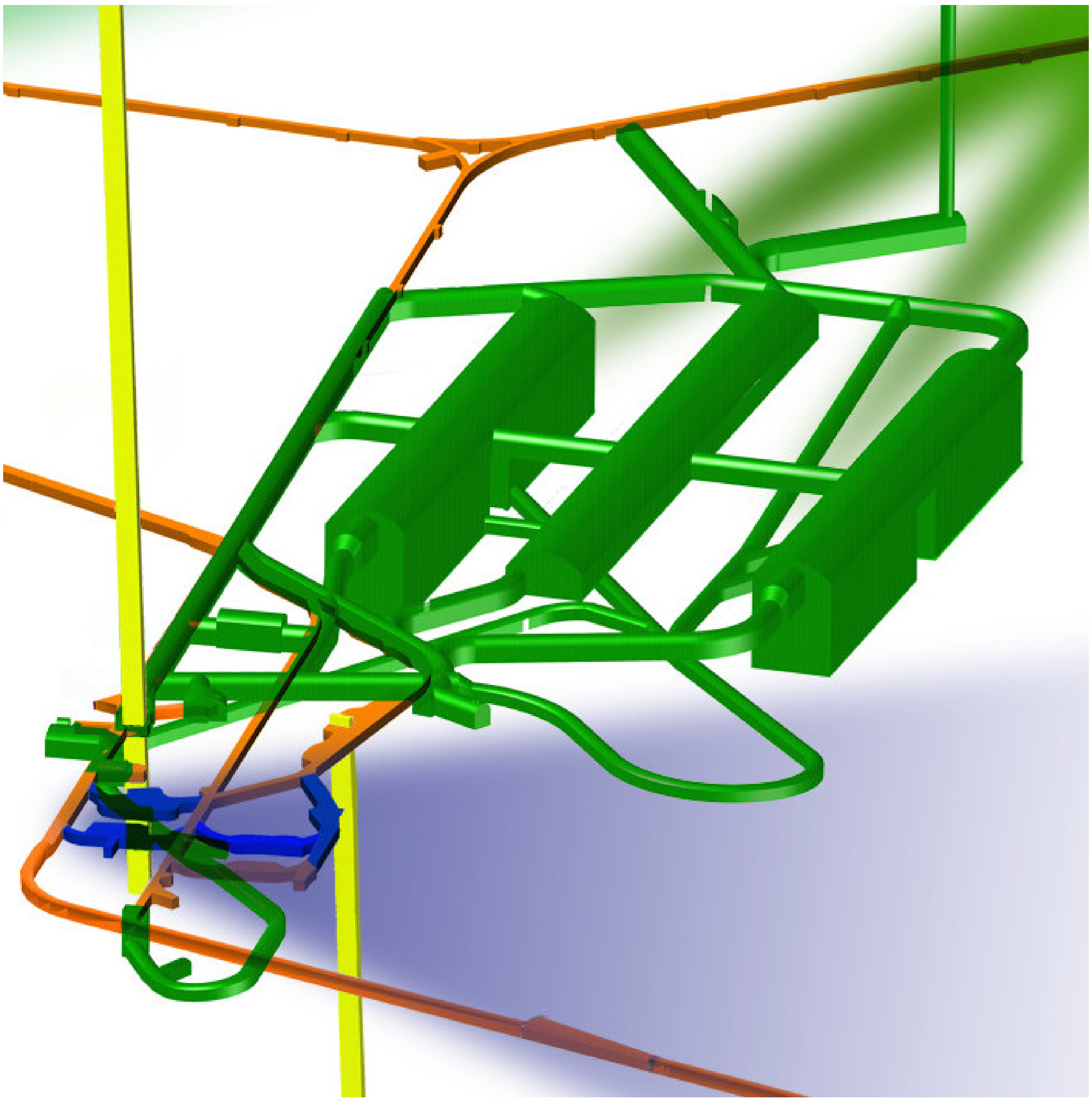
The Long-Baseline Neutrino Facility (LBNF) Far Site Conventional Facilities

Preliminary Design Report



October 8, 2015

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Chapter 1

Introduction

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1.1 The Long-Baseline Neutrino Facility for DUNE

cro-fscf

The global neutrino physics community is developing a multi-decade physics program to measure unknown parameters of the Standard Model of particle physics and search for new phenomena. The program will be carried out as an international, leading-edge, dual-site experiment for neutrino science and proton decay studies, which is known as the *Deep Underground Neutrino Experiment (DUNE)*, supported by the *Long-Baseline Neutrino Facility (LBNF)*.

To achieve its ambitious physics objectives as a world-class facility, this program has been conceived around three central components:

1. an intense, wide-band neutrino beam
2. a fine-grained near neutrino detector just downstream of the neutrino source
3. a massive liquid argon time-projection chamber (LArTPC) deployed as a far neutrino detector deep underground, 1,300 km downstream; this distance between the neutrino source and far detector – the *baseline* – is measured along the line of travel through the Earth

The neutrino beam and near detector will be installed at the Fermi National Accelerator Laboratory (Fermilab), in Batavia, Illinois. The far detector will be installed at the Sanford Underground Research Facility (SURF) in Lead, South Dakota. The experiment's detectors at the two sites will be designed, built, commissioned and operated by the international DUNE Collaboration. LBNF is the facility designed to support the experiment. LBNF will comprise

- the world's highest-intensity neutrino beam at Fermilab
- a set of underground caverns to house the DUNE far detector modules at SURF
- a beamline measurement system at the near site

- conventional facilities at both the near and far sites
- cryogenics infrastructure to support the DUNE detector at the far site

LBNF is hosted by Fermilab and its design and construction is organized as a DOE/Fermilab project incorporating international partners.

1.2 Strategy and Requirements

The strategy for executing the scientific program was presented in the LBNF/DUNE Conceptual Design Report (CDR)[1]. The program has been developed to meet the requirements set out in the P5 report [2] and takes into account the recommendations of the European Strategy for Particle Physics[3]. It adopts a model in which U.S. and international funding agencies share costs on the DUNE detectors, and the European Organization for Nuclear Research (CERN) and other participants provide in-kind contributions to the supporting infrastructure of LBNF. LBNF and DUNE will be tightly coordinated as DUNE collaborators design the detectors and infrastructure that will carry out the scientific program.

The requirements on LBNF derive from the DUNE Collaboration science requirements[4], which drive the space and functional needs of the far detector construction and operation, and from Environment, Safety and Health (ES&H) and facility operations requirements. The LBNF and DUNE requirements are maintained together in [4]. Conventional Facility requirements are detailed in the Arup 100% Preliminary Design Report[5].

The DUNE far detector is designed as a set of four 10-kt fiducial mass modules. The caverns and the services to the caverns will be as similar to one another as possible in order to implement efficiency in design, construction and operation. Figure 1.1 shows the layout of the underground caverns that will house the detector modules, and the separate cavern that will house utilities and cryogenics systems.

While the SURF site already meets many of the requirements from the geological, scientific and engineering standpoints, significant work is required to provide the space and infrastructure for the experiment's installation and operation.

