



June 2018

NATIONAL SCIENCE FOUNDATION

Revised Policies on Developing Costs and Schedules Could Improve Estimates for Large Facilities

Accessible Version

GAO Highlights

Highlights of [GAO-18-370](#), a report to congressional committees

Why GAO Did This Study

NSF uses cooperative agreements and contracts to fund construction of science and engineering research infrastructure, such as telescopes. In 2008, NSF established a policy to manage cost overruns and strengthen oversight of these large facilities projects, which typically have construction costs greater than \$70 million. Among other things, the policy generally requires a project's scope to be reduced before its NSF-authorized cost may be increased.

Senate Report 114-239 and House Report 114-605 included provisions for GAO to review projects funded within NSF's Major Research Equipment and Facilities Construction account used to fund construction of large facilities projects. GAO (1) examined the extent to which NSF's procedures for estimating construction costs and schedules of large facilities met best practices and (2) described the construction cost and schedule performance of NSF's large facilities projects since implementation of its policy to manage cost overruns. GAO compared NSF's procedures documented in its policies with best practices in GAO's cost and schedule guides, analyzed documents for the seven projects covered by NSF's policy to manage cost overruns, and interviewed NSF officials.

What GAO Recommends

GAO recommends that NSF revise its policies for estimating and reviewing the costs and schedules of large facilities projects to better incorporate best practices in GAO's cost and schedule guides. NSF agreed with GAO's recommendations.

View [GAO-18-370](#). For more information, contact John Neumann at (202) 512-3841 or neumannj@gao.gov.

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NATIONAL SCIENCE FOUNDATION

Revised Policies on Developing Costs and Schedules Could Improve Estimates for Large Facilities

What GAO Found

The National Science Foundation's (NSF) procedures for overseeing large facilities construction projects met many best practices for cost estimating but not those for developing project schedules. Specifically, NSF's procedures fully or substantially met 7 of 12 best practices in GAO's cost estimating guide and partially or minimally met others (such as conducting a sensitivity analysis to understand which variables most affect the cost estimate). In addition, they minimally met or did not meet 6 of 10 best practices in GAO's schedule development guide (such as establishing the durations of all activities). Further, while NSF reviews recipients' construction cost and schedule estimates for large facilities, the agency's policies did not incorporate procedures on how NSF officials are to ensure that those estimates meet best practices. An agency's procedures support the creation of reliable cost and schedule estimates when they fully or substantially meet the best practices in GAO's cost and schedule guides. NSF officials said that the agency's approach was to reference rather than repeat best practices in GAO's cost guide, except where agency-specific clarifications were needed. Nevertheless, without policies on how to apply all relevant best practices specifically to NSF's large facilities projects, recipients may develop cost or schedule estimates that are not reliable.

Of the seven projects NSF had funded that were covered by its policy to manage cost overruns, five had experienced cost or schedule increases since starting construction. In particular, two projects—the National Ecological Observatory Network and Daniel K. Inouye Solar Telescope—had both cost and schedule increases that were partly due to permitting challenges that could not be estimated at the time of the projects' proposals, according to NSF officials. Both of these projects also reduced their scopes. NSF required the reductions to the observatory network's scope under the agency's policy for managing cost overruns, whereas the reduction to the telescope project was a separate action. Three other projects had only schedule increases, with no increase in costs, and the remaining two projects had experienced neither cost nor schedule increases as of December 2017.

Cost and Schedule Performance of Large Facilities Projects Covered by NSF's Policy for Managing Cost Overruns, as of December 2017

Project name	Percentage complete	Cost change	Schedule change	Scope reductions
Alaska Region Research Vessel	100	cost decreased	cost or schedule increased;	None
Ocean Observatories Initiative	100	cost decreased	cost or schedule increased;	None
Advanced Laser Interferometer Gravitational Wave Observatory	99	None	cost or schedule increased;	None
National Ecological Observatory Network	94	cost or schedule increased;	cost or schedule increased;	scope reduced.
Daniel K. Inouye Solar Telescope	81	cost or schedule increased;	cost or schedule increased;	scope reduced.
Large Synoptic Survey Telescope	50	None	None	None
Regional Class Research Vessels	4	None	None	None

Legend: - = no cost or schedule increase or scope reductions since starting construction; ▼ = cost decreased; ▲ = cost or schedule increased; ✓ = scope reduced.

Source: GAO analysis of National Science Foundation (NSF) documents. | GAO-18-370

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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
HL-LHC	Large Hadron Collider High Luminosity Upgrade
LHC	Large Hadron Collider
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

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June 1, 2018

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

The National Science Foundation (NSF) supports research and education in nearly all fields of science and engineering and does this in part by funding the construction of research infrastructure—including research instruments, equipment, and facilities—throughout the country and around the world. In particular, through its Major Research Equipment and Facilities Construction (MREFC) account, NSF has supported construction of large facilities projects from polar research stations and telescopes to research vessels and ocean observatories. When the science community identifies a priority for research facilities in an NSF-supported area, NSF may then fund the design of such projects through one or more of its seven directorates that support science and engineering research.¹ However, these directorates typically fund only the design and operations of large facilities projects and not their construction. Instead, NSF typically uses its MREFC account to fund these projects' construction in order to prevent adding large periodic costs

¹NSF's directorates receive an annual allocation from the Research and Related Activities account, which NSF refers to as the directorate budget.

to directorates' budgets, according to NSF's *Large Facilities Manual*.² Since the account was established in 1995, NSF has used it to fund 20 such projects, including the 5 projects under construction as of December 2017. NSF received \$182.8 million in appropriations in fiscal year 2018 for its MREFC account and requested \$94.7 million for fiscal year 2019.³

NSF generally funds and oversees construction of large facilities through cooperative agreements with entities such as nonprofit consortia of universities.⁴ An NSF project team oversees each project, with representatives from the sponsoring directorate, NSF's Large Facilities Office, and a grants and agreements officer or contract officer. As part of its oversight of large facilities, NSF has had a policy for managing cost overruns—its “no cost overrun policy”—for these projects since its fiscal year 2009 budget request. The policy does allow for cost increases; however, under this policy, NSF generally requires that (1) the total project cost estimated for a project during its preliminary design includes adequate funds to cover the potential costs of all foreseeable risks and (2) during construction, those funds must be used and the project's scope reduced before a project's NSF-authorized cost may be increased. According to NSF's *Large Facilities Manual*, the agency established this policy to instill diligence and rigor in establishing a project's construction cost and to give NSF a strong oversight position.

Since 2012, NSF's Office of Inspector General and others have raised concerns about the agency's oversight of its large facilities projects. For example, in 2012, the Office of Inspector General issued a memo to NSF's Director and the head of NSF's Office of Budget, Finance, and

²National Science Foundation, *Large Facilities Manual*, NSF 17-066 (March 2017). NSF's policies for large facilities apply to a project if (1) it is funded through NSF's MREFC account, which has a minimum threshold of \$70 million for a project's total project cost, or (2) it is funded through the Research and Related Activities account and its total project cost exceeds \$100 million or 10 percent of the responsible NSF directorate's annual budget, whichever is less. Total project cost is defined by the construction stage and does not represent a project's full life-cycle cost, according to NSF's manual.

³NSF requested \$198.4 million for construction of large facilities for fiscal year 2019, which included \$94.7 million from the MREFC account and \$103.7 from the Research and Related Activities account.

⁴Cooperative agreements are a form of financial assistance used to enter into a relationship the principal purpose of which is to transfer anything of value to the nonfederal entity, and provide for substantial involvement by the federal awarding agency in 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 for the agency.

Award Management alerting them to serious weaknesses in the agency's oversight of costs for its cooperative agreements, including but not limited to those for large facilities projects. Over the last several years, NSF has taken steps to improve its oversight of cooperative agreements for large facilities projects, including addressing certain concerns raised by the National Academy of Public Administration and the Office of Inspector General, and beginning to address requirements in the American Innovation and Competitiveness Act of 2017.⁵ For example, the National Academy of Public Administration made 13 recommendations to NSF in a 2015 report on the agency's use of cooperative agreements in supporting large-scale investment in research.⁶ Among those, the academy recommended, and NSF has made, changes to the agency's policy on control of projects' budget contingency.⁷

Senate Report 114-239 and House Report 114-605 included provisions for us to review projects funded within NSF's MREFC account.⁸ This report (1) examines the extent to which NSF's procedures for estimating the construction costs and schedules of large facilities projects met best practices for developing reliable estimates and (2) describes the construction cost and schedule performance of NSF's large facilities projects since implementation of its no cost overrun policy.

To examine the extent to which NSF's procedures for estimating the construction costs and schedules of large facilities projects met best practices for developing reliable estimates, we compared NSF policies

⁵Pub. L. No. 114-329, § 110, 130 Stat. 2969, 2988 (2017) (codified at 42 U.S.C. § 1862s-2). Section 110 of the American Innovation and Competitiveness Act states that the Director of NSF shall strengthen oversight and accountability over the full life cycle of each major multiuser research facility project, including planning, development, procurement, construction, operations, and support, and shutdown of the facility, in order to maximize research investment. 42 U.S.C. § 1862s-2(a)(1). The act defines a "major multiuser research facility project" as a science and engineering facility project that (a) exceeds the lesser of 10 percent of a directorate's annual budget or \$100 million in total project costs or (b) is funded by the MREFC account or any successor account. 42 U.S.C. § 1862s-2(g)(2). According to NSF officials, the agency requires major multiuser research facility projects to follow the policies in NSF's *Large Facilities Manual*. Major multiuser research facility projects include those we refer to in this report as large facilities projects.

⁶National Academy of Public Administration, *National Science Foundation: Use of Cooperative Agreements to Support Large Scale Investment in Research* (Washington, D.C.: December 2015).

⁷Budget contingency is estimated and included in budgets for NSF's large facilities projects to address additional project costs that could result from foreseeable risks.

⁸S. Rep. No. 114-239, at 117 (2016); H.R. Rep. No. 114-605, at 68 (2016).

documenting its procedures with best practices defined in GAO's cost and schedule guides.⁹ We reviewed NSF's procedures for the recipients of cooperative agreements or contracts for construction of large facilities projects (referred to as recipients throughout this report) as well as the agency's own procedures for reviewing project costs and schedules. We also reviewed relevant standards for internal control in the federal government.¹⁰ We interviewed NSF officials about their procedures, provided them with copies of our analyses, and incorporated their comments, as appropriate.

To describe the construction cost and schedule performance of NSF's large facilities projects since implementation of its no cost overrun policy, we reviewed NSF documents and interviewed agency officials to identify requirements under the policy. We analyzed documents for the seven projects NSF officials identified as covered by the policy at the time of our review. We focused our review of project documents on the three ongoing projects for which NSF requested fiscal year 2018 construction funding: (1) the Daniel K. Inouye Solar Telescope, (2) the Large Synoptic Survey Telescope, and (3) the Regional Class Research Vessels. We also interviewed NSF officials about these projects. In addition, we reviewed documents and interviewed NSF officials about the National Ecological Observatory Network, which was ongoing at the start of our work but was expected to be completed in November 2018. We reviewed more limited cost and schedule information on another ongoing project expected to be completed in July 2018 (the Advanced Laser Interferometer Gravitational Wave Observatory) as well as two projects completed in 2016 (the Ocean Observatories Initiative and Alaska Region Research Vessel). In addition, we reviewed project documents and interviewed NSF officials for the two projects in design at the time of our review: (1) the Antarctic Infrastructure Modernization for Science and (2) the Large Hadron Collider High Luminosity Upgrade.¹¹ We obtained supporting documentation for project

⁹GAO's cost guide is a compilation of cost estimating best practices drawn from across industry and government. See GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, [GAO-09-3SP](#) (Washington, D.C.: March 2009). GAO's schedule guide develops the scheduling concepts introduced in our cost estimating guide and presents them as 10 best practices associated with developing and maintaining a reliable, high-quality schedule. See GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, [GAO-16-89G](#) (Washington, D.C.: December 2015).

¹⁰GAO, *Standards for Internal Control in the Federal Government*, [GAO-14-704G](#) (Washington, D.C.: September 2014).

¹¹NSF's fiscal year 2018 budget request identified these projects in their sponsoring directorates' budgets under "pre-construction planning."

data when possible and provided our preliminary assessments for each project to NSF officials to help us correct any inaccuracies, which we accounted for as appropriate. Through this process, we determined that the data points were sufficiently reliable for our purpose of describing the projects' cost and schedule performance and current status.

We conducted this performance audit from August 2017 to June 2018 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.

