying poor methodologies as part of the AOA analysis increases, which could result in bias when selecting a preferred alternative.*
II. Identify alternatives		
8. Develop list of alternatives: *The AOA team identifies and considers a diverse range of alternatives to meet the mission needs.*	Fully met	Livermore developed a list of alternatives. These included no action; employ a cloud-based solution; upgrade deployments of existing production systems; procure and deploy a commodity technology system; and, the preferred alternative, to procure and deploy an HPC system. *Effect of not conforming to the practice: If the AOA team does not perform thorough research to capture many diverse alternatives, the optimal alternative could be overlooked and invalidate the AOA's results and bias the process.*

Best practice	GAO assessment[b]	Summary of assessment and effects
9. Describe alternatives: *The AOA team describes alternatives in terms of functional requirements and in sufficient detail to support the viability, cost, and benefit/effectiveness analyses.*	Partially met	The AOA document provides descriptions of the alternatives. However, the descriptions are conclusions as to why an HPC system, the predetermined solution, is needed and why the other alternatives would not meet mission needs. They do not describe the alternatives in sufficient detail to analyze each alternative's viability, cost, benefit, or effectiveness. For example, the description for the cloud-based solution begins by saying that the alternative would pose excessive security risks for data and would not be cost-effective. However, it does not describe the alternative in terms of functional requirements. *Effect of not conforming to the practice: Unless the AOA team adequately describes and documents the alternatives, the analysis will not provide sufficient detail to allow for valid cost/benefit estimates.*
10. Include baseline alternative: *The AOA team includes one alternative to represent the status quo to provide a basis of comparison among alternatives. The baseline is well documented and used to represent the current capabilities and also for explicit comparison later in the study.*	Partially met	The baseline alternative was defined as no action, but it was not well documented, used to represent current capabilities, or used as a basis for comparison with other alternatives. The description of the baseline alternative is that it is to provide no further ASC systems, without describing what the current capabilities are. *Effect of not conforming to the practice: If the status quo is not examined, then there is no benchmark for comparison, allowing arbitrary comparisons between alternatives and hindering the credibility of the study.*
11. Assess alternatives' viability: *The AOA team screens the list of alternatives to eliminate those alternatives that are not viable, and it documents the reasons for eliminating any alternatives.*	Partially met	The AOA documentation provides some information about the viability of the alternatives and eliminates two alternatives as nonviable. However, there are no details about the qualitative and operational factors used to determine the alternatives' viability or details about the assessment, only the conclusions. For example, the no action alternative is deemed not viable because it includes nonacceptable levels of risk, but no information is provided about how the AOA team made this determination. *Effect of not conforming to the practice: Not eliminating alternatives based on viability could needlessly extend the study's duration and burden the AOA team or lead to the selection of a technically nonviable alternative. Documenting the alternatives that are not deemed viable is important so that decision makers can clearly see that the AOA team examined those alternatives, confirming that the AOA process is comprehensive.*

Best practice	GAO assessment[b]	Summary of assessment and effects
III. Analyze alternatives		
12. Identify significant risks and mitigation strategies: *The AOA team identifies and documents the significant risks and mitigation strategies for each analyzed alternative.*	Minimally met	The AOA documentation includes only a limited number of risks for some alternatives and does not provide any mitigation strategies. For example, the documentation indicates that the cloud-based solution alternative poses security risks for the production and analysis of critical data but does not provide risks for other alternatives, including the selected alterative to procure and deploy and HPC system. According to agency officials and laboratory representatives, they did not develop mitigation strategies because they were almost certain from the beginning of the process that the preferred alternative was the only viable alternative. *Effect of not conforming to the practice: Not documenting the risks and related mitigation strategies for each alternative prevents decision makers from performing a meaningful trade-off analysis necessary to select a preferred alternative.*
13. Determine and quantify benefits/effectiveness: *The AOA team uses a standard process to identify and document benefits and effectiveness of each analyzed alternative, developing a framework that details the methods used to evaluate and quantify the measures of effectiveness and performance and quantifying the benefits and effectiveness of each alternative over its full life cycle.*	Minimally met	The AOA documentation provides benefits and effectiveness information for only two of the five alternatives. In addition, the benefits described are not quantified. For example, the documentation says that the preferred alternative—to purchase an HPC system—would exploit the most advanced computing technology available to provide a cost-effective solution but does not provide information as to how this was measured or provide any quantification of the cost-effectiveness. *Effect of not conforming to the practice: If the AOA team does not determine a standard process to quantify benefits and clearly establish criteria against which to measure all alternatives, bias is introduced to the study. Additionally, if the AOA team does not examine effectiveness over the entire life cycle, decision makers cannot see the complete picture and are prevented from making an informed decision.*
14. Tie benefits/effectiveness to mission need: *The AOA team explains and documents how each measure of effectiveness supports the mission need and functional requirements.*	Minimally met	The AOA documentation does not discuss potential benefits for all viable alternatives and does not tie benefits to mission need. For example, the documentation says that the alternative to procure and deploy a commodity technology system has the benefits that commodity technology systems are highly reliable and utilize proven technology and are low-cost, high-performance computers, readily available in the commercial market. However, the documentation does not indicate how these benefits tie to mission needs. *Effect of not conforming to the practice: Unless the AOA team thoroughly explains and documents how the measures of effectiveness relate to the specific mission need and functional requirements, decision makers will not have proper insight into the impact of each alternative.*