This PDR presents the scope of the LBNF Far Site Conventional Facilities (FSCF) at SURF, the present and future states of the site, evaluation and assessment of its facilities and the provisioning of associated infrastructure such as power, water, plumbing, ventilation, etc. Also described are the tasks and processes planned for developing the surface and underground structures and the requisite safety measures.

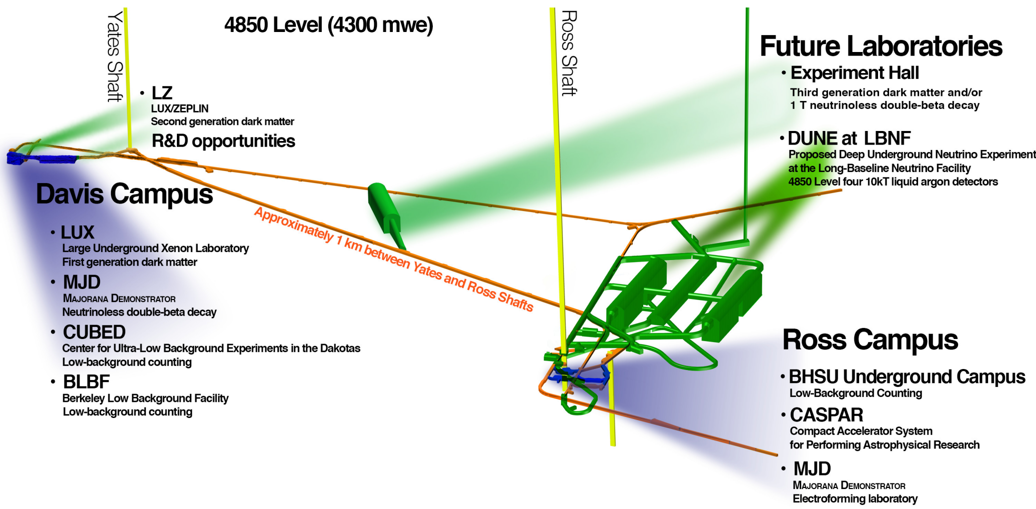

Figure 1.1: Underground cavern layout (SRK, Courtesy SURF)

1.3 Introduction to the Far Site Conventional Facilities

The scope of the FSCF includes design and construction for facilities on the surface and underground at SURF for DUNE.

The primary element of the Far Site Conventional Facilities (FSCF) is the set of underground spaces required to install, operate and support the multi-module cryogenic DUNE far detector. The underground conventional facilities include new excavated spaces at the 4850L for the detector modules, utility spaces for experiment equipment, utility spaces for facility equipment, drifts for access, and spaces required for construction. Underground infrastructure that FSCF must provide for DUNE includes power to experiment equipment, cooling systems for that equipment and cyberinfrastructure for data collection. Underground infrastructure required for the facility includes domestic (potable) water, industrial water for process use and fire suppression, fire detection and alarm systems, normal and standby power systems, a sump-pump drainage system for native and leak water around the detector, water drainage to the facility-wide pump discharge system, and cyberinfrastructure for communications and security. In addition to providing new spaces and infrastructure underground, FSCF enlarges some existing spaces for use, such as the access drifts from the Ross Shaft to the new caverns, and provides infrastructure for these spaces. New piping is provided in the shaft for cryogens (gas argon transfer line and nitrogen compressor suction and discharge lines) and water as well as for power cables and cyberinfrastructure.

Many buildings and utilities exist above-ground at SURF, some of which will be utilized for LBNF. The scope of the surface FSCF includes only that work necessary for LBNF; it does not include the general rehabilitation of buildings on the site, which remains the responsibility of SURF. Electrical substations and distribution will be upgraded to increase power and provide standby capability for life safety. An existing building will be remodeled to house both office space and an experiment/facility control room, and a new building will be constructed near the existing Ross Shaft to support cryogen transfer from the surface to the 4850L. To reduce the risk of failure of aging but essential support equipment during the construction and installation periods, several SURF infrastructure-reliability activities are included in the earlier phases of the LBNF Project. These include completion of the Ross Shaft rehabilitation, rebuilding of hoist motors, and replacement of the Oro Hondo fan. Failure of any of this aging infrastructure could limit or stop access to the underground.

1.4 The LBNF Far Site CF Preliminary Design Report

The *LBNF Far Site Conventional Facilities Preliminary Design Report* describes the preliminary designs for the conventional facilities planned for the Sanford Underground Research Facility (SURF), the LBNF Far Site. This document is an evolution of *LBNF/DUNE CDR Annex 3C: Conventional Facilities (CF) at the Far Site*, which was prepared for the LBNF/DUNE CD-1-Refresh Review in July 2015. The original LBNF/DUNE Conceptual Design Report volumes have been updated [6, 7, 8, 9] as required to provide context for the LBNF Far Site Conventional Facilities design.

The scope of this Preliminary Design Report (PDR) is limited to the LBNF Far Site Conventional Facilities (FSCF); the cryogenics infrastructure is not included.

1. This chapter provides a short introduction to LBNF, DUNE and the FSCF.
2. Chapter 2 summarizes the management structure for LBNF.
3. Chapter 3 describes the existing site conditions at SURF.
4. Chapter ?? describes the existing and planned surface buildings that will support the DUNE far detector, planned for installation at the 4850L of SURF.
5. Chapter ?? discusses the planned underground excavation.
6. Chapter ?? describes the underground infrastructure necessary to facilitate installation and operation of the DUNE far detector modules.
7. Chapter ?? describes the restoration and maintenance activities required at the SURF site that are included in the overall LBNF Project and planned to be executed as early Site Preparation.

This PDR is supported by a Design Report from the independent engineering firm, Arup, USA[5].

Chapter 2

Project Management

2.1 Project Structure and Responsibilities

The LBNF Project is charged by Fermilab and DOE to design and construct conventional and technical facilities needed to support the DUNE Collaboration. LBNF is organized as a DOE/Fermilab project incorporating in-kind contributions from international partners. At this time, the major international partner is CERN, the European Organization for Nuclear Research. LBNF works closely with DUNE through several coordinating groups to ensure scientific direction and coordination for executing the LBNF Project such that the requirements of the program are met.

LBNF works closely with SURF management to coordinate design and construction for the far site conventional facilities for the DUNE far detector. CERN is providing cryogenics equipment and engineering as part of the cryogenics infrastructure at SURF. The design and construction of LBNF is supported by other laboratories and consultants/contractors that provide scientific, engineering, and technical expertise. A full description of LBNF Project Management is contained in the LBNF/DUNE Project Management Plan[**?**].

LBNF coordinates with DUNE through regular technical team interactions between the two Projects as well as more formally through the Joint Management Team where day-to-day management coordination occurs, and the Experiment-Facility Interface Group, where major issues regarding interfaces and items affecting both Projects are discussed. In addition, the Projects share common Project Office staff and systems, and include a single, integrated project resource-loaded schedule and configuration management system.

LBNF consists of two major L2 subprojects, Far Site Facilities and Near Site Facilities, coordinated through a central Project Office located at Fermilab. Each L2 Project consists of two large L3 subprojects corresponding to the conventional and technical facilities, respectively, at each site. The project organizational structure, which includes leadership from major partners, is shown in Figure **??**.