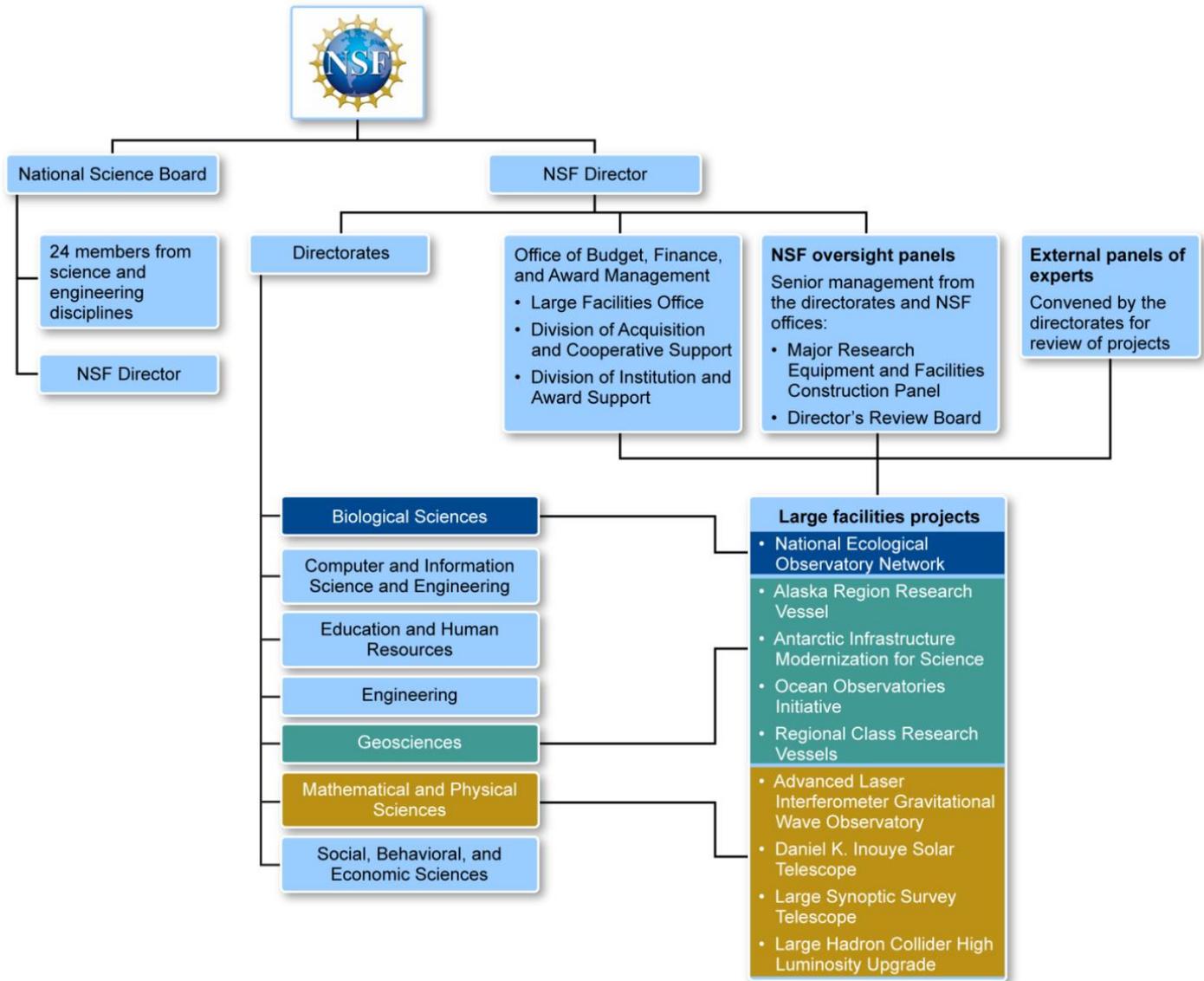
Background

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 who represent a variety of science and engineering disciplines. The NSF Office of the Director and the National Science Board provide high-level oversight of large facilities projects, including the approval of new projects to be included in NSF's budget request. Two bodies advise the Director of NSF on large facilities projects:

- **Major Research Equipment and Facilities Construction Panel.** Composed of senior management representatives from across NSF, the MREFC Panel reviews and recommends projects for advancement through the large facilities design process.¹²
- **Director's Review Board.** Also composed of senior management representatives 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.

¹²In their technical comments on this report, NSF officials stated that the agency was in the process of transitioning the MREFC Panel to the Facilities Readiness Panel, which they said is composed of experienced program officers and division-level staff to provide facilities expertise on evaluating project readiness for advancement.

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



Source: GAO analysis of NSF documents. | GAO-18-370

Note: Figure does not include all NSF offices and includes only those large facilities projects that GAO reviewed.

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 a potential project, proposes projects for funding through NSF's MREFC account,

and is responsible for overseeing and funding the facility's eventual operation and use. Within the sponsoring office, a program officer has primary oversight responsibility within NSF for all aspects of a large facilities project, including conducting periodic reviews of the project during design and construction using an external panel of experts.

Several offices within NSF's Office of Budget, Finance, and Award Management contribute to the oversight of large facilities projects.¹³ In particular, 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 *Large Facilities Manual*, which contains NSF policies for agency staff and recipients on the planning, management, and oversight of large facilities.¹⁴ Prior to requesting the National Science Board's approval 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 leadership that summarizes key technical and financial status information on all ongoing large facilities in construction and candidate projects in design.

The *Large Facilities Manual* defines five stages of the life cycle of large facilities projects:

- **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 of interest to NSF.
- **Design.** Entrance into this stage occurs when the NSF Director approves the proposed research infrastructure as a national priority and the sponsoring directorate makes an award (either through a

¹³For example, 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. NSF staff within the Division of Institution and Award Support perform cost analyses and review recipients' accounting systems, among other things.

¹⁴For the 2017 version, see National Science Foundation, *Large Facilities Manual*.

cooperative agreement or contract) for developing detailed 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. An external panel of experts reviews the project at the culmination of each of these design phases; accordingly, those are known as conceptual, preliminary, and final design reviews.

- **Construction.** The construction stage begins when NSF awards construction funds to external recipients for acquisition or construction of research infrastructure. Such awards generally take the form of cooperative agreements, although NSF occasionally uses contracts, according to agency officials.¹⁵ The policies and procedures in NSF's *Large Facilities Manual* apply to research infrastructure projects regardless of the award instrument employed.¹⁶ According to NSF's *Large Facilities Manual*, the transition from construction to operations is rarely abrupt, and many projects require an integration and testing phase, followed by commissioning and acceptance, to bring the facility up to the design level of operational readiness. Commissioning and acceptance are part of the construction stage.
- **Operations.** The operations stage includes the day-to-day work to operate and maintain the research infrastructure, including refurbishment or upgrade activities, and to perform research. Operations awards, which are separate from construction awards, may be awarded to the construction award recipients or to a different

¹⁵NSF uses two types of cooperative agreements: (1) stand-alone cooperative agreements, which are single, unified awards where there is no need to provide separate, discrete funding and oversight for projects or programs under the award, and (2) master cooperative agreements, which consist of a master agreement with no funding attached to it plus separate cooperative support agreements funded individually under the umbrella of the master agreement. Each cooperative support agreement has its own terms and conditions in addition to those of the master agreement. The ongoing large facilities projects reviewed in this report use the master cooperative agreement framework.

¹⁶In 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. All contracts are entered into under the Federal Acquisition Regulation. See chapter 1 of title 48 of the *Code of Federal Regulations*, with NSF-specific provisions found in chapter 25 of title 48 of the *Code of Federal Regulations*. According to NSF's *Large Facilities Manual*, contracts with nonprofit and educational institutions may also include provisions under the Uniform Guidance.

entity. Depending on the project, 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 research infrastructure to another entity's operational and financial control or the decommissioning of the research infrastructure, including its complete deconstruction and removal. 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, which is funded by NSF's Research and Related Activities account. Construction funding generally comes from the MREFC account. However, if the Research and Related Activities account is used to fund construction, the policies and procedures in NSF's *Large Facilities Manual* apply if total project costs exceed \$100 million or 10 percent of the responsible directorate's annual budget, whichever is less.

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 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 that the National Science Board authorized is the amount against which NSF measures cost increases to implement its no cost overrun policy.

NSF's *Large Facilities Manual* defines the following components that together make up the total project cost and schedule of large facilities projects. The total project cost awarded in a project's construction agreement may be less than the not-to-exceed cost that the National Science Board authorized, but it 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 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.¹⁷

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,

¹⁷Use 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.

according to NSF officials. According to agency officials and the *Large Facilities Manual*, NSF rarely uses management reserve.

NSF's No Cost Overrun Policy for Large Facilities Projects

In February 2008, NSF released its fiscal year 2009 budget request, which included language to implement a no cost overrun policy for large facilities projects. This policy generally requires that the cost estimate developed at the preliminary design phase have adequate contingency to cover all foreseeable risks and that any cost increases not covered by contingency be accommodated by reductions in scope. NSF officials 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. According to agency officials, NSF implemented this policy in response to rising costs during design for NSF projects under consideration and congressional concerns over cost overruns on projects at other agencies.

According to NSF officials, each large facilities project typically has a science advisory committee that provides advice to the recipient during the design stage on options for potential scope reductions during construction. In addition, the external panels that periodically review projects during design and provide advice to NSF—and that include individuals from the science community, according to NSF officials—also review the scope reduction options, which are documented in a scope management plan. NSF also reviews projects' scope management plans as part of the agency's oversight procedures. Actions to reduce a project's scope during construction are to be documented through a formal process. NSF officials said that use of previously approved scope reduction options generally does not involve additional external scientific review but that the agency could seek additional review if needed.

In 2015, NSF added several requirements to its no cost overrun policy. In particular, it added a requirement that at the preliminary design review, projects have a prioritized, time-phased list of options for reducing scope, known as scope contingency, during construction and that the potential cost savings associated with those options 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. According to the head of NSF's Large Facilities Office, the agency added this requirement to identify options for reducing scope because previously the mechanisms to implement the policy were not defined and were not clear to either NSF or the science community. In addition, the official stated that NSF required that potential cost savings total at least 10 percent in order to instill diligence for both NSF and recipients in establishing realistic, substantive options for reducing scope. In 2015, NSF also began requiring that recipients determine the amount of contingency funds using more rigorous and uniform methods. Finally, NSF added a requirement that the research directorate responsible for the project cover all or part of a cost overrun, instead of the MREFC account covering all of it. Specifically, the directorate is to fund the cost overrun up to an amount equal to the first 10 percent of the original total project cost for construction. This step relies on NSF's transfer authority—authority granted by Congress for NSF to transfer a certain amount of appropriations between the agency's budget accounts.¹⁸

Best Practices for Estimating Project Costs and Developing Project Schedules

Without reliable cost and schedule estimates for their projects, agencies are at risk of experiencing cost overruns, missed deadlines, and performance shortfalls. GAO's cost guide describes 12 best practices that federal cost estimating organizations and industry use to develop and maintain reliable cost estimates for making informed decisions throughout the life of an acquisition program or project.¹⁹ A cost estimate cannot be considered credible if it does not account for the cost effects of schedule slippage, according to GAO's schedule guide. Consequently, an effective methodology for developing, managing, and evaluating cost estimates includes an integrated and reliable master schedule that defines when and how long work will occur and how each activity is related to the others. To expand on the scheduling concepts included in our cost guide, GAO's schedule guide presents 10 best practices for developing and maintaining reliable, high-quality program or project schedules.²⁰ According to GAO's schedule guide, a well-planned schedule is a

¹⁸As the *Large Facilities Manual* notes, NSF's transfer authority depends on continued inclusion in annual appropriations acts. See, e.g., Pub. L. No. 115-31, 131 Stat. 135, 216 (2017).

¹⁹[GAO-09-3SP](#).

²⁰[GAO-16-89G](#).

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.

In 2017, the American Innovation and Competitiveness Act required the Director of NSF, in order to maximize research investment, to strengthen oversight and accountability over the full life cycle of each major multiuser research facility project, which include projects funded by NSF's MREFC account, or projects that meet certain cost thresholds if funded by other accounts.²¹ Among other things, the act requires the Director of NSF to ensure that policies for estimating and managing project costs and schedules are consistent with the best practices described in GAO's cost and schedule guides.²² It also requires certain cost oversight prior to approval of agreements to start construction on any proposed major multiuser research facility project, such as an independent cost estimate for construction costs; certain oversight during construction, such as audits of the costs incurred by projects; and independent cost analyses of each project's operational proposal.²³

NSF's Procedures for Large Facilities Met Many Best Practices for Cost Estimating, but Minimally Met or Did Not Meet Most Best Practices for Schedule Development

NSF's procedures for overseeing large facilities construction projects met many best practices for cost estimating but not those for developing project schedules. Specifically, NSF's procedures fully or substantially met 7 of 12 best practices in GAO's cost guide and partially or minimally met others. However, they minimally met or did not meet 6 of 10 best practices in GAO's schedule development guide. Further, while NSF

²¹Pub. L. No. 114-329, § 110, 130 Stat. 2969, 2988 (2017) (codified at 42 U.S.C. § 1862s-2). Specifically, as noted previously, section 110 of the American Innovation and Competitiveness Act defines a major multiuser research facility project as "a science and engineering facility project that (a) exceeds the lesser of 10 percent of a directorate's annual budget or \$100,000,000 in total project costs, or (b) is funded by the major research equipment and facilities construction account or any successor account." 42 U.S.C. § 1862s-2(g)(2).

²²42 U.S.C. § 1862s-2(a)(2)(D).

²³42 U.S.C. § 1862s-2(c).

reviews recipients' construction cost and schedule estimates for large facilities, the agency's policies did not incorporate procedures on how NSF officials are to ensure that those estimates meet best practices.

NSF's Procedures Fully or Substantially Met 7 of 12 Cost Estimating Best Practices and Partially Met Most of the Remaining Practices

Cost estimating procedures documented in NSF's policies for large facilities projects fully or substantially met many of the GAO cost guide's best practices and partially or minimally met others.²⁴ According to NSF policy outlined in the agency's *Large Facilities Manual*, recipients of funding for large facilities projects must follow best practices in GAO's cost guide and any deviations must be documented. In addition, the American Innovation and Competitiveness Act requires NSF to ensure that policies for estimating and managing project costs are consistent with the best practices described in GAO's guide.²⁵ We found that NSF's procedures fully or substantially met 7 of the 12 best practices for cost estimating, partially met 4 practices, and minimally met the remaining practice (see table 1; app. II provides more details on the documents we reviewed and our assessment of each best practice).

