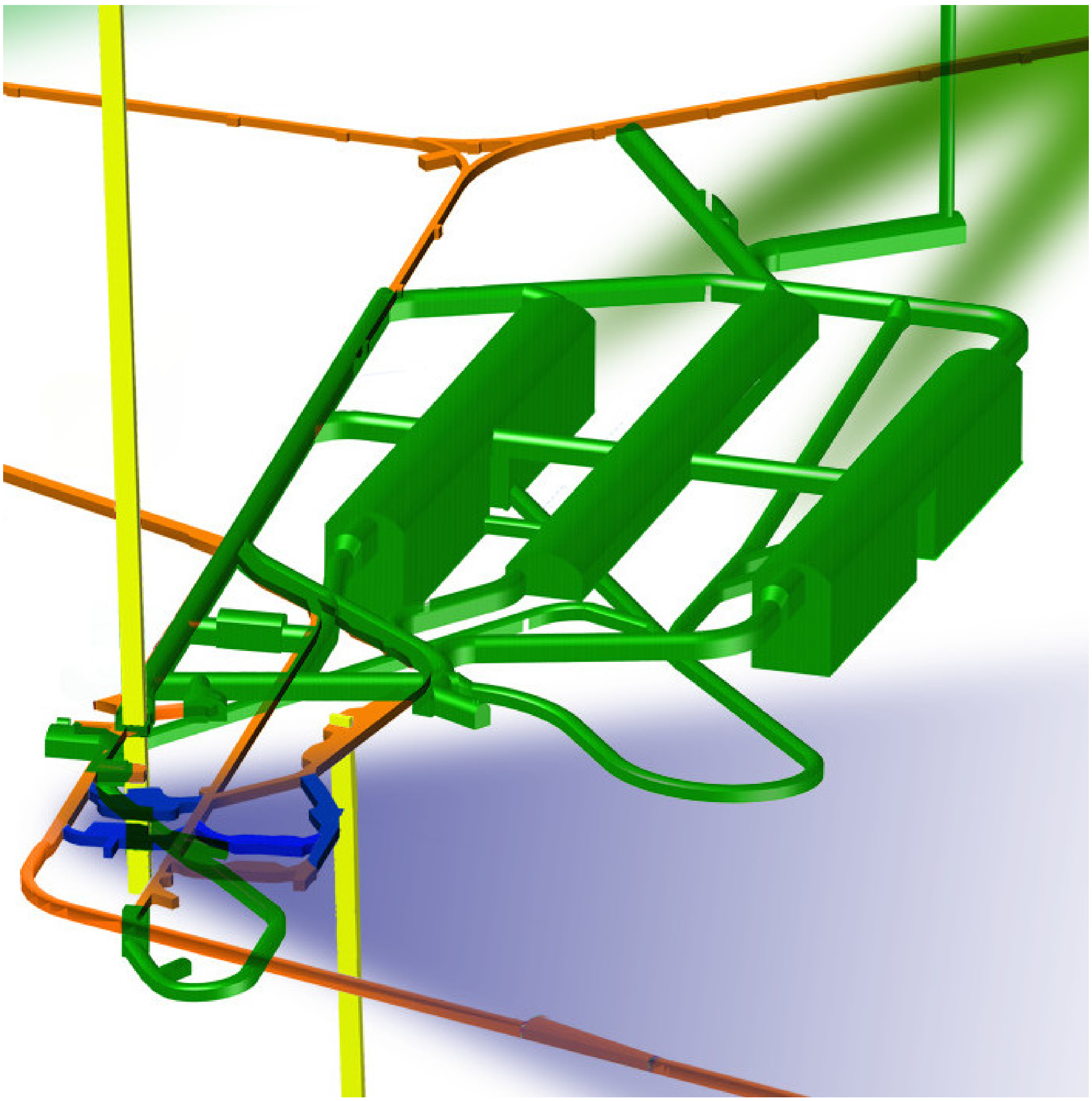
The Long-Baseline Neutrino Facility (LBNF)
Far Site Facilities

Preliminary Design Report



October 5, 2015

1

Contents

List of Figures

List of Tables

Todo list

Chapter 1

Introduction

1.1 The Long-Baseline Neutrino Facility for DUNE

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)*. The detectors for this experiment will be designed, built, commissioned and operated by the international DUNE Collaboration. The facility required to support this experiment, the *Long-Baseline Neutrino Facility (LBNF)*, is hosted by the Fermi National Accelerator Laboratory (Fermilab) and its design and construction is organized as a DOE/Fermilab project incorporating international partners.

Together LBNF and DUNE will comprise the world's highest-intensity neutrino beam at Fermilab, in Batavia, IL, a high-precision near detector on the Fermilab site, a massive liquid argon time-projection chamber (LArTPC) far detector installed deep underground at the Sanford Underground Research Facility (SURF), 1,300 km away in Lead, SD, and all of the conventional and technical facilities necessary to support the beamline and detector systems.

The strategy for executing the experimental 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 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 scope of LBNF is

- an intense neutrino beam aimed at the far site

- a beamline measurement system at the near site

now part of LBNF/beamline, right?

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

The DUNE detectors include

- a high-performance neutrino detector located a few hundred meters downstream of the neutrino source
- a massive liquid argon time-projection chamber (LArTPC) neutrino detector located deep underground at the far site

The scope of LBNF at SURF includes both conventional facilities (CF) and cryogenics infrastructure to support the DUNE far detector. The requirements on LBNF derive from DUNE Collaboration science requirements[4], which drive the space and functions necessary to construct and operate the far detector. Environment, Safety and Health (ES&H) and facility operations requirements also provide input to the design. 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 to enable efficiency in design and construction as well as operation. Figure 1.1 shows the layout of the underground caverns that will house the detector modules, with a separate cavern to house utilities and cryogenics systems.

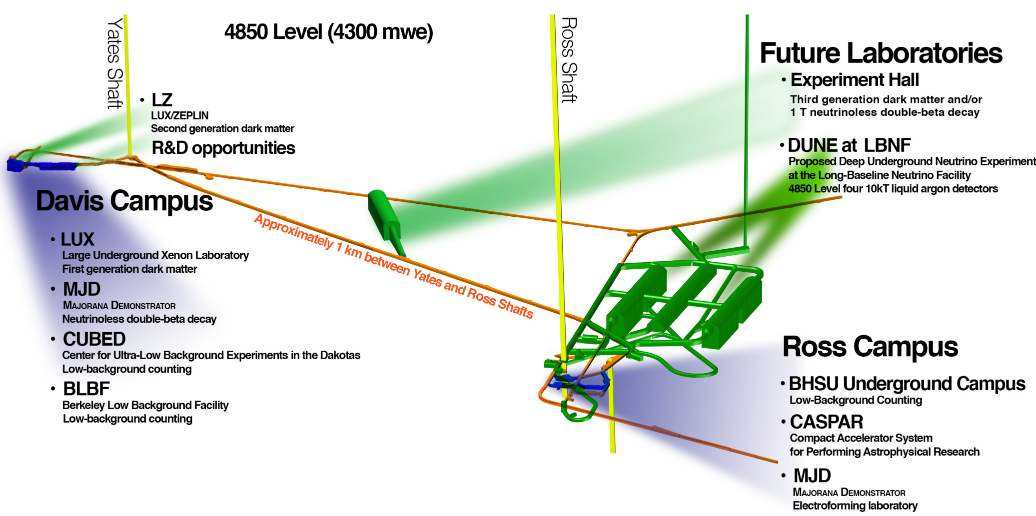


Figure 1.1: Underground cavern layout (SRK, Courtesy SURF)

1.2 Introduction to the Far Site Conventional Facilities

This PDR presents the scope and necessary steps required to develop the LBNF Far Site Conventional Facilities (FSCF) at SURF. The key element of the FSCF is the underground space required to install and support the operations of the multi-module DUNE far detector. An overview of the 4850L at SURF where the underground facilities will be developed is shown in Figure 1.2.