The LBNF Project team consists of members from Fermilab, CERN, South Dakota Science and

Technology Authority (SDSTA), and Brookhaven National Laboratory (BNL). The team, including members of the Project Office as well as the L2 and L3 managers for the individual subprojects, is assembled by the Project Director. The Project team is shown in Figure 2.2. Line management for environment, safety and health, and quality assurance flows through the Project Director.

Through their delegated authority and in consultation with major stakeholders, the L2 Project Managers determine which of their lower-tier managers will be Control Account Managers (CAMs) for the Project WBS. L2 and L3 Project Managers are directly responsible for generating and maintaining the cost estimate, schedule, and resource requirements for their subprojects and for meeting the goals of their subprojects within the accepted baseline cost and schedule.

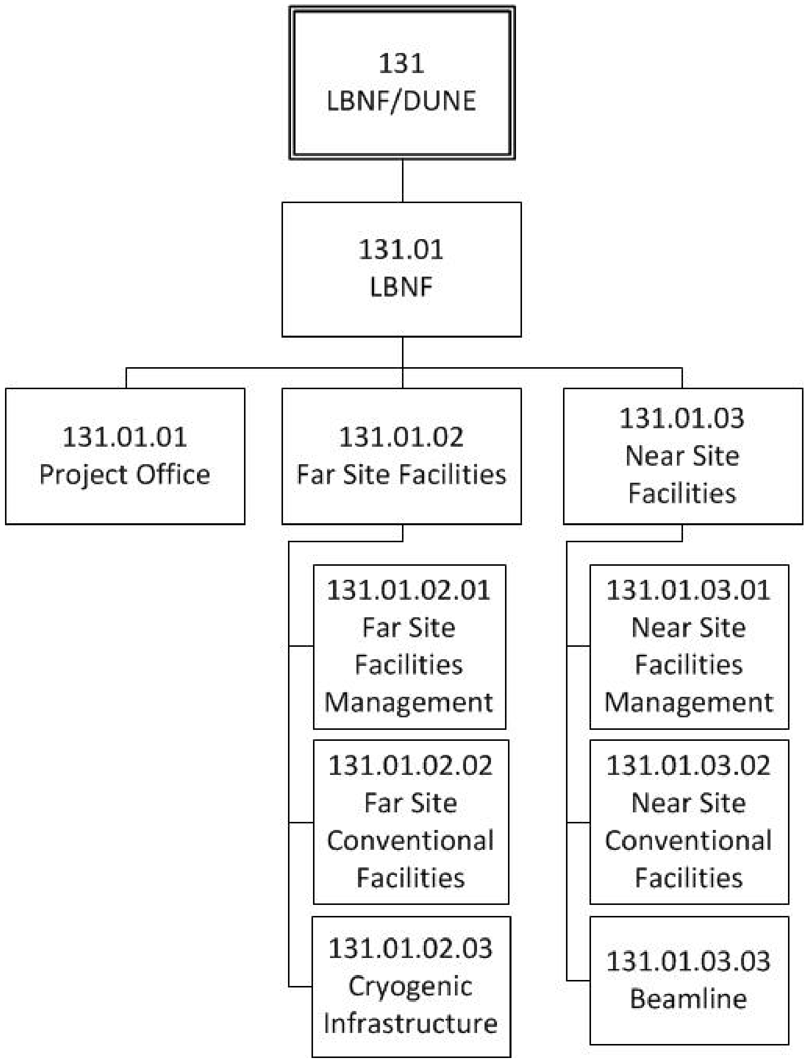

Figure 2.1: LBNF Work Breakdown Structure (WBS) to Level 3 (L3)

2.2 SDSTA and SURF

LBNF plans to construct facilities at SURF to house and support the DUNE far detector. SURF is owned by the state of South Dakota and managed by the SDSTA.

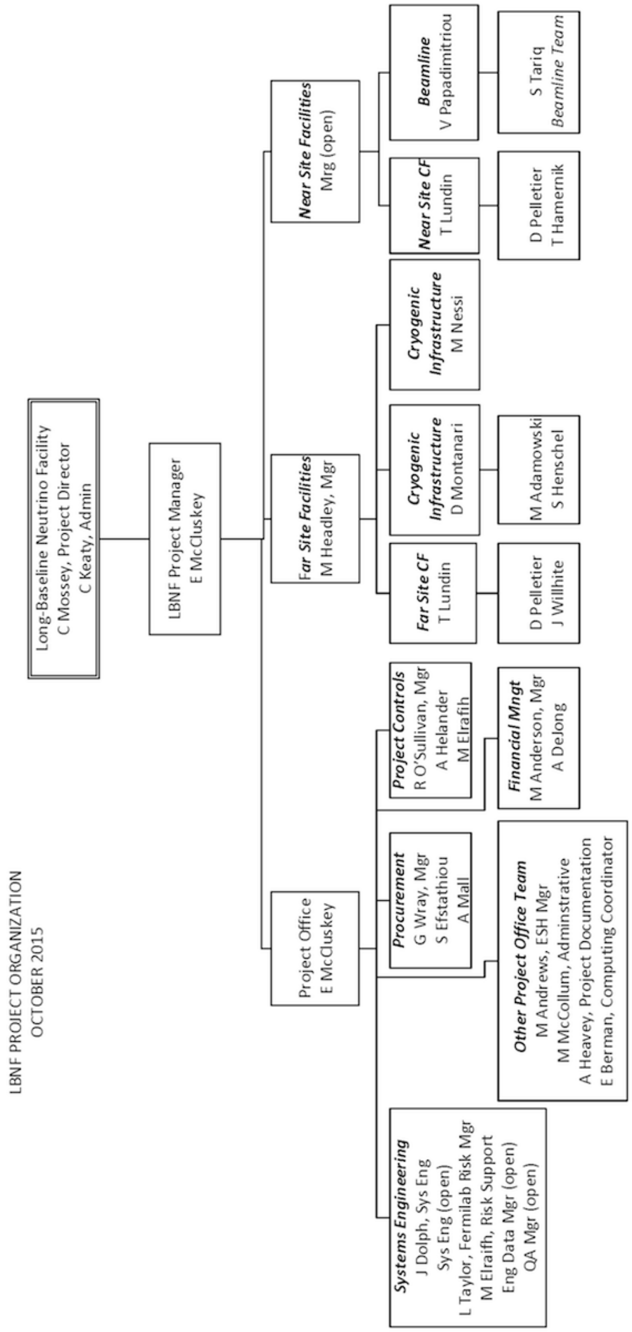

Figure 2.2: LBNF Organization

fig:lbnf

Current SURF activities include operations necessary for allowing safe access to the 4850L of the former mine, which houses the existing and under-development science experiments. The DOE is presently funding SDSTA ongoing operations through Lawrence Berkeley National Laboratory (LBNL) and its SURF Operations Office through FY16; starting in FY17 it is expected that this will change, and that funding will flow through Fermilab.

