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Report to Congressional Committees

March 2019

NATIONAL SCIENCE FOUNDATION

Cost and Schedule Performance of Large Facilities Construction Projects and Opportunities to Improve Project Management

GAO-19-227

GAO Highlights

Highlights of GAO-19-227, a report to congressional committees

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Cost and Schedule Performance of Large Facilities Construction Projects and Opportunities to Improve Project Management

Why GAO Did This Study

NSF awards cooperative agreements and contracts to external funding recipients to fund construction of science and engineering research infrastructure, such as telescopes. These large facilities projects typically have construction costs of at least $70 million and may take many years to design and construct. Having expertise in project management can help keep complex projects on schedule and on budget, and identifying lessons learned from projects can help improve project oversight and performance.

Senate Report 114-239 and House Report 114-605 included provisions for GAO to review NSF's large facilities projects. This report examines, among other things, (1) steps NSF has taken to ensure the project management expertise of NSF staff and award recipients, (2) the extent to which NSF identifies and shares lessons learned on large facilities projects, and (3) the cost and schedule performance of NSF's ongoing large facilities projects. GAO analyzed NSF policies and documents for the seven projects in design or construction, interviewed agency officials, and compared NSF's processes to leading practices identified in prior GAO work.

What GAO Recommends

GAO is making four recommendations to NSF including that NSF assess any gaps in its oversight staff's project management expertise, establish criteria for recipients' project management expertise, and ensure that recipients provide any lessons learned on projects to NSF. NSF generally agreed with GAO's recommendations.

View GAO-19-227. For more information, contact John Neumann at (202) 512-6888 or neumannj@gao.gov.

What GAO Found

The National Science Foundation (NSF) took some steps to help ensure that its own oversight staff for large facilities projects and the agency's award recipients—such as universities or companies that design, construct, and operate the projects on a day-to-day basis—have project management expertise, but it had not taken certain additional steps. For example, as called for by leading practices, in 2018 NSF identified competencies needed by its oversight staff to ensure their project management expertise. In contrast, the agency had not yet assessed potential gaps in how well its staff met the competencies or established a time frame for doing so. Having such an assessment would help NSF target workforce strategies to fill any gaps identified. To assess the expertise of recipients, NSF relies on the judgment of external panels of experts it periodically convenes to review large facilities projects during design and construction. However, NSF had not established criteria for project management expertise needed by recipients, potentially increasing the risk of awarding funds to recipients that may not be well-qualified to manage large construction projects.

In 2017 NSF formalized its process to identify and share lessons learned on large facilities projects. This process was consistent with key practices from GAO's prior work on lessons learned. However, the agency had not established a requirement for all recipients to provide potential lessons learned. Ensuring, through a requirement or other means, that all recipients provide lessons learned could help NSF identify lessons that would benefit other projects.

NSF completed construction of the Advanced Laser Interferometer Gravitational Wave Observatory in 2018, continued construction on four other large facilities projects, and advanced the design of two; these projects had varying cost and schedule performance. Since GAO's June 2018 report, NSF delayed completion of the National Ecological Observatory Network by 3 months, for a total delay of 2.6 years; other projects under construction had no cost or schedule increases.

Cost and Schedule Performance of NSF Large Facilities Projects Recently Completed or Under Construction, as of September 2018

Project name	Percentage complete	Scheduled completion date	Cumulative performance since starting construction: Cost	Schedule	Scope reductions[a]
Advanced Laser Interferometer Gravitational Wave Observatory	100	2018	-	▲	-
National Ecological Observatory Network[b]	98	2019	▲	▲	✓
Daniel K. Inouye Solar Telescope	88	2020	▲	▲	✓
Large Synoptic Survey Telescope	60	2022	-	-	-
Regional Class Research Vessels	7	2024	-	-	-

Legend: - = no cost or schedule increase or scope reductions; ▲ = cost or schedule increased; ✓= scope reduced.

Source: GAO analysis of National Science Foundation (NSF) documents and information from NSF officials. | GAO-19-227

[a]Scope reductions are in response to NSF's policy on cost overruns or as part of a cost increase.
[b]The percentage complete and schedule for the National Ecological Observatory Network are as of November 2018, when NSF extended the project's schedule.

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Abbreviations

AIMS	Antarctic Infrastructure Modernization for Science
ATLAS	A Toroidal Large Hadron Collider Apparatus
CERN	European Organization for Nuclear Research
CMS	Compact Muon Solenoid
DKIST	Daniel K. Inouye Solar Telescope
DOE	Department of Energy
EVM	Earned value management
HL-LHC	Large Hadron Collider High Luminosity Upgrade
LHC	Large Hadron Collider
LIGO	Laser Interferometer Gravitational Wave Observatory
LSST	Large Synoptic Survey Telescope
MREFC	Major Research Equipment and Facilities Construction
NSF	National Science Foundation
OMB	Office of Management and Budget
RCRV	Regional Class Research Vessels

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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March 27, 2019

The Honorable Jerry Moran
Chairman
The Honorable Jeanne Shaheen
Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
United States Senate

The Honorable José Serrano
Chairman
The Honorable Robert Aderholt
Ranking Member
Subcommittee on Commerce, Justice, Science, and Related Agencies
Committee on Appropriations
House of Representatives

The National Science Foundation (NSF) supports the design, construction, and operations of various large facilities projects—science and engineering research infrastructure, such as telescopes and research vessels, with construction costs that are typically at least $70 million. These projects are complex and often cost hundreds of millions of dollars to construct. In the annual appropriations process for fiscal year 2018, NSF received appropriations of almost $183 million for construction of such facilities. NSF's large facilities projects respond to the needs of the scientific community and are designed and developed in collaboration with that community. For example, NSF is supporting the Large Synoptic Survey Telescope project under construction in Chile at an authorized construction cost to NSF of $473 million. The astronomy community intends to use this telescope to better understand the formation and structure of our galaxy and address other research questions.

The agency uses cooperative agreements and contracts to fund and oversee large facilities projects throughout their life cycles, including their design, construction, and operations stages.[1] The recipients of these awards, which may include universities, nonprofit associations, and companies, manage the projects' day-to-day activities. An NSF project team oversees each project and shares responsibility with the recipient for the project's success. Each NSF project team, at a minimum, includes (1) a representative with scientific expertise from the NSF office sponsoring the project; (2) a representative from NSF's Large Facilities Office, which assists on aspects of project planning, budgeting, implementation, and management practices and provides assurance that NSF's oversight processes are being followed; and (3) a grants and agreements officer or contract officer with expertise in managing agreements between NSF and recipients.

The size and complexity of large facilities projects require project management expertise to manage their scope, cost, and schedule. For example, expertise is needed to develop or review detailed project cost estimates and schedules and track the cost and schedule performance of a construction project. Having such expertise may help NSF staff overseeing the projects and the recipients constructing them to identify and address potential problems early enough to prevent cost and schedule increases or scope reductions. NSF's experience with its National Ecological Observatory Network project—a network of ecological observation sites under construction nationwide—highlights the importance of project management expertise. In 2011, NSF awarded funding to a newly founded organization to manage construction of the project. By 2016, NSF had increased the cost and schedule of the project, reduced its scope, and awarded a cooperative agreement to a new recipient to take over construction of the project. A 2016 internal report NSF commissioned to analyze the project's problems and the root causes found that the original recipient failed to build a project team that could overcome the project's issues. The report also found that the factors affecting the project included partial or improper project planning and the recipient's inability to mature and properly utilize their management tools.

[1]NSF generally funds large facilities projects using cooperative agreements rather than contracts. Cooperative agreements are a form of financial assistance used to enter into a relationship the principal purpose of which is to transfer a thing of value to a nonfederal entity for a public purpose, with an expectation of substantial involvement by the federal awarding agency when carrying out the activities contemplated by the federal award. According to agency officials, NSF occasionally uses contracts for large facilities projects when the activity is considered a procurement action.

A 2015 review by the National Academy of Public Administration made recommendations regarding NSF's processes for ensuring appropriate project management expertise for large facilities projects and for sharing lessons learned on projects throughout their life cycles.[2] For example, the academy recommended that NSF

- identify requirements for project management and financial management expertise related to construction of large facilities projects and explicitly add the requirements to the criteria for selecting external reviewers who participate in panels that periodically review NSF's large facilities projects;
- identify project management skill requirements for NSF project team members and provide them with role-specific training;
- require that award recipient project managers be certified in project management and specify the minimum project management experience thresholds for project positions in the terms and conditions of the cooperative agreement; and
- formally establish communities of practice to share best practices and implement a "lessons learned" requirement for all large facilities projects.

More recently, the American Innovation and Competitiveness Act directed NSF to establish the appropriate project management and financial management expertise required for its staff to effectively oversee large facilities projects, including by improving project management training and certification, and to coordinate the sharing of the best management practices and lessons learned from these projects, among other things.[3]

Planning, executing, and monitoring project cost and schedule are core aspects of project management, and NSF policy directs recipients to use best practices from GAO's cost estimating and schedule assessment guides for large facilities projects. GAO's cost and schedule guides describe the best practices that federal organizations and industry use to develop and maintain reliable cost estimates, earned value management

[2]National Academy of Public Administration, *National Science Foundation: Use of Cooperative Agreements to Support Large Scale Investment in Research* (Washington, D.C.: December 2015).

[3]Pub. L. No. 114-329 § 110(a)(2), 130 Stat. 2969, 2988, 2989 (2017) (codified at 42 USC 1862s-2(a)(2)).

systems, and schedules.[4] Earned value management is a project management tool that can provide decision makers with reliable cost and schedule performance data by measuring the value of work accomplished in a given period and comparing it with (1) the planned value of work scheduled for that period and (2) the actual cost of work accomplished. Similarly, a well-planned schedule can help agencies more effectively manage projects by specifying when work will be performed and measuring program performance against an approved plan.

Senate Report 114-239 and House Report 114-605, issued in 2016, included provisions for us to review projects funded within NSF's Major Research Equipment and Facilities Construction (MREFC) account, which the agency typically uses to fund construction of its large facilities projects.[5] In our first large facilities report in June 2018, we reviewed NSF's procedures for cost estimating and developing project schedules and found that they fully or substantially met seven of 12 best practices in GAO's cost guide but did not meet or minimally met six of 10 best practices in GAO's schedule guide.[6] In addition, five of the seven projects we reported on had experienced schedule delays. We recommended that the Director of NSF revise the agency's policies for estimating the costs and schedules of large facilities projects, and for reviewing those costs and schedules, to better incorporate the best practices in GAO's cost and schedule guides. NSF agreed with our recommendations and planned to take several steps to implement them.

This report, our second in response to the Senate and House report provisions,

1. examines the extent to which NSF has taken steps to ensure that NSF staff and recipients of awards for its large facilities projects have project management expertise,

[4]GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, GAO-09-3SP (Washington, D.C.: March 2009) and *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015).

[5]S. Rep. No. 114-239, at 117 (2016); H.R. Rep. No. 114-605, at 68 (2016).

[6]GAO, *National Science Foundation: Revised Policies on Developing Costs and Schedules Could Improve Estimates for Large Facilities*, GAO-18-370 (Washington, D.C.: June 1, 2018).

2. examines the extent to which NSF identifies and shares lessons learned on large facilities projects,
3. examines the extent to which a selected large facilities project under construction—the Large Synoptic Survey Telescope—applied best practices for earned value management and scheduling, and
4. describes the cost and schedule performance of NSF's large facilities projects in construction or design.

To examine the extent to which NSF has taken steps to ensure that NSF staff and award recipients have project management expertise, we reviewed NSF policies, such as the agency's *Large Facilities Manual*[7] and standard operating guidance documents, and interviewed agency officials to determine the agency's requirements and plans. We evaluated the extent to which NSF implemented certain leading principles for strategic human capital management with respect to its large facilities oversight staff, such as identifying competencies and assessing workforce gaps, developing strategies to address gaps, and monitoring and evaluating progress. We identified leading principles in our past work on human capital management and selected for this review those principles most directly related to the American Innovation and Competitiveness Act requirement for NSF to establish project management and financial management expertise among oversight staff.[8] We did not review any NSF efforts to ensure the expertise of its contracting officers; competencies for these staff are determined by the Federal Acquisition Institute.[9] We also reviewed project documents for the four most recent projects of the seven that were under construction or in design at the beginning of our review to assess how NSF considered the recipients' project management expertise; our observations on these projects are not generalizable to projects we did not review. Specifically, because NSF's oversight processes have changed in recent years, we selected the two

[7]National Science Foundation, *Large Facilities Manual*, NSF 17-066 (March 2017).

[8]Other leading principles include aligning workforce planning with strategic planning and budget formulation; involving managers, employees, and other stakeholders in planning; and building the capabilities needed to support workforce strategies through steps that ensure the effective use of human capital flexibilities. See GAO, *Defense Acquisition Workforce: Actions Needed to Guide Planning Efforts and Improve Workforce Capability*, GAO-16-80 (Washington, D.C: Dec. 14, 2015).

[9]According to a NSF document, all four of the agency's contracting officers assigned to major acquisitions have achieved the highest level of certification awarded by the Federal Acquisition Institute.

projects that received their initial construction funding in the last 5 years—the Large Synoptic Survey Telescope in Chile and Regional Class Research Vessels being built in Louisiana—and the two projects in design at the time of our review—the Antarctic Infrastructure Modernization for Science at McMurdo station in Antarctica and the Large Hadron Collider High Luminosity Upgrade near Geneva, Switzerland. We reviewed project documents to assess, among other things, how NSF had directed external panels of experts that it convened to review the projects during their development or design stages.

To examine the extent to which NSF identifies and shares lessons learned for large facilities projects, we reviewed applicable agency policies and documentation and interviewed agency officials. We compared NSF's policies—such as its *Large Facilities Manual*, standard operating guidance documents, *Proposal and Award Policies and Procedures Guide*,[10] and *Proposal and Award Manual*—and procedures with the six key practices we previously reported for identifying and applying lessons learned.[11] We also reviewed relevant project documents for two projects to assess how NSF has directed NSF oversight staff, recipients, and external panels to identify lessons learned, including cooperative agreements, recipients' annual progress reports, and NSF's written questions—known as charge questions—to guide external panels in reviewing projects. Specifically, we reviewed the Large Synoptic Survey Telescope and the Regional Class Research Vessels projects because NSF's oversight processes have changed in recent years, and these were the two projects that received their initial construction funding in the last 5 years. Our observations on these two projects are not generalizable to projects we did not review.

To examine the extent to which a selected large facilities project under construction applied best practices for earned value management and scheduling, experts from our Center for Science, Technology, and Engineering completed two separate analyses of the Large Synoptic Survey Telescope project. We selected this project because it had been under construction long enough to allow our analysis but had enough time remaining in construction to allow for changes, if necessary.

[10]NSF, *Proposal and Award Policies and Procedures Guide*, NSF18-1 (Jan. 29, 2018).

[11]GAO, *Telecommunications: GSA Needs to Share and Prioritize Lessons Learned to Avoid Future Transition Delay*s, GAO-14-63 (Washington, D.C: Dec. 5, 2013).

We chose to examine earned value management and scheduling because

- earned value management is an important project management tool that can provide accurate assessments of project progress and be used to predict future performance—for example, by providing early warning signs of potential schedule delays or cost overruns and by providing unbiased estimates of anticipated costs at completion; and
- a well-planned schedule is another fundamental management tool that provides a road map for systematic execution of a project as well as a means to gauge progress, identify and address potential problems, and promote accountability.

We (1) compared the telescope project's earned value management system data to best practices in GAO's cost guide and (2) compared the project's construction schedule to best practices in GAO's schedule guide. Specifically, we reviewed agency policies—such as NSF's *Large Facilities Manual* and a standard operating guidance document on earned value management—and project documents—such as the telescope project's baseline schedule and current schedule as of June 1, 2018, the schedule dictionary, work breakdown structure, risk management plan and risk register, and monthly progress reports dated May 2017 to June 2018. We also interviewed agency officials and project management officials from the recipient organization. We provided our criteria and draft analyses to NSF for review by agency and recipient officials and incorporated their technical comments as appropriate.