Figure 1.2: Far Site: Main components at the 4850 level (underground)

While the SURF site already meets many requirements from the geological, scientific and engineering standpoint, significant work is required to provide adequate space and the infrastructure support needed for the experiment's installation and operation. The present and future state of the site, evaluation and assessments of the facilities and the associated provisioning of infrastructure such as power, water, plumbing, ventilation, etc., are described in this report. Also described are the safety measures and planned steps to develop the surface and underground structures.

The scope of the FSCF includes design and construction for facilities on the surface and underground at SURF. The underground conventional facilities include new excavated spaces at the 4850L for the detector, utility spaces for experimental equipment, utility spaces for facility equipment, drifts for access, as well as construction-required spaces. Underground infrastructure provided by FSCF for the experiment includes power to experimental equipment, cooling systems and cyberinfrastructure. Underground infrastructure necessary for the facility includes domestic (potable) water, industrial water for process and fire suppression, fire detection and alarm, 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 and provides infrastructure in some existing spaces for use, such as the access drifts from the Ross Shaft to the new caverns. 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 power conduits and cyberinfrastructure.

As it exists today, SURF has many surface buildings and utilities, some of which will be utilized for LBNF. The scope of the above ground FSCF includes only that work necessary for LBNF, and not for 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. Additional surface scope includes remodeling of an existing building for both office space and to house an experiment/facility control room, and a new building to support cryogen transfer from the surface to the underground near the existing Ross Shaft. To reduce risk of failure of essential but aging support equipment during the construction and installation period, several SURF infrastructure-reliability activities are included as early activities in LBNF. These include completion of the Ross Shaft rehabilitation, rebuilding of hoist motors, and replacement of the Oro Hondo fan; if not addressed, failure of any of this aging infrastructure could limit or stop access to the underground.

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

1.3 Structure of this Report

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 4 describes the existing and planned surface buildings that will support the DUNE far detector, planned for installation at the 4850L of SURF.
5. Chapter 5 discusses the planned underground excavation.
6. Chapter 6 describes the underground infrastructure that will directly interface to the DUNE far detector modules.

Chapter 2

Project Management

intro-pm

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[?]. PMP-10770

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.

from CDR vol 3 ch 2

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 2 1.

from CDR vol 1 4.2

The LBNF Project team consists of members from Fermilab, CERN, South Dakota Science and Technology Authority (SDSTA), and 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 to WBS Level 3 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.

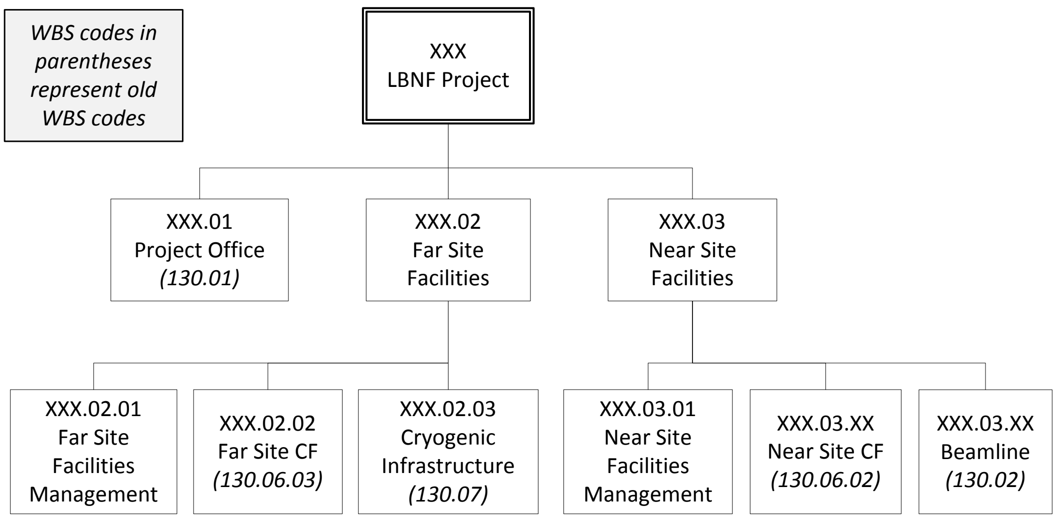


Figure 2.1: LBNF Work Breakdown Structure (WBS) to level 3

2.2 SDSTA and SURF

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

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; this is expected to change to funding through Fermilab starting in FY17.

The LBNF Far Site Facilities Manager is also an employee of SDSTA and is contracted to Fer-

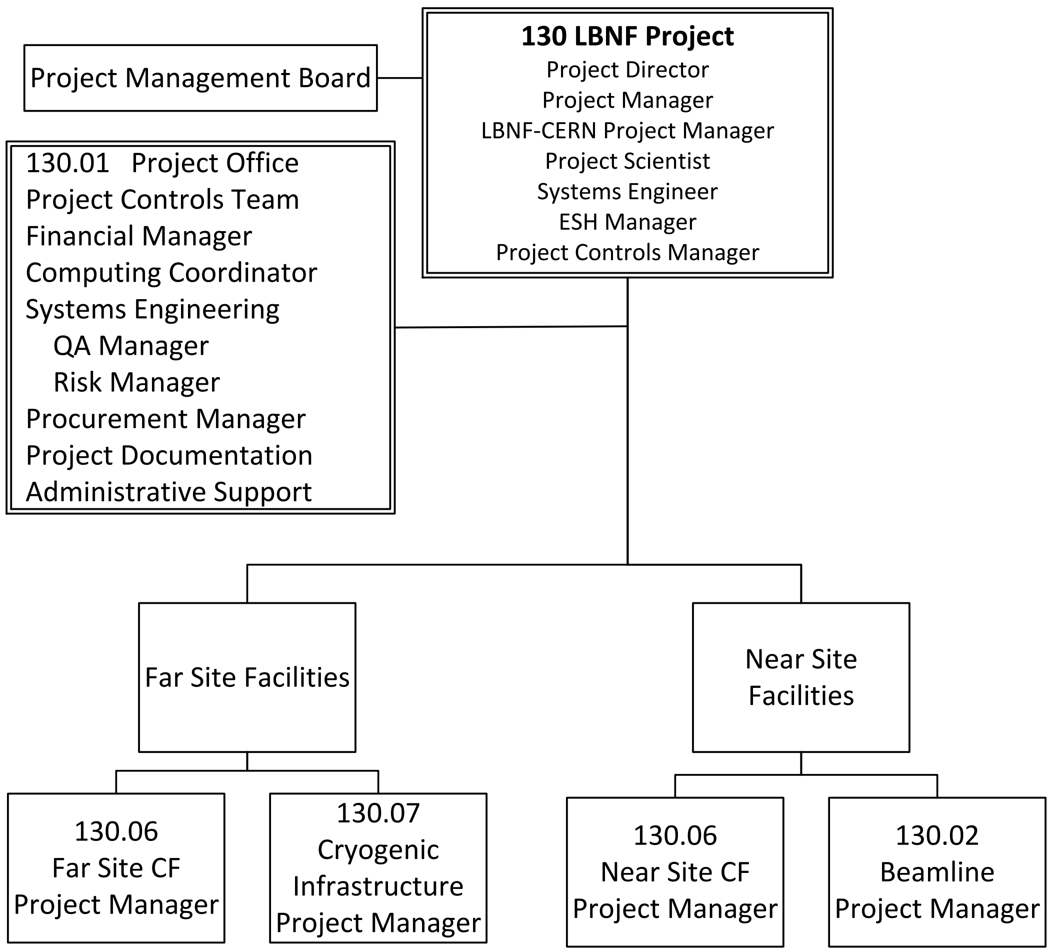


Figure 2.2: LBNF organization fig:lbnf

milab 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

new reference; is it 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, required to support the deployment of the DUNE detectors and of 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 Fermilab's organization, two new divisions are being created to execute the Far Site Facilities and Near Site Facilities subprojects. The heads of these divisions will 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 in part-time roles from other Fermilab Divisions. The heads of the other Fermilab Divisions work with the L1 and L2 project managers to supply the needed resources on an annual basis. The management structure described above is currently being transitioned into and will not be fully in place until the Fall of 2015.