15. Develop life cycle cost estimates (LCCE): *The AOA team develops a life cycle cost estimate for each analyzed alternative, following best practices.*	Minimally met	The LCCEs are incomplete. For example, the cost estimates do not consider inflation and are not expressed in net present value. According to agency officials, they did not include inflation because they did not think it was a factor in determining costs. *Effect of not conforming to the practice: Without a full accounting of life cycle costs, decision makers will not have a comprehensive picture of the costs for each alternative and will have difficulty comparing the alternatives because comparisons may not be based on accurate information.*
16. Include a confidence interval or range for LCCEs: *The AOA team presents the life cycle cost estimate for each alternative, with a confidence level or range to convey a level of confidence for each alternative to achieve a most likely cost.*	Not met	The cost range for the predetermined solution reflects the range of cost estimates provided by the vendors in their responses to a request for information. According to agency officials and laboratory representatives, there was no risk or uncertainty analysis performed, and no confidence levels or ranges were developed by the AOA team. *Effect of not conforming to the practice: For decision makers to make informed decisions, the alternatives' LCCEs must reflect the degree of uncertainty. Without cost risk and uncertainty analysis, the LCCEs for the viable alternatives are not credible.*
17. Perform sensitivity analysis: *The AOA team tests and documents the sensitivity of the cost and benefit and effectiveness estimates for each analyzed alternative to risks and challenges in key assumptions.*	Not met	According to agency officials and laboratory representatives, no sensitivity analysis was performed. They said that they did not do this because they maintain communication with vendors to keep apprised of what costs should be. *Effect of not conforming to the practice: Failing to conduct a sensitivity analysis to identify the uncertainties associated with different assumptions negatively impacts the credibility of the AOA process by increasing the chance the AOA team will recommend an alternative without an understanding of the full impacts on life cycle costs, which could lead to cost and schedule overruns.*
IV. Document and review the AOA process		
18. Document AOA process in a single document: *The AOA team documents in a single document all steps taken to initialize, identify, analyze, and select alternatives.*	Minimally met	Agency officials told us that there is no final report for the AOA and that the AOA is presented in several documents, including El Capitan's mission need and draft conceptual baseline/execution readiness packages. *Effect of not conforming to the practice: Without a clear document that compiles all information, including standards used to rate and perform the analysis, it will not be apparent that the study is comprehensive, unbiased, and credible. Having all the information related to all best practices of the AOA process in a single document also makes it easier for an independent reviewer to assess the AOA process.*
19. Document assumptions and constraints: *The AOA team documents and justifies all assumptions and constraints used in the AOA process.*	Minimally met	The AOA documentation provides assumptions and constraints with the preferred alternative—acquiring an HPC system—in mind. One of the assumptions states that there are no anticipated quality issues with the systems and equipment that will be purchased. Another indicates that the assumptions for the system build and integration are aggressive. *Effect of not conforming to the practice: Without documented and justified assumptions and constraints, it will be difficult for decision makers to evaluate the alternatives.*