The LBNF Far Site Facilities Manager is also an employee of SDSTA and is contracted to Fermilab to provide management and coordination of the Far Site Conventional Facilities (CF) and Cryogenics Infrastructure subprojects. LBNF contracts directly with SDSTA for the design of the required CF at SURF; whereas the actual construction of the CF will be directly contracted from Fermilab. Coordination between SDSTA and the LBNF Project is necessary to ensure efficient operations at SURF. This will be facilitated via an agreement between SDSTA and Fermilab (not yet available) that defines responsibilities and methods for working jointly on LBNF Project design and construction. A separate agreement will be written for LBNF Operations.

2.3 CERN

The European Organization for Nuclear Research (CERN) is expected to significantly contribute to LBNF with technical components that are required to support the deployment of both the DUNE detectors and the neutrino beamline.

2.4 Coordination within LBNF

The LBNF Project organization is headed by the LBNF Project Director, who is also the Fermilab Deputy Director for LBNF; this person reports directly to the Fermilab Director.

Within FermilabâĂŹs organization, the LBNF organization includes two new divisions – Far-Site Facilities and Near-Site Facilities – as well as a project office, all led by the LBNF Project Director. They have been created to execute the Far Site Facilities and Near Site Facilities subprojects. The heads of these divisions report to the LBNF Project Manager. Any personnel working more than half-time on these subprojects would typically be expected to become a member of one of these divisions, while other contributors will likely be matrixed into part-time roles from other Fermilab Divisions. The heads of the other Fermilab Divisions work with the L2 and L3 project managers to supply the needed resources on an annual basis.

The LBNF WBS defines the scope of work. All changes to the WBS must be approved by the LBNF Project Manager prior to implementation. The current WBS is shown in Figure 2.1. For work on specific tasks required for the LBNF Project at the SURF site, SDSTA assigns engineers and others as required. This is listed in the resource-loaded schedule as contracted work from Fermilab for Far Site CF activities. CERN and Fermilab are developing a common cryogenics team to design and produce the Cryogenics Infrastructure subproject deliverables for the far site. CERN provides engineers and other staff as needed to complete their agreed-upon deliverables.

LBNF has formed several management groups with responsibilities as described below. More detail is provided in the PMP

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LBNF uses a *Project Management Board* to provide formal advice to the Project Director on matters of importance to the LBNF Project as a whole. Such matters include (but are not limited to) those that

- have significant technical, cost, or schedule impact on the Project
- have impacts on more than one L2 subproject
- affect the management systems for the Project
- have impacts on or result from changes to other Projects on which LBNF is dependent
- result from external reviews or reviews called by the Project Director

The Project Management Board serves as the

- LBNF Change Control Board, as described in the Configuration Management Plan[?]
- Risk Management Board, as described in the Fermilab Risk Management Procedure for Projects [?]

The Far Site CF (FSCF) Project has engaged three international experts in hard-rock underground construction to advise it periodically through the design and construction process regarding excavation at SURF. This team, the FSCF *Neutrino Cavity Advisory Board (NCAB)*, meets at the request of the FSCF-PM, generally on-site, to discuss specific technical issues. The NCAB produces a report with its findings and conclusions for Project information and action.

2.5 LBNF/DUNE Advisory and Coordinating Structures

A set of structures has been established to provide coordination among the participating funding agencies, oversight of the LBNF and DUNE projects, and coordination and communication between the two projects. These structures and the relationships among them are shown in Figure 2.3 and are described in this section.

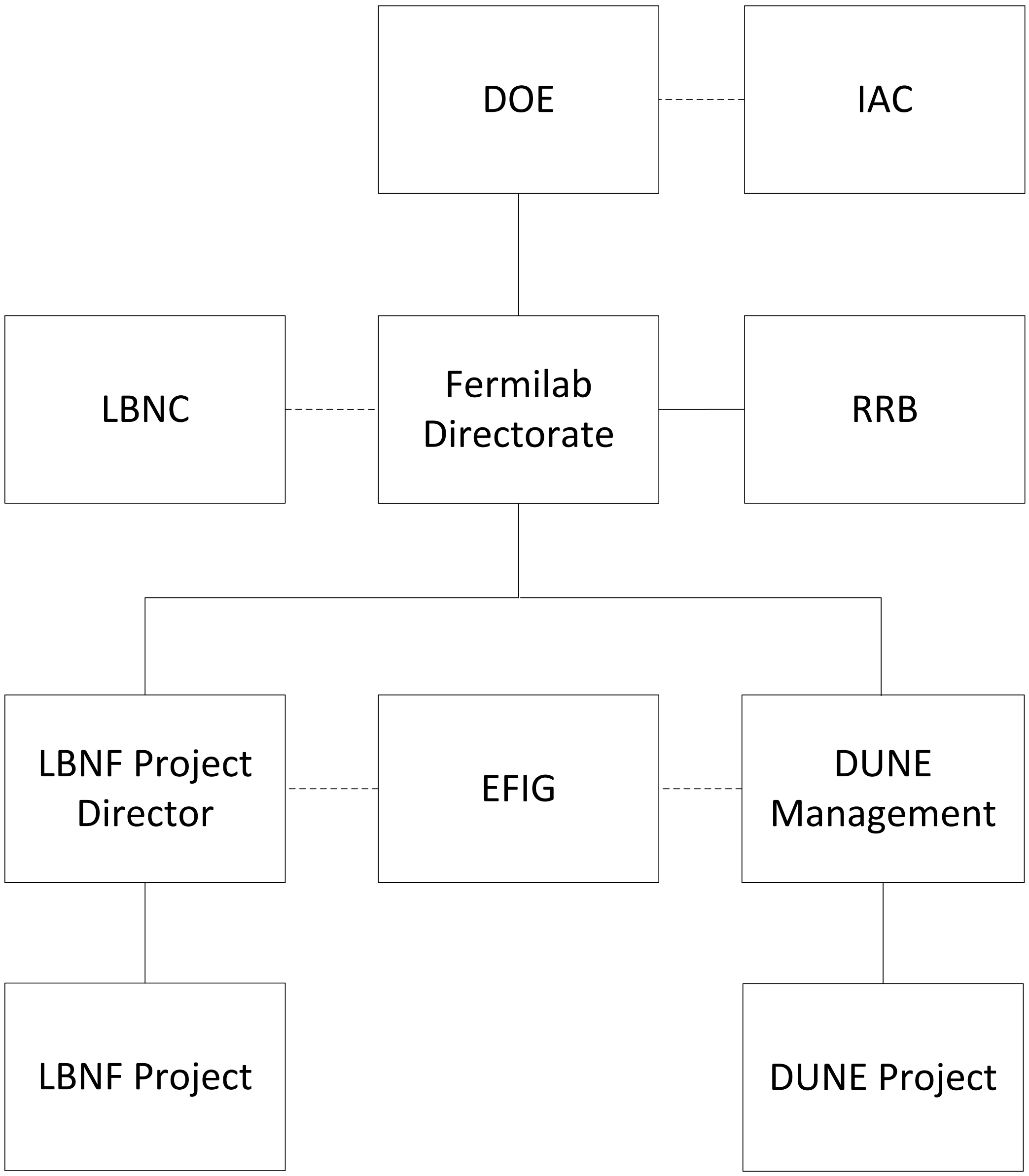

Figure 2.3: Joint LBNF/DUNE management structure

2.5.1 International Advisory Council (IAC)

The International Advisory Council (IAC) is composed of regional representatives, such as CERN, and representatives of funding agencies that make major contributions to LBNF infrastructure or to DUNE. The IAC acts as the highest-level international advisory body to the U.S. DOE and the FNAL Directorate, and facilitates high-level global coordination across the entire enterprise (LBNF and DUNE). The IAC is chaired by the DOE Office of Science Associate Director for High Energy Physics and includes the FNAL Director in its membership. The council meets as needed and provides pertinent advice to LBNF and DUNE through the Fermilab Director.