The LBNF WBS defines the scope of the work. All changes to the WBS must be approved by the LBNF Project Manager prior to implementation. At the time of CD-1-Refresh, the LBNF WBS is in transition. Both the current (post CD-1-Refresh Review) WBS is shown in Figure 2.1 fig:lbnf-wbs to demonstrate how the scope will map from one WBS to the other. SDSTA assigns engineers and others as required to work on specific tasks required for the LBNF Project at the SURF site. 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.

Project Management Board: 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 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 [?]

FSCF Neutrino Cavity Advisory Board: 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. The Board meets at the request of the FSCF-PM, generally on site to discuss specific technical issues. The Board produces a report with its findings and conclusions for Project information and action.

2.5 LBNF/DUNE Advisory and Coordinating Structures

from CDR vol 1 sec 4.4

A set of structures is 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.

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

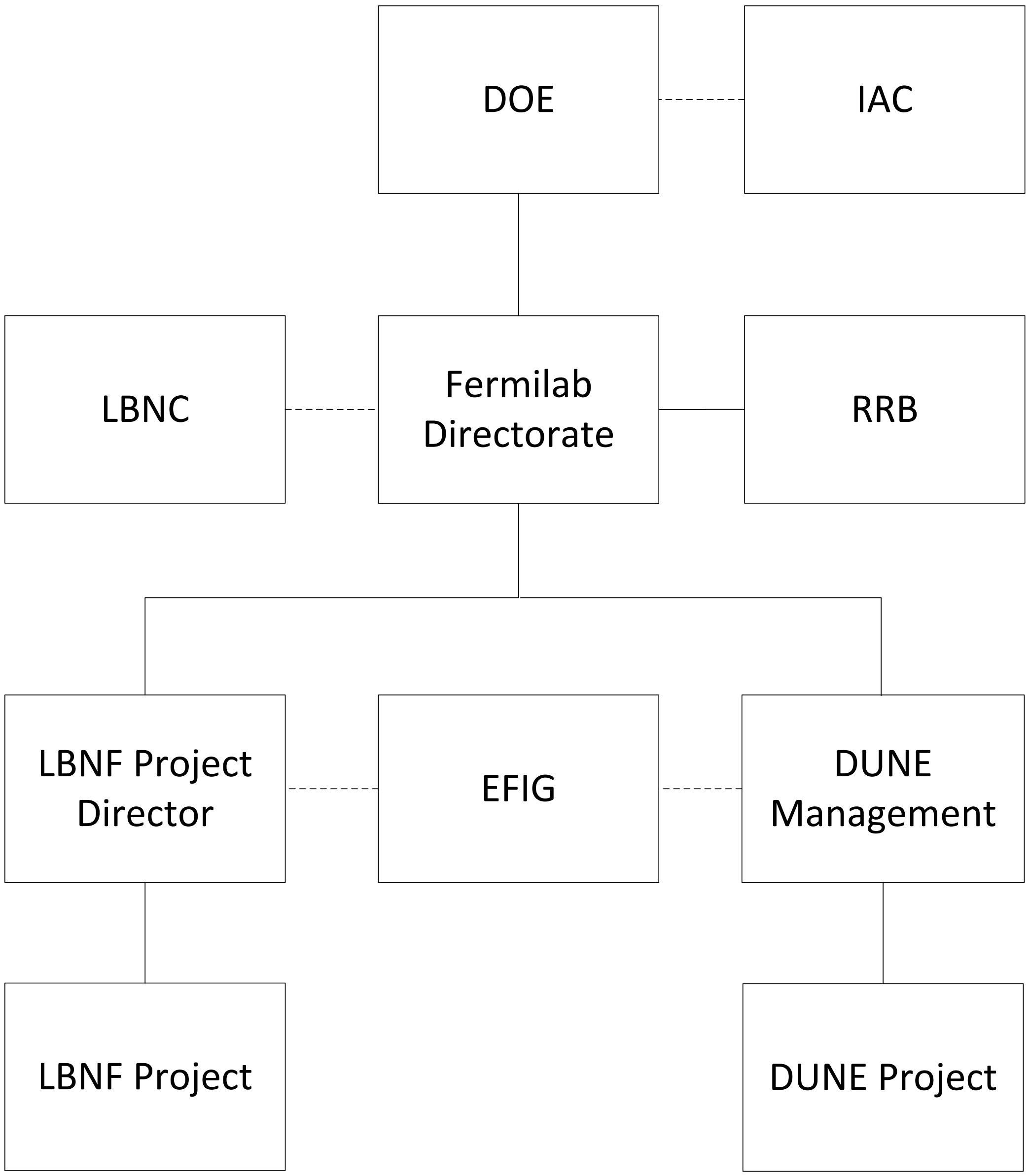


Figure 2.3: Joint LBNF/DUNE management structure

fig:lbnf

(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 certain geographic regions make major contributions to LBNF and DUNE.

2.5.2 Resources Review Boards (RRB)

The Resources Review Boards (RRB) are composed of representatives of all funding agencies that sponsor LBNF and DUNE, and of 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 organize 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 participates in the RRB meetings and make regular reports to the RRB on technical, managerial, financial and administrative matters, as well as status and progress of the DUNE Collaboration.

There are two groups 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 will meet biannually; these meetings will start with a plenary opening session and be followed by RRB-LBNF and RRB-DUNE sessions. As DUNE progresses toward experimental operations, RRB-Computing sessions will convene.

DUNE Finance Board members who serve as National Contacts from the sponsoring funding agencies will be invited to RRB sessions.

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.

Roles of the RRB includes:

- 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
- 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 construction, and maintenance and operation common fund budget of DUNE

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 (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 interface issues 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 PAC and 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 two deputy directors of Fermilab. Its membership includes the LBNF Project Director, Project Manager and Project Scientist, 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 South Dakota Science and Technology Authority (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 independent of the former Deep Underground Science and Engineering Laboratory (DUSEL) efforts and funding.

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.

3.1 Existing Site Conditions Evaluation

The existing facility conditions were assessed as part of the DUSEL Preliminary Design and documented in the DUSEL PDR, Section 5.2.4, [10] which is excerpted below. The portions of DUSEL's assessment included here have been edited to reflect current activities and to reference only that portion of the assessment that are pertinent to the LBNF Project. References to the DUSEL Project are from that time, and are now considered historic.