To describe the cost and schedule performance of NSF's large facilities projects in construction or design, we reviewed project documents and NSF's written responses to our questions on the Advanced Laser Interferometer Gravitational Wave Observatory, the Daniel K. Inouye Solar Telescope, the Large Synoptic Survey Telescope, the National Ecological Observatory Network, and the Regional Class Research Vessels projects, which were under construction at the start of our review, as well as the Antarctic Infrastructure Modernization for Science and the Large Hadron Collider High Luminosity Upgrade projects, which were in design at the time of our review. We reviewed, for example, cooperative agreements, progress reports, risk reports and risk registers, documentation on available scope reduction options, and other NSF, recipient, or external panel project documents, as applicable, related to project cost, schedule, scope, and risks. We assessed the reliability of project data by obtaining supporting documentation for data points when possible, conducting routine checks for consistency with other information contained in the documentation provided by NSF, and clarifying any discrepancies with NSF project officials. Through this process, we determined that the data points were sufficiently reliable for our purpose of describing information available on the projects' cost and schedule performance and current status.[12]

We conducted this performance audit from June 2018 to March 2019 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

Stages in the Life Cycles of NSF's Large Facilities Projects

Each large facilities project has a sponsoring office from within NSF's seven directorates. The directorates support research and education in various areas of science and engineering, such as biological or computer science. The sponsoring office assesses the scientific merit of potential projects, proposes projects for funding through NSF's MREFC account, and oversees the projects during the following five stages of their life cycle:

- **Development.** Initial project ideas emerge and a broad consensus is built within the relevant scientific community for the potential long-term needs, priorities, and general requirements for research infrastructure that NSF may consider funding. For example, NSF's Large Hadron Collider High Luminosity Upgrade project—in design at the time of our review—would address some of the highest priorities identified by the U.S. particle physics community's long-term strategic plan (a document that serves NSF and the Department of Energy as the country's ten-year strategic plan for high energy physics). According to NSF officials, priorities for large facilities projects are informed by

[12]With the exception of our objective in this report to review the earned value management system and schedule for the Large Synoptic Survey Telescope project, we did not evaluate recipients' underlying systems for tracking and measuring cost and schedule progress during construction.

advisory committees for each directorate as well as by assessments that the National Academies of Sciences, Engineering, and Medicine conduct every 10 years in various scientific areas, such as astronomy and astrophysics, biological and physical sciences, and solar and space physics.

- **Design.** Entrance into this stage occurs when the NSF Director approves the proposed large facilities project as a national priority and the sponsoring directorate makes an award (either through a cooperative agreement or contract) for developing details about project cost, scope, and schedule for possible construction. This stage is divided into conceptual, preliminary, and final design phases, with cost and schedule estimates progressively developed during each phase.
- **Construction.** The construction stage begins when NSF awards construction funds to external recipients for acquisition or construction of a large facilities project. Such awards generally take the form of cooperative agreements, although NSF occasionally uses contracts, according to agency officials. The policies and procedures in NSF's *Large Facilities Manual* apply to research infrastructure projects regardless of the award instrument employed.[13] According to this manual, the transition from construction to operations is rarely abrupt, and many projects require an integration and testing phase, followed by a commissioning phase to bring the facility up to the design level of operational readiness. The construction stage ends after final delivery and acceptance of the defined scope of work and facility performance per terms of the award agreement.
- **Operations.** The operations stage includes the day-to-day work to operate and maintain the facility and to perform research. Operations awards, which are separate from construction awards, may be

[13]In addition, cooperative agreements with universities, consortia of universities, or nonprofit organizations are governed by the Office of Management and Budget's (OMB) *Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards* (Uniform Guidance). *See* 78 Fed. Reg. 78,590 (Dec. 26, 2013) (OMB's final Uniform Guidance) (codified as amended at 2 C.F.R. pt. 200). In December 2014, NSF and other federal awarding agencies issued a joint interim final rule to implement this Uniform Guidance. 79 Fed. Reg. 75,871 (Dec. 19, 2014). NSF received approval from OMB to implement the Uniform Guidance using a policy rather than a regulation. Acquisitions by contract of supplies or services by and for the use of the federal government are governed by the Federal Acquisition Regulation. *See* 48 C.F.R. §§ 1.104, 2.101(b); see also chapter 25 of title 48 of the *Code of Federal Regulations* for NSF-specific provisions. According to NSF's *Large Facilities Manual*, contracts with nonprofit and educational institutions are also governed by the Uniform Guidance.

awarded to the construction award recipients or to a different entity. Depending on the project, initial operations may begin before completion of construction. Integration and testing activities may continue during the operations stage, depending upon the complexity and time needed to reach design specifications.

- **Divestment.** Divestment can include the transfer of the facility to another entity's operational and financial control or the decommissioning of the research infrastructure, including its complete deconstruction and removal. NSF generally decides to divest when the agency or the scientific community determine that the facility is no longer considered an operational priority with regard to advancing science, according to NSF's *Large Facilities Manual*. Entrance into the divestment stage occurs when the first financial investment is made to divest or decommission the research infrastructure.

With the exception of the construction stage, NSF funding for these stages generally comes from the sponsoring directorate. Construction funding generally comes from the MREFC account. However, if the sponsoring directorate funds construction, the policies and procedures in NSF's *Large Facilities Manual* apply if total project costs meet the definition of a major multiuser facility project under the American Innovation and Competitiveness Act—that is, if the costs exceed $100 million or 10 percent of the responsible directorate's annual budget, whichever is less.[14]

Management of Large Facilities Construction Projects

External recipients of NSF awards—such as universities, nonprofit associations, and companies—are responsible for the day-to-day management of large facilities projects throughout their design, construction, and operations stages. According to NSF officials, a recipient's key personnel may vary depending on the stage of the project and from one project to another but generally include several positions:

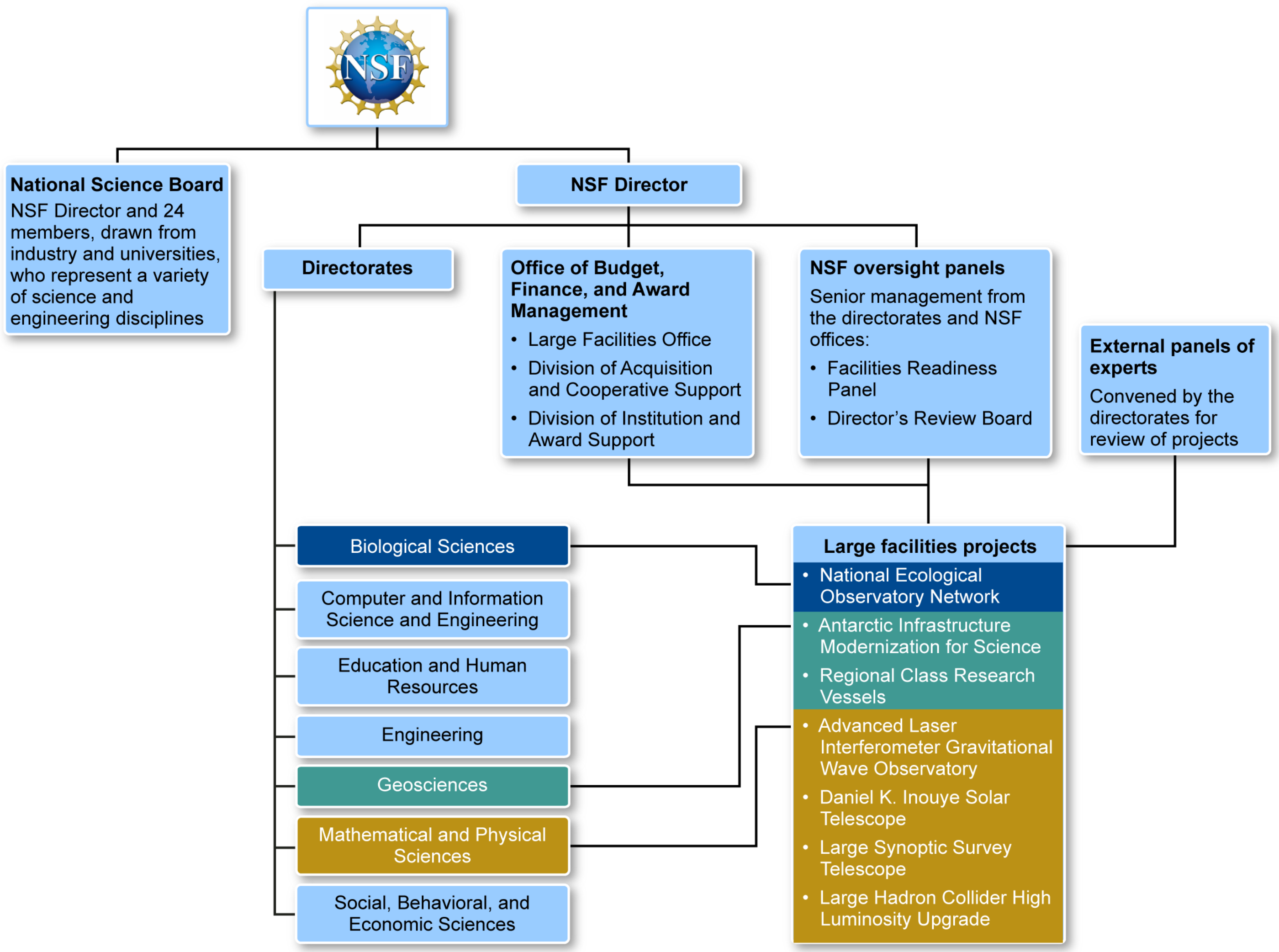
[14]Section 110 of the act refers to "major multiuser research facility projects," which it defines as science and engineering facility projects that (a) exceed the lesser of 10 percent of a directorate's annual budget or $100 million in total project costs or (b) are funded by the Major Research Equipment and Facilities Construction account or any successor account. Pub. L. No. 114-329 § 110(g)(2) (codified at 42 U.S.C. § 1862s-2(g)(2)). Major multiuser research facility projects include those we refer to in this report as large facilities projects.

- **Principal investigator.** In general, the principal investigator is the individual submitting the project proposal to NSF. This could be a faculty member at an academic institution or the chief executive of a non-profit organization or a multi-institution consortium. The principal investigator is ultimately responsible for all aspects of successfully executing the project, including ensuring that it meets its strategic science and technical goals and interfacing with NSF and the science community.
- **Project director.** The project director is typically responsible for the day-to-day management of the project, generally reports to the principal investigator, and may be named as a co-principal investigator. This individual may stay on after construction to oversee long-term operation of the facility.
- **Project manager.** The project manager is the individual responsible for the project's construction stage on a day-to-day basis, including managing major deliverables and the project's schedule and using earned value management to monitor the project's progress. The project manager is often considered the deputy project director but is generally not named as a co-principal investigator. This individual typically leaves the project once construction is complete.

NSF Oversight of Large Facilities Projects

NSF has established an oversight structure for large facilities projects that includes offices from across the agency (see fig. 1). This includes the National Science Board, a policy and advisory body that is part of NSF and consists of the NSF Director and 24 members—drawn from industry and universities—who represent a variety of science and engineering disciplines. The NSF Office of the Director and the National Science Board provide high-level, ongoing oversight of large facilities projects, including the approval of new projects to be included in NSF's budget request.

Figure 1: Organization of National Science Foundation (NSF) Oversight for Large Facilities Projects



Source: GAO analysis of NSF documents. | GAO-19-227

Note: Figure does not include all NSF offices and includes only the large facilities projects in design or construction at the time of GAO's review.

Two bodies advise the Director of NSF on large facilities projects:

- **Facilities Readiness Panel.** In 2018, NSF established this panel to advise the NSF Director on the readiness of projects to advance from one phase to another within the design stage, and from the design stage to the construction stage.[15] The panel comprises senior management representatives from across the agency, including NSF's Chief Officer for Research Facilities;[16] the heads of the Large Facilities Office and Office of General Counsel; the director of the Division of Acquisition and Cooperative Support; and at least three experienced division directors, section heads, or program officers from the directorates for mathematical and physical sciences, geosciences, biological science, computer and information science and engineering, and engineering.

- **Director's Review Board.** Also composed of senior management representatives and advisors from across the agency, the Director's Review Board reviews and approves materials submitted to the National Science Board for information or action, including materials related to large facilities projects.

Within NSF's Office of Budget, Finance, and Award Management, the Large Facilities Office (1) develops business-related oversight policies for all life-cycle stages with a focus on the design and construction stages and (2) provides assistance on nonscientific and nontechnical aspects of project planning, budgeting, implementation, and management. To that end, the office maintains the agency's *Large Facilities Manual*, which contains NSF policies for agency staff and recipients on the planning, management, and oversight of large facilities. Prior to requesting the National Science Board's authorization to include a proposed project in a future NSF budget request, the Large Facilities Office provides independent assurance—apart from the sponsoring office and external panels—that NSF oversight processes have been followed, project plans are construction ready, and construction and operations budgets are justified. In addition, it prepares a periodic status report for NSF

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[15]The Facilities Readiness Panel replaced NSF's former MREFC Panel, which had also served to review and recommend projects for advancement through the large facilities design process. NSF officials said the change in panels responded to the American Innovation and Competitiveness Act, which directed NSF to clarify the roles and responsibilities of all organizations involved in supporting a major multiuser research facility project, including the role of the MREFC Panel. Pub. L. No. 114-329 § 110(a)(2)(B), 130 Stat. 2969, 2989 (2017) (codified at 42 U.S.C. § 1862s-2(a)(2)(B)).

[16]NSF appointed its inaugural Chief Officer for Research Facilities in January 2018 to advise the NSF Director on all aspects of NSF major multiuser research facilities throughout their life cycles. This action responded to the American Innovation and Competitiveness Act, which directed NSF to appoint a senior agency official whose responsibility is oversight of the development, construction, and operations of major multiuser research facilities. Pub. L. No. 114-329 § 110(a)(2)(H), 130 Stat. 2969, 2989 (2017) (codified at 42 U.S.C. § 1862s-2(a)(2)(H)).

leadership that summarizes key technical and financial status information on all ongoing large facilities in construction and candidate projects in design.

NSF establishes an integrated project team to provide the primary, direct oversight for each project that comprises the following key personnel, according to NSF policy documents:

- **Program officer.** A program officer from within a division or office of the sponsoring directorate leads the integrated project team and has primary oversight responsibility within the agency for all aspects of a large facilities project, including monitoring its scope as well as budget and schedule performance during construction. The program officer is a scientist or engineer with experience or training in the management of large projects and is NSF's primary interface with the research community for the project. The program officer's responsibilities include conducting periodic reviews of the project during design and construction using external panels of experts.
- **Large Facilities Office liaison**. The Large Facilities Office liaison provides assistance on aspects of project planning, budgeting, implementation, and management that do not require scientific or technical expertise within a certain discipline. The liaison works alongside the program officer and other NSF staff in overseeing large facilities projects but does not interact directly with recipients. The liaison contributes to the planning and implementation of project reviews by external panels and is to independently assess those reviews with a focus on project management issues.
- **Grants and agreements officer or contracting officer.** These NSF staff within the Division of Acquisition and Cooperative Support assist with solicitations and are responsible for the negotiation, award, and administration of cooperative agreements or contracts. In this capacity, they serve as the primary point of contact for recipients on business and financial matters.

Other NSF staff may also be members of the integrated project teams, such as staff within the Office of General Counsel; staff within the Division of Institution and Award Support that perform cost analyses and review recipients' accounting systems, among other things; and other senior program officers and program support staff from NSF's directorates. In addition, NSF can supplement the expertise of the agency's oversight staff with contractors if needed. For example, the agency has made targeted use of contractor support for independent cost assessments, audits of incurred costs, and verification of earned value management systems, according to agency officials.

