

**Critical Decision 1, Approve Alternative Selection and Cost Range
for the
Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment
at
Fermi National Accelerator Laboratory and
Sanford Underground Research Facility**

**Office of High Energy Physics
Office of Science**

A. Purpose

The purpose of this paper is to document the review and approval by the DOE Office of Science Energy Systems Acquisition Advisory Board-equivalent for Critical Decision 1 (CD-1) “Approve Alternative Selection and Cost Range” for the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE) Project at the Fermi National Accelerator Laboratory (FNAL) and Sanford Underground Research Facility (SURF).

B. Mission Need

The U.S. Department of Energy (DOE) Office of High Energy Physics (HEP) mission is to understand how our universe works at its most fundamental level. HEP supports elementary particle physics research, which explores the fundamental constituents of matter and energy, revealing the profound connections underlying everything we see, including the smallest and the largest structures in the universe. Neutrinos are elementary particles that may hold the key to explaining the existence of matter in the universe and could unveil new, exotic physical processes currently beyond reach.

On January 8, 2010, the Department of Energy Deputy Secretary approved CD-0, Mission Need, for a new long-baseline neutrino experiment that would enable a world-class program and firmly establish the U.S. as a leader in neutrino science. A facility to carry out this science requires a specialized detector of very large size with sensitivity surpassing that of current experiments, and that can be located 1000-1500 km from the neutrino beam source.

The earlier Long-Baseline Neutrino Experiment (LBNE) project was formulated primarily as a domestically funded experiment, having a minimal CD-1 configuration of a 10 kiloton far detector on the surface, with an experiment baseline of 1300 km. LBNE’s CD-1, approved December 2012, was tailored to allow for enhancement of scientific capabilities and additional scope opportunities (such as a near neutrino detector, and far detector sited underground with additional mass), should the opportunity attract the support of other funding agencies. This opportunity has now attracted increasing international support following a May 2014 report issued by the High Energy Physics Advisory Panel (HEPAP) Particle Physics Project Prioritization Panel (P5), *Building for Discovery, Strategic Plan for U.S. Particle Physics in a Global Context*. This report noted that a more ambitious long-baseline neutrino facility has been called for by the Snowmass particle physics community study and in expressions of interest from physicists in other regions of the world. Minimum requirements to meet scientific goals of this more ambitious program are not met by the prior LBNE project’s CD-1

minimum scope, requiring a change in approach. P5 recommended that a new international collaboration form to design and execute a highly capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S, to meet the minimum specified requirements in beam power, detector mass and exposure. These requirements are intended to achieve desired sensitivity to Charge-Parity (CP) violation, along with capability to search for phenomena such as supernova bursts and proton decay in support of meeting mission need. A large detector located underground and shielded from cosmic backgrounds can provide the required sensitivity and capability.

An international collaboration has recently formed, called the Deep Underground Neutrino Experiment (DUNE), bringing together a global neutrino community to pursue an accelerator based long-baseline neutrino experiment, as well as neutrino astrophysics and nucleon decay. DUNE proposes to build a large liquid-argon detector located deep underground at SURF in Lead, SD (called the “far site”) and a high-resolution near detector located at FNAL in Batavia, IL (called the “near site”). The name LBNF/DUNE refers to this new vision of the project developed to support this program.

In July 2015, the Office of Science conducted an external Independent Project Review (IPR) as part of the CD-1 refresh (CD-1R) approval process. The preliminary baseline was found to be complete and comprehensive and in some areas, mature beyond CD-1. The IPR committee recommended reevaluation of some contingency and risk assumptions to confirm a realistic assessment. This was done, and as a result the project shifted work to ensure contingency availability in the early years and added schedule float on project completion, to reduce risk. Risk-based contingency was also increased. HEP also worked with the project to optimize the funding profile, within the Total Project Cost (TPC) point estimate of \$1,457 million.

C. Alternative Analysis and Selected Alternative

The alternative analysis was updated in response to P5’s recommendation for a change in approach to the long baseline neutrino program, and subsequent formation of the international DUNE collaboration. The previously selected CD-1 alternative to construct a neutrino beamline at FNAL with a 10 kiloton liquid argon detector on the surface at SURF was reconsidered against the new alternative enabled by international cooperation, for a larger, deep underground detector and other enhancements. This new alternative is to construct a new Long Baseline Neutrino Facility (LBNF) at FNAL and SURF, and support construction of the international DUNE detectors, up to a 40 kiloton liquid argon detector located deep underground at SURF, with a high resolution near detector at FNAL. This is the selected alternative based on P5 recommendations.