Site and facility assessments were performed during DUSEL's Preliminary Design phase by HDR to evaluate the condition of existing facilities and structures on the Yates, and Ross Campuses. The assessments reviewed the condition of buildings proposed for continuing present use, new use, or potential demolition. Building assessments were performed in the categories of architec-

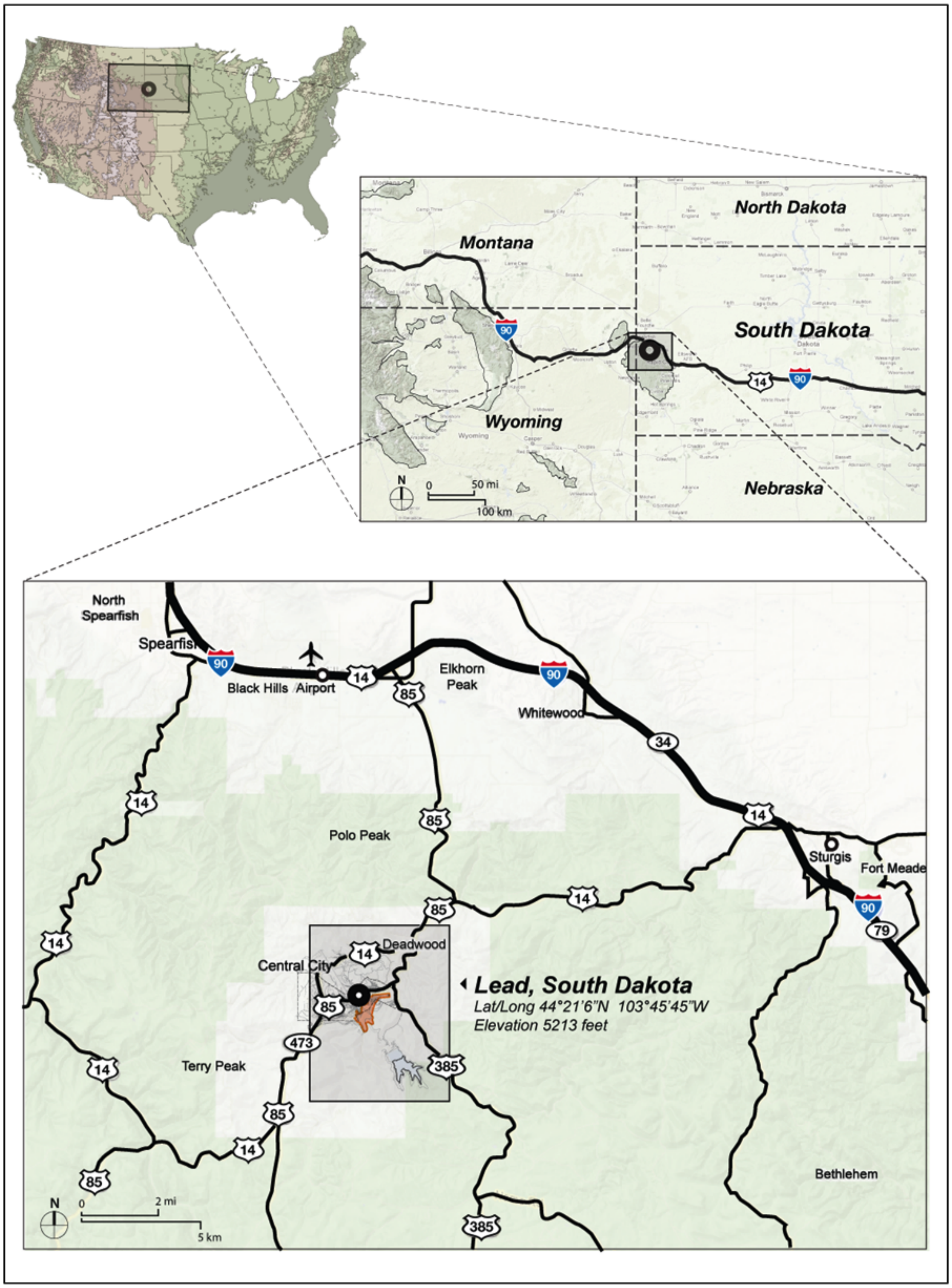


Figure 3.1: Regional context showing the city of Lead, South Dakota. (Dangermond Keane Architecture, Courtesy SURF)

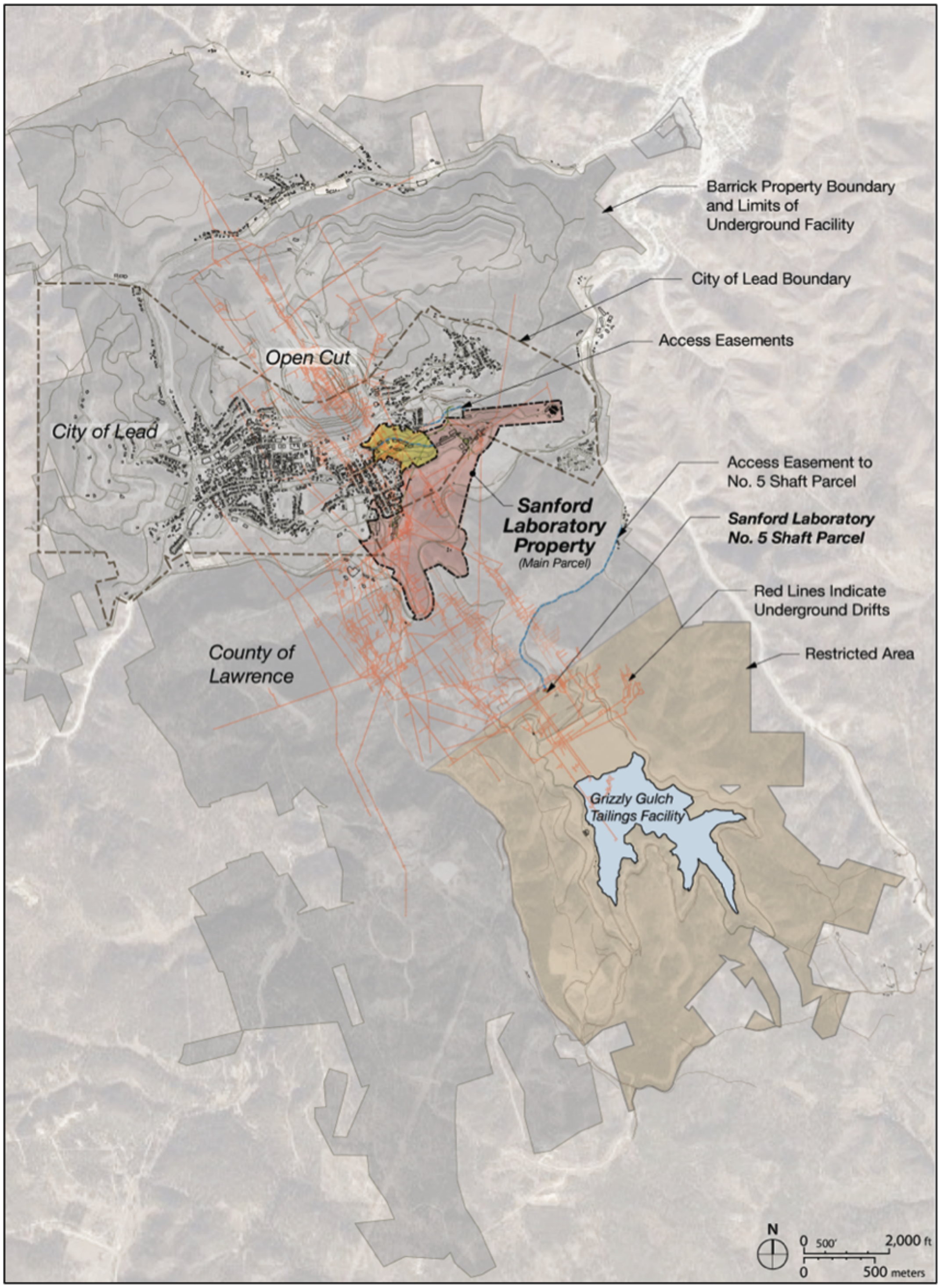


Figure 3.2: SURF Complex shown in the context of the city of Lead, South Dakota, and the property remaining under ownership of Barrick. Area shown in yellow is a potential future expansion of the SDSTA property. [Dangermond Keane Architecture, Courtesy of SURF]

tural, structural, mechanical/electrical/plumbing (MEP), civil, environmental, and historic. Site assessments looked at the categories that included civil, landscape, environmental, and historic. Facility-wide utilities such as electrical, steam distribution lines, water, and sewer systems were also assessed. The assessment evaluation was completed in three phases. The detailed reports are included in the appendices of the DUSEL PDR as noted and are titled:

- 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)

The site and facility assessments outlined above were performed during DUSEL's Preliminary Design as listed above and includes a review of the following:

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

3.2 Evaluation of Geology and Existing Excavations

cond-geo

LBNF Far Site facilities are planned to be constructed at SURF which is being developed within the footprint of the former Homestake Gold Mine, located in Lead, South Dakota. The accessible underground mine workings are extensive. Over the life of the former gold mine over 360 miles of drifts (tunnels) were mined and shafts and winzes 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 developed at the 4850L, the same level as proposed for LBNF facilities. Geotechnical investigations and initial geotechnical analyses were completed for the DUSEL Preliminary Design [10] and are described in detail in the DUSEL PDR. Additional geotechnical investigation and analysis was performed in 2014 specific to the LBNF project. Below are summaries these two effort, including work completed for DUSEL that is applicable to LBNF as excerpted from the DUSEL Preliminary Design Report, Chapter 5.3. Much of the work completed for the alternative detector technology considered during DUSEL [water Cherenkov detector (WCD)] is also applicable to the current design at the 4850L.

3.2.1 Geologic Setting

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. While the Yates Member is the preferred host rock for the LBNF excavations at 4850L, the LBNF cavity has been located in the Poorman formation to isolate it 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 beam line.

3.2.2 Rock Mass Characteristics: LBNF

Following a similar strategy as DUSEL, the LBNF project 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 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 if 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 if 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 induce fracturing near the existing drifts allow the holes to depressurize outside of the test instruments.

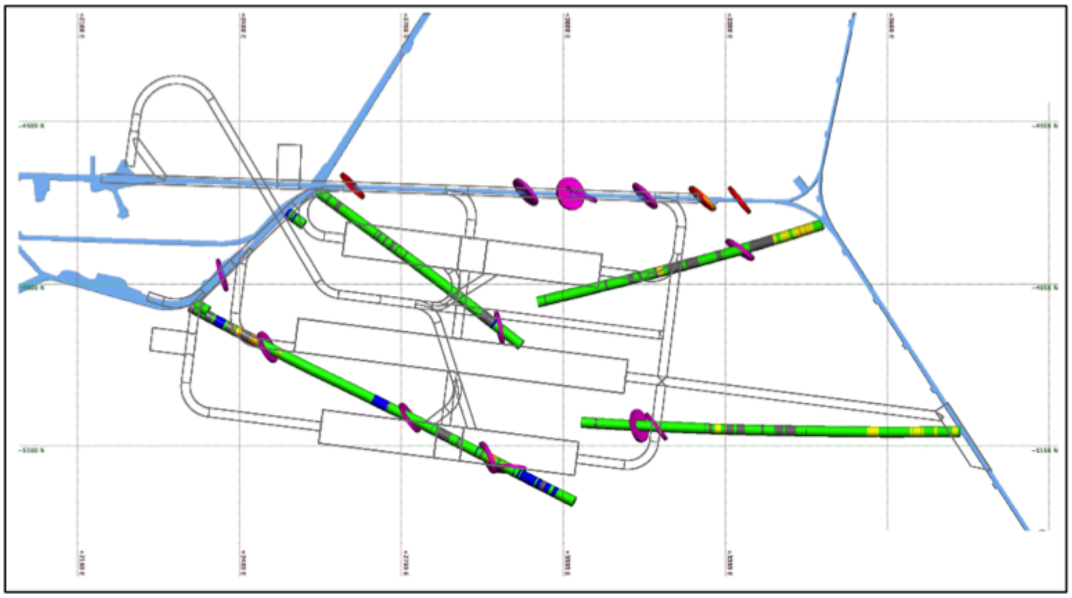


Figure 3.3: LBNF core locations and geological features fig:core

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 gage at 30 – 36 feet within the depth. As the larger diameter core was removed, this strain gage 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.

LBNF followed a review approach for the analysis performed by Arup by enlisting industry leaders as part of a Neutrino Cavity Advisory Board (NCAB). This board reviewed the philosophy 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. They provided many recommendations that will benefit the advancement of design.

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

3.2.3 Geologic Conclusions

The recovery of rock cores, plus geologic mapping, was performed to determine if discontinuities in the rock mass exist that would cause difficulties in the construction and maintenance of planned excavations. In general, the proposed locations of the excavations do not appear to be complicated by geologic structures that cause undue difficulties for construction. This information, along with measurement of in situ stresses, allowed initial numerical modeling of the stresses associated with the anticipated excavations. A sample of some of the modelling done is provided in Figure 3.4.

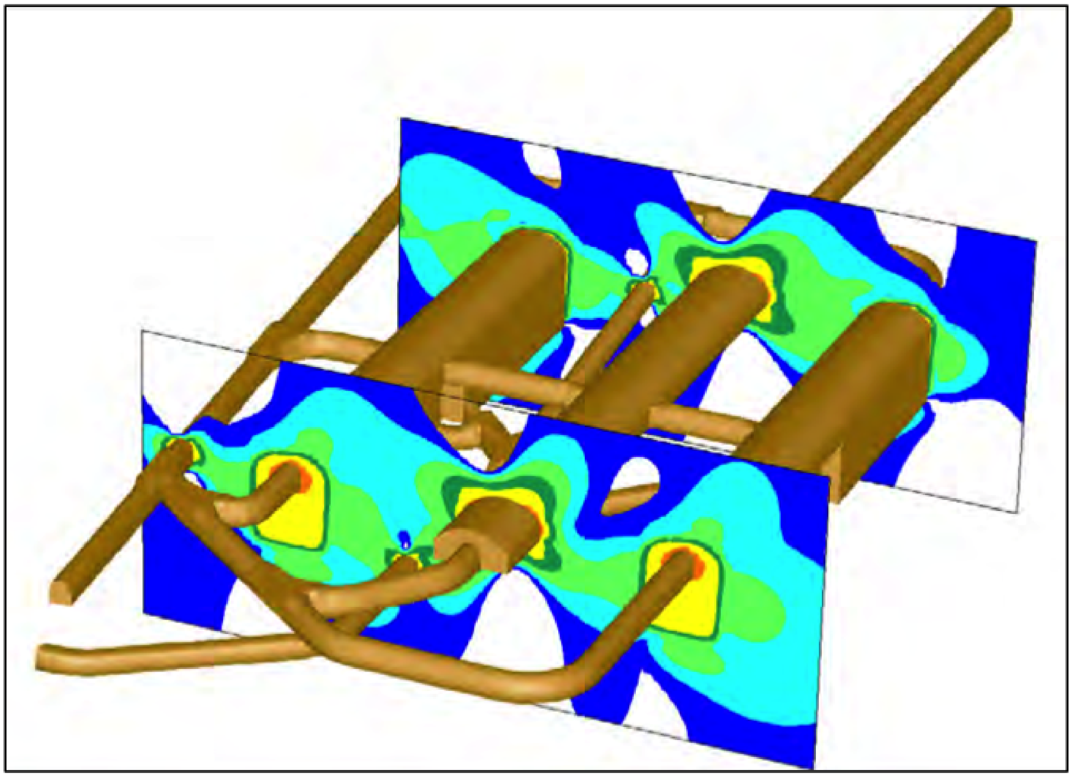


Figure 3.4: Contour of stress safety factor indicating influences between caverns

Chapter 4

Surface Facility

4.1 Existing Surface Facility

The SURF property of 186 acres consists of steep terrain and man-made cuts dating from its mining history. There are approximately 50 buildings and associated site infrastructure in various states of repair. A select few of these buildings at the Ross Complex and the main utilities are needed by the LBNF experiment and will be upgraded and rehabilitated as necessary. A layout of the overall SURF architectural site plan for the LBNF Project is found in Figure 4.1. The Ross Complex will house the facility construction operations, command and control center for the experiment and facility, new cryogenics compressor building, as well as continue to house the SURF maintenance and operations functions. Layout of surface facilities in the vicinity of the Ross Shaft is shown in Figure 4.2.