NSF also uses external panels of experts to review projects at several points during their life cycles. An external panel may first review a project proposal during the development stage. Separate panels then review the project at the culmination of each of its design phases; accordingly, those are known as conceptual, preliminary, and final design reviews. In addition, an external panel periodically reviews each project during both construction and operations; according to NSF officials, those reviews are generally on an annual basis. In consultation with a project's Large Facilities Office liaison, the NSF program officer for a project selects the panelists and prepares the written questions—referred to in this report as charge questions—that guide the panels. According to NSF officials and policy documents, the agency selects panelists based on the questions that need to be addressed and on the type of review taking place. For example, NSF's *Large Facilities Manual* states that panels charged with reviewing all aspects of a project will generally have representation from the academic and broader national or international research community, as well as experts in administrative aspects of facilities and project management. Further, some combination of the program officer, the grants and agreements officer or contracting officer, the Large Facilities Office liaison, and other NSF staff observe the external panels' reviews, according to NSF officials. Each panel is to provide NSF with a report summarizing the review's findings and any recommendations to NSF.[17]

Construction Costs and Schedules of Large Facilities Projects

Under NSF's large facilities construction process, the recipients of design awards develop construction cost and schedule estimates for projects and submit them to NSF for review. In particular, after a project's final design review, the National Science Board authorizes a not-to-exceed cost and award duration. According to NSF officials, this finalizes the initial budget request previously submitted to Congress after the project's preliminary design review. The not-to-exceed cost authorized by the National Science Board is the amount against which NSF measures cost increases to implement its no cost overrun policy.

[17]According to NSF officials, NSF expert panels operate under Federal Advisory Committee Act rules. The act governs the establishment, operation, and termination of advisory committees within the executive branch of the federal government. The General Services Administration prepares regulations on federal advisory committees and issues other administrative guidelines and management controls for advisory committees.

NSF's *Large Facilities Manual* defines the following components that together make up the total project cost and schedule of large facilities projects. According to the manual, total project cost is defined by the construction stage and does not represent a project's full life-cycle cost. For example, it does not include the costs of designing or operating the facility. The total project cost awarded in a project's construction agreement may be less than the not-to-exceed cost but is not to exceed it. These components of the total project cost and schedule include the following:

- **Performance measurement baseline.** During design, the cost and schedule plan for a project's scope of work is known as the project's baseline. Once the baseline has been approved and included in a construction award, it is known as the performance measurement baseline. NSF documents the performance measurement baseline in the terms and conditions of the award instrument and requires that any changes to it be made through a formal change control process. The performance measurement baseline does not include the project's budget or schedule contingency.
- **Contingency.** This is an amount of budget or time for covering the cost increases or delays that would result if foreseen project risks were to occur. During development of a total project cost estimate, the timing and impacts of such risks are uncertain. As a project progresses, the impacts of risks that materialize may exceed the cost or schedule in the performance measurement baseline and lead to use of the project's budget or schedule contingency.[18] According to NSF's standard operating guidance on budget contingency, it is likely that all budget contingency will be required during normal execution of the project to manage known risks and uncertainties. Each time the agency obligates funding to a project, NSF decides how much of the contingency the agency will hold and how much the recipient will hold, according to agency officials. NSF bases this decision on the integrated project team's review of the project's risk, total budget

[18]Use of budget contingency is governed by OMB's Uniform Guidance. *See* 2 C.F.R. § 200.433. OMB's Uniform Guidance and NSF's standard operating guidance on budget contingency define contingency as that part of a budget estimate of future costs (typically of large construction projects, information technology systems, or other items as approved by the federal awarding agency), which is associated with possible events or conditions arising from causes the precise outcome of which is indeterminable at the time of estimate, and that experience shows will likely result, in aggregate, in additional costs for the approved activity or project. Amounts for major project scope changes, unforeseen risks, or extraordinary events may not be included.

contingency, and other factors, including NSF's level of confidence in the project management. NSF approval is needed when use of contingency exceeds certain project-specific thresholds, which are described in the project's execution plan and codified in the award.

In this report, we identified total project costs for projects in design based on the latest estimates available from NSF officials; those estimates are subject to change before construction funds are awarded. For projects under construction, we identified total project costs based on the amounts awarded in the cooperative support agreements for construction. Only at the end of the projects—when construction is complete and the awards have been closed out—will the final total project costs be known.

In addition to the performance measurement baseline and contingency, a project's not-to-exceed cost that the National Science Board authorized may include the following:

- **Fee.** NSF may provide recipients the opportunity to earn a fee (formerly referred to by NSF as a management fee) for large facilities projects. According to NSF's standard operating guidance on negotiation, award, and payment of a fee, such a fee can stimulate efficient performance.
- **Management reserve.** NSF, not the award recipient, holds management reserve to manage budget uncertainties and unknown or unforeseeable risks that the recipient is not able to manage, according to NSF officials. According to agency officials and the *Large Facilities Manual*, NSF does not hold a management reserve except in rare circumstances.

NSF's No Cost Overrun Policy for Large Facilities Projects

Since February 2008, NSF has had a policy to manage cost overruns on large facilities projects.[19] Under this policy, the cost estimate developed at the preliminary design phase should have adequate contingency to cover all foreseeable risks and any cost increases not covered by contingency are generally to be accommodated by reductions in scope.[20] NSF officials

[19]See GAO-18-370 for additional details on the history of this policy.

[20]These reductions in scope differ from re-planning actions on a project. NSF's *Large Facilities Manual* defines re-planning as a normal project management process to modify or re-organize the performance measurement baseline cost and/or schedule plans for future work without impacting total project cost, project end date, or overall scope objectives or the implementation of approved de-scoping options.

said that under this policy, they will only request an increase to the not-to-exceed cost that the National Science Board authorized if the recipient cannot address the increase through use of the project's budget contingency or reductions to the project's scope. Accordingly, at the preliminary design review, projects must have a prioritized, time-phased list of options for reducing scope during construction—known as scope contingency—and the potential cost savings associated with those options is to total at least 10 percent of the project's baseline. As defined by NSF's *Large Facilities Manual*, scope contingency is scope that can be removed without affecting the overall project's objectives but that may still have undesirable effects on facility performance.

NSF Took Steps to Ensure Project Management Expertise but Had Not Assessed Potential Competency Gaps among Oversight Staff or Set Criteria for Recipients' Expertise

NSF took some steps to help ensure that NSF's large facilities oversight staff and award recipients have project management expertise, but the agency had not taken certain additional steps at the time of our review. Specifically, in 2018, NSF identified project management competencies for key positions of its large facilities oversight staff, but the agency had not yet assessed any potential competency gaps among its staff or established a time frame for doing so. Additionally, at the time of our review, NSF was developing a new document to guide the agency's use of external panels to review large facilities, including the recipients; however, NSF had not established criteria for recipients' expertise, such as competencies, certification requirements, or minimum experience thresholds.

NSF Identified Project Management Competencies for Key Oversight Staff but Had Not Assessed Potential Gaps

NSF identified minimum project management competencies for its key large facilities oversight staff but had not assessed potential gaps in how well its staff met these competencies at the time of our review. Specifically, in September 2018, NSF finalized its standard operating guidance on minimum core competencies for oversight of large facilities, which assigned various professional competencies to key oversight positions, such as program officers, Large Facilities Office liaisons, and grants and agreements officers (see table 1).[21] According to the document, professional competencies are those considered optimal by industry standards or professional organizations. For example, the professional competencies assigned to program officers overseeing large facilities projects depend on the life-cycle stage of their projects and included project management process, risk management, and earned value management. NSF established the competencies partially in response to the National Academy of Public Administration's 2015 report, and, according to the document, NSF may revise them as part of its implementation of the Program Management Improvement Accountability Act. The act directed NSF and other agencies to develop a strategy for enhancing the role of program managers, including enhanced training and a plan encouraging the recruitment and retention of highly qualified individuals to serve as program managers.[22]

[21]NSF's standard operating guidance on minimum core competencies for oversight of large facilities defines competency as the ability to do something successfully or efficiently.

[22]Pub. L. No. 114-264 § 2(b)(1), 103 Stat. 1371, 1372 (2016) (codified at 31 U.S.C. § 1126). The act also requires the Office of Personnel Management to issue regulations that identify key skills and competencies needed for a program and project manager in an agency; establish a new job series, or update and improve an existing job series, for program and project management within an agency; and establish a new career path for program and project managers. At the time of our review, NSF was in the early stages of planning how the agency would implement the act, according to NSF officials, and as of January 2019, the Office of Personnel Management had not issued its regulations.

Table 1: Minimum Professional Competencies NSF Identified for Key Large Facilities Oversight Staff

Category	Professional competency	Competency description used by NSF	Program officer[a]	Large Facilities Office liaison[b]	Grants and agreements officer[b, c]	Cost analyst
Financial management	Auditing	On-site verification activity, such as inspection or examination, of a process or quality system to ensure compliance to requirements.				○
	Accounting	System of recording and summarizing business and financial transactions and analyzing, verifying, and reporting the results.				○
	Cost estimating and analysis	Knowledge and methods used to develop and maintain reliable cost estimates throughout the life of a project.		●	○	○
Project management	Project management process	Demonstrating an understanding of project management techniques.	○	●	○	
	Budgeting and forecasting	Development, implementation, and evaluation of financial expenditures and development of estimates based on past, current, and projected financial conditions.		◒		
	Planning and scheduling	Application of skills, techniques, and intuition acquired through knowledge and experience to develop effective schedule models.		◒		
	Risk management	Processes concerned with conducting risk management planning, identification, analysis, responses, and monitoring and control on a project.	○	●	○	
	Earned value management	Methodology for integrating scope, schedule, and resources; for objectively measuring project performance and progress; and for forecasting project outcome.	○	●	○	
	Business systems analysis	Practice of enabling change in an organizational context, by defining needs and recommending solutions that deliver value to stakeholders.		●		

Category	Professional competency	Competency description used by NSF	Program officer[a]	Large Facilities Office liaison[b]	Grants and agreements officer[b, c]	Cost analyst
Grants management	Management, monitoring, and oversight	Governance functions that provide structure, processes, decision-making models, and tools for managing projects.		○	○	
	OMB Uniform Guidance laws and regulations	Knowledge of guidance issued by United States Office of Management and Budget (OMB).[d]			○	○

Legend:
○ = competency recommended for the position. NSF does not expect that every individual grants and agreements officer or cost analyst will have all the competencies recommended for those positions and instead expects staff to collaborate with each other to leverage different individual competencies.

◒= competency expected for the position.
● = competency expected for the position, with certification of at least one staff in each of these competencies.

Source: GAO analysis of the National Science Foundation (NSF)'s 2018 standard operating guidance on minimum core competencies for oversight of major facilities and related documentation. | GAO-19-227

[a]Leader of the integrated project team that provides NSF's primary oversight of a large facilities project. NSF recommends the competencies shown for these staff depending on the life-cycle stage of the project. In addition to these specific competencies, NSF expects program officers to complete high level training in financial management.

[b]Member of the integrated project team.

[c]Professional competencies for contracting officers are determined by the Federal Acquisition Institute, not NSF.

[d]OMB's Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards (Uniform Guidance) governs cooperative agreements with universities, consortia of universities, or nonprofit organizations. See 78 Fed. Reg. 78,590 (Dec. 26, 2013) (OMB's final Uniform Guidance) (codified as amended at 2 C.F.R. pt. 200).

The standard operating guidance also established expectations for certifications—official attestations to a status or level of achievement—for the Large Facilities Office liaison position. Specifically, NSF expected that at least one Large Facilities Office liaison would be certified in each of the following competencies: cost estimating and analysis, project management process, risk management, earned value management, and business systems analysis. NSF's policy does not expect any staff to hold certification in its planning and scheduling competency. According to agency officials, this is because the project management and earned value management certifications that the policy expected Large Facilities Office liaisons to hold adequately covered planning and scheduling skills for NSF's oversight of projects. NSF officials further noted that certification in planning and scheduling is more appropriate for the recipient's role in developing and managing the project schedule than for NSF's role in overseeing the project.

According to NSF's standard operating guidance, the agency identified the minimum core competencies for large facilities oversight staff by researching scholarly publications, academic programs, and industry standards. Specifically, NSF based its descriptions for the various competencies on such sources as GAO's cost estimating guide and published professional standards for risk management, earned value management, and scheduling, according to an agency document. We found that NSF's professional competencies for large facilities oversight staff generally were consistent with the project management knowledge areas published by the Project Management Institute.[23] For example, NSF's cost estimating and analysis professional competency was consistent with the cost management knowledge area. In addition to professional competencies, NSF also established competencies that research has found will improve individuals' effectiveness in performing their roles and responsibilities, according to the policy. Those competencies comprised stakeholder analysis, building trust, conflict resolution, decision-making, cultural awareness, negotiating skills, effective presentations, and professional writing.

Because NSF had so recently identified these competencies for large facilities oversight staff at the time of our review, the agency had not yet used the competencies to assess potential gaps in how well its staff met those competencies, nor had the agency developed any human capital plans for its large facilities oversight staff to address any gaps that may exist. Doing so would be consistent with leading principles for strategic workforce planning that we and the Office of Personnel Management have identified.[24] These leading principles include (1) identifying critical occupations, skills, and competencies and analyzing workforce gaps; (2) employing workforce strategies to fill the gaps, including strategies for hiring, training, performance management, and use of human capital flexibilities, such as recruitment and retention bonuses; and (3) monitoring and evaluating progress toward achieving workforce planning and

[23]Project Management Institute, *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)*, Sixth Edition, 2017. PMBOK is a trademark of Project Management Institute, Inc.

[24]GAO, *Defense Acquisition Workforce: Actions Needed to Guide Planning Efforts and Improve Workforce Capability*, GAO-16-80 (Washington, D.C.: Dec. 14, 2015) and GAO, *Workforce Planning: Interior, EPA, and the Forest Service Should Strengthen Linkages to Their Strategic Plans and Improve Evaluation*, GAO-10-413 (Washington, D.C.: Mar. 31, 2010).

strategic goals.[25] Furthermore, the American Innovation and Competitiveness Act directed NSF to establish the appropriate project management and financial management expertise required for NSF staff to effectively oversee each major multiuser research facility project, including by improving project management training and certification.[26] Agency officials told us that they planned to use the newly developed competencies to assess potential gaps in the future; however, they had not established a time frame for doing so. Assessing any potential project management competency gaps among its large facilities oversight staff would help NSF target its use of workforce strategies to fill identified gaps, monitor its progress in doing so, and ensure that it meets the related requirements of the American Innovation and Competiveness Act.

NSF's Procedures to Ensure Recipients' Project Management Expertise Had Not Established Criteria for Recipients to Meet

NSF has some procedures in place to help ensure that award recipients for large facilities projects have project management expertise, but at the time of our review, the agency had not established criteria for project management expertise needed by recipients or how they should demonstrate it. According to agency officials, NSF uses reviews of projects by external panels of experts as its primary means of ensuring recipients have project management expertise. NSF convenes those external panel reviews to assess projects during development, at multiple points during design, and annually during construction.

As of October 2018, NSF was in the process of developing a new internal policy document to formalize how external panel reviews are conducted for large facilities projects. According to an NSF official, the purpose of this document will be to provide better guidance to NSF staff to improve consistency and effectiveness of oversight across projects. The reviews are to independently assess a project's management team—including its organization, experience, knowledge, and adequacy of staffing—with the same level of rigor as the technical evaluations, according to the draft guidance we reviewed. In particular, the draft specified that the preliminary and final design reviews should, among other things, assess the project management team in terms of number of personnel, skill set,

[25]The other three leading principles are aligning workforce planning with strategic planning and budget formulation; involving managers, employees, and other stakeholders in planning; and building the capabilities needed to support workforce strategies through steps that ensure the effective use of human capital flexibilities.

[26]Pub. L. No. 114-329 § 110(a)(2)(E), 130 Stat. 2969, 2988, 2989 (2017) (codified at 42 USC 1862s-2(a)(2)(E)).

effectiveness, and quality and verify that the management team can successfully complete the final design and execute the project. NSF planned to continue the agency's internal reviews of the document and finalize it by the end of June 2019, according to an agency official.