Table 1: Summary of the Extent to Which NSF's Procedures for Large Facilities Projects Met Best Practices for Cost Estimating

GAO assessment of NSF procedures ^a	Best practices for cost estimating
Fully met	<ul style="list-style-type: none"> Define the project's characteristics Document the estimate Present the estimate to management for approval Update the estimate to reflect actual costs and changes
Substantially met	<ul style="list-style-type: none"> Develop the estimating plan Develop the point estimate and compare it to an independent cost estimate Conduct a risk and uncertainty analysis

²⁴Of the policies we reviewed that documented NSF's procedures for large facilities projects, only NSF's *Large Facilities Manual* and certain internal *Standard Operating Guidance* (documents on standardized cost analysis and earned value management system verification, acceptance, and surveillance and draft guidance on selection of independent cost estimate reviews) addressed best practices for cost estimating.

²⁵42 U.S.C. § 1862s-2(a)(2)(D).

GAO assessment of NSF Best practices for cost estimating procedures^a

Partially met	Determine the estimating structure Identify ground rules and assumptions Obtain the data Conduct a sensitivity analysis
Minimally met	Define the estimate’s purpose
Not met	NA

Legend: - = not applicable.

Source: GAO analysis of National Science Foundation (NSF) documents. | GAO-18-370

Note: For details on the twelve best practices for cost estimating, see GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, [GAO-09-3SP](#) (Washington, D.C.: March 2009).

^aThe ratings we used in this analysis are as follows: “Fully met” means there was complete evidence that satisfied the entire best practice. “Substantially met” means there was evidence that satisfied a large portion of the best practice. “Partially met” means there was evidence that satisfied about half of the best practice. “Minimally met” means there was evidence that satisfied a small portion of the best practice. “Not met” means there was no evidence provided that satisfied any of the elements of the best practice.

For example, NSF’s procedures substantially met the cost estimating best practice of conducting a risk and uncertainty analysis. According to GAO’s cost guide, because a cost estimate is a forecast, there is always a chance that the actual cost will differ from the estimate—for example, because of errors resulting from historical data inconsistencies. Recognizing the potential for error and deciding how best to quantify it are the purposes of risk and uncertainty analysis, which helps determine the amount of budget contingency needed and whether a project’s cost is realistic. In accordance with this best practice, the *Large Facilities Manual* required risk and uncertainty analysis and highly encouraged rigorous, quantitative risk management practices, such as use of probabilistic methods to estimate confidence levels for total project costs. NSF’s *Standard Operating Guidance* on standardized cost analysis also addressed the performance of risk and uncertainty analysis.

In contrast, NSF’s procedures partially met the best practice, for example, of conducting a sensitivity analysis. According to GAO’s cost guide, since uncertainty cannot be avoided, sensitivity analysis should also be used to quantify risks by examining the effects of changing one assumption or cost driver at a time while holding other variables constant.²⁶ Doing so makes it easier to understand which variables most affect the cost estimate. As called for by this best practice, the *Large Facilities Manual*

²⁶Sensitivity analysis tries to isolate the effects of changing one variable at a time, while risk or uncertainty analysis examines the effects of many variables changing all at once.

stated that a sensitivity analysis should be conducted, but it did not address how this practice should be applied. For example, it did not address what types of cost drivers, ground rules, or assumptions a sensitivity analysis should test for large facilities projects. NSF officials stated that it is up to the recipient to decide how the sensitivity analysis is performed.

An agency's procedures support the creation of reliable cost estimates when they fully or substantially meet the best practices in GAO's cost guide. NSF officials said that the agency's approach was to reference best practices in GAO's cost guide when possible and not to repeat them in NSF documents unless further agency-specific guidance was necessary. However, without policies on how to apply all relevant best practices in GAO's cost guide specifically to NSF's large facilities projects, NSF's recipients may develop cost estimates that inadvertently omit or conflict with these practices. As a result, recipients' estimates may not be reliable and the projects they manage may be at increased risk of cost growth. Conversely, NSF may award more funds than needed if costs are overestimated. Among other things, standards for internal control in the federal government direct agency management to (1) design control activities to achieve objectives and respond to risks and (2) implement control activities through policies.²⁷ Revising NSF policies to apply the best practices to large facilities projects would be consistent with these standards.

The agency's policies also did not incorporate procedures on how NSF officials are to ensure that the estimates meet relevant best practices for estimating project costs. NSF developed a standardized approach for analyzing recipients' estimates using a template that NSF calls its cost proposal review document; however, the template did not specifically address best practices in GAO's cost guide, which highlights the importance of validating the estimates.²⁸ Reviewing recipients' estimates is an internal control activity. Without establishing and implementing policies on how NSF is to conduct reviews to ensure that recipients' cost estimates meet GAO's best practices, the agency cannot provide assurance that these estimates are reliable and high quality.

²⁷Control activities are the policies, procedures, techniques, and mechanisms that enforce management's directives to achieve the entity's objectives and address related risks. See [GAO-14-704G](#).

²⁸According to GAO's cost guide, validation involves ensuring that cost estimates are comprehensive, accurate, well-documented, and credible. The guide maps its 12 best practices to these four characteristics of cost estimates. See [GAO-09-3SP](#).

Implementing such policies would be consistent with standards for internal control in the federal government.

NSF’s Procedures Minimally Met or Did Not Meet 6 of 10 Best Practices for Developing Project Schedules

The procedures documented in NSF’s policies for large facilities projects minimally met or did not meet most of the GAO schedule guide’s best practices (see table 2; app. II provides more details on the documents we reviewed and our assessment of each best practice).²⁹ NSF policy outlined in the *Large Facilities Manual* noted that recipients are to follow the best practices in GAO’s schedule guide. The American Innovation and Competitiveness Act also requires NSF to ensure that its policies for estimating and managing project schedules are consistent with the best practices in GAO’s guide.³⁰ We found that NSF’s procedures for recipients to follow substantially met one best practice—conducting a schedule risk analysis. A schedule risk analysis is a statistical simulation that can be used to predict the level of confidence in meeting a project’s completion date and to determine the schedule contingency, or reserve of time, needed to achieve a desired level of confidence. In particular, the *Large Facilities Manual* described the process for quantifying possible effects of project risks and uncertainty on schedules.

Table 2: Summary of the Extent to Which NSF’s Procedures for Large Facilities Projects Met Best Practices for Developing Project Schedules

GAO assessment of NSF procedures ^a	Best practices for developing project schedules
Fully met	NA
Substantially met	Conducting a schedule risk analysis
Partially met	Capturing all activities Assigning resources to all activities Maintaining a baseline schedule

²⁹Of the policies we reviewed that documented NSF’s procedures for large facilities projects, only NSF’s *Large Facilities Manual* and an internal *Standard Operating Guidance* document on earned value management system verification, acceptance, and surveillance addressed best practices for developing project schedules.

³⁰42 U.S.C. § 1862s-2(a)(2)(D).

GAO assessment of NSF procedures ^a	Best practices for developing project schedules
Minimally met	Sequencing all activities Verifying that the schedule can be traced horizontally and vertically Updating the schedule using actual progress and logic
Not met	Establishing the durations of all activities Confirming that the critical path is valid Ensuring reasonable total float

Legend: - = not applicable.

Source: GAO analysis of National Science Foundation (NSF) documents. | GAO-18-370

Note: For details on the ten best practices for developing project schedules, see GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, GAO-16-89G (Washington, D.C.: December 2015).

^aThe ratings we used in this analysis are as follows: “Fully met” means there was complete evidence that satisfied the entire best practice. “Substantially met” means there was evidence that satisfied a large portion of the best practice. “Partially met” means there was evidence that satisfied about half of the best practice. “Minimally met” means there was evidence that satisfied a small portion of the best practice. “Not met” means there was no evidence provided that satisfied any of the elements of the best practice.

In contrast, NSF’s procedures for recipients to follow partially met 3 of the 10 best practices for developing project schedules, minimally met 3, and did not meet 3 best practices. For example, we found that NSF’s procedures did not meet the best practice of establishing the durations of all activities because the NSF documents we reviewed did not include policy or guidance related to this practice, such as guidance on using realistic assumptions in estimating durations. According to GAO’s schedule guide, if activities are too long in duration, the schedule may not have enough detail for effectively measuring and reporting on progress. Conversely, if they are too short, the schedule may be too detailed and lead to excessive work in updating and managing many short-duration activities.

A key factor in our assessment that NSF’s procedures minimally met or did not meet many of the best practices was the absence of details on how recipients should apply the best practices to developing schedules for large facilities projects. The *Large Facilities Manual* did not have a section devoted solely to scheduling, and NSF did not define what a quality project schedule is or how schedules are to be developed and maintained. The manual contained three references to GAO’s schedule guide; however, two of the references were made in the cost analysis section, thus blurring their applicability to scheduling. One of those references stated that recipients are required to follow the best practices in GAO’s guide, “taking into consideration NSF policy and practice” as provided in the manual, and that recipients must note and explain the

rationale for any “departures” from GAO’s guide. However, it is unclear what NSF policy and practice recipients must consider relative to GAO’s schedule guide because the manual does not describe scheduling best practices in detail. In addition, it is unclear what departures from GAO’s schedule guide are acceptable. Elsewhere in the manual, NSF referred to GAO’s schedule guide as “one source of complete scheduling best practices,” implying that there are other sources that recipients can use as best practices even though the manual states that recipients are required to use GAO’s guide.³¹

An agency’s procedures support the development of reliable project schedules when they fully or substantially meet the best practices in GAO’s schedule guide. According to agency officials, NSF’s policies did not provide detailed procedures on developing project schedules partly because the agency’s no cost overrun policy had led it to focus on developing procedures for costs rather than schedules. In addition, they noted that GAO’s schedule guide was issued relatively recently,³² and that recipients are allowed to deviate from it if deviations are clearly articulated and properly justified. For example, NSF officials stated that recipients could deviate from the best practice of capturing all activities in a project’s schedule. Specifically, they said that project schedules will typically include NSF’s major oversight activities but because the recipient develops and maintains the schedules, they do not necessarily include all NSF activities.

However, without policies that describe how to apply best practices in GAO’s schedule guide specifically to NSF’s large facilities projects or what types of deviations are acceptable, NSF’s recipients may develop schedules that do not follow the practices. This could potentially result in unreliable schedules and increase the risk of schedule delays, which could, in turn, increase project costs. Further, as with policies on cost estimating, establishing policies on applying best practices in developing schedules for NSF’s large facilities projects would be consistent with standards for internal control in the federal government. NSF officials stated that clearly articulated procedures and expectations for recipients support development of reliable project schedules and that the agency had been considering inclusion of a new section on schedule

³¹As noted in GAO’s guide, other sets of scheduling best practices differ both in their recommended practices and their uses.

³²GAO’s cost guide was issued in March 2009. GAO’s schedule guide was issued in December 2015.

development in the next revision of the *Large Facilities Manual*, planned for fiscal year 2019.

As with cost estimates, NSF engages in internal control activities through its reviews of recipients' project schedules. However, the agency's policies did not incorporate procedures on how NSF officials are to ensure that schedules meet relevant best practices. We found limited policies or guidance detailing how NSF conducts its reviews to ensure that recipients' project schedules are reliable and of high quality. GAO's schedule guide notes that the government program management office is ultimately responsible for the quality of a project's schedule and that the office should ensure that the schedule is as logical and realistic as possible and can be used to reliably forecast key dates. Without establishing and implementing policies on how it is to conduct reviews to ensure that recipients' project schedules meet GAO's best practices, NSF cannot provide assurance that these schedules are reliable and high quality. Implementing such policies would be consistent with standards for internal control in the federal government.

According to NSF officials, they rely on the agency's use of external review panels at key project milestones to assess project schedules as well as reviews by NSF's internal Major Research Equipment and Facilities Construction Panel. However, the agency did not have a policy to ensure that those panels assess project schedules and determine whether the schedules meet relevant best practices described in GAO's schedule guide. For example, NSF did not have standard questions to guide the external panels' reviews of projects, known as charge questions. According to NSF officials, this was due to the varying nature of NSF's science programs and the large facilities projects within those programs. In addition, NSF's *Standard Operating Procedures* for its Major Research Equipment and Facilities Construction Panel did not address how the panel ensures that project schedules are reliable and of high quality. In response to our assessment of NSF's schedule procedures, agency officials provided several project documents as examples of schedule information and related reviews. Those documents were specific to individual projects, though, and did not represent a cohesive policy on how NSF ensures that all large facilities project schedules are

reliable and meet best practices.³³ NSF officials said that policies on conducting reviews of large facilities had been a lower priority than their more urgent need to strengthen oversight of project costs. However, agency officials said they were in the process of developing guidance to formalize how external panel reviews are conducted, and that the guidance would include sample charge questions to allow the panel to adequately address GAO criteria for project schedules, as well as costs. According to agency officials, they planned to implement such guidance in early fiscal year 2019.

Five of the Seven Projects Funded under NSF's No Cost Overrun Policy Experienced Cost or Schedule Increases since Starting Construction

Of the seven projects NSF had funded that were covered by its no cost overrun policy, five experienced cost or schedule increases since starting construction.³⁴ Two of the seven projects had both cost and schedule increases, three had only schedule increases, and two had neither cost nor schedule increases as of December 2017.

Projects with Cost and Schedule Increases

The two projects with both cost and schedule increases—the National Ecological Observatory Network and the Daniel K. Inouye Solar

³³In addition, the examples provided did not demonstrate that the external panels assessed project schedules against all relevant best practices. For example, NSF provided us the charge questions for the preliminary design review for the Large Hadron Collider High Luminosity Upgrades project (conducted in December 2017 through January 2018) and for the final design review for the Regional Class Research Vessels project (conducted in November 2016). Some of the charge questions provided to each review panel addressed the projects' schedules, but the questions did not refer to NSF's requirement that project schedules follow the best practices, nor did they address all best practices in GAO's schedule guide. For example, neither project's charge questions addressed the schedule best practice of ensuring reasonable total float—the amount of time by which an activity can slip before its delay affects the project's estimated completion date.