4.2 Surface Buildings

Surface facilities utilized for the LBNF include those necessary for safe access and egress to the underground through the Ross Shaft, as well as spaces for offices. Existing buildings necessary for LBNF will be rehabilitated to code-compliance and to provide for the needs of the experiment. The only new building will be to provide space for compressors used to transfer cryogens from new receiving tanks on surface to the detectors underground. The existing Ross Dry building will be modified to provide space for a surface control room and offices. Much of the text below is excerpted from the 100% Preliminary Design Report [12] provided by Arup, USA.

A new building and surrounding concrete slabs are planned to provide space for equipment to allow conversion of liquid argon and liquid nitrogen to gaseous form and compression of the nitrogen for delivery through the shaft to the underground where they are returned to liquid form as described later in this PDR in Chapter 4.

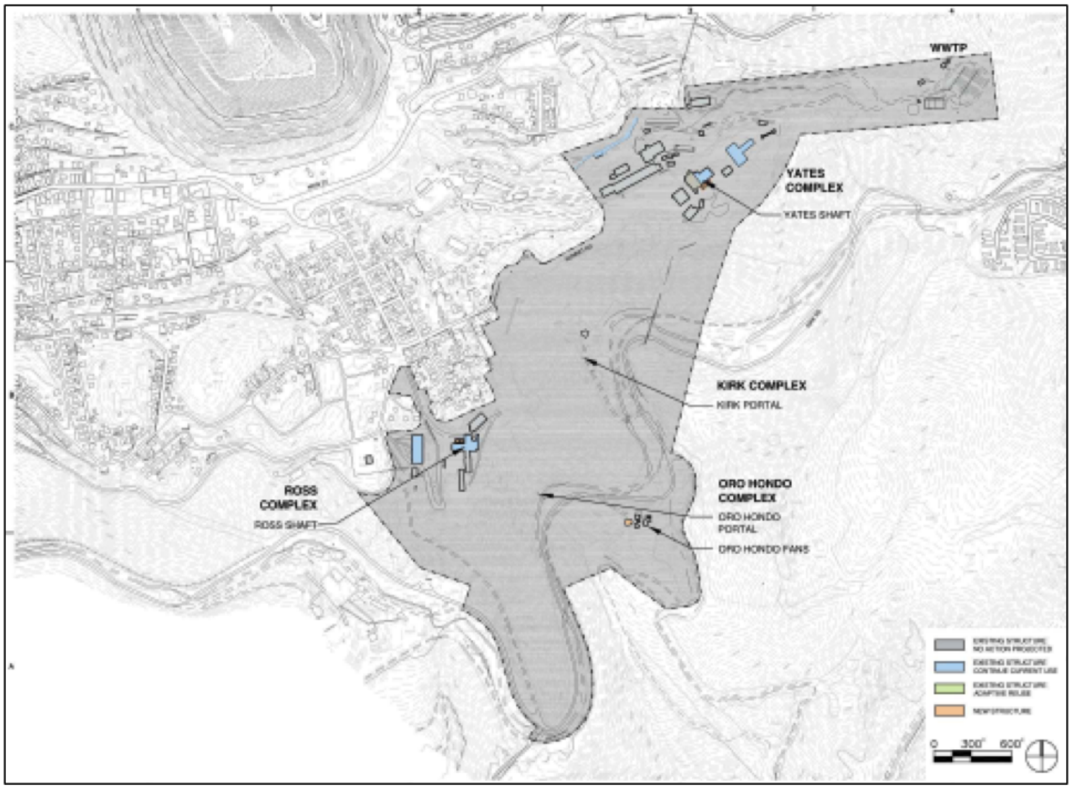


Figure 4.1: Architectural site plan (HDR)

I don't find this; probably described in cryo annex

The location of this building was selected based on proximity to the shaft and truck accessibility, as thousands of truckloads of argon are required to fill the detectors underground.

In addition to housing nitrogen compressors inside the building, concrete slabs are provided around the building to allow for installation of argon and nitrogen receiving dewars for truck unloading, vaporizers to boil the liquids into gas, and electrical transformer to supply power to the (4) 1,500 Hp compressors, a standby generator, and cooling towers to reject heat generated through compression. All equipment except the cooling towers and associated circulation pumps is provided by the Cryogenics Infrastructure Project. The architectural layout of this building and surrounding equipment is provided in Figure 4.3.

4.2.1 Ross Dry

The Ross Dry building is in use by SURF to provide office and meeting space in addition to men's and women's dry facilities and emergency response capabilities. As a scope option, the design has included a complete renovation of this building to upgrade those existing capabilities and add space for an above-ground control room. This design includes flexible space that can be tailored to individual user's needs as the project transitions from construction through operations.