We found inconsistencies in the scope of NSF's previous questions to guide panels in assessing recipients. Specifically, we reviewed NSF's charge questions to the 15 external panels convened to review four projects during their development or design stages—the Regional Class Research Vessels, the Large Synoptic Survey Telescope, the Antarctic Infrastructure Modernization for Science, and the Large Hadron Collider High Luminosity Upgrade—and found that for four of the 15 panels, NSF did not include any questions related to the qualifications or expertise of the recipients.[27] In addition, when NSF did include related questions for panels, the questions sometimes focused more on the recipients' management structure or staffing and not directly on their qualifications or expertise. Further, NSF's construction awards for the research vessels project and telescope project identify specific key personnel, but we found no evidence that NSF asked the panels to evaluate these individuals' project management expertise.

Moreover, neither NSF's draft policy on external panels nor other NSF policies had established any criteria that recipients could use to demonstrate project management expertise to NSF and its external panels. For example, NSF's policies and its financial and administrative terms and conditions for cooperative agreements—as well as the agency's modification to terms and conditions applicable to large facilities projects—had not established requirements that any of the recipients' key personnel hold any certifications in project management or meet minimum experience thresholds, and NSF did not identify which credentials would ensure appropriate skill with respect to managing large projects. The cooperative agreements we reviewed for the two projects that received their initial construction funding in the last 5 years—the Regional Class Research Vessels and Large Synoptic Survey Telescope—also did not identify such criteria. NSF officials said that

[27]Specifically, according to an agency official and NSF documents, NSF's charge questions did not ask the panel for the review held in 2010 or the panel for the preliminary design review held in 2011 to assess the expertise of the recipient for the Large Synoptic Survey Telescope project. In addition, NSF's charge questions did not ask the panels for the two conceptual design reviews held in 2016 to assess the expertise of the recipients for the Large Hadron Collider High Luminosity Upgrade project.

instead of using specific criteria, the agency generally looks for a combination of technical background, experience with major facilities, education, training, and certification, depending on the positions of the key personnel. According to NSF officials, the agency was considering including criteria for recipients' expertise in a future revision to the *Large Facilities Manual* sometime after September 2019—such as project management, risk management, earned value management, cost estimation, schedule analysis, and grants management. However, NSF had not established such criteria for recipients in the past because, according to agency officials, these efforts had been a lower priority. The officials stated that this was because NSF believed the recipients' teams were adequately staffed, and the agency had a more urgent need to document procedures for strengthening oversight of project costs.

Federal requirements applicable to NSF's cooperative agreements and contracts include provisions for agencies to evaluate the risks associated with potential recipients or ensure their experience and skills. Specifically, the Office of Management and Budget's Uniform Guidance, which applies to cooperative agreements, directs agencies to have a framework in place to evaluate the risks posed by applicants before they receive federal awards.[28] Similarly, under the Federal Acquisition Regulation, which applies to contracts, prospective contractors must have the necessary organization, experience, accounting and operational controls, and technical skills, or the ability to obtain them.[29] Without criteria for evaluating recipients' project management expertise, NSF and its external panels may not be able to ensure recipients have the necessary expertise. As a result, NSF is at risk of awarding funds to organizations that may not be well-qualified to manage construction of large facilities projects.

[28] 2 C.F.R. § 200.205(b).

[29] Federal Acquisition Regulation, 48 C.F.R. § 9.104-1(e).

NSF Has a Process to Identify and Share Lessons Learned on Large Facilities Projects but Has Not Required All Recipients to Provide Potential Lessons Learned

According to agency officials, in 2017 NSF formalized a process for its large facilities projects that encourages the agency's oversight staff and award recipients to identify and share lessons learned on projects; however, it has not required that all recipients provide information on potential lessons learned to NSF. According to agency officials, the process, which NSF refers to as its knowledge management program, responds to a 2015 recommendation by the National Academy of Public Administration and the American Innovation and Competitiveness Act's requirements to coordinate the sharing of best management practices and lessons learned from large facilities projects. Officials said that the objective of the process is to foster a learning culture that supports routine knowledge transfer. The process seeks to use multiple sources to identify lessons learned on projects. Internal groups of NSF oversight staff consider and prioritize which lessons could be applied to other projects or that are best addressed through changes to NSF policies or guidance. NSF then shares the lessons through the agency's knowledge management website and its annual public workshop for stakeholders who are involved in the construction or operation of the agency's large facilities projects.[30] Agency officials said that some activities, such as NSF's annual large facilities workshop, predate the agency's formal lessons learned process.

NSF's process corresponds to the six key practices that we previously reported for identifying and applying lessons learned.[31] These key practices are: to collect information on potential lessons by capturing data on projects, analyze collected information to identify lessons learned, validate the lessons' applicability to other projects, prioritize lessons for application to other projects, share lessons learned, and archive lessons in a searchable form. Table 2 describes these practices and summarizes related steps in NSF's lessons learned process.

[30]NSF hosts its large facilities workshop annually to provide a collaborative forum for continuous learning and information-sharing among participants. The website for the workshop provides information on lessons learned on large facilities. NSF Major Facilities Knowledge Sharing Gateway, accessed November 28, 2018, https://www.largefacilitiesworkshop.com/knowledge-gateway/.

[31]GAO, *Telecommunications: GSA Needs to Share and Prioritize Lessons Learned to Avoid Future Transition Delays*, GAO-14-63 (Washington, D.C.: Dec. 5, 2013).

Table 2: Comparison of NSF's Lessons Learned Process for Large Facilities Projects to Key Practices for Identifying and Applying Lessons Learned

Key Practices for a Lessons Learned Process[a]	Related Steps in NSF's Lessons Learned Process
Collect information on potential lessons through activities such as project critiques, written forms, interviews of participants, and direct observation.	NSF staff capture project data through their oversight of projects, including reviews of key systems and documents. Recipients manage the projects and report project information to NSF in monthly and annual progress reports.
Analyze information collected to identify lessons learned, determine root causes and identify appropriate recommendations.	NSF oversight staff evaluate collected information to identify lessons learned for individual projects. Recipients may submit information on lessons learned on their large facilities projects to NSF oversight staff.
Validate the accuracy and applicability of lessons to other projects.	Groups of NSF's staff, such as the Major Facilities Working Group and program officers forum, assess lessons identified for individual projects for broader applicability.
Prioritize and apply lessons learned based on determining the most important issues on which to apply limited resources.	NSF's Facilities Governance Board approves revisions to NSF policies, including the agency's standard operating guidance, based on proposals from the Large Facilities Office and review and recommendation by the Major Facilities Working Group. NSF's planning committee for its large facilities workshop annually reviews lessons identified through the program officers forum and other sources to prioritize lessons to share.
Share lessons learned through a variety of communication media.	Recipients or NSF staff present selected lessons learned at NSF's annual large facilities workshop, and NSF shares those presentations on its knowledge management website.
Store lessons in a manner that allows users to perform information searches using key words and functional categories.	NSF categorizes and archives information on the agency's knowledge management website.

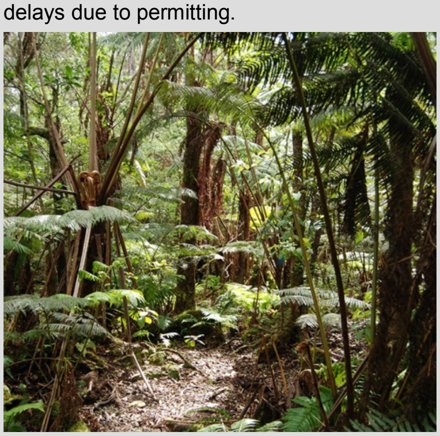
Source: GAO analysis of National Science Foundation (NSF) statements, documents, and website. | GAO-19-227

[a]Key practices are based on our prior work and a related U.S. Army handbook. See GAO, *Telecommunications: GSA Needs to Share and Prioritize Lessons Learned to Avoid Future Transition Delays*, GAO-14-63 (Washington, D.C.: Dec. 5, 2013) and Center for Army Lessons Learned, *Handbook 11-33: Establishing a Lessons Learned Program: Observations, Insights, and Lessons* (Fort Leavenworth, KS: June 2011).

Lessons Learned on Environmental Compliance and Permitting for Construction of NSF's Large Facilities

At the agency's 2016 large facilities workshop, NSF shared lessons learned regarding the environmental compliance and permitting challenges that contributed to delays and cost increases during construction of the Daniel K. Inouye Solar Telescope and the National Ecological Observatory Network. NSF described legal requirements for environmental compliance and outlined the responsibilities of NSF staff and recipients to complete compliance and permitting requirements. Lessons learned included the importance of understanding the local culture at the construction site and the need to begin the permitting process for projects early. According to NSF officials, the challenges faced by these large facilities projects also led to inclusion of the agency's Office of General Counsel in the teams of NSF staff overseeing design and construction of large facilities projects.

A trail in the Pu'u Maka'ala Natural Reserve Area in Hawaii, one site of the National Ecological Observatory Network that had delays due to permitting.



Sources: GAO analysis of National Science Foundation (NSF) documents (text); Hawaii Department of Land and Natural Resources (photo). | GAO-19-227

Our review of NSF policy documents, knowledge management documents, and project documents for two large facilities projects found that NSF was implementing its lessons learned process by collecting information from the agency's oversight staff on potential lessons learned and by analyzing, validating, prioritizing, sharing, and archiving these lessons. For example, NSF's standard operating guidance directed the integrated project teams of NSF staff that oversee large facilities to identify and document potential lessons learned as part of their periodic meetings. For the two projects we reviewed, NSF's integrated project team charter for the Large Synoptic Survey Telescope reflected this guidance, while NSF officials said the agency was in the process of revising the charter for the Regional Class Research Vessels project. In addition, NSF's program officers forum—a group that discusses issues relating to large facilities and helps validate lessons learned—considered nine potential best practices in October 2018 that were identified by NSF oversight staff and the recipient for a large facilities project currently in operation. According to NSF officials, results of those discussions and input from a workshop planning committee of NSF staff and recipients will inform priorities for the agency's 2019 large facilities workshop.

However, for the two projects we reviewed in assessing NSF's lessons learned process, NSF required only one of the two recipients to report on potential lessons learned that they identify. We found that NSF included a requirement in the award for construction of the Regional Class Research Vessels for the recipient to annually report lessons learned information, but the agency did not do so for the Large Synoptic Survey Telescope project. According to NSF officials, they had considered an NSF-wide requirement for recipients to report on lessons learned for large facilities projects but were concerned that a requirement would negatively affect the lessons learned environment they try to foster. This could occur if, for example, large facilities project recipients perceive NSF's lessons learned program as an evaluation, inspection, or internal review and are therefore reluctant to share problems and corrective actions. NSF included a requirement in the 2017 award for the research vessels project, but officials stated that they need more time both to assess the effects of that requirement before applying it to other projects and to consider other options. Agency officials also stated that lessons learned from recipients could be captured by other activities in the agency's lessons learned process, such as NSF oversight staff activities. For example, NSF staff, aided by a third-party contractor, identified a potential best practice in a review of the earned value management system of the Large Synoptic Survey Telescope.

Without ensuring the collection of information on potential lessons learned from recipients, NSF may miss lessons that could benefit other projects by helping improve project oversight and performance. As the day-to-day managers of large facilities projects, recipients are well-positioned to identify potential lessons from their projects and to provide information on these lessons to NSF. As stated in the U.S. Army's handbook on establishing a lessons learned program, the goal of any collection effort is to gather enough information to have informed analysis of potential lessons learned so other organizations can benefit from the experiences of those who have gone before them.[32] However, the handbook states that most organizations are passive when it comes to reporting problems and potential solutions to other organizations so those other organizations do not encounter the same difficulties. Similarly, the Project Management Institute's guide for project management states that even the best knowledge management tools and techniques will not work if people are not motivated to share what they know or to pay attention to what others know.[33] Ensuring through a requirement or other means that recipients provide information to NSF on their lessons learned would stress the importance of these activities and help NSF identify lessons that may benefit other large facilities projects.

Further, such action would help address provisions of the American Innovation and Competitiveness Act and Program Management Improvement Accountability Act. These acts, respectively, call for NSF to coordinate the sharing of the best management practices and lessons learned from each large facilities project and to develop a strategy to, among other things, improve the means of collecting and disseminating best practices and lessons learned.

[32]Center for Army Lessons Learned, *Handbook 11-33: Establishing a Lessons Learned Program: Observations, Insights, and Lessons* (Fort Leavenworth, KS: June 2011).

[33]*PMBOK® Guide*.

Telescope Project Fully or Substantially Met All Characteristics of a Reliable Earned Value Management System and Two of Four Characteristics of a Reliable Schedule

Project Fully or Substantially Met All Three Characteristics of a Reliable Earned Value Management System

Our research has identified a number of best practices that are the basis of effective earned value management and should result in reliable and valid cost and schedule performance data that can be used to make informed decisions.[34] The best practices are grouped into three high-level characteristics of a reliable earned value management system—comprehensive, accurate, and informative. NSF's Large Synoptic Survey Telescope project fully or substantially met nine of 10 best practices for earned value management (see table 3).[35] We found that the project's earned value management system was comprehensive, accurate, and informative and could, therefore, be considered a reliable source of information on the project's performance. A reliable earned value management system provides information that is necessary for understanding the health of a project and an objective view of project status.

[34]GAO-09-3SP.

[35]For the ratings described here, "partially met" means the project team provided evidence that satisfies about half of the criterion. "Substantially met" means the project team provided evidence that satisfies a large portion of the criterion. "Fully met" means the project team provided complete evidence that satisfies the entire criterion.

Table 3: Comparison of Earned Value Management (EVM) Data and Practices for NSF's Large Synoptic Survey Telescope (LSST) Project to Best Practices, as of June 1, 2018

Characteristics of EVM data and practices	Overall GAO assessment of characteristics for LSST	Best practices for each characteristic[a]	GAO assessment of best practices for LSST[b]
Comprehensive	Fully met	Project has a validated EVM system	Fully met
		Project conducted an integrated baseline review to ensure the performance measurement baseline captures all work	Substantially met
		Schedule reflects the work breakdown structure, logical sequencing of activities, and the necessary resources	Substantially met
		Independent and qualified staff are performing EVM surveillance	Fully met
Accurate	Substantially met	EVM data do not contain any anomalies	Partially met
		EVM data are consistent among various reporting formats	Fully met
		Estimate at completion—the sum of the actual cost to date and the expected cost to finish the remaining project work—is realistic	Fully met
Informative	Fully met	EVM data, including variances between the actual and planned cost and schedule, are reviewed on a regular basis	Fully met
		Management uses EVM data to develop corrective action plans	Fully met
		Management updates the performance measurement baseline to reflect changes	Fully met

Source: GAO analysis of information for the National Science Foundation's (NSF) Large Synoptic Survey Telescope project. | GAO-19-227

[a]See GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, GAO-09-SP (Washington, D.C.: March 2009).

[b]For the best practice ratings described here, "partially met" means the project team provided evidence that satisfies about half of the criterion. "Substantially met" means the project team provided evidence that satisfies a large portion of the criterion. "Fully met" means the project team provided complete evidence that satisfies the entire criterion.

- **Comprehensive.** The Large Synoptic Survey Telescope's earned value management system fully met the comprehensive characteristic because, among other things, the system was validated in an independent review; the preliminary and final design reviews NSF convened for the project included efforts to ensure the performance measurement baseline captured all necessary work; and NSF and external experts were performing oversight of the earned value management system.
- **Accurate.** The earned value management system substantially met the accurate characteristic because earned value management data were consistent among various reporting formats and the system

included a realistic estimate for the total cost of completing all work. However, the earned value management data contained anomalies that were not explained in the project's monthly earned value management reports. NSF officials and the recipient provided explanations for some of the 80 anomalies we found over 12 months of data. For example, some anomalies were due to the project's use of software development methods that allow for continuous planning and changes within an activity. Nevertheless, according to our work on earned value management, all anomalies should be identified, and the reason for each should be fully explained in the monthly earned value management reports.[36] Further, earned value management experts in the public and private sectors that we interviewed in our prior work agreed that the occurrence of such anomalies should be rare.[37] Despite these anomalies, we found the earned value management system substantially met the accurate characteristic based on our assessment of all three best practices related to this characteristic as a whole.

