INDEPENDENT COST REVIEW OF THE LONG BASELINE NEUTRINO FACILITY/ DEEP UNDERGROUND NEUTRINO EXPERIMENT PROJECT AT FERMI NATIONAL ACCELERATOR LABORATORY

REVISED CRITICAL DECISION 1 (CD-1R), APPROVE ALTERNATIVE SELECTION AND COST RANGE

U.S. DEPARTMENT OF ENERGY

OFFICE

OF

PROJECT MANAGEMENT OVERSIGHT AND ASSESSMENTS

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Independent Cost Review of the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment Project at Fermi National Accelerator Laboratory

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Executive Summary

In 2009, the Long Baseline Neutrino Experiment (LBNE) was envisioned as a joint project of the U.S. Department of Energy (DOE) and National Science Foundation (NSF). NSF would provide the Deep Underground Science and Engineering Laboratory (DUSEL) in the Homestake Mine in Lead, SD, as a site for the DOE LBNE remote detector. DOE would also provide the neutrino beam in addition to the detector. DOE approved CD-0 in January 2010, but the National Science Board terminated the DUSEL project in December 2010 because it believed the facility was too large an undertaking for NSF.

In March 2012, the Director of the DOE Office of Science asked the Director of the Fermi National Accelerator Laboratory (FNAL) to lead the development of an affordable and phased approach to LBNE based on alternate configurations that would enable important science at reduced scope and cost. This reconfiguration of LBNE was the basis for DOE approval of Critical Decision (CD) 1, Approve Alternative Selection and Cost Range, in December 2012 with an estimated cost range of $805 million to $1.110 billion.

In May 2014, the new national strategic plan for U.S. particle physics recommended "a change in approach,"[1] which reformed the project under the auspices of a new international collaboration. It became an internationally coordinated and funded program, with Fermilab as host and international participation in defining the program's science and capabilities. This resulted in the original LBNE project being reconfigured as a single project comprised of the Long Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE). The project comprises two subprojects: (1) LBNF, a DOE project with an international

[1] Particle Physics Project Prioritization Panel, *Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context* May 2014.

contribution, and (2) the international DUNE project, managed by the DUNE collaboration, primarily supported by multiple international partners but including a DOE contribution.

An independent cost review (ICR) team from the Office of Project Management Oversight and Assessments (PMOA) reviewed the estimated cost and schedule for this project, in accordance with the requirements for CD-1.[2] This review supports a revised CD-1 (CD-1R) for the LBNF/DUNE project and differs from the original CD-1 for the LBNE project as follows:

- The original CD-1 project included construction of a neutrino beamline at FNAL and a 10-kiloton liquid argon (LAr) near-surface detector at the Sanford Underground Research Facility (SURF). The current project includes a neutrino beamline and near detector at FNAL and a 40-kiloton LAr detector deep underground at SURF.

- The original project utilized a 30-year experiment life while the current project uses a 20-year life.

- The original LBNE project was formulated primarily as a domestically funded project. The LBNF/DUNE project contains a substantial international contribution.

- The original project was based on a final beam power of 700 kW. The current project is planned to handle beam power ranging from 700kW to 2.4 MW beam power.

This revised CD-1 ICR includes the DOE-funded portions of the project only. The project team developed a $1.457 billion point estimate with a cost range of $1.255 billion to $1.727 billion. This cost estimate reflects an Association for the Advancement of Cost Engineering International (AACEI) Class 3 estimate with a 10 to 40 percent degree of project definition. The project spent $107 million to date, leaving to-go costs of $1.35 billion based on the point estimate. The contingency on estimated work to complete is $344 million of the $1.457 billion total project cost estimate (34 percent). This cost range applies to the DOE contribution to both the LBNF and DUNE components and does not include the international contributions to both projects.

The project will have a phased CD-4 (CD-4a and a final CD-4). The preliminary project CD-4a date is the first quarter FY23, which represents the completion of cavern excavation and supporting utilities at the far site and includes 24 months of schedule contingency. The preliminary project CD-4 (final) date, including attainment of all key performance parameters, is fourth quarter FY29 and includes 31 months of schedule contingency.

[2] DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, November 29, 2010.

The ICR team examined project-specific documentation supporting the cost estimate and schedule ranges, including the conceptual design report, bases of estimate (BOEs), project execution plan, mission need statement, alternative selection analysis, detailed resource schedules, and risk management plan. The team drilled down into the major work breakdown structure (WBS) elements, which amounted to $709 million in work, or 64 percent of the total project cost.

The project cost estimate and supporting documentation are excellent. In general, the estimate is based on bottom-up techniques, historical data, vendor/subcontractor quotes, preliminary drawings, and level of effort based on staffing plans. The project is fortunate to be able to draw on Fermilab experience, using cost information from previously built systems and structures, as well as the previously approved LBNE project. Overall, the project team's cost estimating effort meets U.S. Government Accountability Office requirements and meets all four requirements for being comprehensive, well-documented, accurate, and credible.

The project team's $1.255 billion to $1.727 billion cost range is based on a selected estimate accuracy range of minus 15 percent to plus 20 percent for a Class 3 estimate under AACEI guidelines. However, due to the project complexity, extended duration, and dependency on international partners to deliver contributions on schedule, the ICR team recommends expanding the upper end of the range to AACEI's maximum of 30 percent, which expands the cost range from $1.255 billion to $1.862 billion.

Based upon our review, PMOA endorses the project's readiness for CD-1 approval with a recommended cost estimate range of $1.255 billion to $1.862 billion. The ICR team found the project team well prepared with a solid cost estimating process in place. The organization and details available in the cost book and associated bases of estimate were very advanced for this early project stage. Project cost and schedule contingency, estimate quality, assumptions, and risks are all reasonable and well documented.

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Section 1
Introduction

1.1 PURPOSE

This report contains an independent review of the proposed cost and schedule ranges for the Long Baseline Neutrino Facility (LBNF)/Deep Underground Neutrino Experiment (DUNE) project at Fermi National Accelerator Laboratory (FNAL), in accordance with the requirements for Critical Decision (CD) 1, Approve Alternate Selection and Cost Range.[1] This review examines the project cost range and process in support of a revised CD-1 to give confidence to the Project Management Executive (PME) and senior DOE leadership that they are reasonable. The report also highlights scope changes between this project and the original Long Baseline Neutrino Experiment (LBNE) project, which obtained CD-1 approval in December 2012,

1.2 PROJECT BACKGROUND

In 2009, the LBNE was envisioned as a joint U.S. Department of Energy (DOE)–National Science Foundation (NSF) project. The NSF would provide the Deep Underground Science and Engineering Laboratory (DUSEL) in the Homestake Mine in Lead, SD, as a site for the LBNE remote detector. In January 2010, DOE approved CD-0, but the National Science Board terminated the project in December 2010 because it believed this facility was too large an undertaking for NSF.

In March 2012, the Director of the DOE Office of Science asked the Director of Fermilab to lead the development of an affordable and phased approach to LBNE based on alternate configurations that would enable important science at reduced scope and cost. The selected alternative included a reduced mass detector, not sited underground, and eliminated the smaller detector at Fermilab for monitoring the neutrino beam near its source.

The LBNE project was formed primarily as a domestically funded effort, having a minimal CD-1 configuration of a 10-kiloton far detector on the surface, about 1,300 km from the near site. LBNE was tailored to allow for enhancement of scientific capabilities and additional scope (such as a near neutrino detector and a far detector underground with additional mass) should opportunities attract the support of other domestic and international agencies. This reconfiguration was the

[1] U.S. Department of Energy (DOE) Order (O) 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, November 29, 2010.