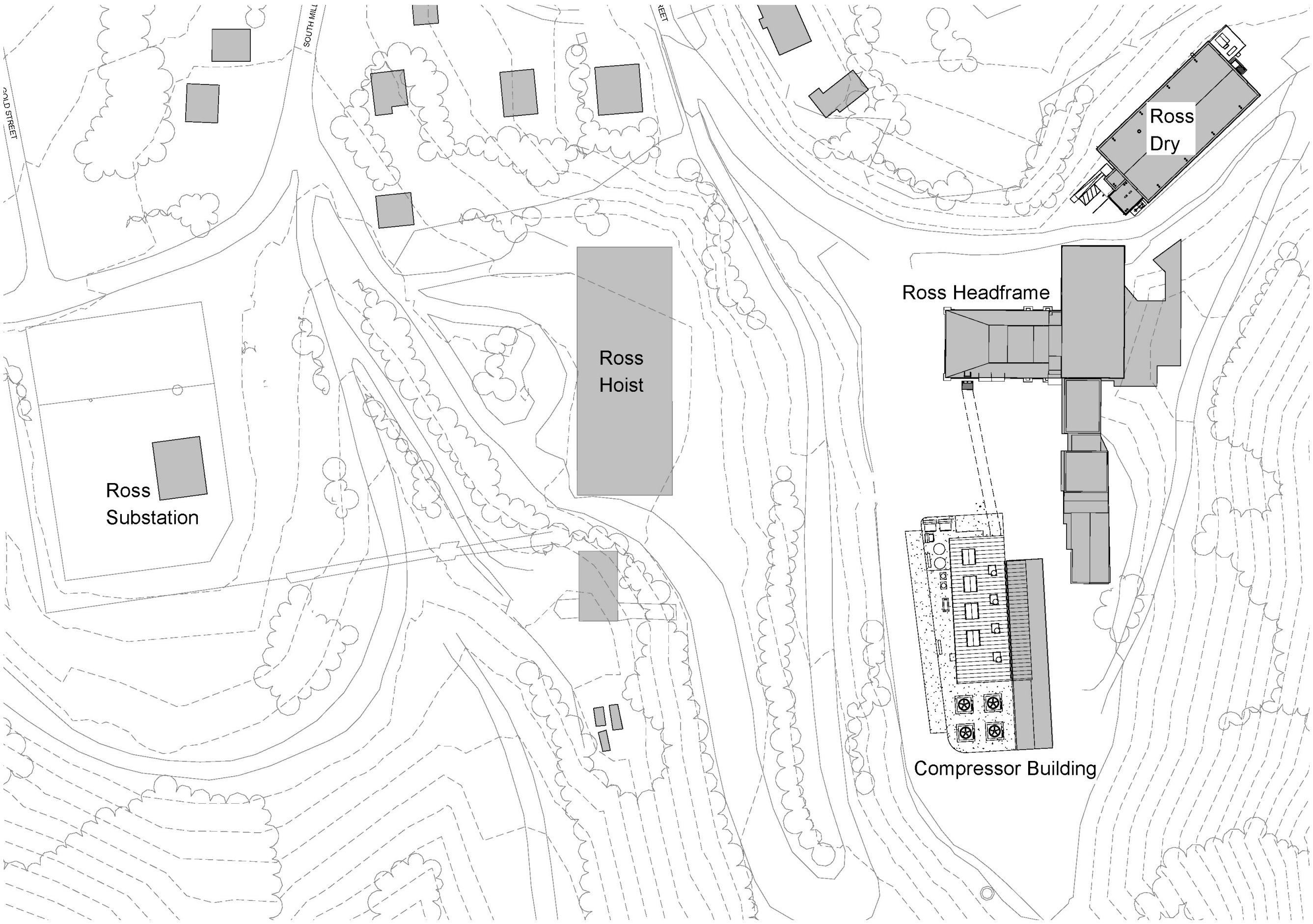


Figure 4.2: Ross Complex architectural site plan (Arup)

fig:ross

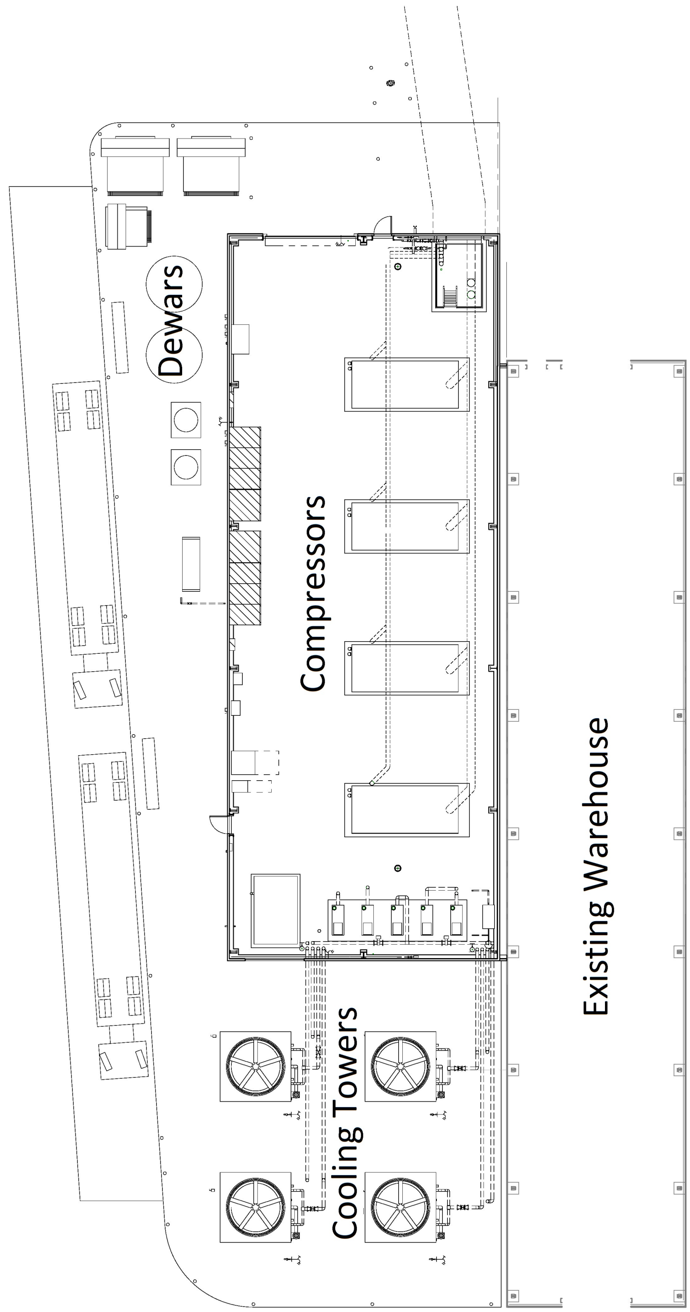


Figure 4.3: Architectural layout of LBNF Cryogenics Compressor Building

fig:comp

The exterior of the Ross Dry is shown in Figure 4.4. The renovations of this building are shown in Figures 4.5 and 4.6.

Figure 4.4: Photo of Ross Dry exterior (HDR)

Need orig; too fuzzy

4.2.2 Ross Headframe and Hoist Buildings

The headframe and hoist buildings at the Ross Campus provide services for LBNF use. The Ross Headframe Building will be the main entry point for construction activities as well as the ongoing operations and maintenance functions. Gas pipe from the LBNF Cryogenics Compressor Building will pass through this building to get to the shaft.

4.2.3 Ross Crusher Building

The existing Ross Crusher Building is a high bay space that contains rock crushing equipment that will be used for construction operations. The exterior of the building will be repaired to create a warm, usable shell. The upgrade of the existing crusher equipment is part of the waste rock handling work scope (see Section 6.7) and not part of the building rehabilitation.

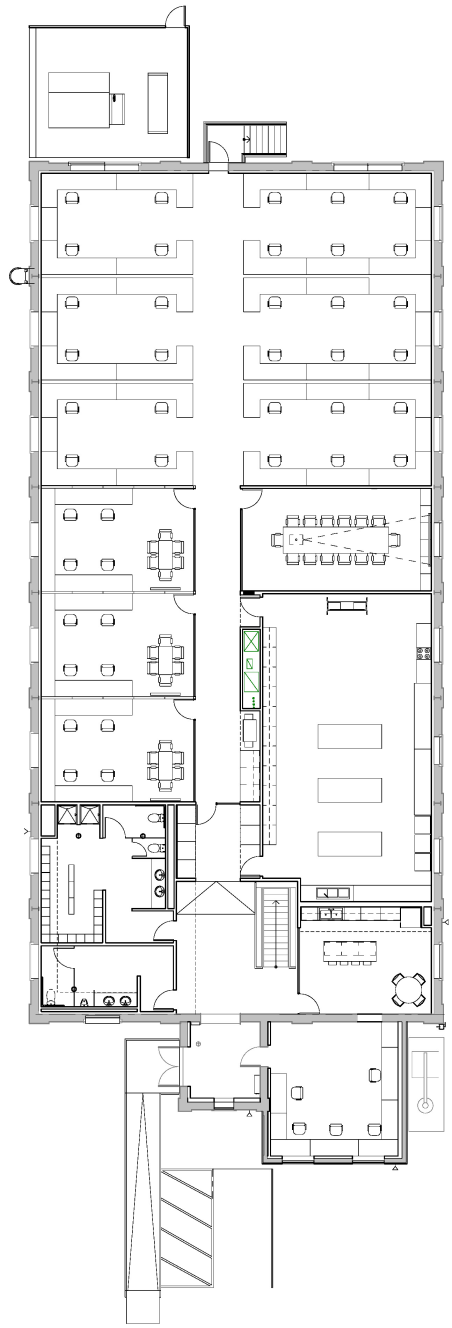


Figure 4.5: Location of new Command and Control Center (SURF), main floor. fig:cmd-