It should be noted that selection of the SURF site was the result of extensive prior analysis conducted during the early phases of planning. Extensive earlier analysis also evaluated near/far site options, as well as neutrino beamline and detector technologies and configurations. These, combined with several independent worldwide efforts developed through years of studies, have all converged around the opportunity and selected alternative for the LBNF/DUNE Project.

D. Preliminary Project Scope Description

The LBNF/DUNE Project scope includes construction of facilities at two separate geographical locations, the near site (FNAL) in Batavia, IL and the far site (SURF) 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 SURF. Scope is described below for each of the two parts: LBNF, a DOE project with international contributions, and the international DUNE project, managed by the DUNE collaboration and primarily supported by multiple international partners, including a DOE contribution.

For LBNF the preliminary project scope includes the following:

- Conventional facilities and excavation:
 - at the far site, to house and support the technical components of the far detector
 - at the near site, to support technical components of the primary proton beam, neutrino beam and near neutrino detector
- Far site cryogenic infrastructure required for underground installation and operation of the far detector (*this element includes international contributions*)
- Near site beamline magnets and support equipment for primary proton beam transport; neutrino target and magnetic focusing horns to direct pions and kaons into a decay tunnel where these particles decay into neutrinos, and a beam absorber and muon detectors at the end of the decay tunnel (*this element includes international contributions*)

For the international DUNE project, preliminary project scope includes DOE contributions to:

- the far detector at SURF, implemented as four separate ten kiloton liquid argon Time Projection Chamber detector modules
- neutrino near detector at FNAL

E. Acquisition Strategy

Acquisition of the LBNF/DUNE will be conducted through Fermi Research Alliance (FRA), the FNAL M&O contractor, which will have the ultimate responsibility to successfully execute the LBNF/DUNE project for DOE. FNAL is the site of the only existing neutrino beam facility in the U.S. and has extensive experience managing complex construction, fabrication and installation projects involving multiple national and international partners at on-site and off-site locations.

FRA/FNAL, in coordination with DOE-OHEP and the DUNE collaboration has established a set of structures to provide coordination among participating funding agencies, oversight of LBNF/DUNE project, and coordination between LBNF and DUNE parts of the project. DOE is adopting the successful model for international cooperation that was used by CERN to construct the Large Hadron Collider (LHC), i.e. a host lab to construct a facility, with international contributions, and detector construction managed by an international collaboration with contributions from many institutions. DOE will cooperate and coordinate with interested international and domestic partners to plan and execute the overall LBNF/DUNE project. International contributions to the design and construction of LBNF/DUNE will be defined in the context of agreements between the U.S. and other

participating countries. Mechanisms are in place to facilitate joint consultation between the partner funding agencies, such that coordinated oversight and actions will be taken to ensure the success of the overall program. These mechanisms include an International Advisory Council, and Resource Review Boards with representatives of funding agencies that meet regularly to facilitate global coordination and monitoring across the entire LBNF/DUNE enterprise, analogous to the mechanisms used by CERN for the LHC.

DOE will be responsible for providing LBNF scope (e.g. conventional facilities, cryogenic support systems and beamline), and for incorporating in-kind technical or material contributions from CERN and other European countries, India and other partners. For DUNE, DOE will be providing in-kind contributions for detector systems, as agreed upon with the international DUNE collaboration. At the far site, all project work will be planned and coordinated with the South Dakota Science & Technology Authority (SDSTA), owner and operator of SURF and partner on the LBNF/DUNE Project. Further details on the LBNF/DUNE business and acquisition approach can be found in the Acquisition Strategy.

The overall acquisition approach will include requests for long lead actions at the far site and the near site (a CD-3a and a CD-3b). CD-3a is for conventional construction at the far site and CD-3b is for advanced site preparation at the near site and far site cryogenic infrastructure activities. Completing these actions early, and prior to CD-2, will enable the first module of the DUNE detector to be completed to initiate science as early as possible, and will advance availability of the neutrino beam. These actions are described further in the Tailoring Strategy section of this document.

F. Preliminary Cost & Schedule

The CD-1 cost range for the LBNF/DUNE Project DOE contributions is \$1,260 million to \$1,860 million, with a Total Project Cost (TPC) estimate of \$1,457 million. The proposed funding profile for this project is shown in Table 1.