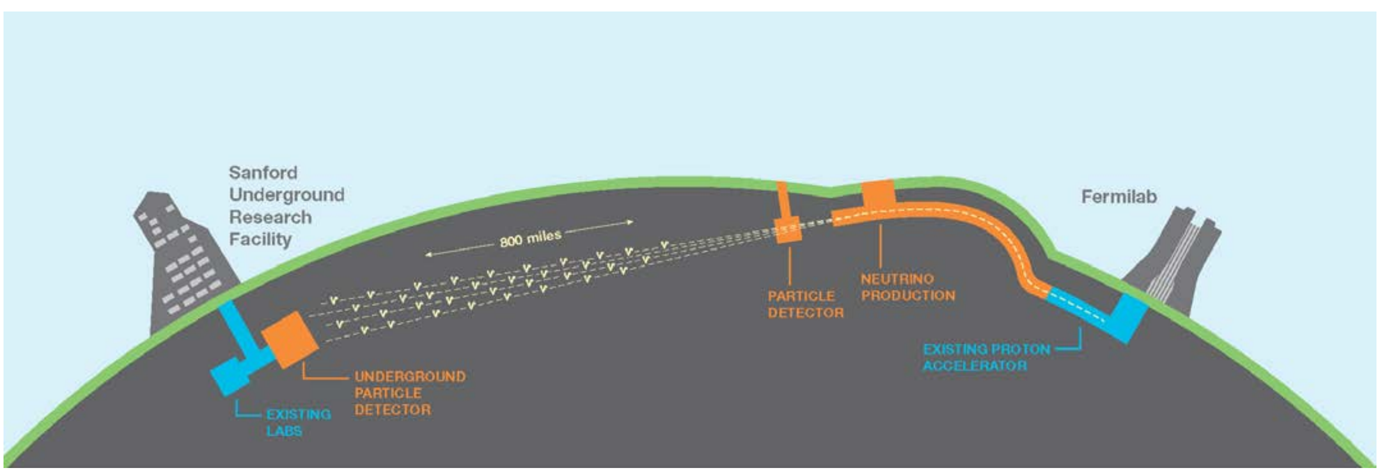
basis for DOE approval of CD-1 in December 2012 with a DOE cost range of $805 million to $1.110 billion.

In May 2014, the new national strategic plan for U.S. particle physics—developed by the Particle Physics Project Prioritization Panel (P5) and approved by the High Energy Physics Advisory Panel—recommended "a change in approach" for the LBNE project.[2] The project reformed as an internationally coordinated and funded program under the auspices of a new international collaboration. Fermilab hosts and international participation defines the science and capabilities.

The LBNF and DUNE became a single project with two subprojects: (1) LBNF, a DOE project with an international contribution, and (2) the international DUNE project, managed by the DUNE collaboration and primarily supported by multiple international partners, with a contribution by DOE. The DUNE collaboration brings together a global neutrino community to pursue an accelerator-based, long-baseline neutrino experiment, as well as neutrino astrophysics and nucleon decay, with a large liquid argon (LAr) detector deep underground at the Sanford Underground Research Facility (SURF) and a high-resolution near detector at FNAL.

LBNF/DUNE refers to this new vision of the project. In the DOE system, it is defined as a single project. The LBNF/DUNE project scope includes construction of facilities at two locations, the FNAL site in Batavia, IL, and the SURF site (on the former Homestake Mine property) in Lead, SD. LBNF/DUNE's scope is to build an intense neutrino beam originating at FNAL aimed at a large neutrino detector located underground at the far detector site (Figure 1-1).

Figure 1-1. LBNF/DUNE Project



[2] P5, *Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context*, May 2014.

The LBNF main scope elements at the FNAL site (the “near site”) include the following:

- Conventional facilities and excavation to support the technical components of the primary proton beam, neutrino beam, and near neutrino detector
- Magnets and support equipment to transport the primary proton beam to the neutrino target hall (which may include an international contribution)
- Target and magnetic focusing horns to direct pions and kaons into a decay tunnel (which may include an international contribution)
- A decay tunnel where the pions and kaons decay into neutrinos
- A beam absorber at the end of the decay tunnel.

The LBNF main scope elements at the SURF site (the “far site”) include the following:

- Conventional facilities and excavation at SURF to house and support the technical components of the far detector
- Cryogenic infrastructure required for underground installation and operation of the far detector (which includes an international contribution).

The DUNE main scope elements on the FNAL near site include the near neutrino detector and Muon detectors to monitor the beam downstream of the absorber (which includes a DOE contribution).

The DUNE main scope element at the SURF far site includes the far detector (LAr time projection chamber), implemented as four separate 10-kiloton modules (which includes a DOE contribution).

Table 1-1 shows the proposed project key performance parameters (KPPs) as identified in the Preliminary Project Execution Plan (PPEP).

Table 1-1. LBNF/DUNE KPPs

Subproject	Scope	Threshold KPP	Objective KPP
LBNF	Primary beam to produce neutrinos directed to the far detector	Beamline hardware commissioning complete and demonstration of protons delivered to the target	System enhancements to maximize neutrino flux, enable tunability in neutrino energy spectrum, or improve neutrino beam capability
	Far site conventional facilities (FSCF)	Caverns excavated for the 4×10 fiducial kiloton detector modules; a beneficial occupancy granted for the first and second caverns	Beneficial occupancy granted for the third and fourth caverns
	Cryogenic infrastructure	DOE-provided components for cryogenic subsystems installed and pressure tested for 2×10 fiducial kiloton detector modules	Additional DOE contributions to cryogenic subsystems installed and pressure tested for additional 2×10 fiducial kiloton detector modules; DOE contributions to cryostats
DUNE—US	Long-baseline distance between neutrino source and far detector	1,000 to 1,500 kilometers	
	Far detector	DOE-provided components installed in cryostats to support 2×10 fiducial kiloton detector modules, with cosmic ray interactions detected in each	Additional DOE contributions to support up to 4×10 fiducial kiloton detector modules

[a] A “fiducial” volume is the interior volume of the detection medium (LAr), which excludes the most external portion of the detection medium where most background events would occur.

1.3 SCOPE AND LIMITS

This report focuses on the proposed cost range, schedule, and risks for the LBNF/DUNE project represented by the scope described in Subsection 1.2 and in accordance with the KPPs in Table 1-1. It is limited to a review for reasonableness of the cost and schedule information provided by the project team. The report also briefly addresses the results of the previously conducted analysis of alternatives and assesses the cost estimating and scheduling processes employed by the project team relative to best practices identified by the U.S. Government Accountability Office (GAO).[3] Appendix A contains professional information on the report authors. Appendix B details the ICR team assessment of whether the project team followed GAO best practices for cost estimating.

[3] GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, GAO-09-3SP, March 2009.

Section 2

Review Approach

2.1 OVERVIEW

The ICR team reviewed documentation received from the project team, including the cost and schedule estimates, bases of estimate (BOEs) and assumptions, work breakdown structure (WBS), risk analysis, and other CD-1 documents. All project documentation was placed on a FNAL website and continually updated during the ICR process. The ICR team found the documentation adequate for the ICR.

A review meeting was held in FNAL offices in Batavia, IL, on July 7–8, 2015. During the meeting, the project staff briefed the ICR team on all cost and schedule aspects of the project, with particular attention to how estimates were derived and the changes made since the original LBNE project. The briefings focused on preselected WBS drilldown areas that constitute the majority of the total project cost (TPC). After the on-site review, the ICR team further analyzed the information and documentation, and drafted this ICR report.

2.2 METHOD

The project team provided sufficient information for an ICR. Specifically, 130 BOEs explain the assumptions and resources the project team used to create the cost and schedule estimates. This ICR focuses on project cost and schedule. Its principal lines of inquiry are as follows:

1. Estimate methods and approach

    - Assess the method of estimation and the strengths and weaknesses of the estimates for the alternatives considered. Ensure they follow GAO best practices in cost estimating.
    - Verify that ground rules and assumptions (GR&As) are clearly identified, including those related to programmatic, technical, cost, and schedule basis and economic factors.
    - Verify that the GR&As do not impose biases on future alternative selection.

- Verify that credible, applicable tools and benchmarks, including historical data, have been used to develop the cost and schedule estimates, including best practices such as those identified in the GAO Cost Estimating and Assessment Guide.

2. Cost range and schedule basis

   - Identify and assess the basis for, and reasonableness of, key programmatic, economic, and project cost assumptions as related to the quality of the estimates for the alternatives considered.

   - Identify whether the estimated costs for the project are reasonable based on professional expertise, parametric estimates, historical data, etc.