- **Informative.** The earned value management system fully met the informative characteristic because the project's management reviewed the earned value management data—including cost and schedule variances—on a regular basis; management used the data to develop corrective action plans; and the performance measurement baseline was updated to reflect changes.

Project Substantially Met Two Characteristics of a Reliable Schedule but Partially Met Two Others

NSF's Large Synoptic Survey Telescope project fully or substantially met five of 10 scheduling best practices and partially met the remainder (see table 4).[38] GAO's schedule guide identifies 10 best practices for developing and maintaining reliable project schedules. These best practices are grouped into four characteristics of a reliable schedule—comprehensive, well-constructed, credible, and controlled.[39] In our assessment of the project's construction schedule, as of June 1, 2018, we

[36]GAO, *Secure Border Initiative: DHS Needs to Strengthen Management and Oversight of Its Prime Contractor*, GAO-11-6 (Washington, D.C.: Oct. 18, 2010).

[37]GAO-11-6.

[38]For the ratings described here, "partially met" means the project team provided evidence that satisfies about half of the criterion. "Substantially met" means the project team provided evidence that satisfies a large portion of the criterion. "Fully met" means the project team provided complete evidence that satisfies the entire criterion.

[39]GAO-16-89G.

found the schedule was comprehensive and controlled but partially well-constructed and partially credible. As a result, the project's schedule could not be considered reliable. A schedule provides a road map for systematic project execution and the means by which to gauge progress, identify and resolve potential problems, and promote accountability. The credibility of decision-making on a project will be negatively impacted if the schedule is not reliable.

Table 4: Comparison of the Schedule for NSF's Large Synoptic Survey Telescope (LSST) Project to Best Practices, as of June 1, 2018

Characteristics of a schedule	Overall GAO assessment of characteristics for LSST	Best practices for each characteristic[a]	GAO assessment of best practices for LSST[b]
Comprehensive	Substantially met	Capturing all activities	Fully met
		Assigning resources to all activities	Substantially met
		Establishing the durations of all activities	Substantially met
Controlled	Substantially met	Updating the schedule using actual progress and logic	Substantially met
		Maintaining a baseline schedule	Substantially met
Well-constructed	Partially met	Sequencing all activities	Partially met
		Confirming that the critical path is valid	Partially met
		Ensuring reasonable total float	Partially met
Credible	Partially met	Verifying that the schedule can be traced horizontally and vertically[c]	Partially met
		Conducting a schedule risk analysis	Partially met

Source: GAO analysis of information for the National Science Foundation's (NSF) Large Synoptic Survey Telescope project. | GAO-19-227

[a]GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015).

[b]For the best practice ratings described here, "partially met" means the project team provided evidence that satisfies about half of the criterion. "Substantially met" means the project team provided evidence that satisfies a large portion of the criterion. "Fully met" means the project team provided complete evidence that satisfies the entire criterion.

[c]A schedule with horizontal and vertical traceability accounts for the interdependence of detailed activities, and activities are traceable among various levels of the schedule.

- **Comprehensive.** The Large Synoptic Survey Telescope's schedule substantially met the characteristic of being comprehensive. Our analysis found that the schedule contained sufficient, detailed activities that defined the work necessary to complete the project. The schedule included over 7,000 activities that comprise the telescope's construction, of which about 3,500 activities were still in progress or had not started. Further, we found that the schedule identified various resources needed for the project's construction activities, including resources for labor, materials, travel, and equipment, and we found resource assignments that allow management to view resource allocations and their costs. In addition, the schedule generally reflected reasonable amounts of time for how long each activity was expected to take, allowing for discrete progress measurement with specific start and finish dates. However, 5 percent of the in-progress or near-term activities had long durations that were not justified. GAO's schedule guide recommends that activities with long durations be broken into shorter activities if logical breaks can be identified in the work being performed.

- **Controlled.** The project's schedule substantially met the characteristic of being controlled. For example, our analysis found that the schedule was well-maintained and updated periodically by a trained scheduling team, and that it contained valid baseline dates for measuring performance. However, we were unable to find information in the schedule documentation relating to some project elements, such as the assumptions the project team made when creating the baseline schedule.
- **Well-Constructed.** The project's schedule partially met the characteristic of being well-constructed. According to GAO's schedule guide, a schedule should be substantially or fully well-constructed in order to respond to changes and reliably predict dates. However, our analysis found certain issues related to the construction of the telescope's schedule, including (1) the sequencing of activities, (2) the schedule's critical path, and (3) the amount of float calculated in the schedule. For example, we found that 251 (or 7 percent) of the project's remaining activities were not logically sequenced with links to other activities or milestones. As a general rule, every activity within a schedule should have at least one predecessor and successor.

  We also found that the schedule contained date constraints for 300 (or 8 percent) of the project's remaining activities and milestones. These date constraints prevented key milestones from shifting in the project's schedule in response to changes. GAO's schedule guide recommends minimizing and justifying date constraints because they may override the calculated start or finish dates of activities by imposing calendar restrictions on when an activity can begin or end. Recipient officials acknowledged that the schedule contained date constraints and activities that were not logically sequenced but said that they were constantly working to update and refine the schedule's sequencing.

  Moreover, we were not able to confirm the validity of the schedule's critical path—the chain of dependent activities that drive the project's earliest completion date. In addition, we found that the schedule included unreasonably high amounts of float—the amount of time by which a project activity can slip before the delay affects the project's estimated completion date.

- **Credible.** The project's schedule partially met the characteristic of being credible. A schedule is credible if, among other things, it (1) can be traced horizontally and vertically and (2) includes a robust schedule risk analysis to identify high-priority risks and schedule contingency needed to address risks. For a schedule to be traceable horizontally and vertically, it must reflect the sequencing of activities necessary for the project. However, as described above, our assessment found issues related to the sequencing of activities in the telescope's schedule, including activities that were not logically sequenced and the presence of constraints on the start or finish dates of activities. These issues also affect confidence in the results of the project's risk analysis. We found that the recipient conducted a yearly comprehensive and complex schedule risk analysis on the schedule. However, we reviewed the recipient's risk analysis for the schedule as of April 2018 and found, among other things, issues related to logical sequencing within the risk analysis, such as activities without a successor. Consequently, the risk analysis did not address how those activities might affect others or the project's overall schedule.

Improving the schedule so that it meets the well-constructed and credible characteristics of a reliable schedule, as defined in GAO's schedule guide, could give the recipient, NSF, and Congress greater confidence in the project's schedule, including the likelihood of on-time completion, and improve decision-making over the remaining years of the telescope's construction. NSF officials said that the recipient had made changes to the project's schedule after our review, and that NSF planned to provide us a revised schedule in 2019 that would address the issues we identified in the schedule as of June 2018.

Cost and Schedule Performance Varied on Recently Completed and Ongoing Large Facilities Projects

NSF completed one large facilities project in 2018, continued construction on four, and advanced the design of two; these projects had varying cost and schedule performance (see table 5) and ranged in cost from $150 million to $471 million (see fig. 2), based on our review of project data as of September 2018. Since our last report on these projects in June 2018, which used project data as of December 2017, NSF completed construction of the Advanced Laser Interferometer Gravitational Wave Observatory and again delayed completion of the National Ecological

Observatory Network; other projects in construction had no cost or schedule changes.

Table 5: Construction Cost and Schedule Performance of NSF's Large Facilities Projects Recently Completed, under Construction, or in Design, as of September 2018

		Cumulative performance since starting construction			Changes since December 2017	
Project name	**Total project cost in millions of dollars**	**Percentage complete**	**Cost change in millions of dollars (percentage)**	**Schedule change in months (percentage)**	**Cost change in millions of dollars**	**Schedule change in months**
Advanced Laser Interferometer Gravitational Wave Observatory	**205.1**	100	-[a]	▲ 40 (47)	-	-
National Ecological Observatory Network[b]	**469.3**	98	▲ 35.5[c] (8)	▲ 31 (53)	-	▲ 3
Daniel K. Inouye Solar Telescope	**344.1**	88	▲ 46.2[d] (16)	▲ 30 (31)	-	-
Large Synoptic Survey Telescope	**471.2**	60	-	-	-	-
Regional Class Research Vessels	**354.0**	7	-	-	-	-
Antarctic Infrastructure Modernization for Science[e]	**355.0**	N/A	N/A	N/A	N/A	N/A
Large Hadron Collider High Luminosity Upgrade[e]	**150.0**	N/A	N/A	N/A	N/A	N/A
Total	**2,348.7**					

Legend: - = no cost or schedule increase since starting construction. N/A = not applicable.

Source: GAO analysis of National Science Foundation (NSF) documents and information from NSF officials. | GAO-19-227

Note: Positive values and ▲ indicate cost or schedule increased since starting construction.

[a]At the end of the project's construction in July 2018, NSF had obligated all of the total project cost. The final total project cost and amount of any unexpended funds to be returned to NSF will be determined after closeout of the award by the recipient in November 2018.

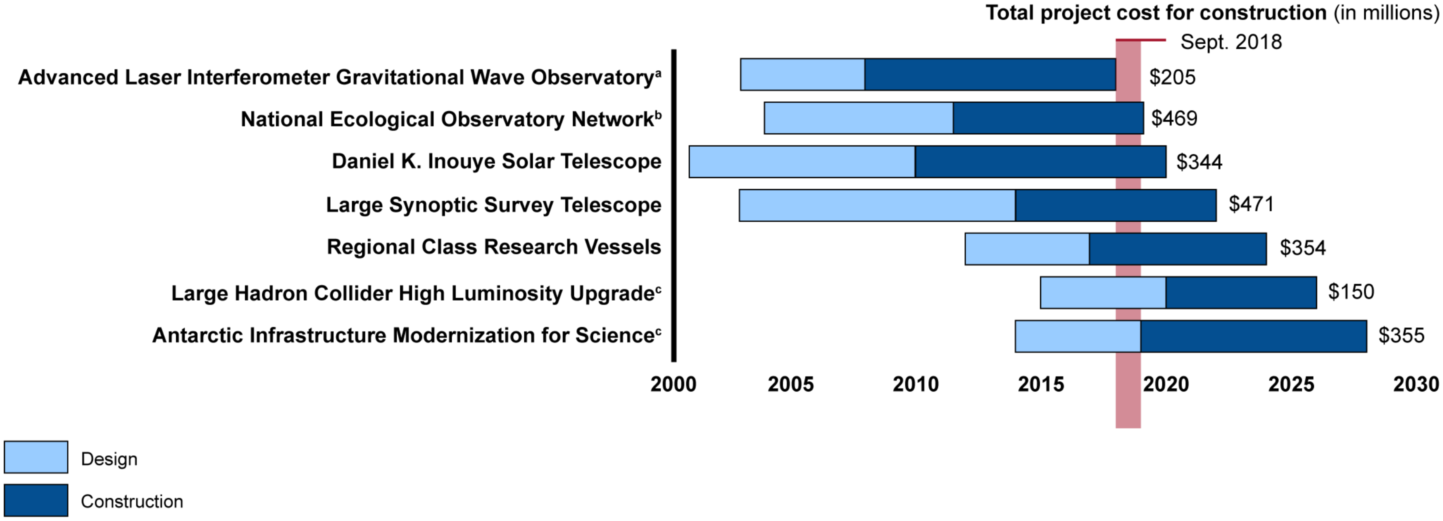
[b]The schedule and percentage complete for the National Ecological Observatory Network are as of November 2018, when NSF extended the project's schedule.

[c]NSF also took actions to reduce the project's scope by an estimated $62.4 million in response to NSF's policy for managing cost overruns.

[d]The recipient of NSF's award also took actions to reduce the project's scope by an estimated $5.9 million as part of the cost increase.

[e]The project's total project cost for construction was subject to change because the National Science Board had not yet authorized a total project cost and the project had not started construction.

Figure 2: Schedules and Total Project Costs for Construction for National Science Foundation (NSF) Large Facilities Projects, as of September 2018



Source: GAO analysis of information from NSF. | GAO-19-227

[a]NSF completed the Advanced Laser Interferometer Gravitational Wave Observatory in July 2018.

[b]The schedule for the National Ecological Observatory Network is as of November 2018, when NSF extended the project's schedule.

[c]The project's schedule and total project cost for construction were subject to change because the National Science Board had not yet authorized a total project cost and the project had not started construction.

NSF Completed the Advanced Laser Interferometer Gravitational Wave Observatory

NSF completed the Advanced Laser Interferometer Gravitational Wave Observatory project in 2018 within its total project cost but with a schedule increase of 3.3 years. In April 2008, NSF awarded funding to California Institute of Technology for construction of upgrades to facilities in Washington and Louisiana that search for gravitational waves—signatures of the warping of time and space. The project was originally scheduled for completion in March 2015 at a total project cost of $205.1 million. At the time of its completion in July 2018, NSF had approved a schedule increase of 3.3 years (47 percent). According to NSF officials, this schedule delay resulted from intentionally deferring the procurement of remaining computers for data analysis for as long as possible in order to benefit from continual performance improvements being made in the computing industry. At the end of construction in July 2018, NSF had obligated all $205.1 million of the total project cost. By the financial closeout of the award in November 2018, the recipient was to have determined the final total project cost and the amount of any unexpended funds to be returned to NSF.

NSF-Funded Observatory Enables Entirely New Way of Seeing the Universe

In 2015, the Laser Interferometer Gravitational Wave Observatory (LIGO) made the world's first direct observation of gravitational waves. The waves resulted from the collision of two black holes—regions of space where gravity is so strong, nothing can escape—in a galaxy a billion light-years away. Albert Einstein first predicted the existence of gravitational waves in his theory of general relativity, but it took 100 years to develop the technology to observe them. LIGO's ability to measure gravitational waves enables study of the universe beyond electromagnetic radiation and particles and may help scientists better understand, among other things, the nature of gravity itself and the dynamics of black holes, stars, and galaxies.

LIGO detector site in Livingston, Louisiana

LIGO began initial operations in 2002 with a pair of interferometers located in Livingston, Louisiana and Hanford, Washington. The interferometers merge beams of light traveling through 4-km-long vacuum tubes to create an interference pattern that can be used to measure distances of 1/10,000th the width of a proton. NSF's Advanced LIGO project upgraded the observatory's original detectors to increase their sensitivity and enabled the first detection of gravitational waves.

Source: GAO analysis of National Science Foundation (NSF) documents and other project documentation. Photo courtesy of California Institute of Technology/Massachusetts Institute of Technology/Laser Interferometer Gravitational Wave Observatory Lab. | GAO-19-227

NSF Delayed the Completion of the National Ecological Observatory Network

As of November 2018, construction of the National Ecological Observatory Network was, overall, 98 percent complete, and 78 of the project's 81 observation sites were complete, according to NSF officials. However, in November 2018, NSF officials delayed the completion of the project by 3 months, from November 2018 to February 2019, due to difficulties obtaining permits needed for construction at the remaining site in Hawaii. According to NSF officials and project documentation, this change was due in part to several natural disasters that affected the timelines for obtaining the permits.[40] Since starting construction of this nationwide network of ecological observation sites, NSF has delayed the project's completion date from July 2016 to February 2019, an increase of 2.6 years (53 percent), and increased the total project cost from $433.8 million to $469.3 million (an increase of $35.5 million, or 8 percent). The agency had approximately $1.4 million in management reserve remaining as of November 2018 and planned to use less than $0.1 million of this, according to NSF officials. The project also had approximately $1.6 million in budget contingency remaining, according to agency officials, which they said exceeded the $0.8 million the project team anticipated needing to use. As a result, agency officials expected the total project cost to remain below the not-to-exceed cost that the National Science Board authorized.

NSF Continued Construction on Three Other Projects and Advanced the Design of Two

In 2018, construction continued on three other projects—the Daniel K. Inouye Solar Telescope, the Large Synoptic Survey Telescope, and the Regional Class Research Vessels—that had no changes to their costs or scheduled completion dates since our last report. As of September 2018, the combined total project cost of these three projects was $1.2 billion, and their construction covered the period from 2010 to 2024. However, the Daniel K. Inouye Solar Telescope previously experienced both cost and schedule increases and scope reductions since starting construction in 2010. Appendix I provides additional details on the telescopes and research vessels projects.