Table 1- Proposed DOE Funding Profile for the LBNF/DUNE Project (\$M)

Fiscal Year	Prior Yrs	FY 15	FY 16	FY 17	FY 18	FY 19	FY 20	FY 21	FY 22	FY 23	FY 24	FY 25	FY 26	Total
TEC	24	12	16	70	110	150	180	180	178	180	160	79	20	1359
OPC	76	10	4						2			3	3	98
TPC	100	22	20	70	110	150	180	180	180	180	160	82	23	1457

The Total Contributions to the LBNF/DUNE Project include the DOE TPC contribution and non-DOE contributions from partner agencies and institutions. DOE TPC costs use standard DOE project cost accounting methods and include materials, services, all labor and a contingency estimate, with escalation added. Non-DOE in-kind contributions to LBNF/DUNE are based on a common accounting method for developing and maintaining cost estimates used by CERN on the international Large Hadron Collider (LHC). This focuses on direct production cost and provides direct labor hour estimates and doesn't include escalation, contingency or indirect costs. A total cost estimate for the entire LBNF/DUNE scope (DOE and non-DOE) was developed by Work Breakdown Structure (WBS) using this common

accounting method. This enables an initial allocation among partners by WBS items. Partner funding agencies and institutions will be responsible for providing assigned WBS deliverables, covering costs for escalation, contingency or institutional indirect charges in accordance with each agency's own policies, and subject to the monitoring and coordination of international Resources Review Boards.

The preliminary schedule is shown in Table 2.

Table 2 -LBNF/DUNE Preliminary DOE Schedule

Critical Decision Milestone	Schedule
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)	1 st Quarter, FY2016
CD-3a ⁽¹⁾ , Approve Initial Far Site Construction	2 nd Quarter, FY2016
CD-3b ⁽²⁾ , Approve Near Site Preparation/Far Site Long Lead Procurement	2 nd Quarter FY2019
CD-2, Approve Performance Baseline	1 st Quarter, FY2020
CD-3 ⁽³⁾ , Approve Start of Construction	1 st Quarter, FY2020
CD-4 , Approve Project Completion	4 th Quarter FY2030

⁽¹⁾CD-3a is for the critical path LBNF Far Site Conventional Facilities construction to mitigate risks and minimize delay in providing a facility ready to accept detectors for installation.

⁽²⁾CD-3b is for critical path LBNF Near Site Site Preparation to build an embankment that requires 1 year of settling before beamline conventional facilities work proceeds; and for critical path LBNF Far Site cryogenic infrastructure long lead procurement

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

Status of milestones for LBNF project and DOE contributions to the international DUNE project will be included in monthly project progress reports and EVMS updates. The international DUNE project will be responsible for monitoring and reporting status of all contributions to DUNE, independent of their funding source, and DOE will monitor international DUNE progress through those means. DOE LBNF/DUNE project milestones will include LBNF/DUNE interface milestones, and DUNE-US milestones which represent DOE deliverables to the international DUNE project. Milestones and dates are subject to further revision and refinement as the performance baseline schedule is prepared for CD-2.

G. Tailoring Strategy

Long lead approvals will be requested for activities at the far and near sites, prior to CD-2. This strategy reduces cost and schedule risk and will ensure optimum use of resources, while awaiting CD-2 and CD-3 authority. In addition, a combined CD-2/3 will be requested.

The project will request a CD-3a: Approve Initial Far Site Construction for critical path far site conventional facilities construction. This scope includes excavation of caverns and spaces needed for the DUNE detector. Completing this long lead work enables start of the first DUNE 10 kiloton detector module installation by 2021-22, in ~seven years, to meet the needs of the global neutrino community. This action reduces project cost due to extended management and escalation and allows outfitting of caverns while excavation continues. It advances completion of the overall project and availability of first detector for science. The project will present a

design and procurement plan, cost basis, and contingency estimate and will demonstrate that there is a low, manageable risk relative to construction and detector design.

The project will request a CD-3b: Approve Near Site Preparation/Far Site Long Lead Procurement to construct a near site beamline embankment and to procure, fabricate and install far site cryogenic infrastructure if needed. The long lead is necessary for the embankment to allow time for soil settlement before beamline construction. The far site cryogenic infrastructure long lead may be necessary so that equipment will be in place in time to support DUNE detector installation.

The project will request a combined CD-2/3: Approve Performance Baseline and Approve Start of Construction for the balance of LBNF/DUNE scope. The scheduling of this milestone is driven by the ~4 year duration needed for DUNE to incorporate development and prototyping work into the detector design, and to develop fabrication/installation plans aligned with international resources and partners. Concurrent CD's maximizes resource utilization to enable fabrication, assembly and construction for the remaining technical systems to start under a tailored final design plan.