   - Assess the basis for escalation.

   - Verify that life-cycle costs (LCCs) have been considered.

3. Risk uncertainty analysis

   - Verify that reasonable and credible risks and uncertainties have been identified and documented.

   - Verify that a reasonable risk assessment has been conducted using qualitative and/or quantitative risk assessment methodologies.

   - If new technology or technology applied in a new application is identified, verify that associated risks have been identified and quantified.

4. Mission and functional requirements

   - Verify that appropriate inputs from the requirements are used for the cost and schedule ranges.

   - Verify that a mission need date (CD-4) and a path to achieve it have been clearly identified.

5. Alternatives considered. Verify that appropriate alternatives were considered to ensure that the breadth and depth of possible solutions are encompassed in the cost and schedule range.

Section 3

Project Team Estimates

3.1 Cost Estimate and Range

This subsection identifies the project team's TPC and range estimate, as well as the LCC for the LBNF/DUNE project. It discusses the approach the project team used to prepare its estimates.

3.1.1 TPC Estimate and Range

The CD-1 cost range for the LBNF/DUNE project is $1.255 billion to $1.727 billion, with a TPC estimate of $1.457 billion using an FY15 base year. The TPC estimate, around which the cost range was developed, includes all direct, indirect, and contingency project costs and is fully escalated. This cost range only applies to the DOE contribution for both the LBNF and DUNE components. It does not include the international contributions to both projects.

This product reflects an AACE International Class 3 estimate with a 10–40 percent degree of project definition. The project has spent $107 million to date, leaving to-go costs of $1.350 billion based on the point estimate. The contingency on estimated work to complete is $344 million of the $1.457 billion TPC estimate (or 34 percent of the base work-to-go). Table 3-1 shows a summary of the TPC.

Table 3-1. LBNF/DUNE TPC

	Estimated Costs through FY15 K $	Base Cost Beyond FY15 K $	Est. Uncertainty Contingency K $ "to-go" costs	TPC K $	% Contingency "to-go" costs	TPC "to-go" K $
Project Office - LBNF	**$18,373**	**$95,355**	**$9,799**	**$123,527**	**10%**	**$105,154**
Far Site - SURF	**$24,282**	**$405,974**	**$111,632**	**$541,887**	**27%**	**$517,606**
Far Site CF	$13,848	$298,095	$81,739	$393,681	27%	$379,833
Cryogenics Infrastructure	$10,434	$107,879	$29,893	$148,206	28%	$137,772
Near Site - FNAL	**$25,104**	**$390,315**	**$105,419**	**$520,838**	**27%**	**$495,734**
Near Site CF	$8,115	$270,597	$68,995	$347,706	25%	$339,591
Beamline	$16,989	$119,719	$36,424	$173,131	30%	$156,143
LBNF Total	**$67,758**	**$891,644**	**$226,850**	**$1,186,252**	**25%**	**$1,118,494**
Project Office - DUNE	**$445**	**$28,773**	**$2,922**	**$32,140**	**10%**	**$31,695**
Far Detector	**$20,775**	**$70,238**	**$25,888**	**$116,901**	**37%**	**$96,126**
NDS Near Detector Systems	**$7,888**	**$14,508**	**$4,736**	**$27,132**	**33%**	**$19,244**
Water Cherenkov Detector	**$10,537**			**$10,537**		
DUNE Total	**$39,644**	**$113,519**	**$33,546**	**$186,709**	**30%**	**$147,065**
Top Down Contingency			**$84,039**	**$84,039**	**8%**	**$84,039**
LBNF-DUNE Total	**$107,403**	**$1,005,163**	**$344,435**	**$1,457,000**	**34%**	**$1,349,598**

For the DOE-funded portion of the project, each DOE laboratory budget office determines the labor and materials and supplies (M&S) escalation. The annual escalation on labor is 3 percent, while M&S are assigned a 1.9 percent annual escalation rate.

According to the project team, the maturity of the project design work averages between 20 and 50 percent complete, which is based on the following:

- Designs for conventional facilities follow relatively standard engineering designs and use outside engineering firms that also provide cost and schedule estimates.
- Specialized beamline equipment and systems are largely designed by laboratory scientists and engineers based on experience and similar designs—particularly from Neutrinos at the Main Injector (NuMI)—and engineering standards.
- Technical systems such as the cryogenic infrastructure are designed initially by laboratory engineers and scientists with experience on similar systems, according to laboratory and industry standards, and then may be contracted to industry for final design prior to fabrication.
- Detector equipment and systems have largely been designed by laboratory or university engineers and scientists, using prototyping or similar experiment experience.

Figures 3-1 and 3-2 show the project team’s assessment of the quality of the current TPC estimate.

Figure 3-1. LBNF Quality of Estimate ($000)

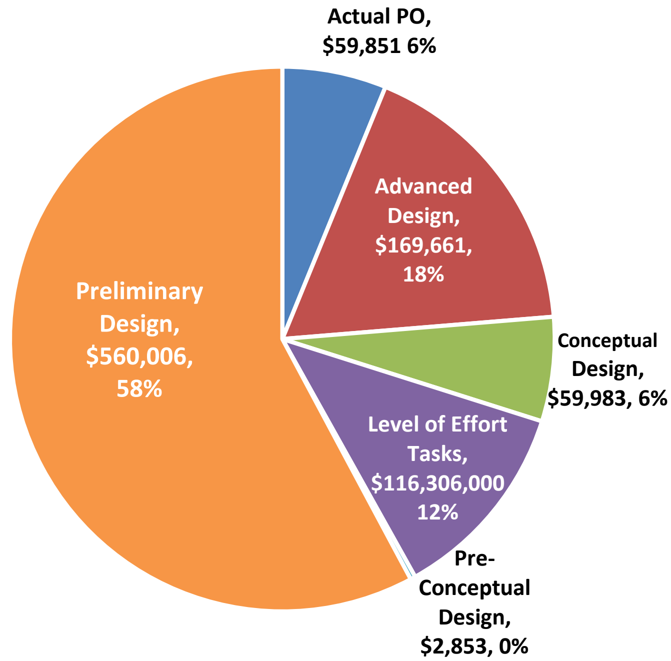
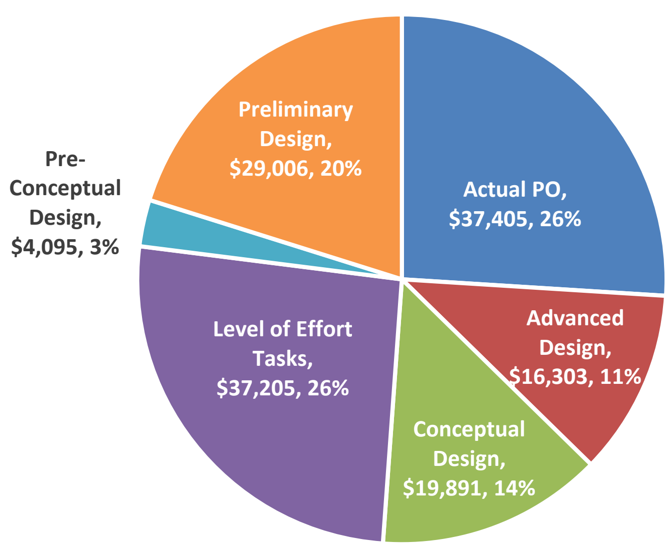


Figure 3-2. DUNE Quality of Estimate ($000)



<u>Cost Range.</u> Based on the degree of project definition and maturity, the project team classifies its TPC as a Class 3 estimate according to AACE International guidelines. The range of expected accuracy for a Class 3 estimate is –20 to +30

percent (Appendix C). The project team determined a cost range from –15 to +20 percent of to-go costs, plus costs expended to date (Table 3-2).