³⁴As previously noted, the not-to-exceed cost that the National Science Board authorized is the amount against which NSF measures cost increases to implement its no cost overrun policy. Therefore, we define cost increases since starting construction as increases to the not-to-exceed cost that the board authorized. We define schedule increases as delays in the planned or actual completion date compared to the date in the original construction award.

Telescope—were still under construction as of December 2017. NSF had approved construction award increases for these two projects totaling \$81.7 million. According to NSF officials, the cost increases for both projects were caused in part by challenges in obtaining the permits needed for construction. These permitting challenges delayed these projects' schedules, which, in turn, increased their costs. Prior to approving the cost increases, NSF also approved actions to reduce the projects' scopes, which NSF officials said resulted in total estimated cost savings of \$68.3 million.

National Ecological Observatory Network

In August 2011, NSF awarded funding to NEON, Inc., for construction of a nationwide network of ecological observation sites. The project was originally scheduled for completion in July 2016,³⁵ with a total project cost equal to the \$433.8 million not-to-exceed cost that the National Science Board authorized. However, as of December 2017, NSF had increased the total project cost and the not-to-exceed cost to \$469.3 million (an increase of \$35.5 million, or 8 percent). NSF had also delayed its scheduled completion date to November 2018 (an increase of 2.3 years, or 47 percent).

National Ecological Observatory Network

The National Science Foundation (NSF) funded the National Ecological Observatory Network to address environmental challenges and associated research questions that require ecological and environmental measurements on a regional to continental scale. Upon completion, it will comprise a network of 81 observation sites distributed across the United States, each with networked sensors linked to computational, analytical, and modeling capabilities.

Example of a Constructed Observation Tower



Source: © 2017 Battelle Memorial Institute. All rights reserved. | GAO-18-370

According to the award for the project, it will enhance researchers' ability to investigate complex ecological processes across regional, continental, and global scales, and it will help develop predictions for the effects of climate and land use change on the biosphere.

Source: GAO analysis of NSF documents. | GAO-18-370

In reviewing NSF's projects to describe their cost and schedule performance, we also collected information on actions related to the agency's no cost overrun policy. NSF's no cost overrun policy had been implemented for the National Ecological Observatory Network project as follows.

- The policy generally requires a project's scope to be reduced before the cost can be increased. Prior to increasing the National Ecological Observatory Network project's cost and schedule in 2016, NSF reduced the scope of the project in 2015. According to NSF officials, implementing these scope reductions resulted in estimated cost savings of \$62.4 million. For example, NSF reduced the number of observation sites to be constructed from 106 to 81. One effect of this action was that it eliminated the project's 6 sites that would have provided data from urban ecosystems. NSF also eliminated certain scientific instruments at the project's observation sites and removed an experimental component of the project. According to officials, these reductions did not compromise the overall science capabilities of the project.
- NSF's policy generally requires a project's budget contingency to be used to cover cost increases resulting from foreseeable risks. The National Ecological Observatory Network project had used all of its original \$69.1 million of budget contingency prior to NSF's approval of the cost increase, according to NSF officials.
- The current policy requires the NSF directorate responsible for a project, rather than NSF's MREFC account, to fund the cost increase

³⁵According to NSF officials, the project's original schedule did not include any schedule contingency because the project's schedule was initially developed before the NSF policy requiring schedule contingency was implemented.

up to an amount equal to 10 percent of the original total project cost. The cost increase for the National Ecological Observatory Network project was less than 10 percent of the original total project cost that the National Science Board authorized. Therefore, according to NSF's fiscal year 2019 budget request, NSF planned to fund the entire cost increase by transferring funds from the directorate responsible for the project.³⁶

According to NSF officials, the project's cost and schedule increases resulted from a variety of factors, including inability of the recipient to perform as well as challenges related to obtaining permits. Officials stated that NEON, Inc., was a new nonprofit organization formed specifically for the project and that its inability to perform stemmed from issues related to its business processes, project leadership and high turnover, and underestimation of the permitting challenges. These and other issues ultimately led to NSF's decision to change managing organizations for the project, and when NSF increased the project's cost in June 2016, the agency awarded a new cooperative agreement to Battelle Memorial Institute for the remainder of the construction.³⁷

In October 2017, NSF approved an additional schedule increase for the project, further delaying its completion to November 2018. According to NSF officials and the recipient's request for the extension, this further delay was due primarily to continued permitting challenges. As of December 2017, construction of the overall project was 94 percent complete, and 47 of the project's 81 observation sites were complete. In addition to permitting challenges, NSF officials said that retention of staff through the end of construction remained a key risk for the project. They also stated that the project had no remaining options to reduce its scope if needed and no remaining schedule contingency. However, the approximately \$1.1 million in budget contingency and \$1.8 million in management reserve remaining for the project together exceeded the \$0.7 million of remaining risks estimated and weighted for the probability

³⁶Of the \$35.5 million transfer amount that NSF officials said had been authorized, \$25.9 million had been transferred from the Research and Related Activities account to the MREFC account, according to NSF's fiscal year 2019 budget request, and NSF was monitoring the project to determine if any of the remaining approved transfer amount would be needed to complete the project.

³⁷According to NSF officials, Battelle Memorial Institute assumed control of NEON, Inc., under the name of Battelle Ecology Institute to facilitate the transfer and management of permits and land use agreements.

of the risks occurring.³⁸ According to NSF officials, the project was not at risk of exceeding its revised cost that the National Science Board authorized, and NSF did not foresee any further changes to the project's schedule or scope.

Daniel K. Inouye Solar Telescope

In January 2010, NSF awarded funds to the Association of Universities for Research in Astronomy, Inc., for construction of a solar observatory in Hawaii.³⁹ The project was originally scheduled for completion in December 2017, with a total project cost equal to the \$297.9 million not-to-exceed cost that the National Science Board authorized. However, in August 2013, following National Science Board authorization, NSF increased the total project cost and not-to-exceed cost to \$344.1 million (an increase of \$46.2 million, or 16 percent) and delayed its scheduled completion date. As of December 2017, NSF had delayed completion to June 2020 (an increase of 2.5 years, or 31 percent).

According to NSF officials, the cost and schedule increases resulted primarily from unforeseeable legal and administrative challenges to the required permit for construction in Hawaii, which delayed access to the site and resulted in increased legal, staff, travel, and other costs for the project. NSF officials said that these challenges were beyond the control of the recipient or NSF, and that NSF does not normally hold management reserve to fund the costs of unforeseeable events.⁴⁰ Therefore, the agency's standard practice when such events occur is to request that the National Science Board authorize an increase in the not-to-exceed cost, according to officials.

The recipient also reduced the project's scope by an estimated \$5.9 million but as part of the process of developing the revised project cost, according to NSF officials, and not because NSF required reductions under its no cost overrun policy. NSF did not require further reductions

³⁸As of December 2017, NSF retained \$1.8 million of the project's \$3.2 million of management reserves—funds available to address unforeseeable risks. Those funds were included in the revised project cost of \$469.3 million.

³⁹NSF funding for the project included an award funded by appropriations under the American Recovery and Reinvestment Act of 2009 and an award funded by NSF's MREFC account.

⁴⁰According to NSF's *Large Facilities Manual*, unforeseeable events—or “unknown unknowns”—are events that are not or cannot be identified during planning and may also include low-probability, extreme events that are beyond project control.

because the options available were not sufficient to cover the increased costs without significant negative effects or risks to the project, according to NSF officials and project documents we reviewed. Such options were not identified during design because the project's design predated the current policy's requirement to identify scope reduction options during design. In addition, according to project documentation, NSF expected most of the actions taken to reduce the project's scope to have low or no impact on its science capability, operations, technical aspects, or safety, health, and environmental aspects. Appendix III provides more details on this project, including its implementation of NSF's no cost overrun policy.

Projects with Schedule Increases

Three other projects had experienced schedule increases of approximately 1 to 3 years as of December 2017—the Alaska Region Research Vessel, the Ocean Observatories Initiative, and the Advanced Laser Interferometer Gravitational Wave Observatory. However, they had not experienced cost increases and, according to agency officials, had not reduced their scopes. Of these projects, two had already completed construction with final total project costs that were less than the original costs in the projects' construction awards.

Alaska Region Research Vessel

In August 2007, NSF awarded funding to the University of Alaska, Fairbanks, for construction of a polar research vessel later named the R/V *Sikuliaq*.⁴¹ The project was originally scheduled for completion in April 2014. However, according to NSF officials, the vessel was delivered in June 2014, and the project experienced a schedule increase of 1.9 years (29 percent) by the time it was completed in March 2016. This resulted from delayed delivery of the vessel from the shipyard to the university, according to NSF officials, because of the need to resolve various issues with the vessel's systems following tests and trials at the shipyard. NSF officials said that the delayed vessel delivery was then followed by the need for the university to complete certain trials of the vessel, such as ice trials that require specific environmental conditions in order to be scheduled. By the completion of construction, NSF had approved use of all of the project's \$31.3 million in budget contingency, according to NSF

⁴¹NSF funding for the project included an award funded by appropriations under the American Recovery and Reinvestment Act of 2009 and an award funded by NSF's MREFC account.

officials. The final total project cost at the closeout of the awards (including contingency) was \$0.9 million less than the construction awards' original total project cost of \$199.5 million, and according to project documentation, those funds were returned to NSF.

Ocean Observatories Initiative

In September 2009, NSF awarded funding to the Consortium for Ocean Leadership for construction of a globally distributed network of systems to observe the ocean.⁴² The project was originally scheduled for completion in February 2015 but had experienced a schedule increase of 1.3 years (23 percent) by the time it was completed in May 2016. According to NSF officials, this was due to both (1) a need to reschedule testing at sea of certain technology to take place during favorable weather conditions and (2) a need for required additional development and testing for the project's cyber-infrastructure and data distribution system. By the completion of construction, NSF had approved use of all of the project's \$88.1 million in budget contingency, according to NSF officials. The final total project cost at the closeout of the awards (including contingency) was \$1.2 million less than the construction awards' original total project cost of \$386.4 million, and according to project documentation, those funds were returned to NSF.

Advanced Laser Interferometer Gravitational Wave Observatory

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 but as of December 2017 had experienced a schedule increase of 3.3 years (47 percent). The project was 99 percent complete, with full completion planned for July 2018. In order to benefit from continual performance improvements being made in the computing industry, the project deferred the procurement of additional computers for data analysis for as long as possible, resulting in a schedule increase, according to NSF officials. As of December 2017, NSF had approved use of all of the \$39.1 million in budget contingency included in the construction award's total project cost of \$205.1 million, according to NSF

⁴²NSF funding for the project included an award funded by appropriations under the American Recovery and Reinvestment Act of 2009 and an award funded by NSF's MREFC account.

officials. The final total project cost will be determined at closeout of the award, which was planned for September 2018.

Projects with No Cost or Schedule Increases

The remaining two projects funded under NSF's no cost overrun policy had experienced no cost or schedule increases and no scope reductions as of December 2017—the Large Synoptic Survey Telescope under construction in Chile and the Regional Class Research Vessels under construction in Louisiana (see app. III for additional details on these projects). However, NSF changed the construction award's total project cost for the Large Synoptic Survey Telescope from \$467.8 million to \$471.2 million. We do not count this change as a cost increase because the new total project cost remained below the not-to-exceed cost of \$473.0 million that the National Science Board authorized. This anticipated change occurred in April 2015, 9 months after the original construction award in July 2014, to increase the amount of budget contingency. At the time of the original award, NSF had not yet approved the amount of budget contingency needed and expected to amend the award. The recipient updated the estimate in response to a change in NSF policy on the methodology to be used for determining budget contingency, according to NSF officials. The cost change did not increase the overall project schedule. As of December 2017, the Regional Class Research Vessels project had experienced no cost or schedule increases since NSF first awarded construction funds in July 2017.

In addition, NSF had two projects in the design phase as of December 2017 that were planned for construction as large facilities projects. These projects would involve construction of upgrades to two existing facilities that may begin in 2019 and 2020, depending on availability of funds. Appendix IV contains summaries of NSF's plans for these future projects.

Conclusions

NSF has developed policies to oversee construction of its large facilities projects, such as telescopes, observatories, and other research stations. Those policies, such as NSF's *Large Facilities Manual*, documented procedures for estimating and reviewing project costs and schedules, and we found that NSF's cost estimating procedures for recipients fully or substantially met 7 of the GAO cost guide's 12 best practices. However, NSF's procedures partially or minimally met the other 5 cost estimating best practices. Further, NSF's procedures for recipients to follow in

developing project schedules minimally met or did not meet 6 of the GAO schedule guide's 10 best practices, primarily because they did not include details on how recipients should apply those best practices to large facilities projects. According to agency officials, NSF's policies did not provide such details partly because the agency's no cost overrun policy had led it to focus on project costs rather than schedules. Further, we found that NSF's policies for its reviews of recipients' cost and schedule estimates did not incorporate procedures on how NSF officials are to ensure that the estimates meet best practices in GAO's cost and schedule guides. Policies that address use of all best practices for estimating and reviewing project costs and schedules are needed to be consistent with standards for internal control in the federal government. Without such policies, NSF cannot provide assurance that estimates for its large facilities projects meet all relevant best practices. Cost and schedule estimates that do not meet best practices may be unreliable and face increased risks of cost growth and schedule delays, while reliable estimates can provide NSF and congressional decision makers with increased confidence in the agency's investments in large facilities.