20. Ensure AOA process is impartial: *The AOA team conducts the analysis without having a predetermined solution in mind.*	Not met	Agency officials told us that they had already determined that the only viable alternative was to procure and deploy an HPC system before beginning the AOA process. *Effect of not conforming to the practice: An AOA process is not considered valid if it is biased. Performing a study with a predetermined solution distorts the results. The validity of the analysis is affected if bias is introduced to the inputs.*
21. Perform independent review: *An entity independent of the AOA process reviews the extent to which all best practices are followed.*	Minimally met	NNSA officials reviewed and approved an early AOA document. However, they did not review the final AOA document. According to NNSA officials, they did not review the final document because they believed they were exempt from following a Department of Energy policy document that includes requirements related to AOAs. *Effect of not conforming to the practice: Without independent reviews, the results are more likely to include organizational bias or lack the thoroughness needed to ensure that a preferred solution is chosen and not a favored solution, calling into question the credibility of the AOA process.*
V. Select a preferred alternative		
22. Compare alternatives: *The AOA team or decision maker compares the alternatives in order to select a preferred alternative that best meets the mission need, using net present value, if possible*	Not met	Agency officials told us that they had already determined the preferred alternative before beginning the AOA process. Therefore, they did not perform an in-depth comparison of the alternatives. *Effect of not conforming to the practice: Comparing items that have not been discounted (or normalized) does not allow for time series comparisons, since alternatives may have different life cycle durations. Additionally, not clearly documenting the rationale used to select a preferred alternative will lower the confidence in the results of the AOA process and present the appearance of bias surrounding the selected alternative.*

Source: GAO analysis of NNSA information. | GAO-21-194.

[a]For this report, we used the best practices for an AOA process as identified in GAO, Amphibious Combat Vehicle: Some Acquisition Activities Demonstrate Best Practices; Attainment of Amphibious Capability to Be Determined, GAO-16-22 (Washington, D.C.: Oct. 28, 2015). Subsequent to our review, these best practices were updated in GAO, Cost Estimating and Assessment Guide, GAO-20-195G (Washington, D.C.: March 2020). There are minor differences between the two versions, the primary one being that some of the best practices have been moved among the characteristics, but these differences did not impact the results of our review.

[b]The ratings were assigned as follows: not met—provided no evidence that satisfies any of the best practice or characteristic; minimally met—provided evidence that satisfies a small portion of the best practice or characteristic; partially met—provided evidence that satisfies about half of the best practice or characteristic; substantially met—provided evidence that satisfies a large portion of the best practice or characteristic; and fully met—provided complete evidence that satisfies the best practice or characteristic.

Combining the ratings for the best practices, we found that the AOA process for El Capitan partially met the characteristic of a comprehensive AOA process and minimally met the characteristics of a well-documented, unbiased, and credible AOA process. After we completed our review,

the updated best practices and found that the updates did not impact the results of our review (see table 8).[3]

Table 8: Final Assessment of the El Capitan Analysis of Alternatives (AOA) Process Against Characteristics of a High-Quality, Reliable AOA Process

AOA characteristic	GAO assessment against previous version of GAO best practices	Related best practices under previous version of GAO best practices	Related best practices under updated version of GAO best practices
Comprehensive: *The AOA ensures that no alternatives were omitted and that each alternative is examined thoroughly for the program's entire life cycle.*	Partially met	1. Define mission need.	1. Define mission need.
			2. Define functional requirements.
		3. Develop AOA time frame.	3. Develop AOA time frame.
		8. Develop list of alternatives.	8. Develop list of alternatives.
		11. Assess alternatives' viability.	11. Assess alternatives' viability.
		15. Develop life cycle cost estimates.	15. Develop life cycle cost estimates.
Well documented: *The AOA process is thoroughly described in a single document, including all source data; clearly detailed methodologies, calculations, and results; as well as providing explanations regarding selection criteria.*	Minimally met		9. Describe alternatives.
		12. Identify significant risks and mitigation strategies.	12. Identify significant risks and mitigation strategies.
		14. Tie benefits/ effectiveness to mission need.	14. Tie benefits/ effectiveness to mission need and functional requirements.
		18. Document AOA process in a single document.	18. Document AOA process in a single document.
		19. Document assumptions and constraints.	19. Document ground rules, assumptions, and constraints.
Unbiased: *The AOA process ensures that it does not have a predisposition toward one alternative over another but is based on traceable and verifiable information*.	Minimally met	2. Define functional requirements.	
		4. Establish AOA team.	4. Establish AOA team.
		6. Weight selection criteria.	6. Weight selection criteria.
		7. Develop AOA process plan.	7. Develop AOA process plan.
		13. Determine and quantify benefits/effectiveness.	13. Determine and quantify benefits/effectiveness.