Table 3-2. LBNF/DUNE Cost Range

Item	Cost ($ million)
Estimated actuals through FY15	107
TPC-to-go (estimate to complete + contingency)	1,350
TPC	1,457
Low range (–15% on TPC-to-go)	1,255
High range (+20% on TPC-to-go)	1,727

Changes since last CD-1. The significant changes between the original CD-1 review (LBNE project) and the current revised CD-1 (LBNF/DUNE project) are as follows:

- The original CD-1 project included construction of a neutrino beamline at FNAL and a 10-kiloton LAr near-surface detector at SURF. The current project includes a neutrino beamline and near detector at FNAL and a 40-kiloton LAr detector deep underground at SURF.
- The original project utilized a 30-year experiment life while the current project uses a 20-year life.
- The original LBNE project was formulated primarily as a domestically funded project. The LBNF/DUNE project contains a substantial international contribution.
- The original project was based on a beam power of 700 kW. The current project is based on 1.2 MW beam power.
- A new, near site neutrino detector is included in the current project.
- Better mining costs are used.
- Deep foundations are omitted.
- Higher costs are used for custom shielding on the target hall shield pile due to a longer target path and wider chase.
- Several elements included in the original CD-1 review are now classified as non-DOE work, including magnet dipoles and correctors, horns, and support structures.

3.1.2 Life-Cycle Cost

The DOE LBNF/DUNE TPC has a CD-1 point estimate of $1.457 billion, including escalation. The experiment and far site facility are assumed to operate for 20 years with a fully complete far detector in 2027, after which the far detector is decommissioned.

The operations at each site are assumed to be incremental to the existing operations of facilities or experiments. The overall increase in operations costs at both FNAL and SURF would be $494 million for 20 years of running. The detector and facilities at SURF would cost $173 million to operate for 20 years, but the international DUNE collaboration will support the detector operations cost, which will be funded through a common fund supported by all of the international partners that contributed to detector construction. DUNE detector maintenance and operations cost estimates will be refined as design matures, and individual partner contributions will be defined as the international and common fund agreements are established.

The LBNF beamline will not be decommissioned or demolished upon conclusion of the experiment; other experiments are assumed to use this facility at that time. Far detector decommissioning and demolition (D&D) at SURF would occur in FY47–48 and include removal of detector components and restoring the surface. This is estimated to cost $75 million in FY15 dollars.

Table 3-3 shows a comparison of LCCs between the original LBNE project and the current LBNF/DUNE project.

Table 3-3. Life-Cycle Cost Comparison ($ million)

Project	Construction	Operations	D&D	LCC
LBNE	867	321	61	1,250
LBNF/DUNE	1,457	494	75	2,025

3.2 Schedule Range

The project will have a phased CD-4, as described in the tailoring strategy below. The preliminary project CD-4a date, representing the completion of cavern excavation and supporting utilities at the far site, is first quarter FY23, which includes 24 months of schedule contingency. The preliminary project CD-4 date, representing attainment of all KPPs, is fourth quarter FY29 and includes 31 months of schedule contingency. Figure 3-3 shows a preliminary summary project schedule.

Figure 3-3. LBNF/DUNE Project Schedule

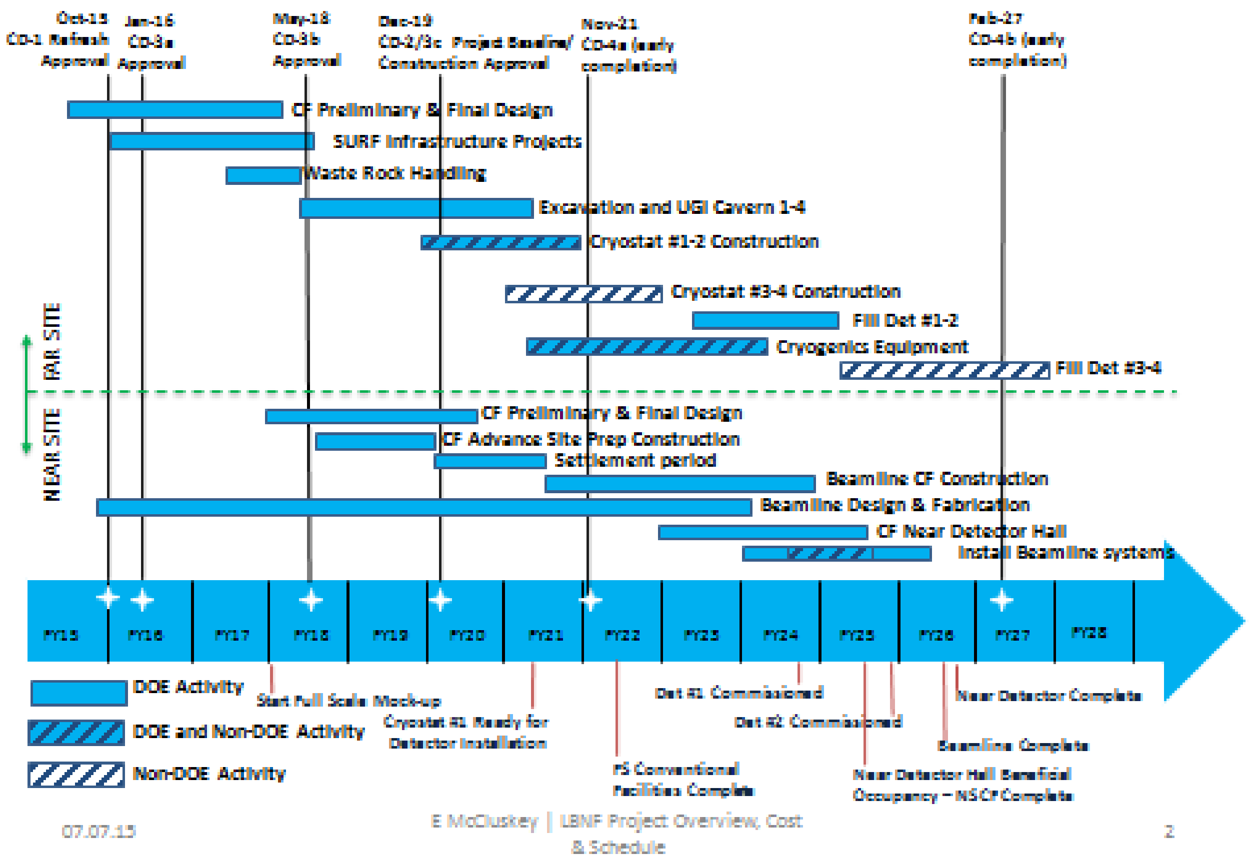


Table 3-4 shows the project execution plan (PEP) milestone schedule.

Table 3-4. Project Milestones

Milestone	Date
CD-0, Approve Mission Need	1/8/2010 (actual)
CD-1, Approve Alternative Selection and Cost Range	12/10/2012 (actual)
CD-1, Approve Alternative Selection and Cost Range (update)	1Q FY16
CD-3a, Approve LLP[a]	2Q FY16
CD-3b, Approve LLP[b]	3Q FY18
CD-2, Approve Performance Baseline	1Q FY20
CD-3c, Approve Start of Construction[c]	1Q FY20
CD-4a, Approve Completion, Far Site Caverns[d]	1Q FY23
CD-4 , Approve Project Completion	4Q FY29

Table 3-4. Project Milestones

Milestone	Date

Note: Q = quarter; LLP = long-lead procurement.

a CD-3a LLP is for the critical path LBNF FSCF and cryogenic infrastructure to mitigate risks and minimize delay in providing a facility ready to accept detectors for installation.

b CD-3b LLP is for critical path LBNF near site advanced site preparation to build an embankment that requires 1 year of settling before beamline conventional facilities work proceeds; it may include some far site cryogenic infrastructure.

c CD-2/3c is to baseline LBNF/DUNE and construction approval for the balance of LBNF and full DUNE scope.

d CD-4a is for the completion of the FSCF, meeting the threshold KPP for four caverns excavated.

Section 4
Findings

4.1 Overview

This section provides the principal findings of the ICR team. It contains an independent evaluation and assessment of (1) the summary results from the project team's alternatives analysis, (2) the risk and contingency analysis, (3) the reasonableness of the project team's cost range, (4) the reasonableness of the project team's schedule range, and (5) the project team's application of GAO best practices to the cost estimate. This section also presents the ICR team's recommended cost estimate range.