Recommendations for Executive Action

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

- The Director of NSF should revise the agency's policies for estimating the costs of large facilities projects, and for reviewing those costs, to better incorporate the best practices in GAO's cost guide. (Recommendation 1)
- The Director of NSF should revise the agency's policies for developing schedules for large facilities projects, and for reviewing those schedules, to better incorporate the best practices in GAO's schedule guide. (Recommendation 2)

Agency Comments and Our Evaluation

We provided a draft of this report to NSF for review and comment. In its comments, reproduced in appendix V, NSF agreed with our recommendations. NSF further stated in its comments that it was reassuring that our assessment found that several of NSF's procedures already reflect GAO's best practices and that NSF will continue to incorporate best practices from the GAO cost and schedule guides.

NSF also provided technical comments, which we incorporated as appropriate. In its technical comments, NSF generally agreed with our findings but disagreed with the “not met” scores we assigned to NSF’s schedule development procedures for four best practices. NSF also provided additional documents intended to help support higher scores. However, those documents generally pertained to individual projects and did not constitute agency policy. In our assessment, we determined the extent to which NSF’s procedures met best practices for cost and schedule estimates as documented in the agency’s policies—not as implemented for individual projects. We did not change the scores we assigned to NSF’s schedule development procedures, with one exception—the best practice of verifying that the schedule can be traced horizontally and vertically. For this best practice, we raised the score to “minimally met” in response to comments from NSF about how the agency’s *Standard Operating Guidance* addressed the best practice.

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) 512-3841 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 VI.



John Neumann
Director, Natural Resources and Environment

Appendix I: Objectives, Scope, and Methodology

To examine the extent to which the National Science Foundation's (NSF) procedures for estimating the construction costs and schedules of large facilities projects met best practices for developing reliable estimates, staff with cost and schedule estimating expertise from our Center for Science, Technology, and Engineering compared the procedures documented in NSF's policies with the best practices defined in GAO's cost and schedule guides.⁴³ Specifically, we reviewed the Office of Management and Budget's *Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards*;⁴⁴ internal NSF policies, including those documenting the agency's procedures for reviewing project costs and schedules (*Proposal Award Manual*, *Standard Operating Guidance* documents, and *Standard Operating Procedures* documents for NSF's Major Research Equipment and Facilities Construction Panel); and NSF's policies for the recipients of cooperative agreements or contracts for construction of large facilities projects (called recipients throughout) (*Proposal and Award Policies and Procedures Guide*, *Business Systems Review Guide*, and *Large Facilities Manual*). We also reviewed examples of project documents that NSF officials provided related to project schedules and NSF reviews of those schedules. In comparing NSF's procedures to best practices in GAO's cost and schedule guides, we used the following ratings:

- "Fully met" means there was complete evidence that satisfied the entire best practice.
- "Substantially met" means there was evidence that satisfied a large portion of the best practice.
- "Partially met" means there was evidence that satisfied about half of the best practice.

⁴³GAO's cost guide is a compilation of cost estimating best practices drawn from across industry and government. See GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, [GAO-09-3SP](#) (Washington, D.C.: March 2009). GAO's schedule guide develops the scheduling concepts introduced in our cost estimating guide and presents them as 10 best practices associated with developing and maintaining a reliable, high-quality schedule. See GAO, *Schedule Assessment Guide: Best Practices for Project Schedules*, [GAO-16-89G](#) (Washington, D.C.: December 2015).

⁴⁴2 C.F.R. pt. 200.

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- “Minimally met” means there was evidence that satisfied a small portion of the best practice.
 - “Not met” means there was no evidence provided that satisfied any of the elements of the best practice.

After conducting our initial assessments of NSF’s procedures, we shared our draft analyses with NSF officials to provide them an opportunity to comment. Based on their comments and additional information provided, we revised our draft assessments, as appropriate, to produce the final assessments. We also interviewed NSF officials from the Office of the Director and the Office of Budget, Finance, and Award Management (including the Large Facilities Office and the Cooperative Support Branch) on the agency’s procedures. We also reviewed relevant standards for internal control in the federal government.⁴⁵

To describe the construction cost and schedule performance of NSF’s large facilities projects since implementation of its no cost overrun policy, we reviewed NSF documents and interviewed agency officials to identify requirements under the policy, as well as changes to it since 2009. We analyzed documents for the seven projects NSF officials identified as covered by the policy at the time of our review: (1) the Daniel K. Inouye Solar Telescope, (2) the Large Synoptic Survey Telescope, (3) the Regional Class Research Vessels, (4) the National Ecological Observatory Network, (5) the Advanced Laser Interferometer Gravitational Wave Observatory, (6) the Ocean Observatories Initiative, and (7) the Alaska Region Research Vessel. In addition, we reviewed project documents and interviewed NSF officials for the two projects in design at the time of our review: (1) the Antarctic Infrastructure Modernization for Science and (2) the Large Hadron Collider High Luminosity Upgrade.

Our review of project documents included, for example, NSF’s cooperative agreements, cooperative support agreements, and contract documents for the projects, and we compared these agreements as of December 2017 to the original agreements. We also reviewed, as applicable, such documents as the National Science Board resolutions authorizing the projects; the recipients’ project execution plans, risk reports and risk registers, scope management or scope contingency plans, and annual or monthly project reports; NSF’s or external assessments or independent cost estimates; reviews of the recipients’

⁴⁵GAO, *Standards for Internal Control in the Federal Government*, [GAO-14-704G](#) (Washington, D.C.: September 2014).

business and accounting systems; NSF's internal management plans for projects; and project-specific information on scope reductions.

- We focused our review of project documents on the three ongoing projects for which NSF requested fiscal year 2018 construction funding: (1) the Daniel K. Inouye Solar Telescope, (2) the Large Synoptic Survey Telescope, and (3) the Regional Class Research Vessels. We also reviewed documents on the National Ecological Observatory Network, which was ongoing at the start of our work but expected to be completed in November 2018.
- We reviewed more limited cost and schedule information—such as the original and latest or final cooperative support agreements—for another ongoing project expected to be completed in July 2018 (the Advanced Laser Interferometer Gravitational Wave Observatory), and for two projects completed in 2016 (the Ocean Observatories Initiative and the Alaska Region Research Vessel).
- In addition, we reviewed available project planning documents for the two projects in design at the time of our review: (1) the Antarctic Infrastructure Modernization for Science and (2) the Large Hadron Collider Upgrades.⁴⁶

After reviewing project documents, we interviewed project officials from the responsible NSF directorates for most of the projects we reviewed,⁴⁷ as well as officials from the Office of the Director and the Large Facilities Office, to discuss the projects' (1) design or construction status, as appropriate, including upcoming milestones and remaining risks, contingency, and options for reducing scope, and (2) cost and schedule performance history, including each project's implementation of NSF's no cost overrun policy. In addition, we reviewed NSF's bimonthly *Major Facilities Status Report*, which the Large Facilities Office provides to the NSF Director, dated February 1, 2018.

In reviewing project information, we analyzed documentation to identify consistent data points across projects, such as the funding obligated to the projects, their total project costs and planned completion dates, options for reducing projects' scopes, estimated savings from scope

⁴⁶NSF's fiscal year 2018 budget request identified these projects in their sponsoring directorates' budgets under "pre-construction planning."

⁴⁷We did not interview NSF's project officials for the two completed projects (the Ocean Observatories Initiative and the Alaska Region Research Vessel) or for the Advanced Laser Interferometer Gravitational Wave Observatory, which NSF officials expected to be completed in July 2018.

reductions (if applicable), the amount of contingency remaining, and estimated potential impacts of project risks. We interviewed NSF's project officials, obtained the most recent data available at the time of our review, and reviewed data such as budget contingency and scope reduction options for projects in the context of NSF's no cost overrun policy. We assessed the reliability of these data points by conducting routine checks for consistency with other information contained in the documentation provided by NSF and clarifying any discrepancies with NSF project officials. In particular, we obtained supporting documentation for project data when possible, and we drafted preliminary assessments for each project, shared them with NSF officials, and gave these officials an opportunity to submit comments to help us identify and correct any inaccuracies. Through this process, we determined that the data points were sufficiently reliable for our purpose of describing the projects' cost and schedule performance and current status. In assessing the reliability of the data points, we did not evaluate recipients' underlying systems for tracking and measuring cost and schedule progress during construction. Evaluating these systems was outside the scope of this engagement.

We conducted this performance audit from August 2017 to June 2018 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Assessments of the National Science Foundation's Procedures for Estimating Costs and Schedules

GAO's cost and schedule guides can be used to assess an agency's cost estimating and schedule development procedures to determine whether they meet best practices for developing reliable cost and schedule estimates. Tables 3 and 4 present our assessments of the National Science Foundation's (NSF) procedures for large facilities projects against best practices in GAO's cost and schedule guides, respectively. To review NSF's procedures, we relied on the agency's *Large Facilities Manual* and certain internal *Standard Operating Guidance* policies that documented procedures for estimating costs⁴⁸ or developing project schedules.⁴⁹

We also reviewed additional documents because NSF officials stated that their project oversight follows a hierarchy of policies that includes the following documents:

- the Office of Management and Budget's *Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards*;⁵⁰
- internal NSF policies (NSF's *Proposal and Award Manual*, additional *Standard Operating Guidance* documents, and *Standard Operating Procedures* for NSF's Major Research Equipment and Facilities Construction Panel); and
- NSF's policies for recipients (NSF's *Proposal and Award Policies and Procedures Guide* and *Business Systems Review Guide*).

⁴⁸We reviewed NSF's *Standard Operating Guidance* on standardized cost analysis and earned value management system verification, acceptance, and surveillance and draft guidance on selecting independent cost estimate reviews.

⁴⁹We reviewed NSF's *Standard Operating Guidance* on earned value management system verification, acceptance, and surveillance.

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According to NSF officials, these policies pertain generally to all NSF assistance awards. We found that these policies did not address best practices for estimating costs or developing schedules.

Table 3: Details on the Extent to Which NSF's Procedures for Large Facilities Projects Met Best Practices for Cost Estimating

Best practices for cost estimating ^a	GAO assessment of NSF procedures ^b
1. Define the estimate's purpose	Minimally met. The <i>Large Facilities Manual</i> stated that recipients must follow the best practices within GAO's cost guide, but it did not specifically address the reasons why the estimate's purpose should be defined. According to GAO's cost guide, cost estimates have two general purposes: (1) to help managers evaluate affordability and performance against plans, as well as the selection of alternative systems and solutions, and (2) to support the budget process by providing estimates of the funding required.
2. Develop the estimating plan	Substantially met. An analytic approach to cost estimates typically entails a written study plan detailing a master schedule of specific tasks, responsible parties, and due dates. The <i>Large Facilities Manual</i> required the development of a cost estimating plan but did not address developing a master schedule or setting due dates for creating the estimate. It also did not address the need for sufficient time to be scheduled to collect data.
3. Define the project's characteristics	Fully met. The <i>Large Facilities Manual</i> required the development of a project execution plan that includes project characteristics such as schedule, requirements, acquisition plans, and staffing plans. It also stated that the cost estimating plan should be tailored to address all relevant stages and costs of the facility life cycle.
4. Determine the estimating structure	Partially met. The <i>Large Facilities Manual</i> required a work breakdown structure for large facilities projects. A work breakdown structure defines in detail the work necessary to accomplish a project's objectives and how the work will be done; it breaks a project into successive levels with smaller specific elements until the work is subdivided to a level suitable for management control. NSF's manual stated that work breakdown structures should include the number of levels sufficient to identify and measure project progress, but it did not require at least three levels, as the GAO best practice does. Further, the manual did not discuss the need to use standardized work breakdown structures, which could help NSF collect data necessary to support future cost estimates.
5. Identify ground rules and assumptions	Partially met. The <i>Large Facilities Manual</i> stated that recipients should explain ground rules (a common set of agreed-on estimating standards that provide guidance and minimize conflicts in definitions) and assumptions (a set of judgments about past, present, and future conditions) in several parts of the documentation for a project. However, the manual did not discuss several best practices associated with the ground rules and assumptions. For example, it did not discuss best practices that call for the ground rules and assumptions to be (1) developed by estimators with input from the technical community, (2) vetted and approved by upper management, and (3) documented to include the rationale behind the assumptions and historical data to back up any claims.
6. Obtain the data	Partially met. The <i>Large Facilities Manual</i> stated that recipients must submit the cost data used as input to software tools and project reports, known as a Cost Model Data Set, when submitting an estimate and that the data should include basis of estimate source data with clear assumptions and referenced sources. However, the manual did not provide any specific guidance on various data collection best practices identified in GAO's cost guide, such as analyzing data for cost drivers, collecting data from primary sources when possible, and fully reviewing data to understand their limitations and risks.