H. Environment Safety & Health

An Integrated Safety Management Program has been developed for LBNF/DUNE Project to provide consistent ES&H program guidance and implementation for work activities at FNAL and SURF sites. LBNF/DUNE work at each institution will be performed in accordance with applicable Federal, State and local guidelines and standards. A Preliminary Hazards Analysis Report has been developed for LBNF/DUNE, to ensure hazards are identified early and mitigations integrated into the design. All deliverables will meet safety, and operational readiness requirements necessary for installation at FNAL or SURF. All NEPA requirements have been met. An Environmental Assessment (EA) was developed to cover all LBNF/DUNE activities at the near and far sites and the EA has been approved, with a Finding of No Significant Impact issued.

A sustainability strategy for LBNF/DUNE is in place based on DOE's Strategic Sustainability Performance Plan, that includes the requirement for new construction to meet the federal Guiding Principles (GP) for Federal Leadership in High Performance and Sustainable Buildings. A wide range of sustainable strategies and objectives will be incorporated throughout the design and construction process, while meeting the requirements of an advanced technology and experimental research facility and creating a workplace that is environmentally friendly, energy-efficient, and both healthy and functional to be in.

A Preliminary Security Vulnerability Assessment has been completed and no unique safeguard and security issues are presented. LBNF/DUNE work at FNAL will meet all requirements of the Site Security Plan. For LBNF/DUNE Project work at SURF, appropriate site access, safeguards and security considerations, understandings, agreements and requirements will be identified in an agreement developed between FNAL and SDSTA regarding the LBNF/DUNE project, and will be included in contracts or leases as appropriate to address security and protection of personnel and government equipment and capital investment. Security considerations will continue to be evaluated and documented as the project moves forward.

I. Risk Management

LBNF/DUNE Project follows a detailed risk management process in accordance with the FNAL Risk Management Procedure for Projects (RMPP). The RMPP defines the process used to identify and manage project related risks throughout the project's life cycle and ensure minimal impact on the project's cost and schedule. Project risk is mitigated through a structured and integrated process for identifying, evaluating, tracking, abating and managing risks in terms of three risk categories: cost, schedule and technical performance. A Project-managed Risk Register is developed and maintained, to include the risks that represent significant threat or opportunity, and to which cost and/or schedule contingency is assigned for DOE-funded LBNF/DUNE project work .

The RMPP establishes the guidelines for risk management and analysis, defining and describing the Risk Registry, describing roles and responsibilities of project personnel in performing risk management functions, and defining the reporting and tracking requirements for risk related information and Risk Registry updates. The Risk Register captures and monitors the status of risks associated with each WBS. Monthly reports that determine the status of current risks, near term risks, and risks that can be retired are generated and distributed at Risk Management Board meetings for statusing and action. When the status of risks is determined, the Risk Register is updated.

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Submitted by:



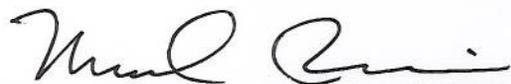
Pepin T. Carolan
Federal Project Director
Fermi Site Office

10/21/2015
Date



Michael J. Weis
Site Manager
Fermi Site Office

10/21/15
Date



Michael Procario
Program Manager
Office of High Energy Physics

11/5/15
Date



James L. Siegrist
Associate Director for High Energy Physics
Office of Science

11/5/15
Date

**Critical Decision 1, Approve Alternative Selection and Cost Range
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Recommendations:

The undersigned "Do Recommend" (Yes) or "Do Not Recommend" (No) approval of CD-1, Approve Alternative Selection and Cost Range, for the LBNF/DUNE Project at Fermilab and SURF site as noted below.

Stephen W. Merder 11/5/15 Yes No
ESAAB Secretariat, Office of Project Assessment Date

Timothy H. O'Connell 11/5/15 Yes No
Representative, Non-Proponent SC Program Office Date

Kathleen Neawing 11/5/15 Yes No
Representative, Office of Budget Date

Stephanie Short 11/5/15 Yes No
Representative, Non-Proponent SC Program Office Date

Michael A. Post 11/5/15 Yes No
Representative, Office of Project Management
Oversight and Assessment Date

Concurrence:

Patricia M. Dehmer 11/5/15 Yes No
Patricia M. Dehmer Date
Acting Director, Office of Science

Approval:

Based on the information presented in this document and at the ESAAB review, I approve Critical Decision 1, Approve Alternative Selection and Cost Range for the LBNF/DUNE Project.

Franklin M. Orr, Jr. 11/5/15
Franklin M. Orr, Jr. Date
Under Secretary for Science and Energy