4.2 Analysis of Alternatives

The project team updated the original alternatives analysis in response to P5's recommendation for a change in approach to the long baseline neutrino program. It considered the no action alternative, the previously selected CD-1 alternative to construct a neutrino beamline at FNAL with a 10-kiloton LAr detector on the surface at SURF, and the new alternative enabled by international cooperation and collaboration:

1. Continue the status quo (no action); FNAL continues to operate the current generation neutrino program experiments to completion.

2. Construct a new, low-energy FNAL neutrino beamline with a 10-kiloton LAr time projection chamber surface detector at the SURF Homestake Mine site in South Dakota, 1,300 km from FNAL.

3. Construct a new LBNF at FNAL and SURF and support construction of the international DUNE detectors, up to a 40-kiloton modular LAr time projection chamber detector deep underground at SURF and a high-resolution near detector at FNAL.

The project team considered the SURF (Homestake) site because of extensive prior analysis during the early phases of LBNE planning, documented in the LBNE alternative analysis. The LBNF/DUNE alternatives analysis updates the prior LBNE analysis of alternatives. In the previous analysis, the project team compared Alternative 2 with other alternatives, including using the existing FNAL NuMI beamline to produce a neutrino flux directed toward Northern Minnesota. The prior analysis found Alternative 2 preferable on the basis of its longer distance baseline, risks with long-term NuMI operation, and inability to upgrade

NuMI to higher beam powers to support potential future upgrades to the program. Likewise, several independent worldwide efforts, developed through many years of detailed studies, have now converged on the opportunity provided by the proposed new FNAL and SURF facilities.

The project team excluded Alternative 1 from further consideration because it does not meet the mission need. It developed LCCs for the other two alternatives: $1,250 million for Alternative 2 and $2,025 million for Alternative 3. It assumed the following:

- Operations at each site are incremental to the existing operations of facilities or experiments.
- The Alternative 2 beamline operates at 700 kW and Alternative 3 at 1.2 MW for the life of the experiment.
- The experiment and far site facility operate for 30 years for Alternative 2, and they operate for 20 years for Alternative 3, after which the far detector is decommissioned.
- The beamline is neither decommissioned nor demolished upon conclusion of the experiment; other experiments use this facility at that time.
- Far detector D&D at SURF includes removal of detector components and restoring the surface.

The detailed comparison of LCC estimates between the various alternatives did not drive the selection of the preferred Alternative (3). The project team considered the following: the ability to meet mission need, technical considerations, scientific capability, site conditions and location, and additional resources external to DOE to support a broader-based physics program in support of the mission need.

Based on these considerations, the project team selected Alternative 3 as the recommended alternative for LBNF/DUNE. It has the scientific advantages of a long-distance baseline between the neutrino source and detector, with a deep underground location and additional far detector mass, and a near detector afforded by international contributions. This alternative requires a new neutrino beamline to meet the necessary beam directional, energy, long-term operability requirements and the upgrade capability needed to sustain the LBNF/DUNE program. Alternative 3 is the best alternative for realizing a scientifically capable LBNF/DUNE program, and it provides a solid foundation for continued international cooperation in science.

The ICR team concurs with the selection of Alternative 3, based on its ability to meet the mission need.

4.3 RISK ANALYSIS

The LBNF/DUNE project follows a detailed risk management process, in accordance with the Fermilab Risk Management Procedure for Projects, which describes the project's risk identification and management approach. It has an associated risk register, which has been updated several times. The project team mitigates LBNF/DUNE risk through a structured, integrated process for identifying, evaluating, tracking, abating, and managing risks. It evaluates and manages opportunities—risks presenting positive implications for the project—through the same process. A comprehensive risk management workshop in April 2015 included external participants and evaluated all aspects of LBNF/DUNE.

4.3.1 Project Team Risk Assessment

LBNF/DUNE has built on previous LBNF/LBNE risk assessments and evaluated new risks. To ensure it understood the full risk landscape, the project team considered risks across LBNF/DUNE regardless of the party responsible. The risk assessment takes into account schedule slips on the international side, but not cost impacts.

The highest-rated cost impact risks (those with a probability of 50 percent or greater) are as follows:

- Escalation rate greater than predicted
- LAr market risk
- Multiple contractor interfaces at SURF
- Missing scope due to poor interfaces
- Insufficient rock cover at the near detector, requiring more cavern support
- Installation of cryogenics or detector overlapping with excavation work
- Chase cooling panels needing to be stainless steel instead of carbon steel
- Insufficient cryogenic engineering labor at FNAL

The highest rated schedule impact risks (those with a probability of 50 percent or greater) are as follows:

- Insufficient rock cover at the near detector, requiring more cavern support
- Chase cooling panels needing to be stainless steel instead of carbon steel
- Adverse ground conditions in far site underground excavations

- Customs delays and costs.

The contingency on estimated work to complete for the DOE contributions is $344 million of the $1.457 billion TPC estimate (or 34 percent of base work-to-go). The project team estimated preliminary risk-based cost contingency across the project, which accounts for 8 percent of work to-go. Table 4-1 shows the breakdown.

Table 4-1. Contingency Breakdown ($ million)

Description	Contingency
Technical and programmatic risks	53
Schedule risk (based on 17 months)	29
Unknown unknowns	2
Total	84

The project team derived the risk-based contingency in accordance with DOE guidance. It identified and qualitatively rated risks according to probability and consequence, ranking them as high, moderate, or low. It then used quantitative analysis to assign a range of cost and schedule impacts to each of the higher-rated risks and used the range values in a Monte Carlo probabilistic simulation to determine contingency at the 90 percent confidence level.

The project team assigned the remaining $260 million of contingency as estimate uncertainty, representing nearly 26 percent of the base costs to-go. FNAL uses a site-wide method for establishing estimate uncertainty (contingency) factors to apply to cost estimates. It defines estimate uncertainty by the level of maturity of the design and how well FNAL believes that it understands the costs. Thus, at the current conceptual design stage, FNAL's contingency rules may apply an additional 20 percent to the point cost estimate for engineering and design of conventional facilities, for example, and an additional 30 percent for construction tasks. It makes no allowance for the possibility that tasks may underrun the point estimate.

The project team combines top-down contingency ($84 million) with the estimate uncertainty ($260 million) to establish the total contingency for the DOE portion of the project.

4.3.2 ICR Team Assessment

The ICR team reviewed the project team's risk assessment and found the following:

- The risk management process meets DOE guidelines for CD-1.[6]
- The project team identified and documented reasonable and credible risks and uncertainties.
- The risk assessment takes into account schedule slips on the international side, but not cost impacts.
- It appropriately determined the contingency associated with technical and programmatic risks using cost and schedule ranges coupled with Monte Carlo simulation techniques.
- The contingency associated with estimate uncertainty appears high, especially for a project with a cost estimate basis as well developed as the LBNF/DUNE project.

4.4 REASONABLENESS OF PROJECT TEAM COST RANGE

This subsection describes and assesses the reasonableness of the project team's cost range. The ICR team drilled down to review several major work elements (Table 4-2) and looked at over $642 million of the DOE preliminary costs during this revised ICR. Coupled with $67 million in project components reviewed in the first CD-1 ICR in 2012 and verified in this review, the total reviewed costs were approximately $709 million, or 64 percent.

[6] DOE, DOE Guide 413.3-7A, *Risk Management Guide*, January 12, 2011.

Table 4-2. Target WBS Elements for Detailed ICR Review

WBS	Description	CD-1 cost ($)
130.02.01	Beamline project management	22,353,157
130.02.02.03	Magnet power supplies	6,288,705
130.02.03.08	Target hall shield pile	24,371,328
130.05.06	Far detector installation and commissioning	24,815,647
130.06.02.04	NSCF final design	11,399,714
130.06.02.05	NSCF construction	240,866,154
130.06.03.05	FSCF construction	251,325,346
130.07.05	Cryogenics system	60,857,676
	Total for revised review	642,277,727
	Total for prior review	66,860,307
	Total reviewed	709,138,034
	DOE preliminary costs	1,106,948,192[a]
	Percent reviewed = 64	

Note: NSCF = near site conventional facilities.
a Does not include contingency.