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Best practices for cost estimating^a	GAO assessment of NSF procedures^b
7. Develop the point estimate and compare it to an independent cost estimate	Substantially met. The <i>Large Facilities Manual</i> discussed the detailed information that should be included in the point estimate, the best guess at the cost estimate, given the underlying data. The manual also required the use of an independent cost review but did not include a requirement for an independent cost estimate. 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. An independent cost estimate would allow for a comparison to examine where and why there are differences between the cost proposed for the project and an independent cost estimate. According to NSF officials, as of December 2017 the agency was in the process of revising its <i>Standard Operating Guidance</i> on standardized cost analysis, and finalizing the guidance on selection of independent cost estimate reviews, to reflect the requirement in the American Innovation and Competitiveness Act for NSF to obtain an independent cost estimate prior to approval of construction awards for major multi-user research facility projects. ^c
8. Conduct a sensitivity analysis	Partially met. The <i>Large Facilities Manual</i> stated that a sensitivity analysis should be included in cost estimates in order to examine the effects of changing assumptions and ground rules on cost estimates, but it did not address how the analysis should be performed. For example, the manual did not address what types of cost drivers, ground rules, or assumptions a sensitivity analysis should test for large facilities projects. To implement this practice, the cost estimator must examine the effect of changing one assumption or cost driver at a time while holding all other variables constant to understand which variable most affects the cost estimate.
9. Conduct a risk and uncertainty analysis	Substantially met. The <i>Large Facilities Manual</i> required risk and uncertainty analysis of the cost estimate and encouraged rigorous probabilistic cost estimating methods to estimate confidence levels for total project cost, including the associated budget contingency. NSF's <i>Standard Operating Guidance</i> on standardized cost analysis also addressed the performance of risk and uncertainty analysis. However, neither document contained information on documenting risk analysis data, assumptions, or methodologies.
10. Document the estimate	Fully met. The <i>Large Facilities Manual</i> described the required contents of recipient proposals, including detailed information required in the cost estimating plan and construction cost book. It also discussed additional high-level information to be provided to assist with the review process. Additionally, NSF's <i>Standard Operating Guidance</i> on standardized cost analysis addressed the requirement for NSF's grants and agreements officer to maintain a cost proposal review document that records the evolving cost analysis throughout a project's design and construction.
11. Present the estimate to management for approval	Fully met. The <i>Large Facilities Manual</i> discussed the required documentation and management approval process and best practices for presenting the estimate for review.
12. Update the estimate to reflect actual costs and changes	Fully met. The <i>Large Facilities Manual</i> described how the level of detail available and estimating methods improve through the design phases and called for review of updated budgets at each review stage. Additionally, the <i>Standard Operating Guidance</i> on earned value management system verification, acceptance, and surveillance included guidance for verifying that the system provides reliable data and required the recipient to periodically develop revised estimates throughout the project life cycle.

Source: GAO analysis of National Science Foundation (NSF) documents. | GAO-18-370

^aSee GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, [GAO-09-3SP](#) (Washington, D.C.: March 2009).

^bThe ratings we used in this analysis are as follows: "Fully met" means there was complete evidence that satisfied the entire best practice. "Substantially met" means there was evidence that satisfied a large portion of the best practice. "Partially met" means there was evidence that satisfied about half of the best practice. "Minimally met" means there was evidence that satisfied a small portion of the best

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practice. "Not met" means there was no evidence provided that satisfied any of the elements of the best practice.

^cPub. L. No. 114-329, § 110(c)(1)(A)(iv), 130 Stat. 2969, 2990 (2017) (codified at 42 U.S.C. § 1862s-2(c)(1)(A)(iv)). Specifically, the act provides that the Director of NSF may not approve or execute any agreement to start construction on any proposed major multi-user research facility project unless, among other things, an independent cost estimate of the construction project has been conducted using the same detailed technical information as the project proposal estimate to determine whether the estimate is well-supported and realistic.

Table 4: Details on the Extent to Which NSF's Procedures for Large Facilities Projects Met Best Practices for Developing Project Schedules

Best practices for developing project schedules^a	GAO assessment of NSF's procedures^b
1. Capturing all activities	Partially met. The <i>Large Facilities Manual</i> required a work breakdown structure hierarchy, and NSF standard operating procedures required schedules to include major milestones. However, the standard operating procedures offered no other procedures for ensuring that activities were captured. Moreover, NSF had no policy or guidance on other activities, such as ensuring that government and subcontractor work is integrated appropriately or preserving data integrity.
2. Sequencing all activities	Minimally met. NSF's <i>Standard Operating Guidance</i> on earned value management system verification, acceptance, and surveillance included a reference to the sequencing of work and the identification of task interdependencies. However, the document did not specify aspects of sequencing activities, such as who is responsible for determining whether the sequencing is logical.
3. Assigning resources to all activities	Partially met. The <i>Large Facilities Manual</i> required the use of schedules that include resource allocations for all activities in the schedule—known as resource-loaded schedules—prior to the construction phase and stated that funding profiles at preliminary design review should be based on a resource-loaded schedule. However, the manual did not specify what level of resources should be included for each activity or what constitutes a resource. NSF had no policy or guidance on other specific aspects of assigning resources to activities, such as whether material and equipment should be included or aligning resources to the cost estimate.
4. Establishing the durations of all activities	Not met. NSF had no policy or guidance related to the estimation of activity durations in a schedule. For example, NSF had no policy or guidance on using realistic assumptions for estimating the duration of activities or who is responsible for these estimates.
5. Verifying that the schedule can be traced horizontally and vertically	Minimally met. NSF's <i>Standard Operating Guidance</i> on earned value management system verification, acceptance, and surveillance referred to the need for a schedule to identify significant task interdependencies required for the project. This implies an aspect of horizontal traceability, which GAO's schedule guide defines, in part, as a schedule that accounts for the interdependence of detailed activities. However, NSF had no explicit policy or guidance related to verifying that the schedule is traceable horizontally (i.e., products and outcomes are associated with sequenced activities) or vertically (i.e., activities are traceable among various levels of the schedule). For example, NSF had no policy or guidance on how to identify deliverables or how the dates for deliverables are negotiated.
6. Confirming that the critical path is valid	Not met. NSF had no policy or guidance related to verifying a schedule's critical path, the path of longest duration through the sequence of activities that drive the program's earliest completion date. For example, NSF had no policy or guidance on ensuring that the critical path is properly sequenced or on how management should use the critical path.

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Best practices for developing project schedules^a	GAO assessment of NSF's procedures^b
7. Ensuring reasonable total float	Not met. NSF had no policy or guidance related to determining a reasonable total float—the amount of time by which a project activity can slip before the delay affects the project's estimated finish date. For example, NSF had no policy or guidance on ensuring that these time estimates reflect the true amount of flexibility in a schedule.
8. Conducting a schedule risk analysis	Substantially met. The <i>Large Facilities Manual</i> provided detailed guidance on conducting a schedule risk analysis. For example, the manual included a description of how to derive the contingency and required a confidence level for meeting the planned finish milestone. However, the manual contained no information on documenting schedule risk analysis data, assumptions, or methodologies.
9. Updating the schedule using actual progress and logic	Minimally met. NSF's <i>Standard Operating Guidance</i> on earned value management system verification, acceptance, and surveillance included limited guidance on updating schedules periodically, but did not refer to key aspects of this best practice, such as ensuring that start and finish dates are valid, documenting changes in a schedule narrative, or conducting health checks on an updated schedule.
10. Maintaining a baseline schedule	Partially met. The <i>Large Facilities Manual</i> described the reporting requirements for schedule contingency and discussed the process for making changes to the schedule. In addition, NSF's <i>Standard Operating Guidance</i> on earned value management system verification, acceptance, and surveillance referred to a time-phased budget as the basis for performance measurement. However, NSF had no policy or guidance describing other key aspects of maintaining a baseline schedule, such as analyzing trends related to available float or documenting the schedule in a basis document.

Source: GAO analysis of National Science Foundation (NSF) documents. | GAO-18-370

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

^bThe ratings we used in this analysis are as follows: "Fully met" means there was complete evidence that satisfied the entire best practice. "Substantially met" means there was evidence that satisfied a large portion of the best practice. "Partially met" means there was evidence that satisfied about half of the best practice. "Minimally met" means there was evidence that satisfied a small portion of the best practice. "Not met" means there was no evidence provided that satisfied any of the elements of the best practice.

Appendix III: 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) five large facilities projects under construction as of December 2017: (1) the Daniel K. Inouye Solar Telescope, (2) the Large Synoptic Survey Telescope, and (3) the Regional Class Research Vessels.⁵¹

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 December 2017, such as the project's scheduled completion date for construction, including the project's schedule contingency; the type and latest amounts of the awards for construction;⁵² the responsible NSF directorate; project partners; and expected duration of operations;
- a project description, a summary of the project's current status, and information on the project's cost and schedule performance history, including any cost⁵³ or schedule⁵⁴ increases or scope reductions made under NSF's no cost overrun policy;
- a chart depicting the latest construction award's total project cost for construction, including the performance measurement baseline and budget contingency;
- if applicable, a chart showing the increase in the construction award's total project cost since the original construction award;

⁵¹This appendix does not include the National Ecological Observatory Network or the Advanced Laser Interferometer Gravitational Wave Observatory. NSF officials expected the construction stage of these projects to be completed in November 2018 and July 2018, respectively.

⁵²Costs are reported in then-year dollars, which means that NSF or the recipient converted base-year dollars by applying an inflation index. According to NSF policy, inflation is a part of NSF's budgeting and project planning.

⁵³The not-to-exceed cost that the National Science Board authorized is the amount against which NSF measures cost increases to implement its no cost overrun policy. Therefore, we define cost increases since starting construction as increases to the not-to-exceed cost that the board authorized.

⁵⁴We identified schedule increases by comparing the project's scheduled completion date in the construction award as of December 2017 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.

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- information on the implementation of NSF's no cost overrun policy for the project; and
 - information on remaining project risks and potential for cost or schedule increases, including the amount of remaining contingency and scope reduction options.⁵⁵

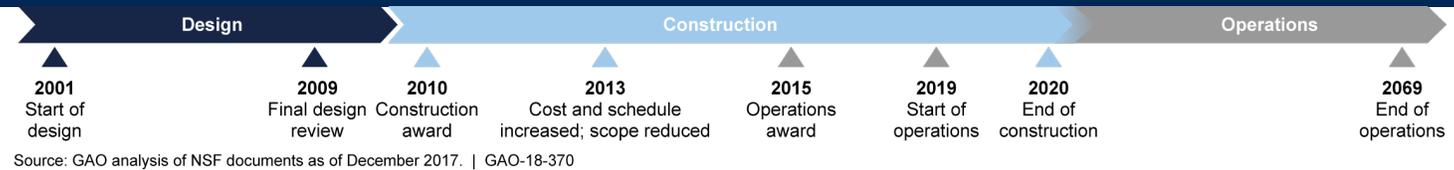
⁵⁵We report each project's estimate of remaining risk exposure as weighted by the recipients for the probability of the risks occurring. According to NSF's *Large Facilities Manual*, risk exposure is the quantitative impact of risks.



DANIEL K. INOUYE SOLAR TELESCOPE

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: Claire Rafferty/Association of Universities for Research in Astronomy, Inc./National Solar Observatory. | GAO-18-370



Project Information

Location: Maui, Hawaii.



Source: GAO. | GAO-18-370

Scheduled construction completion date:

June 2020.

Construction awards:

Cooperative support agreements for a total project cost of \$344.1 million 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: GAO analysis of NSF documents. | GAO-18-370

Project Summary

Construction of NSF’s DKIST project was 81 percent complete as of December 2017. The project was in its 8th year of construction and in the integration, testing, and commissioning phase; NSF officials anticipated the start of operations in October 2019 and completion of construction in June 2020. In October 2017, an external assessment indicated high confidence that the project would be completed within the updated total project cost and schedule that NSF approved in 2013.

As of December 2017, NSF had increased DKIST’s total project cost and not-to-exceed cost by \$46.2 million (16 percent) and delayed its scheduled completion date by 2.5 years, from December 2017 to June 2020. Prior to NSF’s approval of the cost increase in 2013, 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 legal and administrative challenges to the construction site’s environmental permits.

Construction Status of the Daniel K. Inouye Solar Telescope, as of December 2017

Percentage complete	81
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 since original construction awards	
Not-to-exceed cost that the National Science Board authorized	+\$46.2 million / cost increase
Total project cost	+\$46.2 million / cost increase
Scheduled completion date	+2.5 years / cost increase
Scope	-\$5.9 million / scope reduction

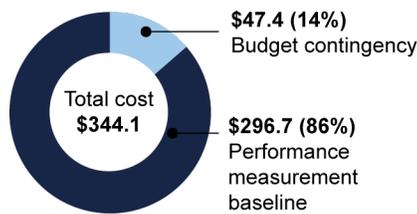
Legend: ▲ = cost or schedule increase; ▼ = scope reduction.

Source: GAO analysis of NSF documents. | GAO-18-370

^aIncludes 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.

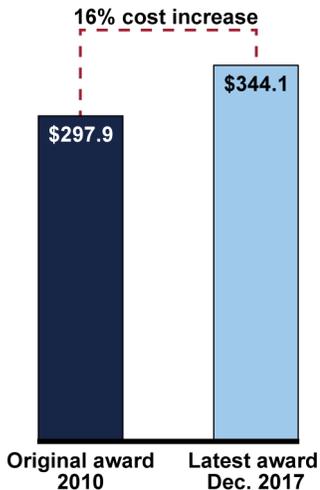
Latest Construction Award^a

Total project cost, then-year dollars in millions, as of December 2017



Increase in Construction Award^a

Total project cost, then-year dollars in millions, as of December 2017



Source: GAO analysis of NSF documents. | GAO-18-370

^aIncludes 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.

Cost and Schedule Performance History

Since starting construction, DKIST's total project cost and the not-to-exceed cost that the National Science Board authorized increased from \$297.9 million in 2010 to \$344.1 million in 2013, an increase of \$46.2 million (16 percent). The project's scheduled completion date was delayed by about 2.5 years (31 percent), from December 2017 to June 2020. According to NSF officials, the cost and schedule increases resulted primarily from environmental permitting issues. In particular, legal and administrative challenges to the required permit for building atop the summit of Haleakala delayed access to the site by approximately 2-1/2 years—from the planned date of June 2010 to November 2012.⁵⁶

According to NSF officials and project documentation, the delays resulted in increased legal, staff, travel, and other costs. For example, the delay increased staffing costs by an estimated \$15 million, according to project documentation. In addition, the project experienced cost increases estimated at \$8 million from additional requirements for several permits that had not been fully included in the project's scope, according to NSF officials, and an estimated \$1 million for certain parts that had been fabricated and had to be held in climate-controlled storage on Maui instead of being delivered to the project site.