Specific responsibilities of the IAC include, but are not limited to, the following:

- During the formative stages of LBNF and DUNE the IAC helps to coordinate the sharing of responsibilities among the agencies for the construction of LBNF and DUNE. Individual agency responsibilities for LBNF will be established in bilateral international agreements with the DOE. Agency contributions to DUNE will be formalized through separate agreements.

- The IAC assists in resolving issues, especially those that cannot be resolved at the Resources Review Boards (RRB) level, e.g., issues that require substantial redistributions of responsibilities among the funding agencies.

- The IAC assists as needed in the coordination, synthesis and evaluation of input from Project reports charged by individual funding agencies, LBNF and DUNE Project management, and/or the IAC itself, leading to recommendations for action by the managing bodies.

The DUNE Co-Spokespersons and/or other participants within the Fermilab neutrino program will be invited to sessions of the IAC as needed. Council membership may increase as additional funding agencies from

2.5.2 Resources Review Boards (RRB)

The Resources Review Boards (RRB) are composed of representatives from all funding agencies that sponsor LBNF and DUNE, and from the Fermilab management. The RRB provides focused monitoring and detailed oversight of each of the Projects. The Fermilab Director in coordination with the DUNE RC defines its membership. A representative from the Fermilab Directorate chairs the boards and organizes regular meetings to ensure the flow of resources needed for the smooth progress of the enterprise and for its successful completion.

The managements of the DUNE Collaboration and the LBNF Project participate in the RRB meetings and make regular reports to the RRB on technical, managerial, financial and administrative matters, as well as on status and progress of the DUNE Collaboration. DUNE Finance Board members who serve as National Contacts from the sponsoring funding agencies will be invited to RRB sessions.

Two groups exist within the RRB: RRB-LBNF and RRB-DUNE. Each of these groups monitors progress and addresses the issues specific to its area while the whole RRB deals with matters that concern the entire enterprise. The RRB meet biannually; these meetings start with a plenary opening session and are followed by RRB-LBNF and RRB-DUNE sessions. As DUNE progresses toward experimental operations, RRB-Computing sessions will convene.

The RRB employs standing DUNE and LBNF *Scrutiny Groups* as needed to assist in its responsibilities. The scrutiny groups operate under the RRB, and provide detailed information on financial and personnel resources, costing, and other elements under the purview of the RRB.

Responsibilities of the RRB include

- assisting the DOE and the FNAL Directorate, with coordinating and developing any required international agreements between partners
- monitoring and overseeing the Common Projects and the use of the Common Funds

  where are these defined?

- monitoring and overseeing general financial and personnel support
- assisting the DOE and the FNAL Directorate with resolving issues that may require reallocation of responsibilities among the Project's funding agencies
- reaching consensus on a maintenance and operation procedure, and monitoring its function
- approving the annual Common Fund budget of DUNE for construction and for maintenance and operation

2.5.3 Fermilab, the Host Laboratory

As the host laboratory, Fermilab has a direct responsibility for the design, construction, commissioning and operation of the facilities and infrastructure (i.e., LBNF) that support the science program. In this capacity, Fermilab reports directly to the DOE through the Fermilab Site Office (FSO). Fermilab also has an important oversight role for the DUNE Project itself as well as an important coordination role in ensuring that interfaces between the two Projects are completely understood.

Fermilab's oversight of the DUNE Collaboration and detector construction project is carried out through

- regular meetings with the Collaboration leadership
- approving the selection of Collaboration spokespersons

- providing the Technical and Resource Coordinators
- convening and chairing the Resources Review Boards
- regular scientific reviews by the Physics Advisory Committee (PAC) and Long-Baseline Neutrino Committee (LBNC)
- Director's Reviews of specific management, technical, cost and schedule aspects of the detector construction project
- other reviews as needed

2.5.4 DUNE Collaboration

The Collaboration, in consultation with the Fermilab Director, is responsible for forming the international DUNE Project team responsible for designing and constructing the detectors. The Technical Coordinator (TC) and Resource Coordinator (RC) serve as the lead managers of this international project team and are selected jointly by the spokespersons and the Fermilab Director. Because the international DUNE Project incorporates contributions from a number of different funding agencies, it is responsible for satisfying individual tracking and reporting requirements associated with the different contributions.

2.5.5 Long-Baseline Neutrino Committee (LBNC)

The Long-Baseline Neutrino Committee (LBNC), composed of internationally prominent scientists with relevant expertise, provides external scientific peer review for LBNF and DUNE regularly. The LBNC reviews the scientific, technical and managerial decisions and preparations for the neutrino program. It acts in effect as an adjunct to the Fermilab Physics Advisory Committee (PAC), meeting on a more frequent basis than the PAC. The LBNC may employ DUNE and LBNF Scrutiny Groups for more detailed reports and evaluations. The LBNC members are appointed by the Fermilab Director.

2.5.6 Experiment-Facility Interface Group (EFIG)

Close and continuous coordination between DUNE and LBNF is required to ensure the success of the combined enterprise. An Experiment-Facility Interface Group (EFIG) was established in January 2015 to oversee and ensure the required coordination both during the design/construction and operational phases of the program. This group covers areas including:

- interface between the near and far detectors and the corresponding conventional facilities

- interface between the detector systems provided by DUNE and the technical infrastructure provided by LBNF
- design and operation of the LBNF neutrino beamline

The EFIG is chaired by the two deputy directors of Fermilab. Its membership includes the LBNF Project Director and Project Manager, and the DUNE Co-Spokespersons, Technical Coordinator, Resource Coordinator and the CERN-LBNF Project Manager. In consultation with the DUNE and LBNF management, the EFIG Chairs will extend the membership as needed to carry out the coordination function. In addition, the DOE Federal Project Director for LBNF, the Fermilab Chief Project Officer, and a designated representative of the SDSTA will serve ex officio. The EFIG Chairs designate a Secretary of the EFIG, who keeps minutes of the meetings and performs other tasks as requested by the Chair.

It is the responsibility of the EFIG Chairs to report EFIG proceedings to the Fermilab Director and other stakeholders. It is the responsibility of the DUNE spokespersons to report EFIG proceedings to the rest of the Collaboration. The EFIG meets weekly or as needed.