[40] In Hawaii, a volcanic eruption beginning in May 2018 and a subsequent hurricane and tropical storm contributed to the delay in permitting because the local staff prioritized response efforts, according to NSF officials. While the officials stated that construction of this site had not yet started as of September 2018, they noted that the recipient had mobilized to the site, and the two final permits—the building permit and electrical permit—were issued in October and November 2018, respectively.

NSF also advanced two projects in the design stage: the Antarctic Infrastructure Modernization for Science and the Large Hadron Collider High Luminosity Upgrade. NSF conducted the final design review for the Antarctic project in October 2018 and preliminary design reviews for the Large Hadron Collider project in December 2017 and January 2018. The combined total project costs estimated for these two projects as of September 2018 was $505 million, and NSF planned to begin their construction in 2019 and 2020, depending on authorization by the National Science Board and eventual appropriations; both projects' costs and schedules were subject to change. Details on those projects are located in Appendix II. According to NSF officials, one potential large facilities project—related to high-performance computing—may enter conceptual design in fiscal year 2019.

Conclusions

In 2017 and 2018, NSF took steps to improve project management capabilities for its large facilities projects, such as identifying project management competencies for its oversight staff and formalizing the agency's lessons learned process for large facilities projects. Successful management and oversight of such projects, including development and maintenance of reliable schedules, requires expertise in project management and application of best practices to ensure that the projects are successfully executed within their National Science Board-authorized costs, schedules, and scopes. Effective management and oversight also benefit from a robust process for identifying lessons learned on projects.

We found that NSF could take additional steps to further improve confidence in the management, oversight, and success of current and future large facilities projects. In particular, assessing NSF's oversight workforce against the newly-established project management competencies would enable NSF to develop strategies to address any gaps identified and monitor progress in closing them, as called for by leading practices for human capital management. Further, NSF officials told us they planned to establish criteria for evaluating recipients' project management expertise after addressing higher priorities, but the agency had not done so at the time of our review. Incorporating such criteria in project requirements and external panel reviews would help the agency ensure recipients are capable of managing these large projects.

NSF had also considered but not established requirements for all recipients to report to NSF on any lessons learned on their projects, relying instead on recipients to participate in the process voluntarily until NSF has time to assess other options for capturing lessons learned from recipients. Lessons learned activities are most successful when all relevant organizations participate, and NSF's recipients are particularly important because they manage the agency's large facilities projects on a day-to-day basis. Ensuring through a requirement or other means that recipients provide NSF with information on their lessons learned could lead to greater identification of lessons learned that could benefit other projects.

Finally, we found that the schedule for the Large Synoptic Survey Telescope project met the comprehensive and controlled characteristics of a reliable schedule; however, it could not be considered reliable because it only partially met the well-constructed and credible characteristics of a reliable schedule. Improving the schedule in these areas could give the recipient, NSF, and Congress greater confidence in the project's schedule, including the likelihood of on-time completion, and improve decision-making over the remaining years of the telescope's construction.

Recommendations for Executive Action

We are making the following four recommendations to the National Science Foundation:

- The Director of NSF should assess the agency's large facilities oversight workforce to identify any project management competency gaps, develop a plan to address any gaps and time frames for doing so, and monitor progress in closing them. (Recommendation 1)
- The Director of NSF should establish criteria for the project management expertise of award recipients for large facilities projects and incorporate the criteria in project requirements and external panel reviews. (Recommendation 2)
- The Director of NSF should ensure, through a requirement or other means, that award recipients for large facilities projects provide information to NSF on any lessons learned or best practices. (Recommendation 3)
- The Director of NSF should ensure that the Large Synoptic Survey Telescope project's schedule meets the well-constructed and credible characteristics of a reliable schedule, as defined in GAO's schedule guide. (Recommendation 4)

Agency Comments

We provided a draft of this report to NSF for review and comment. In its comments, reproduced in appendix III, NSF generally agreed with our recommendations and stated that the agency will carefully consider appropriate implementation of each as it reviews the Large Synoptic Survey Telescope project, updates its *Large Facilities Manual* (to be renamed the *Major Facilities Guide*), and implements the Program Management Improvement and Accountability Act in 2019. NSF also provided technical comments, which we incorporated as appropriate.

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

If you or your staff have any questions about this report, please contact me at (202) 512-6888 or neumannj@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix IV.

John Neumann
Managing Director, Science,
Technology Assessment, and Analytics

Appendix I: Summaries of the National Science Foundation's Large Facilities Projects under Construction

This appendix provides individual summaries of three of the National Science Foundation's (NSF) four large facilities projects under construction as of September 2018: (1) the Daniel K. Inouye Solar Telescope, (2) the Large Synoptic Survey Telescope, and (3) the Regional Class Research Vessels.[41]

Each project's summary is based on project documents and other information that NSF officials provided and includes the following:

- a description of the project and a timeline identifying key project dates, including the date of the original construction award, which we report as the start of construction;
- project information as of September 2018, such as the project's scheduled completion date for construction, including schedule contingency; the type of construction award and the award's latest total project cost for construction;[42] the responsible NSF directorate; project partners; and expected duration of operations;
- a summary of the project's current status and its cost and schedule performance history, including any cost[43] or schedule[44] increases or scope reductions made under NSF's no cost overrun policy and changes since our June 2018 report, which used data as of December 2017;[45]
- a chart depicting the latest construction award's total project cost for construction, including the performance measurement baseline and budget contingency;

[41]This appendix does not include the National Ecological Observatory Network. As of November 2018, the project had a scheduled completion date of February 2019.

[42]Total project costs represent then-year dollars, which NSF or the recipient calculated from base-year dollars by applying an inflation index. According to NSF policy, inflation is a part of NSF's budgeting and project planning.

[43]NSF measures cost increases against the not-to-exceed cost that the National Science Board authorized under the agency's no cost overrun policy. Therefore, we define cost increases since starting construction as increases to the not-to-exceed cost that the board authorized.

[44]We identified schedule increases by comparing the project's scheduled completion date in the construction award as of September 2018 with the scheduled completion date in the original construction award. When a project's scheduled completion date was not identified in the award, we used the expiration date of the award.

[45]GAO-18-370.

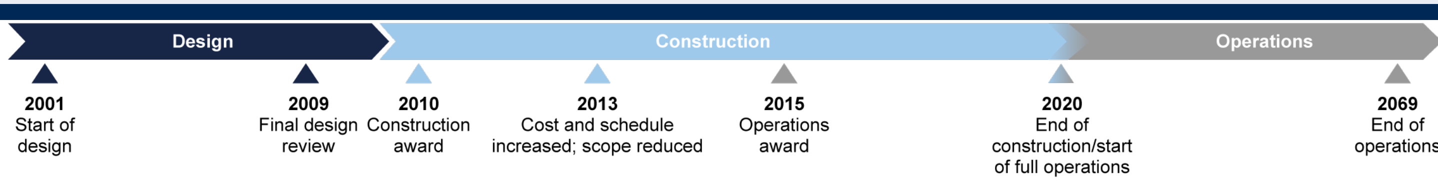
- if applicable, a chart showing the increase in the construction award's total project cost since the original construction award; and
- information on remaining project risks and potential for cost or schedule increases, including the amount of remaining contingency and scope reduction options.[46]

[46]We report each project's estimate of remaining risk exposure as weighted by the recipients for the probability of the risks occurring. According to NSF's *Large Facilities Manual*, risk exposure is the quantitative impact of risks. We report the risk exposure as determined by the Monte Carlo method when available.

DANIEL K. INOUYE SOLAR TELESCOPE

Source: Claire Raftery/Association of Universities for Research in Astronomy, Inc./National Solar Observatory. | GAO-19-227

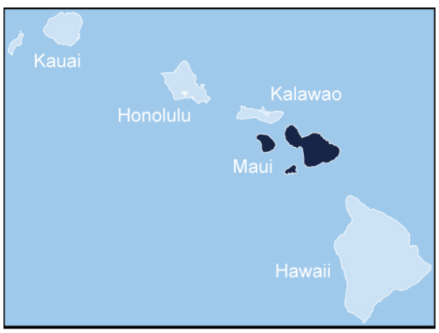
When completed, the National Science Foundation's (NSF) Daniel K. Inouye Solar Telescope (DKIST), formerly named the Advanced Technology Solar Telescope, will be the world's flagship facility for the study of magnetic phenomena in the solar atmosphere. It will help answer fundamental questions in solar physics and enable understanding of solar variability and activity, which can affect Earth through phenomena generally described as space weather.



Source: GAO analysis of information from NSF as of September 2018. | GAO-19-227

Project Information

Location: Maui, Hawaii.



Source: GAO. | GAO-19-227

Scheduled construction completion date, including schedule contingency:

June 2020.

Construction awards:

Cooperative support agreements with the Association of Universities for Research in Astronomy, Inc., consisting of 42 U.S. institutional members and five international affiliates.

Responsible NSF directorate:

Mathematical and Physical Sciences.

Project partners:

More than 20 U.S. and international organizations. Kiepenheuer-Institut für Sonnenphysik (Germany) and Queens University Belfast (Northern Ireland) are supplying additional equipment for the project.

Expected duration of operations:

50 years.

Source: NSF documents and officials. | GAO-19-227

Project Summary

Construction of NSF's DKIST project was 88 percent complete as of September 2018. The project was in its 9th year of construction and in the integration, testing, and commissioning phase. Since our June 2018 report, construction was completed for the telescope mount assembly, the large structure that supports DKIST's optics and instruments. Completion of construction and the beginning of full operations were scheduled for June 2020.

Construction Status of the Daniel K. Inouye Solar Telescope, as of September 2018

Percentage complete	88
Not-to-exceed cost that the National Science Board authorized	$344.1 million
Total project cost in latest construction awards[a]	$344.1 million
National Science Foundation (NSF) funding obligated to date	$324.5 million

Changes in Cost, Schedule, and Scope

	Cumulative changes since original construction awards	Changes since Dec. 2017
Not-to-exceed cost that the National Science Board authorized	+$46.2 million ▲	None
Total project cost	+$46.2 million ▲	None
Scheduled completion date	+2.5 years ▲	None
Scope[b]	-$5.9 million ▼	None

Legend: ▲ = cost or schedule increase; ▼ = scope reduction.

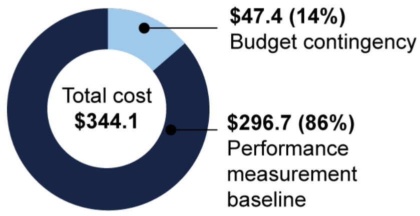
Source: GAO analysis of NSF documents and information from NSF officials. | GAO-19-227

[a]Includes an award funded by appropriations under the American Recovery and Reinvestment Act of 2009 and an award funded by NSF's Major Research Equipment and Facilities Construction account.

[b]Scope changes included are reductions in response to NSF's policy on cost overruns or as part of a cost increase.

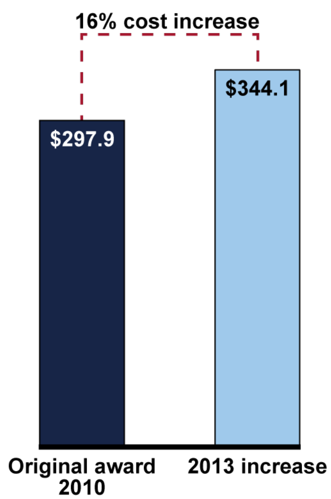
Latest Construction Award[a]

Total project cost, in millions, as of September 2018



Increase in Construction Award[a]

Total project cost, in millions, as of September 2018



Source: GAO analysis of NSF documents. | GAO 19-227

[a]Includes an award funded by appropriations under the American Recovery and Reinvestment Act of 2009 and an award funded by NSF's Major Research Equipment and Facilities Construction account.

Remaining Contingency and Scope Reduction Options

As of September 2018 with construction 88 percent complete.

Budget contingency:

$19.6 million ($0.3 million more than the probability-weighted risk exposure of $19.3 million).

Schedule contingency:

5 months (included in the June 2020 scheduled completion date).

Estimated value of remaining scope reduction options:

$0.3 million.

Source: NSF documents and officials. | GAO-19-227

Cost and Schedule Performance History

NSF's DKIST project had no construction cost increases or changes to its scheduled completion date since our June 2018 report, which used data as of December 2017. According to NSF officials, there had been no reductions to the DKIST project's scope since our June 2018 report, which described the project's past scope reductions and cost increase.[47]

In 2013, NSF increased DKIST's total project cost and the not-to-exceed cost that the National Science Board authorized from $297.9 million to $344.1 million, an increase of $46.2 million (16 percent) since 2010. NSF also delayed the project's scheduled completion date by about 2.5 years (31 percent), from December 2017 to June 2020. Prior to the National Science Board's authorization to increase the total project cost, the recipient also reduced DKIST's scope, resulting in estimated cost savings of $5.9 million but generally low expected impacts for the project. According to NSF officials, these cost and schedule increases resulted primarily from unforeseeable legal and administrative challenges to the construction site's environmental permits.

Remaining Project Risks and Potential for Cost or Schedule Increases

As of September 2018, the project had $19.6 million of budget contingency remaining—$0.3 million more than the estimated remaining risk exposure of $19.3 million when weighted for the risks' probability. The project also had 5 months of schedule contingency remaining to help avoid any potential delays in completing construction by June 2020. According to the October 2018 risk register for DKIST, the largest of the 58 remaining risks was the potential cost of extending construction past the currently scheduled completion date, which could increase costs for such items as labor, utilities, real estate, and equipment. The recipient could mitigate this risk by, among other things, increasing employees' overtime labor to keep the project on schedule, although doing so could partly or fully realize the related risk of paying higher than expected overtime costs. Another remaining project management risk was the potential for higher than planned costs for staff such as engineers to travel to the construction location, particularly since the recipient hired more team members than originally planned and expected a significant amount of travel during the final 2 years of construction, according to the project's risk register. The project also had remaining risks for the integration, testing, and commissioning phase needed to bring the facility up to full operations, such as the possibility that defects or performance issues could be discovered during systems-level testing and lead to re-work on scientific instruments, software, or equipment.

According to project documentation on potential for scope reductions, few options remained available for reducing project costs if needed under NSF's no cost overrun policy. The two available options totaled an estimated $0.3 million in potential cost savings from possible limitations on salary increases for project staff and reductions in their travel. Limiting salary increases would have no impact on the project's science capabilities or operations, but reducing travel could have a medium impact on science capabilities and operations, according to project documentation we reviewed.

[47]GAO-18-370.

Source: LSST Project Office/NSF/Association of Universities for Research in Astronomy, Inc. | GAO-19-227

LARGE SYNOPTIC SURVEY TELESCOPE

The National Science Foundation's (NSF) Large Synoptic Survey Telescope (LSST), an 8-meter, wide-field optical telescope, will initially be used to image the entire visible southern sky—every 3 days for a decade—using the world's largest digital camera (3 billion pixels). Built on a mountaintop in Chile to take advantage of the location's pristine skies, the telescope will collect data and images that will allow for charting billions of galaxies as well as increased knowledge about potentially hazardous asteroids and dark matter and energy. LSST has the potential to advance every field of astronomical study, from the inner solar system to the large-scale structure of the universe.

Source: GAO analysis of information from NSF as of September 2018. | GAO-19-227

Project Information

Location: Cerro Pachón, Chile.

Source: GAO. | GAO-19-227

Scheduled construction completion date, including schedule contingency:

August 2022.

Construction award:

Cooperative support agreement with the Association of Universities for Research in Astronomy, Inc., consisting of 42 U.S. institutional members and five international affiliates.

Responsible NSF directorate:

Mathematical and Physical Sciences.

Project partners:

The LSST Corporation, U.S. Department of Energy (DOE).

Expected duration of operations:

50 years.

Source: NSF documents and officials. | GAO-19-227

Project Summary

As of September 2018, construction of NSF's LSST project was 60 percent complete and LSST was in its fifth year of construction. NSF made the initial operations award in October 2018, and NSF officials anticipated completion of construction in August 2022 and full operations in October 2022. Since our June 2018 report, the project team completed testing of one of the telescope's three mirrors and found that it met the necessary technical specifications. The team also completed assembly of the remaining two mirrors and began testing them, and the project continued site construction activities in Chile, such as the dome that will house the telescope and other buildings.