[3]For this report, we used the best practices for an AOA process as identified in GAO, *Amphibious Combat Vehicle: Some Acquisition Activities Demonstrate Best Practices; Attainment of Amphibious Capability to Be Determined,* GAO-16-22 (Washington, D.C.: Oct. 28, 2015). Subsequent to our review, these best practices were updated in GAO, *Cost Estimating and Assessment Guide,* GAO-20-195G (Washington, D.C.: March 2020). There are minor differences between the two versions, the primary one being that some of the best practices have been moved among the characteristics, but these differences did not impact the results of our review.

AOA characteristic	GAO assessment against previous version of GAO best practices	Related best practices under previous version of GAO best practices	Related best practices under updated version of GAO best practices
		20. Ensure AOA process is impartial.	20. Ensure AOA process is impartial.
		22. Compare alternatives.	22. Compare alternatives.
Credible**:** *The AOA process thoroughly discusses the limitations of the analyses resulting from the uncertainty that surrounds both the data and assumptions for each alternative.*	Minimally met	5. Define selection criteria.	5. Define selection criteria.
		9. Describe alternatives.	
		10. Include baseline alternative.	10. Include baseline alternative.
		16. Include a confidence interval or range for life cycle cost estimates.	16. Include a confidence interval or range for life cycle cost estimates.
		17. Perform sensitivity analysis.	17. Perform sensitivity analysis.
		21. Perform independent review.	21. Perform independent review.

Source: GAO. | GAO-21-194

Appendix III: Comments from the Department of Energy

Department of Energy
National Nuclear Security Administration
Washington, DC 20585

April 14, 2021

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

Dear Ms. Bawden:

Thank you for the opportunity to review the Government Accountability Office (GAO) draft report "High-Performance Computing: NNSA Could Improve Program Management Processes for System Acquisitions" (GAO-21-194). The Department of Energy's National Nuclear Security Administration (NNSA) has over two decades of experience deploying high-performance computing systems in support of the agency's stockpile stewardship mission. This mission has unique requirements and, as the report notes, the agency must navigate some uncertainty in the process of procuring cutting-edge systems that are not yet commercially available. NNSA's Advanced Simulation and Computing program addresses this uncertainty, in part, through the application of best practices for high-performance computing procurements, which it developed from its experience deploying these types of systems. When implemented, El Capitan will provide a significant increase in computational performance while significantly decreasing computational times for weapons simulations. While NNSA has a strong record in this area, we appreciate the auditors' observations and recommendations for further strengthening our practices.

NNSA agrees with the auditors' recommendations, and the attached Management Decision outlines the specific actions planned to address each. Our subject matter experts have also provided technical and general comments under separate cover for your consideration to enhance the clarity and accuracy of the report. If you have any questions about this response, please contact Dean Childs, Director, Audits and Internal Affairs, at (301) 903-1341.

Sincerely,

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

Enclosure

Enclosure

NATIONAL NUCLEAR SECURITY ADMINISTRATION

Management Decision
"High-Performance Computing: NNSA Could Improve Program Management Processes for System Acquisitions" (GAO-21-194)

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

Recommendation 1: Take steps to ensure that, for future high-performance computing (HPC) acquisitions, the Advanced Simulation and Computing (ASC) program follows GAO best practices for Analysis of Alternatives (AOA) processes where possible, and justifies and documents any deviations, as required by agency policy.

Management Response: Concur. For future ASC procurement activities, the program will conduct rigorous AOAs considering the unique requirements of the stockpile stewardship program, while continuing to follow applicable GAO best practices for AOAs where possible and documenting any deviations from those practices. Completion of this action is dependent on the unknown timing of the next major HPC procurement. An initial estimated completion date of December 31, 2023, is being set, to be adjusted once plans for a future acquisition are made.

Recommendation 2: Ensure that the ASC program's future AOA processes are performed by an entity independent of the contractor organization managing and executing the program.