Implementation of NSF's No Cost Overrun Policy

According to NSF officials, the DKIST cost change constituted an increase under NSF's policy because the increased amount was anticipated to exceed the not-to-exceed cost of \$297.9 million that NSF's National Science Board originally authorized. However, NSF officials noted that the cost increase was due to unforeseeable permitting delays and legal challenges that were beyond the control of the recipient or NSF. They stated that NSF does not normally hold management reserve to fund the costs of unforeseeable events.⁵⁷ Therefore, the agency's standard practice when such events occur is to request that the National Science Board authorize an increase in the not-to-exceed cost, according to officials. Because of this practice, as well as the timing of the project's design stage and cost increase, certain requirements of NSF's current no cost overrun policy did not apply to DKIST, according to NSF officials. Specifically, see the following:

- **Use of budget contingency.** NSF's policy generally requires a project's budget contingency to be used to cover cost increases resulting from foreseeable risks. However, according to agency officials, NSF considered the permitting issue that caused the cost increase to have been an unforeseeable event outside the control of

⁵⁶Haleakala is a dormant volcano on the Hawaiian island of Maui. Members of the native Hawaiian community consider Haleakala sacred. According to project documentation, a group from the local native Hawaiian community opposed the project through legal challenges against the University of Hawaii (the landowner of the site) and the state of Hawaii (the entity responsible for issuance of the Conservation District Use Permit allowing construction to proceed).

⁵⁷According to NSF's *Large Facilities Manual*, unforeseeable events—or "unknown unknowns"—are events that are not or cannot be identified during planning and may also include low-probability, extreme events that are beyond project control.

NSF or the recipient.⁵⁸ NSF officials said that as a result the DKIST project did not use its entire budget contingency to cover the cost increase.

- **Use of directorate's budget.** The current policy requires the NSF directorate responsible for a project, rather than NSF's Major Research Equipment and Facilities Construction (MREFC) account, to fund a portion of the cost increase. However, the DKIST cost increase predated the 2015 addition of this requirement to the policy. As a result, NSF officials said that the MREFC account funded all of the DKIST cost increase.
- **Identification of scope reduction options during design.** The current policy requires a project's design to include prioritized options for reducing the project's cost during construction by at least 10 percent of the baseline. However, DKIST's design predated the current policy, which did not begin requiring a project's design to include scope reduction options until 2015. As a result, the recipient had not identified options during design for reducing scope in the event of a cost increase during construction. NSF officials said that the project's plan for managing scope was instead designed primarily to prevent scope expansion, and that the recipient identified options for reducing DKIST's scope as part of the process for increasing the construction cost and schedule in 2013.
- **Scope reduction before approval of cost increase.** In addition, the policy requires a project's scope to be reduced before the cost can be increased. However, the scope reduction options available for DKIST were not sufficient to cover the increased costs without significant negative effects or risks to the project, according to NSF officials and project documents we reviewed. Therefore, the recipient took a variety of actions to reduce the scope of the project by an estimated \$5.9 million as part of developing its revised cost, according to agency officials, and not because NSF required the reductions under its no cost overrun policy. According to project documentation, NSF expected most of the 16 actions taken to have low or no impact on the project's science capability; operations; technical aspects; or safety, health, and environmental aspects.

Only one action taken was expected to have a greater impact on DKIST's science capability: a 50 percent reduction in the number of sensors for the facility's thermal systems, with an estimated cost savings of \$1.1 million. According to project documents, this action was expected to have a medium impact on both science and operations by (1) reducing the project's ability to measure environmental conditions and (2) increasing difficulty in detecting and diagnosing conditions that affect its capabilities. However, the action was also expected to reduce maintenance of the sensor array and, according to project documents, could be upgraded in the future if funds become available.

⁵⁸However, during final design review of the project, an external panel noted that there was a significant chance that the project start could be delayed by permitting issues. According to project documentation, the panel felt that this risk was not adequately captured in the analysis and recommended explicitly adding the risk of a 12-month start-up delay to the contingency. In addition, a 2016 review by NSF's Office of Inspector General reported that although NSF recognized that the permit for DKIST construction likely would be contested, the agency did not anticipate the extent of the delay.

Remaining Contingency and Scope Reduction Options

As of December 2017 with construction 81 percent complete.

Budget contingency:

\$24.9 million (exceeded the probability-weighted risk exposure of \$23.6 million).

Schedule contingency:

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

Estimated value of remaining scope reduction options:

\$1.1 million.

Source: GAO analysis of NSF documents. | GAO-18-370

Remaining Project Risks and Potential for Cost or Schedule Increases

In December 2017, an external assessment of DKIST found that the project was well positioned with respect to its risk management. According to NSF officials, as of December 2017, the project had an estimated remaining risk exposure of \$23.6 million when weighted for the risks' probability. Remaining risks included, for example, those related to project management or to the integration, testing, and commissioning phase needed to bring the facility up to full operations. Based on the project's most recent monthly report available as of December 2017 (dated October through November 2017), \$24.9 million in budget contingency remained available, exceeding the estimated risk exposure. According to the monthly report, the project also had 7.3 months of schedule contingency remaining to help avoid any potential delays in completing construction by June 2020.

According to NSF officials and project documentation, few options remained available for reducing the scope of the project if needed under NSF's no cost overrun policy. As of December 2017, the four available options totaled an estimated \$1.1 million in potential cost savings, according to NSF officials and project documentation. However, three of the four options would have medium-to-high impacts on the project's science capabilities, according to project documentation we reviewed.



Source: LSST Project Office/NSF/Association of Universities for Research in Astronomy, Inc. | GAO-18-370

LARGE SYNOPTIC SURVEY TELESCOPE

The National Science Foundation's (NSF) Large Synoptic Survey Telescope (LSST), an 8-meter, wide-field optical telescope, will 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.



Project Information

Location: Cerro Pachón, Chile.



Source: GAO. | GAO-18-370

Scheduled construction completion date:

August 2022.

Construction award:

Cooperative support agreement for a total project cost of \$471.2 million 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, Department of Energy.

Expected duration of operations:

50 years.

Source: GAO analysis of NSF documents. | GAO-18-370

Project Summary

As of December 2017, construction of NSF's LSST project was 50 percent complete and LSST was in its fourth year of construction. NSF officials anticipated making the operations award in early fiscal year 2019, completion of construction in August 2022, and full operations in October 2022. Since starting construction, LSST had experienced no cost or schedule increases and no scope reductions. As anticipated because of evolving NSF policies on calculating budget contingency, NSF changed the original total project cost of \$467.8 million to \$471.2 million. This change occurred in April 2015, 9 months after the original award. The latest total project cost remained below the not-to-exceed cost of \$473.0 million that the National Science Board authorized.

Construction Status of the Large Synoptic Survey Telescope, as of December 2017

Percentage complete	50
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	\$286.0 million ^a
Changes since original construction award	
Not-to-exceed cost that the National Science Board authorized	None
Total project cost	+\$3.4 million ^b
Scheduled completion date	None
Scope	None

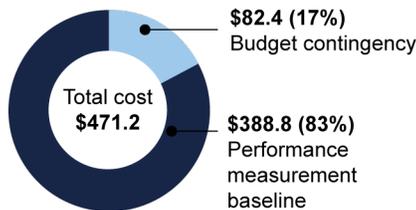
Source: GAO analysis of NSF documents. | GAO-18-370

^aExcludes fee of \$205,000 provided to the recipient to stimulate efficient performance.

^bThis 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. It did not constitute a cost increase under NSF's no cost overrun policy, according to NSF officials, because the updated cost remained below the not-to-exceed cost of \$473.0 million that the National Science Board authorized.

Latest Construction Award

Total project cost, then-year dollars in millions, as of December 2017



Note: Excludes fee of \$205,000 provided to the recipient to stimulate efficient performance.

Contributions of Project Partners

The U.S. Department of Energy (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, DOE is scheduled to deliver the camera to the LSST facility in October 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 December 2017 with construction 50 percent complete.

Budget contingency:

\$61.4 million (exceeded the probability-weighted risk exposure of \$45.8 million).

Schedule contingency:

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

Estimated value of remaining scope reduction options:

\$40 million.

Source: GAO analysis of NSF and DOE documents. | GAO-18-370

Cost and Schedule Performance History

As of December 2017, NSF had not made changes to LSST's scheduled completion date and had made no reductions in its scope. In April 2015, 9 months after the project's original construction award, NSF changed the total project cost from \$467.8 million to \$471.2 million to increase the amount of budget contingency. At the time of the original award, NSF had not yet approved the amount of budget contingency needed and expected to amend the award. The recipient updated the estimate in response to a change in NSF policy on budget contingency, according to NSF officials.

Implementation of NSF's No Cost Overrun Policy

As of December 2017, the total project cost of the LSST project had remained below the not-to-exceed cost of \$473.0 million that the National Science Board authorized. As a result, there had been no cost increase under the agency's no cost overrun policy, according to NSF officials. As of December 2017, NSF's no cost overrun policy had been implemented for the LSST project as follows.

- To implement the policy's requirement to include adequate budget contingency for all foreseeable risks, the total project cost for construction of LSST included \$82.4 million in budget contingency (21 percent of the performance measurement baseline).
- The policy also requires a project's design to include prioritized, time-phased options for reducing its scope during construction. The estimated potential cost savings of the options are to total at least 10 percent of the project's performance measurement baseline. At the time of the LSST construction award, 18 options were identified for reducing the scope of LSST during construction, valued at approximately \$46.5 million (12 percent of the project's performance measurement baseline).

Remaining Project Risks and Potential for Cost or Schedule Increases

As of December 2017, NSF officials said there was a high level of confidence that the project would be completed within its approved total project cost and schedule. According to NSF officials, the project had an estimated remaining risk exposure of \$45.8 million when weighted for the risks' probability. For example, one risk was potential damage to the telescope's mirrors. According to the project's December 2017 monthly report, \$61.4 million in budget contingency remained available, exceeding the estimated risk exposure. As of December 2017, the project had 9 months of schedule contingency remaining to help avoid any potential delays in completing construction by August 2022.

As of December 2017, 27 options were available for reducing the scope of LSST if needed under NSF's no cost overrun policy. These scope reduction options had potential cost savings estimated at \$40 million, according to NSF officials and project documentation. Documentation of these options briefly described their technical impacts. It did not rate or identify their potential effects on the science capabilities, operations, or other aspects of the project.

REGIONAL CLASS RESEARCH VESSELS



Source: Artist Rendering by Glostren. | GAO-18-370

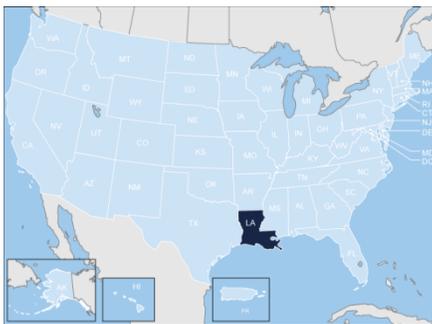
The National Science Foundation's (NSF) Regional Class Research Vessels (RCRV) project will construct two or three ships depending on funding appropriated by Congress. The 193-foot ships to be constructed will support the nation's ability to conduct fundamental scientific research in the coastal zone 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.



Source: GAO analysis of NSF documents as of December 2017. | GAO-18-370

Project Information

Location: Construction site is in Louisiana. Location of ship operations had not been determined as of December 2017.



Source: GAO. | GAO-18-370

Scheduled construction completion date:

July 2024 for three ships.

Construction award:

Cooperative support agreement for a total project cost of \$354.0 million with Oregon State University.

Responsible NSF directorate:

Geosciences.

Project partners:

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

Expected duration of operations:

30 years.

Source: GAO analysis of NSF documents. | GAO-18-370

Project Summary

As of December 2017, construction of NSF's RCRV project was 4 percent complete and the project was in its first year of construction. According to project documents, the recipient contracted with Gulf Island Shipyards, LLC, for construction of the RCRV in Louisiana. As of December 2017, NSF officials expected the actual start of physical construction of the first ship to begin in May 2018, following refinements to the design and incorporation of shipyard-specific methods. NSF officials anticipated completion of the first ship in November 2021; the second in May 2022; and the third, if funded, in March 2023.

Construction Status of the Regional Class Research Vessels, as of December 2017

Percentage complete	4 ^a
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	\$121.9 million
Changes since original construction award	
Not-to-exceed cost that the National Science Board authorized	None
Total project cost	None
Scheduled completion date	None
Scope	None

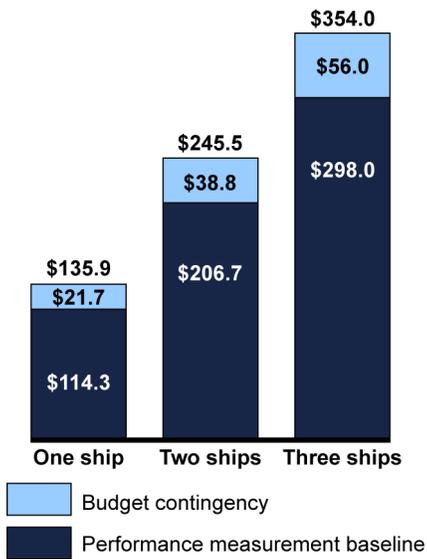
Source: GAO analysis of NSF documents. | GAO-18-370

^aPercentage complete is based on construction of three ships.