The drill-down review examined the scope of work for each target WBS element and the BOE. In general, the ICR team focused on the major cost drivers in each target WBS and had the project team explain and demonstrate how costs were derived. In some cases, this required evidence that a vendor quote was available to support a procurement or that a bottom-up cost estimate was prepared by Fermi Research Alliance, LLC (FRA), estimators. The project team also used costs incurred for equipment installed in previous FNAL projects, such as magnets, surface building construction (based on NuMI), and elevators. All cost information is available via the project website, which contains extensive files and backup for each BOE.

In addition to the eight WBS target areas shown in Table 4-2, the ICR team briefly reviewed updated costs for the WBS elements reviewed in the first ICR accomplished in 2012. These discussions largely focused on the changes in either scope or cost since the first review.

The project team demonstrated a high quality cost estimate to include detailed back-up documentation and provided a clear and thorough explanation for every drill-down area. Assumptions are clearly stated and reasonable. Estimates are supported through bottom-up parametric estimating techniques, vendor/subcontractor quotations, historical data, and staffing plans. In all cases, the project team explained the method for preparation of the estimate.

The strengths of the project team cost estimate are as follows:

- Much is based on costs developed for the original CD-1 review in 2012, which were judged as valid and reasonable.
- It is supported by a well-developed WBS.
- Its overall quality is generally higher than that expected at the conceptual design level.
- Escalation rates are reasonable and appropriately applied.
- The costs for previous structures at FNAL are used to the extent possible to develop costs for the LBNF/DUNE project. For example, the LBNF 40 building for the current project is almost identical to the NuMI building, so costs for NuMI were extensively referenced.
- Many of the project costs were verified through independent estimates, such as site infrastructure costs.
- Costs are supported by 130 BOEs and other documentation.

The weaknesses of the project team cost estimate are as follows:

- Estimate uncertainty is not determined according to a Monte Carlo simulation of the over/under percentages around the base estimate. The project team estimate instead assigns a percentage amount above the base estimate as a measure of the design maturity. The entire percentage amount is assigned as estimate uncertainty. This approach maximizes the estimate uncertainty (which explains why the estimate uncertainty contribution to contingency is nearly 26 percent) and does not account for the fact that some costs will likely underrun the point estimate.
- Construction management (CM) costs for the cryogenics work appear very high: 20 percent of the construction cost. A range of 5–7 percent for CM is more typical.

4.5 ICR Team Cost Range

The project team developed a point cost estimate of $1.457 billion and a preliminary cost range of $1.255 billion to $1.727 billion. The project team indicated that its cost estimate is Class 3 quality (Appendix C), with which the ICR team agrees based on the level of maturity and project definition. Using parameters from the AACE International matrix, the project team selected an expected accuracy range of –15 percent to +20 percent.

The ICR team believes this cost range is too narrow, particularly on the upper end. Because of the inherent difficulty of this project (reliance on international contributions, 10-yr+ duration), the ICR team recommends an expansion of the cost estimate range, staying within the guidelines listed in the AACE International matrix (Appendix C). Instead of +20 percent on the upside, we recommend +30 percent, which expands the range to $1.255 billion to $1.862 billion.

4.6 REASONABLENESS OF SCHEDULE RANGE

The project team prepared detailed schedules for the project. Assuming CD-1 approval in first quarter FY16, the project team expects CD-4 by second quarter FY27. This does not include schedule contingency. Adding the 31 months of schedule float yields a project end date of fourth quarter FY29. The critical path is 11 years, admittedly a long schedule, but it is required due to funding constraints in the early years. For comparison, the original LBNE project approved in 2012 had a10-year critical path duration with an additional 24 months of schedule contingency. Thus, the current LBNF/DUNE project has a similar, but slightly longer, schedule duration.

The schedule contingency of 31 months contains 17 months of float based on Monte Carlo simulation of schedule risks and 14 months of top-down float added by management. The basis for the 14 months of additional top-down schedule contingency is unclear. It is not risk-based.

The project team identified nine risks as having a high probability of impacting the critical path. Most of these would cause less than a 3-month delay. The two biggest schedule risks for the project are (1) straw tube tracker infrastructure delay and (2) the development time for the magnet vendor infrastructure. Both were assessed as having maximum schedule impacts of 24 months, but with a fairly low probability of occurrence. The cost estimate includes hotel load of approximately $1.6 million per month for the 17 months of contingency predicted by the Monte Carlo analysis.

The proposed schedule range is reasonable, including the 31 months of float.

4.7 APPLICATION OF GAO BEST PRACTICES FOR COST ESTIMATING

In executing its federal government oversight responsibility, the GAO has identified best practices for cost estimating and scheduling that can be used across the federal government to "develop, manage, and evaluate capital program cost estimates [and schedules]." The intent of these best practices is to improve federal government and agency "stewardship" of public funds consistent with fiscal accountability. DOE recognizes these practices as a minimum acceptable standard for performance. In this subsection, the ICR team offers its assessment of the project team's CD-1 submittal relative to the GAO's best practices.

The ICR team found the following concerning the project team's application of GAO best practices:

- *Comprehensive—Fully met*. TPC and LCCs were determined for the proposed project. Cost estimates have a well-defined WBS. Contingency is included based on application of contingency rules and a risk analysis. Costs are escalated appropriately. Detailed resource schedules and critical path schedules are included.
- *Well-documented—Fully met*. The project team documented the assumptions and includes over 130 BOEs to explain the source of various costs, as well as their estimating methods. The project team identified the source for escalation rates. The CD-1 package is complete and well-documented, with an extensive conceptual design report, PEP, acquisition strategy, alternatives analysis, and risk analysis.
- *Accurate—Fully met*. The cost estimates are bottom-up estimates largely based on vendor quotes, parametric unit rates, and historical data. The construction costs are derived using unit prices based on expected quantities (such as square feet or metric tons). Level-of-effort tasks are based on current laboratory wage rates. The ICR team found no inaccuracies.
- *Credible—Partially met*. The project team has a very extensive conceptual design. The technology is fully described and costs for scientific instruments and devices are developed based on vendor quotes and previous projects constructed at FNAL. The mining/excavation costs are identified as a key cost driver; the project team solicited excavation cost data from reputable mining specialists. Assumptions are consistently applied throughout the estimate. The ICR team did not identify any omissions. However, a sensitivity analysis on cost elements was not conducted.

Appendix B details the ICR team's assessment of the project team's cost estimate relative to GAO best practices. Overall, the quality of the project team cost estimating effort is excellent with respect to meeting the GAO requirements.

Section 5
Conclusions and Recommendations

5.1 Conclusions

The ICR team concludes the following:

- The project team was well prepared for the ICR.
- The project has a solid cost estimating process in place
- At this stage (CD-1), the organization and detail of the cost book and associated BOEs meet or exceed GAO best practices on estimate documentation.
- Over 75% of design elements are more mature than conceptual design
- Using independent architecture-engineering estimates to reconcile several key project estimates is commendable and lends credibility.
- In general, control account managers consistently followed cost uncertainty guidelines, but in several instances, the applied contingency percentage exceeded the guidance without documented justification/explanation. Suggest documenting deviations in the BOE as appropriate.
- Although the overall project contingency is a reasonable 34 percent, the risk-based contingency (about 8 percent) appears low, while the contingency for estimate uncertainty (26 percent) appears high.
- The cost range appears narrow based on the project complexity, extended duration, and dependency on international partners to deliver contributions on schedule.

5.2 Recommendations

Based on the project's complexity, current design maturity, extended duration, and dependency on international partners to deliver contributions on schedule the ICR team recommends expanding the upper end of the cost range to 30 percent above the point estimate (rather than the current 20 percent), making the cost range $1.255 billion to $1.862 billion.