Chapter 3

Existing Site Conditions

The SDSTA currently operates and maintains the Sanford Underground Research Facility (SURF) at the former Homestake mine in Lead, South Dakota. The SURF property comprises 186 acres on the surface and 7,700 acres underground. The SURF Surface Campus includes approximately 253,000 gross square feet (gsf) of existing structures. Using a combination of private funds through T. Denny Sanford, South Dakota Legislature-appropriated funding, and a federal Department of Housing and Urban Development (HUD) Grant, the SDSTA has made significant progress in stabilizing and rehabilitating the SURF facility to provide for safe access and prepare the site for new laboratory construction. These efforts have included dewatering of the underground facility and mitigating and reducing risks

beyond those identified in the (year) assessment of the existing facility conditions done for (this needs some context)

the former Deep Underground Science and Engineering Laboratory (DUSEL).

Figure 3.1 shows SURF's location within the region as a part of the northern Black Hills of South Dakota. Figure 3.2 outlines the SURF site in relationship to the city of Lead, South Dakota, and points out various significant features of Lead including the surrounding property that still remains under the ownership of Barrick Gold Corporation.

...who owned and operated the Homestake Mine on the site until (whatever year)? (this needs context)

3.1 Existing Site Conditions Evaluation

The facility conditions as of

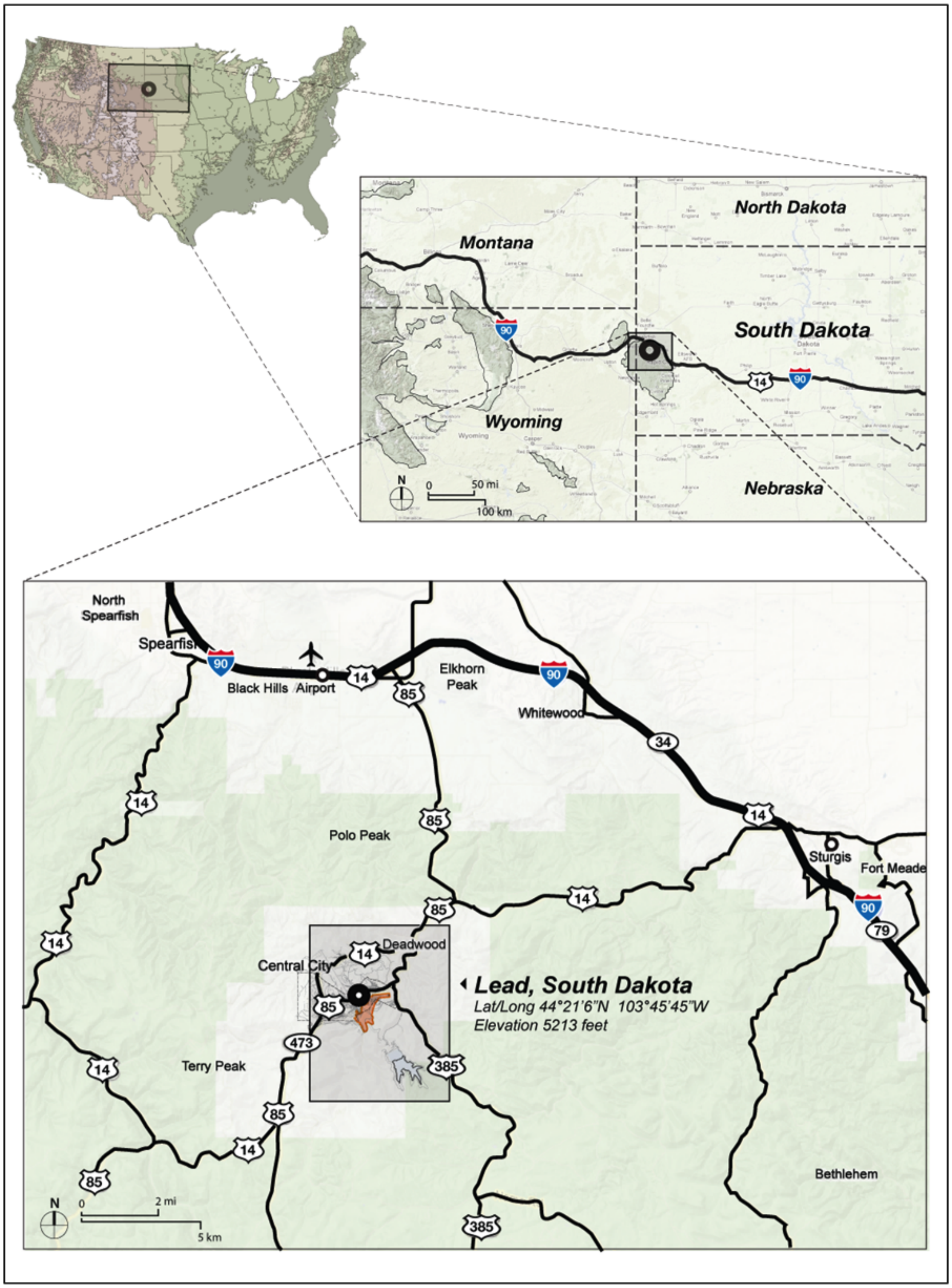

Figure 3.1: Regional context showing the city of Lead, South Dakota. (Dangermond Keane Architecture, Courtesy SURF)