^bThe award as of December 2017 was for one ship, but with the option to build up to three ships at a total project cost of up to \$354.0 million. In March 2018, Congress appropriated \$182.8 million for NSF's Major Research Equipment and Facilities Construction account, of which \$105 million is for continuing construction on the Regional Class Research Vessels project. NSF officials said the amount was sufficient to begin construction of the second ship.

Latest Construction Award

Total project cost, then-year dollars in millions, as of December 2017



Remaining Contingency and Scope Reduction Options

As of December 2017 with construction of three ships 4 percent complete.

Budget contingency:

\$55.8 million (exceeded the probability-weighted risk exposure of \$42 million).

Schedule contingency:

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

Estimated value of remaining scope reduction options:

- \$17.0 million for one ship.
- \$32.6 million for two ships.
- \$49.5 million for three ships.

Source: GAO analysis of NSF documents. | GAO-18-370

Cost and Schedule Performance History

As of December 2017, the RCRV project had experienced no cost increases, changes to its scheduled completion date, or scope reductions. The construction award as of December 2017 was for one ship, but with the option to build up to three ships 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.

Implementation of NSF's No Cost Overrun Policy

As of December 2017, the total project cost of the RCRV project had remained below the not-to-exceed cost that the National Science Board authorized. As a result, there had been no cost increase under the agency's no cost overrun policy, according to NSF officials. NSF's no cost overrun policy had been implemented for the RCRV project as follows.

- To implement the policy's requirement to include adequate budget contingency for all foreseeable risks, the cost for constructing the RCRV project included from \$21.7 million to \$56.0 million in budget contingency (19 percent of the performance measurement baseline), depending on the number of ships built.
- The policy also requires a project's design to include prioritized, time-phased options for reducing the project's cost during construction. The estimated potential cost savings of the options are to total at least 10 percent of the project's performance measurement baseline. The June 2017 scope contingency plan for the RCRV project identified 45 prioritized, time-phased options for scope reductions. At that time, potential cost savings of these options totaled \$18.0 million for one ship, \$34.6 million for two ships, and \$52.7 million for three ships. These potential savings represented from 15 to 17 percent of the performance measurement baseline for one, two, or three ships.

Remaining Project Risks and Potential for Cost or Schedule Increases

As of December 2017, construction of the RCRV project had been under way for 5 months, and project documents indicated confidence that the project would be completed within its approved total project cost and schedule. According to NSF officials, the project had an estimated risk exposure of \$42 million when weighted for the risks' probability. The December 2017 monthly report for the RCRV project stated that one of the most significant risks was increased ship weight or changes to a ship's vertical center of gravity or stability, which could require changes to the ship's design. In addition, delays in delivery of the ships' hulls could increase Oregon State University's project management costs. As of December 2017, \$55.8 million in budget contingency remained available to address these and other potential risks. 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 RCRV project also had 44 options available for reducing its scope if needed under NSF's no cost overrun policy, with potential savings estimated at \$17.0 million for one ship, \$32.6 million for two ships, and \$49.5 million for three ships. Of these options, which had estimated values ranging from \$25,000 to \$7.8 million, 8 would result in a "significant" or "extraordinary" reduction in a major science capability, and 3 would add "significant" lifetime operational costs, according to project documentation.⁵⁹

⁵⁹According to the scope contingency plan for the project, a significant reduction in major mission capability means partial loss of capabilities for a permanently installed system, while an extraordinary reduction means loss of the system entirely. Significant added lifetime costs are \$500,000 to \$1 million.

Appendix IV: 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 December 2017, 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 December 2017, such as the expected date for completion of construction, including the project's schedule contingency; 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, if available, and the budget account NSF planned to use for construction of the project;⁶⁰
- information on the implementation of NSF's no cost overrun policy for the project; and
- information on potential project risks.

⁶⁰Costs are reported in then-year dollars, which means that NSF or the recipient converted base-year dollars by applying an inflation index. According to NSF policy, inflation is a part of NSF's budgeting and project planning.

ANTARCTIC INFRASTRUCTURE MODERNIZATION FOR SCIENCE



Source: Leidos. | GAO-18-370
 Note: Rendering of McMurdo Station's core facility.

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.



Project Information

Location: McMurdo Station, Antarctica.



Source: GAO. | GAO-18-370

Expected construction completion date:

2028.

Construction award:

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

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: GAO analysis of NSF documents. | GAO-18-370

Project Summary

As of December 2017, NSF's AIMS project was in its fourth year of design; consequently, all cost, schedule, scope, and design information for the project was subject to change. NSF officials said that they planned to conduct the final design review of the project by November 2018, 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 for funding through the responsible directorate, rather than through NSF's Major Research Equipment and Facilities Construction (MREFC) account.

Design and Construction Costs

NSF had obligated a total of \$14.8 million to the design of AIMS as of December 2017, with an additional \$0.37 million included in NSF's budget request for fiscal year 2019.

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 determined. NSF's budget request for fiscal year 2019 included \$103.7 million for construction of the AIMS project. NSF officials told us that their intent was for the project to remain within the \$355.0 million total project cost, but that the cost and scope of the project were subject to change before completion of the final design phase. The National Science Board had not yet authorized a not-to-exceed cost for construction as of December 2017. NSF officials said they planned to obtain an independent cost estimate prior to the construction award, as required by the American Innovation and Competitiveness Act, and that the estimate was expected to be completed in July 2018 by an independent, external contractor.

Development of a Capital Improvement Plan for McMurdo Station

According to NSF officials, the AIMS project will address the highest-priority deficiencies at McMurdo Station but does not address all of the needs of the United States Antarctic Program.

- In 2011, the White House Office of Science and Technology Policy and the Director of NSF convened a panel to review Antarctic infrastructure and logistics. The panel concluded that the lack of a capital investment plan, along with the effects of an extremely harsh environment, had contributed to deteriorating and inefficient infrastructure.
- In addition, NSF officials said that after the conceptual design review of the AIMS project in 2015, an NSF panel recommended developing a longer-term, ongoing capital improvement strategy to include AIMS.

Accordingly, NSF's Office of Polar Programs (within the Directorate for Geosciences) was developing a long-term capital investment plan as of December 2017 that officials said would last beyond the AIMS project to maintain and modernize Antarctic infrastructure.

Source: GAO analysis of NSF documents. | GAO-18-370

According to NSF officials, the agency planned to fund the AIMS project through the Research and Related Activities account used to fund NSF's directorates and the design of large facilities projects, rather than through the MREFC account. However, they said that the project would be expected to follow the same processes as other large facilities projects and would receive the same NSF oversight because it would meet the American Innovation and Competitiveness Act's definition of a major multiuser research facility project.⁶¹ Agency officials said that this funding decision enables NSF to initiate a capital improvement investment strategy for McMurdo Station that would extend beyond completion of the AIMS project. They also noted that the project will help contain, rather than increase, NSF's overall requirements for operations and maintenance funding for McMurdo Station.

Implementation of NSF's No Cost Overrun Policy

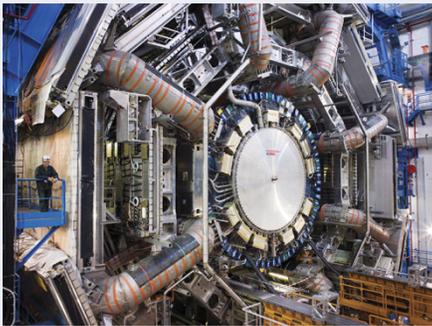
NSF policy requires a project's cost to include enough budget contingency to cover all foreseeable risks. As of December 2017, the \$355.0 million total project cost for construction included budget contingency.

NSF policy also requires 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 required 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 \$54.5 million as of December 2017; these options were subject to change. The plan included 10 options with potential cost savings ranging from \$0.8 million to \$27.6 million. The largest savings from these options would require removing upgrades to the trades and carpenter shops from the scope of the project. According to NSF officials, these options will be reevaluated and updated as the project proceeds through its final design phase.

Project Risks

Because the AIMS project is early in its detailed construction design and procurement, according to NSF officials, two key risks as of December 2017 were potential for errors and omissions in the cost estimates and changing market conditions related to labor and materials. Officials also noted that transportation to Antarctica involves unique logistics, and minor schedule slips in procuring material and equipment could translate to major schedule delays if material or equipment is not received in time to be transported on the annual resupply vessel. NSF officials stated that the project's phased construction strategy under development will reduce the risk of a supply chain delay by allowing sufficient lead time to ensure that procurements are not delayed. Further, they said that the project will also include a commercial shipping allowance to cover transport if needed. In addition, the most potentially costly risk identified in the project's most recent risk assessment, dated November 2016, was the difficulty of hiring qualified labor. According to the assessment, a healthy construction market in the United States may reduce the availability of experienced labor willing to travel for cold weather work in a remote location.

⁶¹ See 42 U.S.C. § 1862s-2(g)(2).



Source: © 2007 CERN. | GAO-18-370
 Note: photograph above depicts the A Toroidal Large Hadron Collider Apparatus detector.

LARGE HADRON COLLIDER HIGH LUMINOSITY UPGRADE

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, multiagency 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 Department of Energy is also contributing to upgrades to the LHC's accelerator and to the ATLAS and CMS detectors.



Project Information

Location: Geneva, Switzerland.



Source: GAO. | GAO-18-370

Expected construction completion date:

2026.

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 the Department of Energy.

Expected duration of operations:

10 years.

Source: GAO analysis of NSF documents. | GAO-18-370

Project Summary

As of December 2017, NSF's HL-LHC project was in its third 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. According to NSF officials, the National Science Board planned to meet in July 2018 to consider authorizing inclusion of the project in a future budget request.

Design and Construction Costs

NSF had obligated a total of \$9.2 million for the design of its detector upgrades as of December 2017, with an additional \$6.3 million included in NSF's budget request for fiscal year 2019.

NSF's total project cost for construction of the ATLAS and CMS detector upgrades will be established in July 2018, according to NSF officials, but will be subject to change before completion of the final design stage. According to agency officials, NSF planned to obtain independent cost estimates for its upgrades to each detector prior to awarding construction funds.

As of December 2017, NSF planned to fund the detector upgrades through its Major Research Equipment and Facilities Construction account. While the upgrades would involve separate cooperative agreements for the equipment for each detector, NSF considers them one project, according to agency officials.

Implementation of NSF's No Cost Overrun Policy

NSF policy requires a project's cost to include enough budget contingency to cover all foreseeable risks. The amount of budget contingency included in the construction cost for the upgrades will be determined following preliminary design review. NSF policy also requires a project's design to include prioritized, time-phased options for reducing its scope during construction if needed. According to NSF officials, identification of options for scope reductions started during the design phase of the project. For example, they said that one preliminary option being considered is a potential simplification of the detector design.

Project Risks

NSF officials said they would assess potential risks following the preliminary design reviews. They noted that they expected a preliminary risk management plan and risk register with these reviews to support the budget contingency and the total project cost to be discussed at the National Science Board's meeting in July 2018.

Appendix V: Comments from the National Science Foundation



National Science Foundation
Office of the Director

May 10, 2018

John Neumann
Director
Natural Resources and Environment
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 GAO draft report, *National Science Foundation: Revised Policies on Developing Costs and Schedules Could Improve Estimates for Large Facilities (GAO-18-370)*. This assessment provides NSF with a valuable independent perspective on our oversight of large facility design and construction.

Large facilities comprise a significant portion of NSF's research portfolio. The agency's investment in scientific research facilities has been critical to the progress of science. For example, the NSF-funded Laser Interferometer Gravitational-Wave Observatory (LIGO) was key to the Nobel Prize in Physics that was awarded in 2017 to three NSF-funded scientists.

Full lifecycle oversight of facilities helps to maintain the health of the research enterprise. To ensure oversight and accountability of the entire facilities portfolio, NSF created a senior-level position: the Chief Officer for Research Facilities.

It is reassuring that your assessment of NSF's policies found that several of NSF's procedures already reflect GAO's best practices. NSF agrees with your recommendations and will continue to incorporate best practices of the GAO cost and schedule guides.

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,

A handwritten signature in black ink, appearing to read 'France A. Córdoba'.

France A. Córdoba
Director

2415 Eisenhower Avenue, Suite 19100 Alexandria, VA 22314

Appendix VI: GAO Contact and Staff Acknowledgments

GAO Contact

John Neumann, (202) 512-3841 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, Jason T. Lee, Krista Mantsch, Patricia Moye, Holly Sasso, Sheryl Stein, and Sara Sullivan made key contributions to this report.

Appendix VII: Accessible data

Agency Comment Letter

Appendix V: Comments from the National Science Foundation

May 10, 2018

John Neumann Director

Natural Resources and Environment

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 GAO draft report, National Science Foundation: Revised Policies on Developing Costs and Schedules Could Improve Estimates for Large Facilities (GAO-18-370). This assessment provides NSF with a valuable independent perspective on our oversight of large facility design and construction.

Large facilities comprise a significant portion of NSF's research portfolio. The agency's investment in scientific research facilities has been critical to the progress of science. For example, the NSF-funded Laser Interferometer Gravitational-Wave Observatory (LIGO) was key to the Nobel Prize in Physics that was awarded in 2017 to three NSF-funded scientists.

Full lifecycle oversight of facilities helps to maintain the health of the research enterprise. To ensure oversight and accountability of the entire facilities portfolio, NSF created a senior-level position: the Chief Officer for Research Facilities.

It is reassuring that your assessment of NSF's policies found that several of NSF's procedures already reflect GAO's best practices. NSF agrees

with your recommendations and will continue to incorporate best practices of the GAO cost and schedule guides.

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 Cordova

Director

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