Appendix A
Professional Information on Report Authors

Peter I. Bako, PMP, CCP, DOE

Mr. Bako has over 20 years of experience in program and project management and is responsible for successful completion of a wide variety of both construction and operations & maintenance projects. Having served over 20 years as a U.S. Air Force Civil Engineering Officer, he planned, programmed, designed, and managed numerous facility and infrastructure projects throughout the United States, Honduras, Germany, England, Iraq, Kuwait, and Saudi Arabia. Mr. Bako has been with the Department of Energy for just over one year in his current position in the Office of Project Management Oversight and Assessments (PMOA) and recently began supporting the Office of Science capital asset program. Mr. Bako has a BS degree in Mechanical Engineering from the University of Connecticut and is a certified Project Management Professional and Certified Cost Professional.

Brian D. Huizenga, MBA, BS, CCP, DOE

Mr. Huizenga has over 32 years of experience in program and project management responsible for successful completion of capital projects around the world. His distinguished career began with 20 years as a U.S. Air Force Officer in the Civil Engineering career field. In this capacity he designed, managed and constructed numerous facilities throughout the United States, England, Egypt, Japan and Thailand. After retiring from the Air Force, Brian went to work for the Missile Defense Agency (MDA) as the Director of Engineering and Environmental Management. This job tested his skills to complete critical Missile Defense facilities in support of a fast-paced program to deploy the Nation's first Missile Defense Shield, managing the design and construction of key assets worldwide. While at MDA, Brian was granted membership in the DoD Defense Acquisition Corps, earned Level III Certification in two career fields: 1) Systems Planning, Research, Development and Engineering, 2) Test and Evaluation Engineering. Mr. Huizenga has been with the Department of Energy for 6 years at his current position in PMOA supporting the Office of Science capital asset program. Mr. Huizenga has a BS degree in Mechanical Engineering, an MBA and is a Certified Cost Professional.

Douglas A Gray, PE

Mr. Gray has 40 years of experience in program and project management, engineering supervision, and independent consulting. Work experience includes the chemical, mining, energy, nuclear, and environmental industries. Mr. Gray's focus over the past 20 years has been in support of the DOE performing independent cost estimates (ICEs), independent cost reviews (ICRs), and external independent reviews (EIRs) of major DOE projects and programs ranging in cost from $5 million to $60 billion. These reviews include independent assessment of baseline life-cycle costs, construction and operations cost estimates, D&D costs, work breakdown structures, risk assessments, and contingency analyses. Mr. Gray performed cost reviews for several DOE capital line-item projects such as the Remote-Handled Low Level Waste Project at Idaho, and the Saltstone Disposal Unit #6 at the Savannah River Site. Independent cost estimates completed by Mr. Gray include the Highly Enriched Uranium Material Facility (HEUMF) Project at the Y-12 National Security Complex, and the Muon-to-Electron Conversion Experiment Project at FermiLab. Mr. Gray was responsible for the cost review and risk assessment portions of the external independent reviews conducted for the DOE Environmental Management baseline programs at Brookhaven National Laboratory, Lawrence Livermore National Laboratory, Pantex, Nevada Test Site, Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, Hanford Reservation, Waste Isolation Pilot Plant, Idaho National Laboratory, Oak Ridge, and the Portsmouth/Paducah sites. He also co-authored the new Level 2 and Level 3 risk management courses for DOE, as well as the new cost-estimating course. Mr. Gray has a BS degree in chemical engineering, and is a licensed Professional Engineer.

Appendix B
GAO Best Practices for Cost Estimating

Table B-1 provides the ICR team assessment of whether the project team followed GAO best practices for cost estimating.

Table B-1. GAO Best Practices Assessment

Step	Description	Associated Tasks	PMOA Notation
1	Define estimates purpose	1. Determine estimate's purpose, required level of detail, and overall scope.	Met. The purpose is stated in the CDR documentation and PEP.
		2. Determine who will receive the estimate.	Met. Documentation states the report is prepared for Office of Science.
2	Develop estimating plan	1. Determine the cost estimating team and develop its master schedule.	Met. The team is identified. Briefings on major WBS components of the project were made by the control account managers to the ICR Team.
		2. Determine who will do the independent cost estimate; outline the cost estimating approach.	Met. An overall ICE has not been completed, but ICEs were received from several contractors as checks on portions of the Project Team's estimate.
		3. Develop the estimate timeline.	Met. The estimate was available prior to the ICR.
3	Define program characteristics	1. Identify the program's purpose and its system and performance characteristics and all system configurations.	Met. The CDR adequately explains the systems and performance characteristics.
		2. Any technology implications.	Met. The CDR adequately explains technology implications, including similarities to past projects.
		3. Program acquisition schedule and acquisition strategy.	Met. An acquisition strategy is prepared.

Table B-1. GAO Best Practices Assessment

Step	Description	Associated Tasks	PMOA Notation
		4. Its relationship to other existing systems, including predecessor or similar legacy systems.	Met. The project has adequately explained the current proposed project versus previous projects considered, including LBNE. Changes are documented.
		5. Support (manpower, training, etc.) and security needs and risk items.	Met. Security and risk are addressed in the PEP and other CDR documents.
		6. System quantities for development, test, and production.	Met. KPPs are defined. More definitive quantities will be developed as the project proceeds to CD-2.
		7. Deployment and maintenance plans.	TBD as part of CD-2.
4	Determine estimating structure	1. Define a work breakdown structure (WBS) and describe each element in a WBS dictionary (a major automated information system may have only a cost element structure).	Met. A WBS and dictionary are prepared.
		2. Choose the best estimating method for each WBS element; Identify potential cross-checks for likely cost and schedule drivers.	Met. The BOEs explain very well how estimates were developed, whether from vendor quotes, past projects, level of effort, bottoms-up, or engineering judgment.
		3. Develop a cost estimating checklist	Met.
5	Identify ground rules and assumptions	1. Clearly define what the estimate includes and excludes.	Met. The Project is clear in defining what DOE's obligations are vs. the international partners.
		2. Identify global and program-specific assumptions, such as the estimate's base year, including time-phasing and life cycle.	Met. An assumptions document is provided showing escalation rates, base year. Life cycle costs are provided, including assumptions.

Table B-1. GAO Best Practices Assessment

Step	Description	Associated Tasks	PMOA Notation
		3. Identify program schedule information by phase and program acquisition strategy.	Met. Detailed and critical path schedules are provided, as well as an acquisition strategy.
		4. Identify any schedule or budget constraints, inflation assumptions, and travel costs.	Met. The project clearly states the money it needs prior to CD-2 to start excavation.
		5. Specify equipment the government is to furnish as well as the use of existing facilities or new modification or development.	Met. Existing facilities at both FNAL and SURF are described, as well as any modifications required.
		6. Identify prime contractor and major subcontractors.	Met. FRA is the prime contractor.
		7. Determine technology refresh cycles, technology assumptions, and new technology to be developed.	Met. Technology is exhaustively described in the CDR.
		8. Define commonality with legacy systems and assumed heritage savings.	Met. Commonality with other particle physics projects at FNAL (e.g. NoVA and Mu2e) are described.
		9. Describe effects of new ways of doing business.	Met. The partnership with the international community is defined, especially for the DUNE project.
6	Obtain data	1. Create a data collection plan with emphasis on collecting current and relevant technical, programmatic, cost, and risk data.	Met. FNAL and FRA have a good database of relevant cost data, based on recent projects that are similar to LBNF/DUNE.
		2. Investigate possible data sources.	Met. Data sources are documented in the BOEs.
		3. Collect data and normalize them for cost accounting, inflation, learning, and quantity adjustments.	Met.

Table B-1. GAO Best Practices Assessment

Step	Description	Associated Tasks	PMOA Notation
		4. Analyze the data for cost drivers, trends, and outliers and compare results against rules of thumb and standard factors derived from historical data.	Met. Unit rates and historical data are predominately used by the Project Team. Unit rates from the mining industry were used to determine excavation/drilling costs.
		5. Interview data sources and document all pertinent information, including an assessment of data reliability and uncertainty.	Met.
		6. Store data for future estimates.	Met. FRA has a database of costs on project components.
7	Develop point estimate and compare it to an independent cost estimate	1. Develop the cost model, estimating each WBS element, using the best methodology from the data collected, and including all estimating assumptions.	Met. A point estimate was developed using the estimating assumptions.
		2. Express costs in constant year dollars.	Met.
		3. Time-phase the results by spreading costs in the years they are expected to occur, based on the program schedule.	Met. The PEP and other documents show the time-phased spend plan.
		4. Sum the WBS elements to develop the overall point estimate.	Met. The point estimate is $1.457B.
		5. Validate the estimate by looking for errors like double counting and omitted costs.	Met. The estimate checked and no errors detected.
		6. Compare estimate against the independent cost estimate and examine where and why there are differences.	N/A. An ICE for the entire project has not been completed.
		7. Perform cross-checks on cost drivers to see if results are similar.	Met.