Construction Status of the Large Synoptic Survey Telescope, as of September 2018

Percentage complete	60
Not-to-exceed cost that the National Science Board authorized	$473.0 million
Total project cost in latest construction award	$471.2 million[a]
National Science Foundation (NSF) funding obligated to date	$327.0 million[a]

Changes in Cost, Schedule, and Scope

	Cumulative changes since original construction award	Changes since Dec. 2017
Not-to-exceed cost that the National Science Board authorized	None	None
Total project cost	+$3.4 million[b]	None
Scheduled completion date	None	None
Scope[c]	None	None

Source: GAO analysis of NSF documents and information from NSF officials. | GAO-19-227

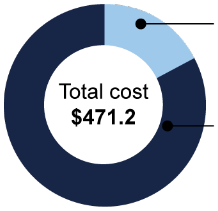
[a]Excludes fee of $489,448 provided to the recipient to stimulate efficient performance.

[b]This cost change was anticipated at the time of the original construction award, according to NSF officials, in order to accommodate evolving NSF policies on budget contingency.

[c]Scope changes included are reductions in response to NSF's policy on cost overruns or as part of a cost increase.

Latest Construction Award

Total project cost, in millions, as of September 2018



Note: Excludes fee of $489,448 provided to the recipient to stimulate efficient performance.

Contributions of Project Partners

DOE, a cosponsor of LSST, is responsible for delivering the LSST camera at a cost of $168 million. SLAC National Accelerator Laboratory manages a collaboration of DOE national laboratories and universities to develop, fabricate, and deliver the camera. According to NSF officials, the LSST project will need to receive the camera from DOE by December 2020. NSF's budget contingency accounts for the risk of a delayed delivery.

The LSST Corporation is a not-for-profit organization representing nearly 40 institutional members and 34 international contributors. It acts as the agent for nonfederal funding contributed to the project and has raised more than $50 million for certain long-lead construction items and additional development efforts.

Remaining Contingency and Scope Reduction Options

As of September 2018 with construction 60 percent complete.

Budget contingency:

$38.3 million ($12.4 million less than the probability-weighted risk exposure of $50.7 million).

Schedule contingency:

8.5 months (included in the August 2022 scheduled completion date).

Estimated value of remaining scope reduction options:

$30 million.

Source: NSF documents and officials and DOE documents. | GAO-19-227

Cost and Schedule Performance History

As of September 2018, NSF's LSST project had no construction cost increases, changes to its scheduled completion date, or scope reductions since our June 2018 report, which used data as of December 2017.

In September 2017, a contractor for NSF completed the agency's first audit of the LSST project's incurred costs during construction, as required by the American Innovation and Competitiveness Act.[48] The audit found that the incurred costs submitted by LSST were generally allowable under NSF guidance and federal regulations and questioned costs amounting to less than one-tenth of a percent of the total incurred costs.

As described earlier in this report, in our review of how the LSST project applied scheduling best practices, we found that the schedule substantially met the comprehensive and controlled characteristics of a reliable schedule, but that it could not be considered reliable because it only partially met the well-constructed and credible characteristics.

Remaining Project Risks and Potential for Cost or Schedule Increases

According to the project's September 2018 monthly report to NSF, the project had 8.5 months of schedule contingency remaining to help avoid any potential delays in completing construction by August 2022. Since our last report, LSST had used budget contingency to, for example, address technical challenges in the mirror assembly and data management systems. However, the estimated cost of the project's remaining risks exceeded the amount of budget contingency left to address them if needed. Specifically, LSST had an estimated remaining risk exposure of $50.7 million when weighted for the risks' probability for all 202 active risks and only $38.3 million in budget contingency remaining (a difference of $12.4 million). The project's top risks included potential damage to the telescope's mirrors and schedule delays related to delivery of the telescope's camera.

In August 2018, NSF and DOE jointly convened an external panel of experts to review the project's construction progress and plans for transitioning from construction to commissioning and operations. The panel expressed concern that the level of budget contingency remaining was low for this stage of the project and noted that the project team must carefully manage risk, budget, and schedule to prevent further use of contingency or schedule slips. As of September 2018, the project team planned to address this concern by updating its estimates for all remaining work to better understand the costs, risks, and contingency.

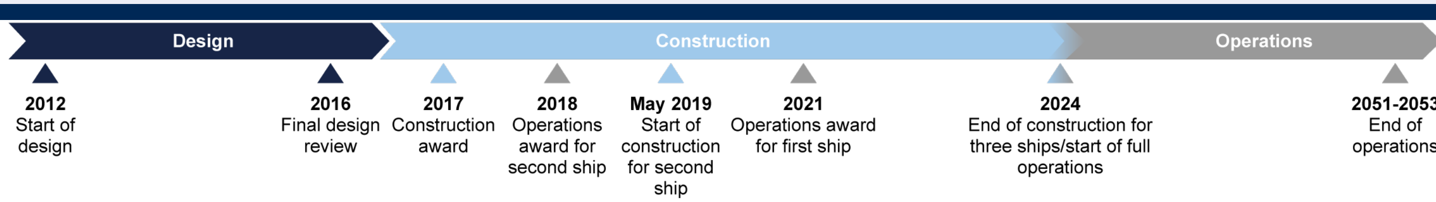
The panel also noted that the project's scope reduction options, last updated by the recipient in July 2018, were somewhat out of date. The panel recommended that the project team update and carefully consider those options to determine when and if any will need to be implemented to complete the project within its cost and schedule. According to project documentation, the LSST project had 38 scope reduction options with potential cost savings estimated at $30 million, including options that would involve some reduction in the project's initially planned capabilities.

[48]The American Innovation and Competitiveness Act requires an incurred cost audit for each of NSF's major multi-user research facility projects at least once during construction at a time determined based on risk analysis and length of the award, with the length of time between audits not to exceed 3 years. Pub. L. No. 114-329 § 110(c)(2)(D).

REGIONAL CLASS RESEARCH VESSELS

Source: Artist Rendering by Glosten. | GAO-19-227

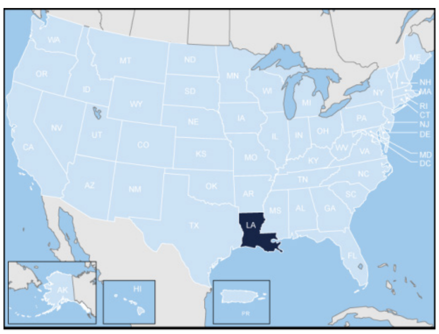
The National Science Foundation's (NSF) Regional Class Research Vessels (RCRV) project will construct two or three ships depending on funding appropriated by Congress. The 199-foot ships to be constructed will support the nation's ability to conduct fundamental scientific research in the coastal zone and continental shelf, including from the ocean's surface through the water column to the sea floor and subsea floor environment. These ships will provide enhanced capabilities beyond those of the retiring ships they will replace. Each ship's research location will depend on the number of ships built and locations of the greatest science demand, but NSF planned to operate the first ship along the west coast of the United States.



Source: GAO analysis of information from NSF as of September 2018. | GAO-19-227

Project Information

Location: Construction site is in Louisiana.



Source: GAO. | GAO-19-227

Scheduled construction completion date, including schedule contingency:

July 2024 for three ships.

Construction award:

Cooperative support agreement with Oregon State University, which contracted with Gulf Island Shipyards, LLC.

Responsible NSF directorate:

Geosciences.

Project partners:

The U.S. Navy performed initial design for the ships.

Expected duration of operations:

30 years.

Source: NSF documents and officials. | GAO-19-227

Project Summary

As of September 2018, construction of NSF's RCRV project was 7 percent complete and in its second year. Since our June 2018 report, the start of physical construction of the first ship had been delayed from May 2018 to November 2018 due to further refinements to the ship's design—namely a lengthening of the ship by 6 feet to achieve the necessary center of gravity. NSF officials anticipated beginning full operations of the first ship, to be named *R/V Taani*, in March 2022; the second in September 2022; and the third, if funded, as soon as March 2023, depending on use of schedule contingency. NSF awarded the University of Rhode Island a cooperative agreement for future operations of the second ship in July 2018 to enable the operator's participation in design refinements and construction, which NSF expected to begin in May 2019.

Construction Status of the Regional Class Research Vessels, as of September 2018

Percentage complete[a]	7
Not-to-exceed cost that the National Science Board authorized	$365.0 million
Total project cost in latest construction award	$354.0 million[b]
National Science Foundation (NSF) funding obligated to date	$209.9 million

Changes in Cost, Schedule, and Scope

	Cumulative changes since original construction award	Changes since Dec. 2017
Not-to-exceed cost that the National Science Board authorized	None	None
Total project cost	None	None
Scheduled completion date[a]	None	None
Scope[c]	None	None

Source: GAO analysis of NSF documents and information from NSF officials. | GAO-19-227

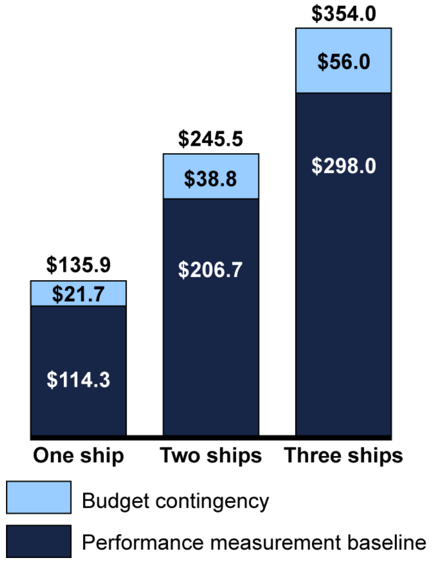
[a]Percentage complete and scheduled completion date are based on construction of three ships.

[b]The award included the option to build up to three ships at a total project cost of up to $354.0 million. As of September 2018, the option for the third ship was contingent upon future appropriations.

[c]Scope changes included are reductions in response to NSF's policy on cost overruns or as part of a cost increase.

Latest Construction Award

Total project cost, in millions, as of September 2018



Remaining Contingency and Scope Reduction Options

As of September 2018 with construction of three ships 7 percent complete.

Budget contingency:

$49.1 million (exceeded the probability-weighted risk exposure of $35.7 million).

Schedule contingency:

10 months (included in the July 2024 scheduled completion date for three ships).

Estimated value of remaining scope reduction options:

$41.8 million.

Source: NSF documents and officials. | GAO-19-227

Cost and Schedule Performance History

As of September 2018, the RCRV project had experienced no cost increases, changes to its scheduled completion date of July 2024 for all three ships, or scope reductions. The construction award as of September 2018 was for two ships, but with the option to build a third ship at a total project cost of up to $354.0 million. The National Science Board had authorized a not-to-exceed cost of $365.0 million for construction of three ships. However, the shipyard bid was ultimately lower than expected, reducing the total project cost of building three ships to $354.0 million. NSF officials said that they considered $140.0 million and $255.5 million to be the not-to-exceed costs for building one and two ships, respectively.

After design refinements indicated that the ships needed more space for system operation and maintenance, NSF approved use of $5 million in budget contingency to address costs of lengthening the ships from 193 feet to 199 feet. The recipient and shipyard opted to lengthen the vessel and rearrange some systems and spaces rather than, for example, remove components needed for the ship's scientific capabilities. This action partially realized the previously identified technical risk of changes to the ship's weight and center of gravity. This change delayed the planned completion dates for each of the first two ships by 4 months.

Remaining Project Risks and Potential for Cost or Schedule Increases

As of September 2018, construction of the RCRV project had been under way for 14 months. According to NSF officials, the project had an estimated risk exposure of $35.7 million and $49.1 million in remaining contingency. In addition, all of the project's 10 months of schedule contingency remained available to help avoid any potential delays in completing construction of three ships by July 2024. The September 2018 monthly report for the RCRV project stated that one of the most significant risks was delays in delivery of the ships' hulls, which could increase the recipient's project management costs by extending the duration of their oversight over the shipyard.

The recipient's project management capacity was another significant risk and had been partially realized due to the August 2018 departure of recipient staff working on the project's schedule and earned value management system. The recipient subsequently acquired schedule and earned value management specialists by contracting with a project management services company. For a time, the recipient also added a risk that NSF would not accept the project's earned value management system in October 2018 as scheduled. Because NSF required this acceptance prior to the RCRV project beginning physical construction, the start of construction for the first ship was at risk of delay. However, NSF conditionally accepted the system on November 13, 2018, and the project began physical construction on November 15, 2018 after the ceremonial laying of the first ship's keel. During the project's 2018 construction review, NSF and the recipient held a session to discuss lessons learned on the project, which, among other things, identified the need for early hiring of earned value management specialists and the importance of ensuring their expertise.

According to NSF officials, 33 options for reducing scope were available as of September 2018, with potential savings estimated at $41.8 million.

Appendix II: Summaries of the National Science Foundation's Plans for Future Large Facilities Projects in Design

This appendix provides individual summaries of the two National Science Foundation (NSF) projects that were in design and planned for construction as large facilities projects: (1) the Antarctic Infrastructure Modernization for Science and (2) the Large Hadron Collider High Luminosity Upgrade. As of September 2018, no construction funds had been awarded for these projects and all cost, schedule, scope, and design information for these projects was subject to change.

Each project's summary is based on project documents and other information that NSF officials provided and includes the following:

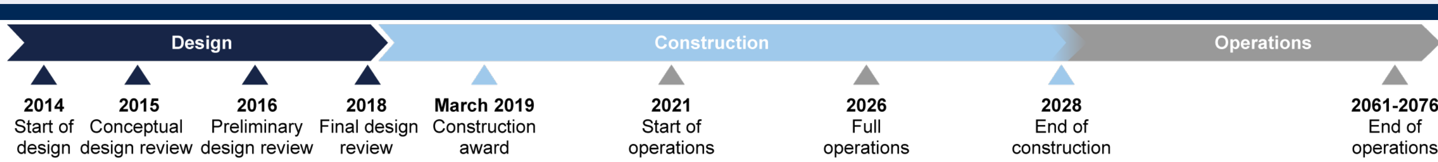
- a description of the project and a timeline identifying key project dates;
- project information as of September 2018, such as the expected date for completion of construction; the anticipated type of awards for construction; the responsible NSF directorate; project partners; and expected duration of operations;
- a summary of the project's current status;
- information on the project's design and construction costs;[49] and
- information on potential project risks and scope reduction options.

[49]Costs represent then-year dollars, which NSF or the recipient calculated from base-year dollars by applying an inflation index. According to NSF policy, inflation is a part of NSF's budgeting and project planning.

Source: Leidos. | GAO-19-227
Note: Rendering of McMurdo Station's core facility.

ANTARCTIC INFRASTRUCTURE MODERNIZATION FOR SCIENCE

The National Science Foundation's (NSF) Antarctic Infrastructure Modernization for Science (AIMS) project will modernize the core infrastructure of McMurdo Station in Antarctica, the largest of three stations operated by NSF's United States Antarctic Program and used by multiple agencies. McMurdo Station serves as a logistics hub for remote field sites and for Amundsen-Scott South Pole Station. The AIMS project is expected to include environmental and safety upgrades to McMurdo Station as well as redevelopment of it into a more compact, energy and operationally efficient core facility to support research. The planned core facility will consolidate critical buildings, such as medical facilities and field science support.



Source: GAO analysis of information from NSF as of September 2018. | GAO-19-227

Project Information

Location: McMurdo Station, Antarctica.

Source: GAO. | GAO-19-227

Expected construction completion date, including schedule contingency:

2028.

Construction award:

Planned for March 2019 as a modification to the existing Antarctic Support Contract with Leidos Innovations Corporation.

Responsible NSF directorate:

Geosciences.

Project partners:

Other federal agencies, such as the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, and the Department of Energy, and international programs, such as the Scientific Committee for Antarctic Research.

Expected duration of operations:

35 to 50 years.