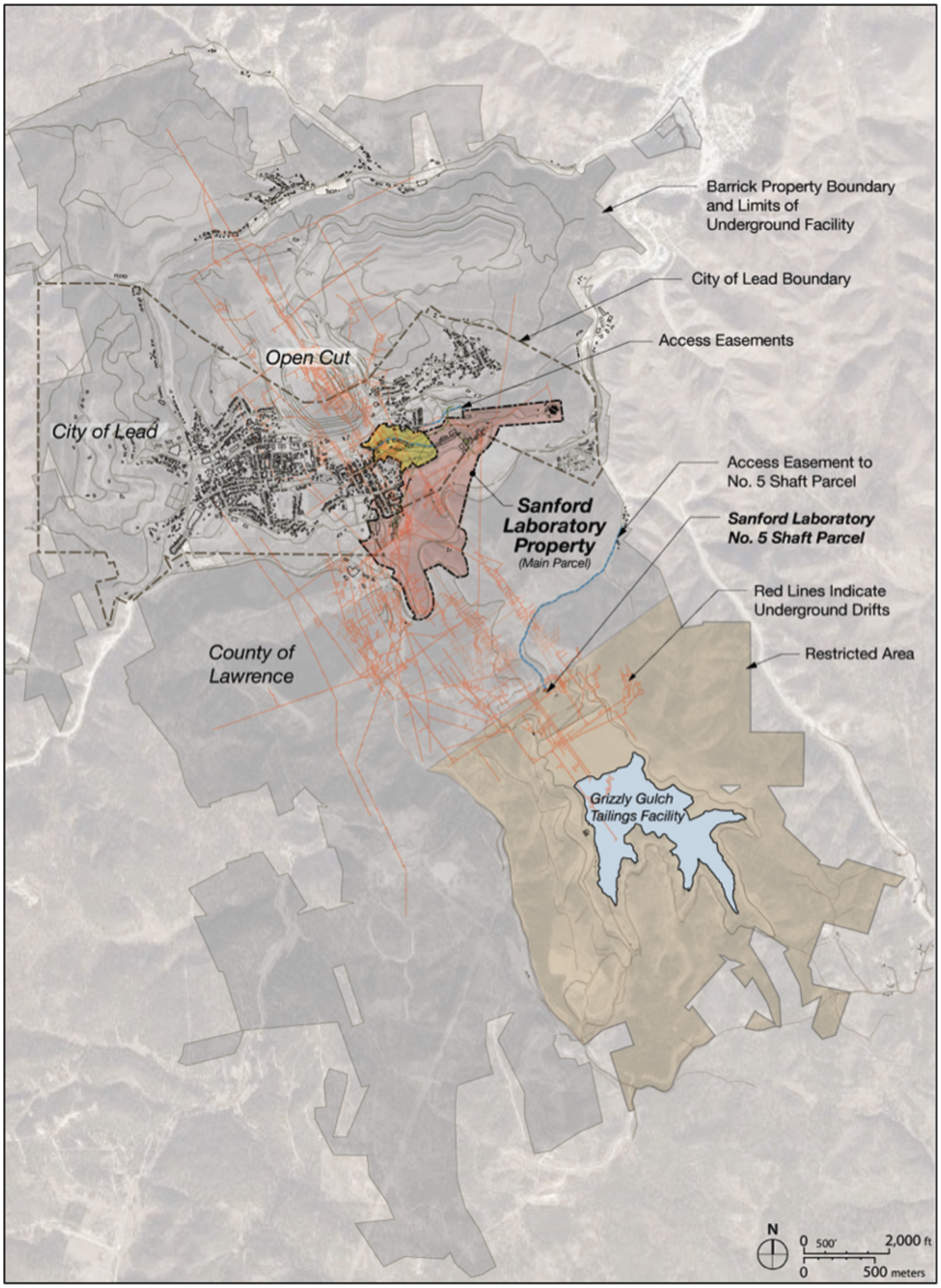

Figure 3.2: SURF Complex shown in the context of the city of Lead, South Dakota, and the property remaining under ownership of Barrick. Area shown in yellow is a potential future expansion of the SDSTA property. [Dangermond Keane Architecture, Courtesy of SURF]

fig:surf

year

were assessed by HDR

who is HDR?

as part of the DUSEL Preliminary Design to evaluate the condition of existing facilities and structures on the Yates, and Ross Campuses. They are documented in the DUSEL PDR, Section 5.2.4, [10]

citation

. The portions of DUSEL's assessment pertinent to the LBNF Project are included here; they have been edited to reflect current activities and conditions. References to the DUSEL Project are from that time, and are now considered historic.

The HDR assessments reviewed the condition of buildings that were proposed for continued use in their then-current function, new use, or potential demolition. Assessments for buildings were performed on their architectural, structural, mechanical/electrical/plumbing (MEP), civil, environmental, and historic aspects. Site assessments looked at civil, landscape, environmental, and historic aspects. Facility-wide utilities such as electrical, steam distribution lines, water and sewer systems were also assessed. In particular:

- Buildings proposed for reuse were evaluated for preliminary architectural and full structural, environmental, and historic assessments.

  you evaluate for an assessment? Not clear what you want to say here. 'evaluated or assessed with regard to these aspects'? 'given a preliminary evaluation to see if they're ready for an assessment'? I'm confused (same comment next bullet)

- Buildings proposed for demolition were evaluated for preliminary historic assessments.
- Preliminary MEP assessments were performed on the Ross Substation, #5 Shaft fan, Oro Hondo fan, Oro Hondo substation, and on the general site utilities for the Ross, Yates, and Ellison Campuses.
- The waste water treatment plant (WWTP) received preliminary architectural and structural assessments and a full MEP assessment.
- Preliminary civil assessments of the Kirk Portal site and Kirk to Ross access road were also completed.

The assessment was completed in three phases and the detailed reports are included in the appendices of the DUSEL PDR as:

- Phase I Report, Site Assessment for Surface Facilities and Campus Infrastructure to Support Laboratory Construction and Operations (DUSEL PDR Appendix 5.E)

- Phase II Site and Surface Facility Assessment Project Report (DUSEL PDR Appendix 5.F)

- Phase II Roof Framing Assessment (DUSEL PDR Appendix 5.G)

3.2 Evaluation of Geology and Existing Excavations

cond-geo

The accessible underground mine workings at SURF within the footprint of the former Homestake Gold Mine are extensive. Over the life of the gold mine, over 360 miles of drifts (tunnels) were mined, and shafts and winzes were sunk to gain access to depths in excess of 8,000 feet. A number of underground workings are being refurbished by SURF, and new experiments are being installed at the 4850L, the same level as proposed for the LBNF underground facilities. Geotechnical investigations and initial geotechnical analyses were completed by Arup, USA

cite

for the DUSEL Preliminary Design and are described in detail in the DUSEL PDR. Additional geotechnical investigation and analyses were performed, also by Arup, in 2014 specific to LBNF. This section provides summaries of these two efforts, including work completed for DUSEL that is applicable to LBNF (the text is excerpted from the DUSEL Preliminary Design Report, Chapter 5 Section 3). Much of the work completed for the alternative detector technology considered during the DUSEL timeframe, a water Cherenkov detector (WCD), is also applicable to the current LBNF design at the 4850L.

3.2.1 Geologic Setting

-geo-set

SURF is sited within a metamorphic complex containing the Poorman, Homestake, Ellison and Northwestern Formations (oldest to youngest), which are sedimentary and volcanic in origin. An amphibolite unit (Yates Member) is present within the lower known portions of the Poorman Formation. The LBNF caverns have been located in the Poorman formation to isolate them from the remainder of the level. The layout adopted on the 4850L attempts to optimize the needs for ventilation isolation, access control, and orientation relative to the beamline.

3.2.2 Rock Mass Characteristics: LBNF

geo-rock

Following a similar strategy as DUSEL, LBNF initiated a second geotechnical program in 2013 to evaluate the specific location under consideration and evaluate its appropriateness for the proposed design. This was undertaken in two phases. The first phase was a mapping of the existing spaces surrounding the proposed rock mass using both visual techniques and laser scanning to understand the rock mass and to inform the scope of the second phase. The second phase included drilling of four HQ (2.5-in diameter) core holes ranging in length from 477 to 801 feet as well as two 6-in diameter core holes ∼30 ft each. The smaller diameter cores were then evaluated for the following characteristics:

- core recovery percent
- rock quality designation (RQD) percent
- rock type, including color, texture, degree of weathering, and strength
- mineralogy and presence of magnetic sulfides
- character of discontinuities, joint spacing, orientation, aperture
- roughness, alteration, and infill (if applicable)

Representative samples were selected from the overall core to test material strength and chemical characteristics. The geotechnical site investigations area on the 4850L, showing boreholes is presented in Figure 3.3.