Management Response: Concur in Principle. Where future HPC acquisitions are determined to be capital asset projects, the ASC program will ensure that the AOA process is conducted independent of the contractor managing and executing the acquisition, and will also exclude from the AOA process contractors managing and operating sites where any alternatives are being considered. However, where future HPC acquisitions are determined to not be capital asset projects, the ASC program will continue to follow its best practices for HPC procurements, which includes reviews by organizations and individuals independent of the contracting and management organization. Completion of this actions is dependent on the unknown timing of the next major HPC procurement. An initial estimated completion date of December 31, 2023, is being set, to be adjusted once plans for a future acquisition are made.

Recommendation 3: Update and maintain acquisition program documents to include current El Capitan requirements and clearly document the relationship between El Capitan's mission and functional requirements.

Management Response: Concur. The ASC program and LLNL El Capitan project team will continue to update and maintain a current set of documents that are important for the management and completion of the acquisition project, to include documented linkages between key mission and functional requirements, and updates to mission needs and functional requirements as deemed significant and necessary. Criteria for closure will be validation of the

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documented linkage between the current high-level mission and functional requirements. The estimated completion date for this action is September 30, 2021.

GAO Draft Report "High-Performance Computing: NNSA Could Improve Program Management Processes for System Acquisitions" (GAO-21-194)

Technical and General Comments

1) Highlights Page: The report covers three objectives, but the first objective – how the cost of NNSA's El Capitan acquisition program will compare to the costs of previous HPC acquisition programs – is not fully addressed in the "What GAO Found" section. While it does note the $600 million cost of the El Capitan HPC acquisition, it does not provide any context for this investment. As the report notes, when implemented, El Capitan will provide a significant increase in computational performance while significantly decreasing computational times for weapons simulations. We believe this information is needed in the "What GAO Found" section for context and balance.

2) Page 7, Figure 1: The word "management" at the end of the "Advanced technology development and management" phrase should be corrected to "mitigation".

3) Page 12, First Paragraph, Fourth sentence: "NA-MB was established in 2019 as the lead for conducting NNSA-initiated AOA processes." Current language may be interpreted as saying NA-MB was established in 2019 for the purpose of conducting AoAs, as opposed to NA-MB, which already existed, being given responsibility for conducting AoAs in 2019. We suggest changing this to read as follows: "NA-MB was appointed as the lead for conducting NNSA-initiated AOA processes in 2019."

4) Page 23, First Paragraph: "According to CEPE officials, an AOA process should be led by the program office with support from CEPE and NA-MB. However, they noted that, if the program office cannot perform the AOA process, for example, due to resource limitations, there are independent resources available to help design and conduct an AOA process. For example, the process can be outsourced to an independent federally funded research and development center or other independent contractor. Additionally, NA-MB can work with the program office to develop AOA study plans, which lay out the approach for the AOA team to conduct the AOA process. NA-MB officials told us that program offices can consult with them concerning AOA and AOA-like analyses. Finally, CEPE can perform independent cost estimates, and CEPE officials told us that they can be consulted on the AOA process, provide independent reviews, and suggest improvements to the process."

   As written, this section has a number of elements that may be confusing. Namely, the AoA is always conducted by NA-MB, although the analysis can be supported by other contractors as needed. In addition, it is not always clear which is the CEPE perspective and which is the MB perspective. We suggest changing this to read as follows: "According to CEPE officials and NNSA policy, the program office leads the AoA by providing direction as the chair of the committee providing guidance to the AoA team. NA-MB has the responsibility to support the program office by conducting the AoA, including developing the study plan in coordination with the program office, managing all AoA teams, and performing the cost, schedule, and risk analyses. However, CEPE officials note that, if NA-MB cannot perform the AoA, for example, due to resource limitations, there are independent resources available

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to help design and conduct the AoA study. For example, the study can be outsourced to an independent federally funded research and development center or other independent contractor. NA-MB officials told us that program offices can consult with them concerning AOA-like analyses. Finally, CEPE can perform independent cost estimates, and CEPE officials told us that they can be consulted on the AOA process, provide independent reviews, and suggest improvements to the process."

Appendix IV: GAO Contact and Staff Acknowledgments

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Staff Acknowledgments

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