Source: NSF documents and officials. | GAO-19-227

Project Summary

As of September 2018, NSF's AIMS project was in its fifth year of design; consequently, all cost, schedule, scope, and design information for the project was subject to change. NSF conducted the final design review of the project in October 2018. Agency officials said that they planned to obtain authorization from the National Science Board in February 2019 for the project's not-to-exceed cost for construction, award construction funding using a contract in March 2019, and complete construction of the project in 2028. In February 2018, NSF included construction of the AIMS project in its fiscal year 2019 budget request. Construction funding for the project was uncertain as of December 2018 because NSF had not received its final appropriations for fiscal year 2019. According to NSF, if the construction award is not made in early March 2019, the project may miss the December 30, 2019 departure of the planned annual resupply cargo vessel to Antarctica, which would cause the schedule to slip by a year.[50]

Design and Construction Costs

NSF had obligated a total of $29.3 million to the design of AIMS as of September 2018. NSF's budget request for fiscal year 2019 included $103.7 million to start construction of the AIMS project, which agency officials said would be used to begin the site preparation work for utilities and initial buildings and procure the first phases of construction materials and equipment.

As presented in NSF's fiscal year 2019 budget request, the estimated total project cost for construction of the AIMS project was $355.0 million, which NSF officials said included budget contingency. The amount of award fee to be provided had not yet been finalized. The cost, scope, and schedule of the project remained subject to change—based in part on the results of an independent cost estimate—before completion of the final design phase and the National Science Board's authorization to award construction funds.

[50]Through Operation Deep Freeze, the U.S. Navy's Military Sealift Command manages an annual resupply mission to McMurdo.

United States Antarctic Program and McMurdo Station

NSF's Office of Polar Programs manages all U.S. activities in the Antarctic as a single, integrated program, including research supported by NSF or other agencies. The program maintains three year-round stations (the McMurdo, Amundsen-Scott South Pole, and Palmer stations), two research vessels, more than 50 field sites, and transportation infrastructure, such as airfields, an icebreaker ship, fuel tanker, cargo vessel, and aircraft.

McMurdo Station is the largest permanent U.S station in Antarctica, although it was designed to be temporary when the U.S. Navy built it in 1956. Depending on the time of year and the level of ongoing science and construction activity, the station's population varies from approximately 130 to 1,100 and includes scientists, a contractor workforce, and support personnel from various agencies. Research performed at or near McMurdo includes such areas as astrophysics, biology, geology, and ocean and climate systems.

As of 2015, the station comprised approximately 100 buildings on 49 acres, including

- a laboratory and other buildings to support field science;
- a wastewater treatment plant, a water distillation plant, and a power plant;
- an air traffic control center, medical dispensary, firehouse, various warehouses, trades and workshops, a hanger, and a spacecraft operations center; and
- a chapel, post office, and fitness and recreation facilities.

NSF anticipated that consolidation of buildings at McMurdo through the AIMS project will reduce operations and maintenance costs by reducing fuel needs through greater energy efficiency, as well as by increasing the efficiency of labor through consolidation of warehousing and work areas.

Source: GAO analysis of NSF documents and U.S. Antarctic Program Blue Ribbon Panel, *More and Better Science in Antarctica through Increased Logistical Effectiveness* (Washington, D.C.: 2012). | GAO-19-227

Through an interagency agreement with the U.S. Army Corps of Engineers, NSF obtained an independent cost estimate for the project, as required by the American Innovation and Competitiveness Act[51] and as called for by best practices in GAO's cost guide.[52] The Corps finalized its independent cost estimate in November 2018. NSF officials intended to reconcile the recipient's estimate with the independent estimate, which officials said would help validate the total project cost and scope and be used to negotiate the construction bids. According to GAO's cost guide, an independent cost estimate is conducted by an organization independent of the acquisition chain of command and is based on the same detailed technical and procurement information used to make the baseline estimate. It allows for a comparison to examine where and why there are differences between the cost proposed for the project and the independent cost estimate.

Project Risks

Under NSF policy, a project's cost should include enough budget contingency to cover all foreseeable risks. According to NSF officials, as of September 2018, the $355.0 million total project cost for construction included budget contingency, but the total cost and the amount of contingency remained subject to change. If the project realizes risks during the final design stage prior to the construction award, NSF could increase the project cost, decrease its scope, or both, according to agency officials.

According to its August 2018 risk management plan, one of the most potentially costly risks the AIMS project faced was the possibility of major increases in the costs for key construction goods and materials such as steel, copper wire, concrete, gypsum, and specialty items, the availability and costs of which can change frequently and unexpectedly. According to NSF officials, the current global trade environment could drive increases in commodity and import prices that could also affect the project's planned costs prior to the construction award. In addition, they noted that planned project costs could be affected prior to construction by labor scarcity resulting from the combination of a robust economy and the U.S. construction market's need to respond to natural disasters. Further, according to the project's risk management plan, the seasonal nature of the workforce was expected to be a major constraint to controlling project risks during construction because of staff turnover rates of 30 to 40 percent per year and restrictions on how long staff can stay in Antarctica (no longer than 13 or 14 consecutive months). These issues result in the need for continually adding and training staff.

According to NSF officials and the project's risk management plan, risks to the AIMS schedule include delays in procuring the modular construction units for the project's lodging facility, which require a long lead time, in time for the annual resupply vessel, as well as potential for the pier at McMurdo station to be unavailable for off-loading materials and equipment. The McMurdo ice pier has been repaired or reconstructed annually in recent years, according to the project's risk management plan. If the existing ice pier is not available for use due to unsafe weather

[51]Pub. L. No. 114-329 § 110(c)(1)(A)(iv).

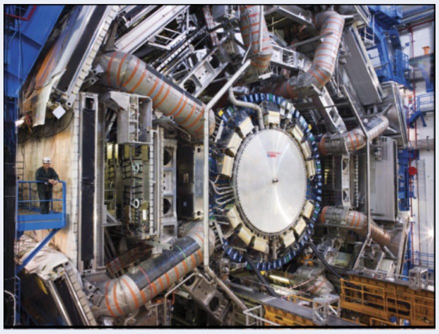
[52]GAO-09-3SP.

conditions or the need for repairs or reconstruction, the project's ability to off-load construction materials and equipment would be limited, delaying project completion.

Potential Scope Reduction Options

NSF policy also directs a project's design to include prioritized, time-phased options for reducing its scope during construction if needed. The estimated potential cost savings of those options is to total at least 10 percent of the project's baseline. According to project documentation, design of the AIMS project included scope reduction options with potential cost savings estimated at $43.9 million (15 percent of the baseline) as of October 2018; these options were subject to change and updates at least annually. The plan included six options with potential cost savings ranging from $0.3 million to $30.8 million. The largest savings from these options would require removing the trades shop from the scope of the project and retaining the trades and carpenter shops currently in use. According to project documentation, removal of this scope could potentially occur as late as fiscal year 2023 if needed, but retaining use of aging buildings could increase long-term maintenance and operating costs at McMurdo Station.

LARGE HADRON COLLIDER HIGH LUMINOSITY UPGRADE



Source: © 2007 CERN. | GAO-19-227
Note: photograph above depicts the A Toroidal Large Hadron Collider Apparatus detector.

The Large Hadron Collider (LHC) is the world's most powerful particle accelerator. The facility's four detectors observe new particles that are produced when high-energy protons are accelerated and collided, providing insight into fundamental forces of nature and the condition of the early universe. Through the National Science Foundation's (NSF) Large Hadron Collider High Luminosity Upgrade (HL-LHC) project, the agency will fund a portion of a larger international effort to upgrade the facility's accelerator and detectors. Specifically, NSF plans to fund the design and implementation of certain parts of the upgrades to two of the facility's detectors, the A Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS) detectors. The U.S. Department of Energy (DOE) is also contributing to upgrades to the LHC's accelerator and to the ATLAS and CMS detectors.

Source: GAO analysis of information from NSF as of September 2018. | GAO-19-227

Project Information

Location: near Geneva, Switzerland.

Source: GAO. | GAO-19-227

Expected construction completion date, not including schedule contingency:

September 2025.

Construction awards:

If approved, planned for 2020 as cooperative agreements with Columbia University (ATLAS detector) and Cornell University (CMS detector).

Responsible NSF directorate:

Mathematical and Physical Sciences.

Project partners:

European Organization for Nuclear Research (CERN) and DOE.

Expected duration of operations:

10 years.

Source: NSF documents and officials. | GAO-19-227

Project Summary

As of September 2018, NSF's HL-LHC project was approaching its fourth year of design; consequently, all cost, schedule, scope, and design information for the project was subject to change. Preliminary design reviews for NSF's upgrades to the CMS and ATLAS detectors took place in December 2017 and January 2018, respectively. NSF planned to conduct the final design review for both detectors in September 2019 and award construction funding in 2020. In July 2018 the National Science Board authorized inclusion of the HL-LHC project in the agency's fiscal year 2020 budget request.

Design and Construction Costs

NSF had obligated a total of $15.2 million for the design of its detector upgrades as of September 2018.

In June 2018, NSF's Facilities Readiness Panel endorsed advancing the project to final design with a planned total project cost of $150 million for construction of the ATLAS and CMS detector upgrades, with costs of $75 million planned for each detector based on NSF's cost analyses. These figures remained subject to change before completion of the final design phase and authorization by the National Science Board to proceed to construction. NSF planned to fund the upgrades with separate cooperative agreements for each detector and to monitor each agreement in accordance with its distinct terms and conditions, total project cost, and earned value management metrics, according to agency officials.

NSF officials planned to convene panels of external experts in September 2019 to review each detector upgrade for their final design reviews. According to agency officials, NSF also planned to complete an independent cost estimate in the fall of 2019, as required by the American Innovation and Competitiveness Act, prior to awarding construction funds for its upgrades to each detector.[53]

[53] Pub. L. No. 114-329 § 110(c)(1)(A)(iv).

Planned Contingency and Scope Reduction Options

As of September 2018 with project in final design phase. Figures were subject to change.

Budget contingency:

$38.9 million as follows

- $20.0 million for the ATLAS detector.
- $18.9 million for the CMS detector.

Schedule contingency:

To be determined.

Estimated value of scope reduction options:

$12.3 million as follows

- $5.2 million for the ATLAS detector.
- $7.1 million for the CMS detector.

Source: NSF documents and officials. | GAO-19-227

DOE's Contributions to Upgrading the Large Hadron Collider

DOE's High Energy Physics program helped fund the construction of the Large Hadron Collider and continues to support researchers using the facility as well as upgrades to it. According to DOE's fiscal year 2019 budget request, the department planned to support the upgrades to the ATLAS and CMS detectors at an estimated cost of $125 million to $155 million for each detector. The scope of DOE's work on the detectors was to focus on areas where the expertise and infrastructure of the department's national labs were needed, whereas the scope of NSF's work was to focus on areas led by university researchers. In addition, DOE planned to support upgrades to the accelerator itself at an estimated cost range of $209 million to $252 million, according to DOE's fiscal year 2019 budget request.

Source: DOE documents. | GAO-19-227

Project Risks

Under NSF policy, a project's cost should include enough budget contingency to cover all foreseeable risks. As of September 2018, the amount of budget contingency included in the construction cost for the upgrades was approximately $38.9 million, or 26 percent of the planned total project cost. External preliminary design review panels for both detectors determined that the amount of contingency at the time of their review was appropriate at this phase of design but encouraged further review of the estimates, citing concerns that the estimate may be too high for the ATLAS detector and too low for the CMS detector.

The panels for both detectors noted that the project teams had generally done a good job of identifying risks and quantifying their potential effects and highlighted certain areas for further assessment. For example, the panel for the CMS detector discussed the risks posed by the use of project labor to be contributed by faculty, postdoctoral positions, and graduate students—approximately 90 U.S. universities participate in LHC experiments. According to project documents, such contributed labor represents 24 percent and 44 percent of the total labor planned for NSF's contributions to upgrading the ATLAS and CMS detectors, although the amounts of such labor were subject to change. Funding for contributed labor would come not from NSF's construction awards for upgrading the detectors but from sources such as NSF and DOE research grants. The panel for the CMS detector expressed concerns that the project team may have underestimated the likelihood that, should such funding decrease, the project would lose contributed labor from faculty, graduate students, and postdoctoral positions. According to a NSF document, the potential impact of this risk for both detectors is significantly larger than either of the project teams had estimated during preliminary design. The document also stated that NSF intends to preserve the educational opportunity for student and postdoctoral participation in developing new high energy physics instrumentation on this scale. NSF and the recipients planned to assess during the final design phase the level of contributed labor support needed and to develop additional scope reduction options to mitigate the risk of reduced research grant funding for such labor.

The preliminary design review panels for both detectors also discussed the importance of expertise in earned value management—a project management tool—for reporting on the project's technical and financial status. Both panels noted that most or much of the project team for each detector was new to earned value management or inexperienced in implementing it. According to NSF officials, the project teams will begin gaining experience by using earned value management during the final design phase, and NSF will evaluate their earned value management systems before construction begins.

In addition, NSF's Facilities Readiness Panel expressed concerns about the division of work between NSF and DOE—which is also contributing to upgrading the ATLAS and CMS detectors—because resources from both agencies are sometimes required to accomplish project tasks. The panel found that a related memorandum of understanding signed by both agencies did not adequately define each agency's scope. According to NSF officials, the final design review will finalize scope for each partner and the scope will be specified in updated memoranda of understanding between NSF, DOE, and CERN.

Potential Scope Reduction Options

NSF policy also directs a project's design to include prioritized, time-phased options for reducing its scope during construction if needed. As of the preliminary design reviews, the project teams had identified a total of $12.3 million of potential scope reduction options for the project, such as certain changes to the detectors that would reduce their capabilities. The five options for reducing the scope of the ATLAS detector upgrade had estimated cost savings ranging from $0.3 to $1.3 million each, while the 27 options for the CMS detector had estimated cost savings of $12,500 to $1.8 million. However, both preliminary design review panels identified a need for additional or more realistic potential scope reductions. According to a NSF document, NSF will ensure during final design that the recipients develop detailed listings of scope reduction options with associated decision logic and information on how the options relate to the project's science requirements.

Appendix III: Comments from the National Science Foundation

National Science Foundation
Office of the Director

March 6, 2019

John Neumann
Managing Director
Science, Technology Assessment, and Analytics
U.S. Government Accountability Office
441 G Street, NW
Washington, D.C. 20548

Dear Mr. Neumann:

The National Science Foundation (NSF) appreciates the opportunity to review and provide comments on the Government Accountability Office (GAO) draft report, *National Science Foundation: Cost and Schedule Performance of Large Facilities Construction Projects and Opportunities to Improve Project Management (GAO-19-227).* This assessment, like GAO's 2018 report on NSF's large facilities, provides NSF with valuable independent recommendations to continue to improve our oversight of large facilities in design and construction. The agency's investment in scientific research facilities remains critical to the progress of science and good oversight will help protect those investments.

We are particularly proud of the progress we have made with implementing cost-effective policies related to verification and acceptance of Earned Value Management Systems, our formal Knowledge Management Program, and core competencies of NSF staff. I appreciate your positive assessment of NSF's progress in these areas. NSF agrees generally with your recommendations in GAO-19-227 and we will carefully consider appropriate implementation of each as we review the Large Synoptic Survey Telescope (LSST) project, update the Major Facilities Guide, and implement the *Program Management Improvement and Accountability Act* in 2019.

On behalf of the NSF staff participating in the GAO review, I would like to acknowledge the GAO team for their diligence and commitment to enhancing NSF's oversight policies and practices. Please contact Veronica Shelley at (703) 292-4384 if you have any questions or require additional information.

Sincerely,

France A. Córdova
Director

2415 Eisenhower Avenue | Alexandria, VA 22314

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

John Neumann, (202) 512-6888 or neumannj@gao.gov

Staff Acknowledgments

In addition to the contact named above, Joseph Cook (Assistant Director), Krista Breen Anderson (Analyst in Charge), Brian Bothwell, Kevin S. Bray, Tara Congdon, Yvette Gutierrez, Sophie M. Jacobson, Jason T. Lee, Tind Shepper Ryen, and Sara Sullivan made key contributions to this report.

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