The holes from which the smaller diameter core was removed were studied in several ways. An absolute survey was conducted to allow the core holes to be plotted relative to cavern designs. An optical televiewer was passed through each small hole to visualize the rock mass. This technique allows visualization of foliation, joint openings, healed joints, and geological contact between rock types. An acoustical imaging device was also used in one hole to complement the optical information. The permeability of the rock was tested by pressurizing the small holes at various intervals to determine whether joints allowed for the flow of water outside of the holes (hydraulic conductivity). In all cases, the hydraulic conductivity was well below what can be accomplished using manmade techniques such as grouting. Two of the small holes were plugged and instrumented to determine whether water would flow into the holes over time. This test found very low flow rates (.0013 – .0087 gpm). Ongoing evaluation of pressure build in these holes was inconclusive, as blast-induced fracturing near the existing drifts allow the holes to depressurize outside of the

range of the?

test instruments.

The larger (6-in) diameter cores and holes were used for strength and stress testing. In situ stress was tested by drilling a smaller diameter hole first, then gluing a strain gauge at 30 – 36 feet within the depth. As the larger diameter core was removed, this strain gauge recorded the relaxation of the rock. The removed core was re-drilled to provide smaller diameter samples at specific orientations for strength testing, as the strength of the material varies based on applied force direction relative to the foliation of the rock. These samples were also tested for time-dependent movement.

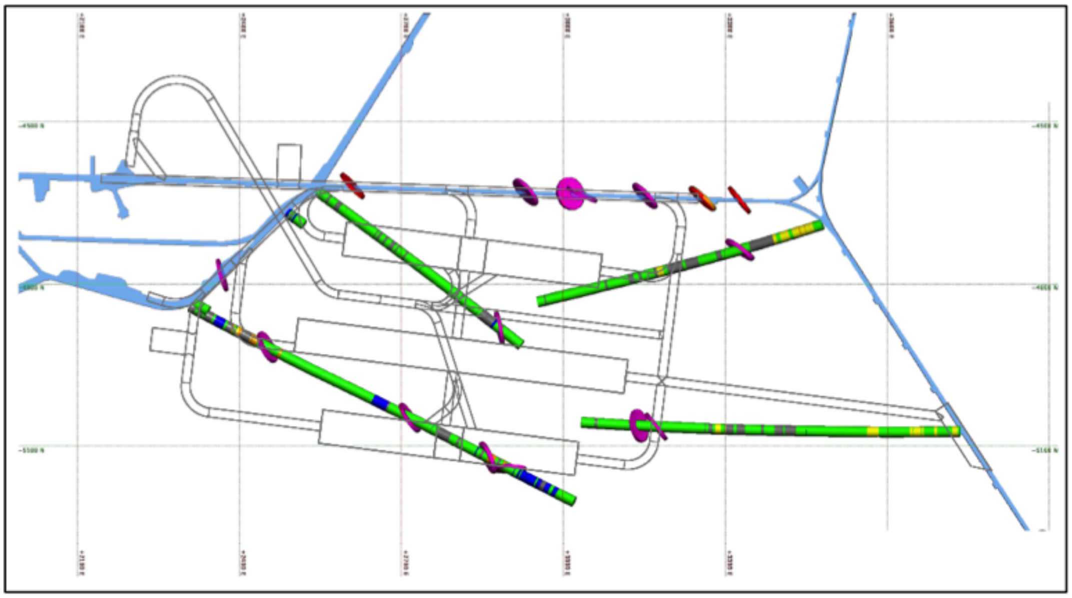

Figure 3.3: LBNF core locations and geological features

LBNF reviewed the analysis performed by Arup by enlisting industry leaders as part of a Neutrino Cavity Advisory Board (NCAB). This board reviewed the approach and results of the geotechnical investigation program as well as the preliminary excavation design. Their conclusions indicated that no additional drilling would be required to provide design information for the project and the overall design approach was appropriate. The board provided many recommendations that will advance the design, for example, replacement of wire mesh with fiber-reinforced shotcrete in all excavations, reduction of the distance between caverns, and optimization of the ground support aimed at replacing cable support wherever possible.

For further details, see Arup's Geotechnical Interpretive Report [11].

citation

3.2.3 Geologic Conclusions

Recovery of rock cores was performed along with geologic mapping to determine if discontinuities in the rock mass exist that could cause difficulties in the excavation and maintenance of the planned caverns. In general, the proposed locations of the excavations appear to be free of problematic structures. This information, along with measurement of in situ stresses, has allowed numerical modeling of the stresses associated with the anticipated excavations. A sample of some of the initial modeling is provided in Figure 3.4.

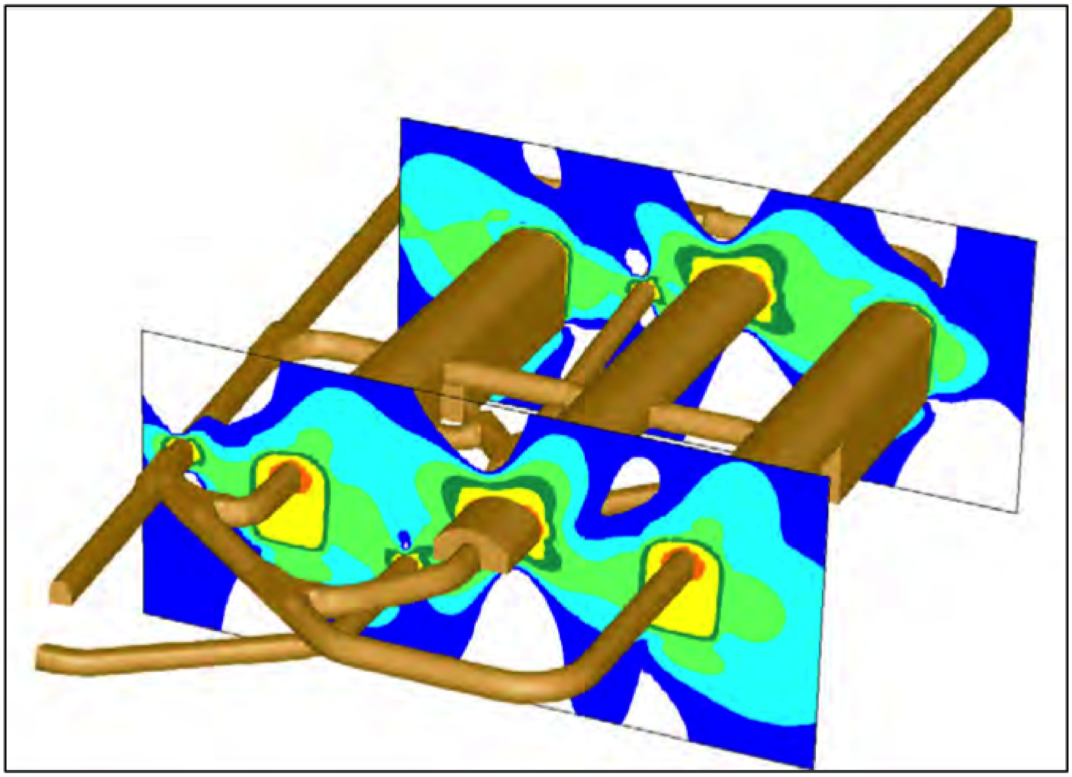

Figure 3.4: Contour of stress safety factor indicating influences between caverns fig:cont

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