Table B-1. GAO Best Practices Assessment

Step	Description	Associated Tasks	PMOA Notation
		8. Update the model as more data become available or as changes occur and compare results against previous estimates.	Will be performed after CD-1.
8	Conduct sensitivity analysis	1. Test the sensitivity of cost elements to changes in estimating input values and key assumptions.	Not met. A sensitivity analysis has not been completed.
		2. Identify effects on the overall estimate of changing the program schedule or quantities.	Not met. A sensitivity analysis has not been completed.
		3. Determine which assumptions are key cost drivers and which cost elements are affected most by changes.	Met. Key cost drivers are identified.
9	Conduct risk and uncertainty analysis	1. Determine and discuss with technical experts the level of cost, schedule, and technical risk associated with each WBS element.	Met. The Project Team conducts risk workshops to go over current risks and determine if new risks should be added.
		2. Analyze each risk for its severity and probability.	Met. Each technical risk is scored.
		3. Develop minimum, most likely, and maximum ranges for each risk element.	Met. Each risk event has a cost and schedule range.
		4. Determine type of risk distributions and reason for their use.	Met.
		5. Ensure that risks are not correlated.	Met.
		6. Use an acceptable statistical analysis method (e.g., Monte Carlo simulation) to develop a confidence interval around the point estimate.	Met. Monte Carlo simulation is used to determine contingency at a 90% CL.
		7. Identify the confidence level of the point estimate.	Met. 90%

Table B-1. GAO Best Practices Assessment

Step	Description	Associated Tasks	PMOA Notation
		8. Identify the amount of contingency funding and add this to the point estimate to determine the risk-adjusted cost estimate.	Met. Contingency is added for both programmatic and schedule risk. Contingency for cost estimating uncertainty is added for each major cost element according to FRA contingency rules.
		9. Recommend that the project or program office develop a risk management plan to track and mitigate risks.	Met. The Project has a RMP.
10	Document the Estimate	1. Document all steps used to develop the estimate so that a cost analyst unfamiliar with the program can recreate it quickly and produce the same result.	Met. The estimate is well-structured, and supported by excellent BOEs.
		2. Document the purpose of the estimate, the team that prepared it, and who approved the estimate and on what date.	Met. The estimate purpose and estimating team are identified. Original CD-1 was approved in 2012.
		3. Describe the program, its schedule, and the technical baseline used to create the estimate	Met. The CDR addresses all these topics.
		4. Present the program's time-phased life-cycle cost.	Met. A LCC was prepared.
		5. Discuss all ground rules and assumptions	Met. GR&As are described.
		6. Include auditable and traceable data sources for each cost element and document for all data sources how the data were normalized.	Met. The cost estimate contains data sources that demonstrate how each element was estimated.

Table B-1. GAO Best Practices Assessment

Step	Description	Associated Tasks	PMOA Notation
		7. Describe in detail the estimating methodology and rationale used to derive each WBS element's cost (prefer more detail over less).	Met. The cost estimate contains extensive backup files that demonstrate how each element was estimated. Estimating methodology is well-documented.
		8. Describe the results of the risk, uncertainty, and sensitivity analyses and whether any contingency funds were identified.	Partially met. Risk and uncertainty are well-documented to show how contingency was estimated. Sensitivity analysis was not performed.
		9. Document how the estimate compares to the funding profile.	An approved funding profile is not available yet for this project.
		10. Track how this estimate compares to any previous estimates.	Met. The Project Team identified all changes to the original CD-1 estimate for the LBNE project. The cost is higher because of the increased scope.
11	Present estimate to management for approval	1. Develop a briefing that presents the documented life-cycle cost estimate.	Met. Project team has developed a briefing for management.
		2. Include an explanation of the technical and programmatic baseline and any uncertainties.	Met. Although a baseline has not been approved, the project has defined the technical scope of work, as well as project uncertainties in its risk plan.
		3. Compare the estimate to an independent cost estimate (ICE) and explain any differences.	Met. An overall ICE has not been completed, but ICEs were received from several contractors as checks on portions of the Project Team's estimate.
		4. Compare the estimate (life-cycle cost estimate (LCCE)) or independent cost estimate to the budget with enough detail to easily defend it by showing	N/A. A Budget is not available for comparison.

Table B-1. GAO Best Practices Assessment

Step	Description	Associated Tasks	PMOA Notation
		how it is accurate, complete, and high in quality.	
		5. Focus in a logical manner on the largest cost elements and cost drivers.	Met. The Project Team pointed out the large cost drivers, such as excavation and its unit costs.
		6. Make the content clear and complete so that those who are unfamiliar with it can easily comprehend the competence that underlies the estimate results.	Met. Briefings given to ICR Team were clear and complete. The estimate could be understood.
		7. Make backup slides available for more probing questions.	TBD
		8. Act on and document feedback from management.	TBD
		9. Request acceptance of the estimate.	TBD when CD-1 approval is given.
12	Update the estimate to reflect actual costs and changes	1. Update the estimate to reflect changes in technical or program assumptions or keep it current as the program passes through new phases or milestones.	Met. The estimate and schedule have been updated to reflect the revised change in approach. This is referred to as the "refresh".
		2. Replace estimates with EVM EAC and independent estimate at completion (EAC) from the integrated EVM system.	Not applicable prior to CD-2.
		3. Report progress on meeting cost and schedule estimates.	Not applicable prior to CD-2.
		4. Perform a post mortem and document lessons learned for elements whose actual costs or	Not applicable prior to CD-2.

Table B-1. GAO Best Practices Assessment

Step	Description	Associated Tasks	PMOA Notation
		schedules differ from the estimate.	
		5. Document all changes to the program and how they affect the cost estimate.	Not applicable prior to CD-2.

Appendix C
AACE International Cost Estimate Classification Matrix

Table C-1, based on AACE International recommended practices, No. 17R-97, Cost Estimate Classification System, and No. 18R-97, Cost Estimate Classification System—As Applied in Engineering, Procurement and Construction for the Process Industries, shows guidance for classifying project cost estimates.

Table C-2. AACE International Cost Estimate Classification

	Primary Characteristic	***Secondary Characteristic***			
ESTIMATE CLASS	**LEVEL OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]	**PREPARATION EFFORT** Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment, or Analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or Bid/ Tender	Detailed Unit Cost with Forced Detailed Take-Off	L: -5% to -15% H: +5% to +20%	4 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Detailed Unit Cost with Detailed Take-Off	L: -3% to -10% H: +3% to +15%	5 to 100

Appendix D

Abbreviations

BOE	basis of estimate
CD	Critical Decision
CM	construction management
D&D	decommissioning and demolition
DOE	U.S. Department of Energy
DUSEL	Deep Underground Science and Engineering Laboratory
DUNE	Deep Underground Neutrino Experiment
FNAL	Fermi National Accelerator Laboratory
FRA	Fermi Research Alliance, LLC
FSCF	Far Site Conventional Facilities
FY	fiscal year
GAO	U.S. Government Accountability Office
ICR	independent cost review
KPP	key performance parameters
LAr	Liquid Argon
LBNE	Long Baseline Neutrino Experiment
LBNF	Long Baseline Neutrino Facility
LCC	life-cycle cost
LLP	long lead procurement
NSCF	Near Site Conventional Facilities
NSF	National Science Foundation
P5	Particle Physics Project Prioritization Panel
PME	Project Management Executive
PMOA	Office of Project Management Oversight and Assessments
SURF	Sanford Underground Research Facility
TPC	total project cost
WBS	work breakdown structure