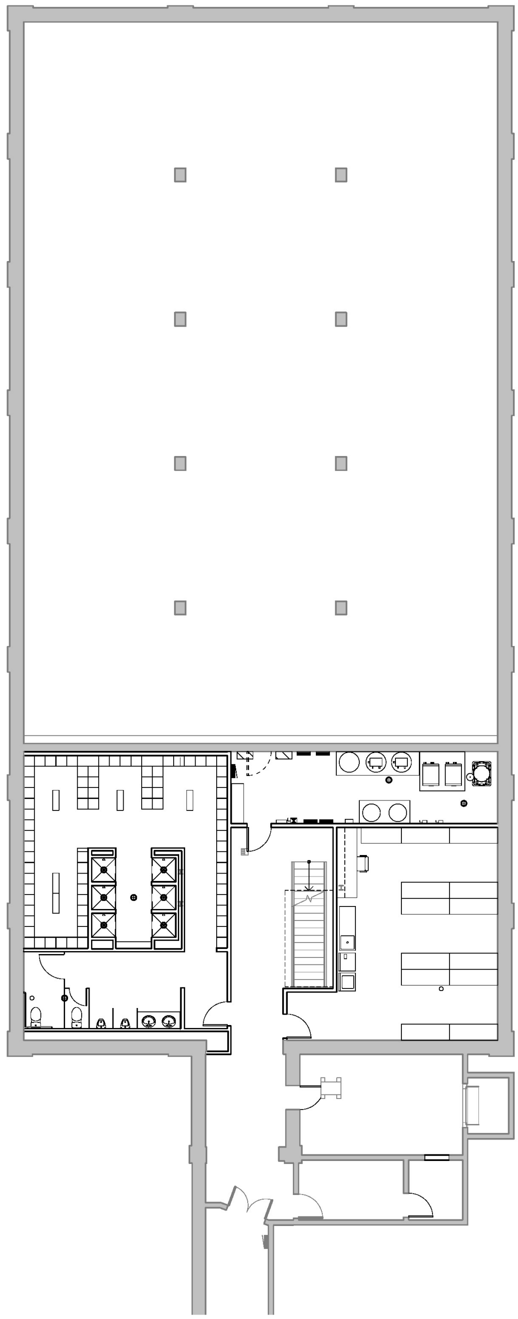


Figure 4.6: Location of new Command and Control Center (SURF), basement. fig:cmd-

4.3 New Surface Infrastructure

Surface infrastructure includes surface structures such as retaining walls and parking lots, as well as utilities to service both buildings and underground areas. Existing infrastructure requires both rehabilitation as well as upgrading to meet code requirements and LBNF needs. The experiment needs were documented in the requirements found in LBNF Requirements Document[4] and combined with facility needs for the design detailed in the Arup 100% Preliminary Design Report[5].

No new roads or parking lots are required for LBNF at SURF. The Ross Complex site will require minor demolition of power lines and a fire hydrant that are no longer used to provide adequate accessibility for truck traffic to the new Cryogenics Compressor Building. An existing space will be designated for handicap parking adjacent to the Ross Dry Building. Additional road work is required for truck transportation of waste rock, as described in the waste rock handling section.

Chapter 5

Underground Excavation

The main excavated spaces necessary to support the LBNF experiment are a combination of excavations required for the experiment and those required for constructability. Experimental spaces on the 4850L include the detector chambers, drifts for access and utility routing, and the Central Utility Cavern. Spaces identified as likely necessary for the excavation subcontractor include mucking drifts connected to the Ross Shaft to enable waste rock handling and equipment assembly shops to provide space to assemble and maintain excavation equipment underground. In addition, a spray chamber is provided for heat rejection from the chilled water system. All spaces are identified on the 100% Preliminary Design excavation drawings produced by Arup[5]. The spaces are shown below in Figure 5.1.

5.1 LBNF Cavities

5.1.1 Detector Cavities

The required experimental spaces were defined through interaction with the DUNE design team and are documented in LBNF Requirements Document [14]. The size and depth of the LBNF cavities were prescribed to suit the scientific needs of the experiment. The overall main cavern sizes are shown graphically in Figure 5.2. The DUNE experiment will be housed in four detector chambers within two main caverns at the 4850L. Siting deep underground is required to shield from cosmic rays, as detailed in Report on the Depth Requirements for a Massive Detector at Homestake [15]. The 4850L is deeper than what is absolutely required, but is used because of existing access at this level.

The limits on size for the detector are determined by rock strength and the limits on the ability to produce large dimension anode and cathode plane arrays. Space occupied by the free-standing steel structure, vessel insulating liner, and an intentional exclusion zone reduce the fiducial volume of the detector below the volume of the excavation. Current assessment of rock quality indicates that a cavity of this size is reasonable with the rock quality assumed for this formation.

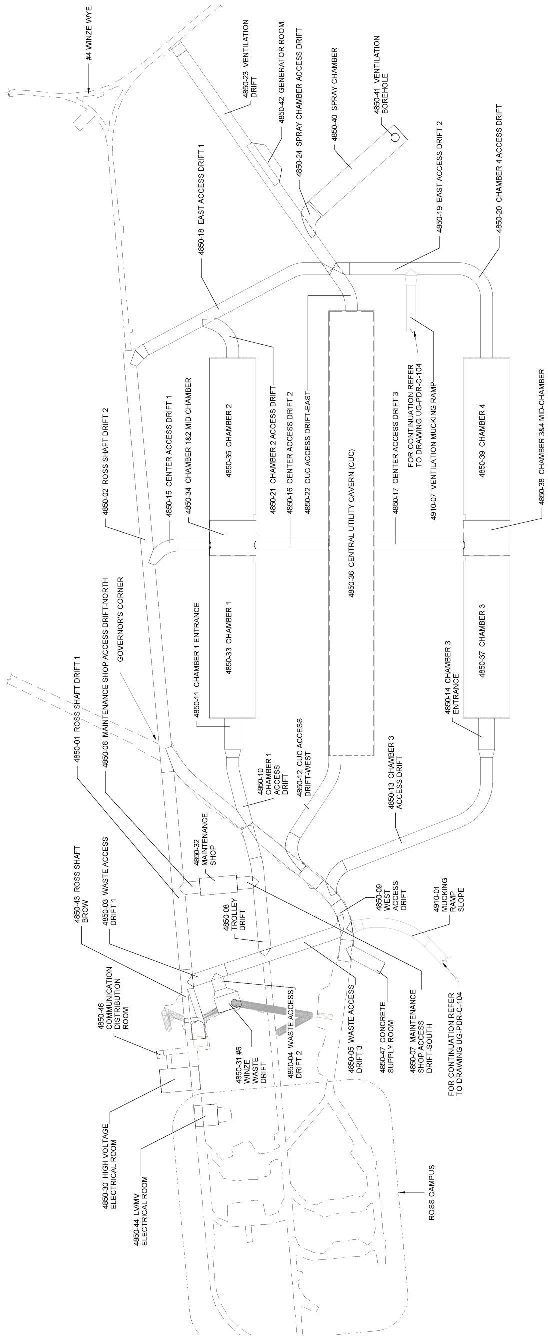


Figure 5.1: Spaces required for LBNF at 4850L (SURF)

fig:spac

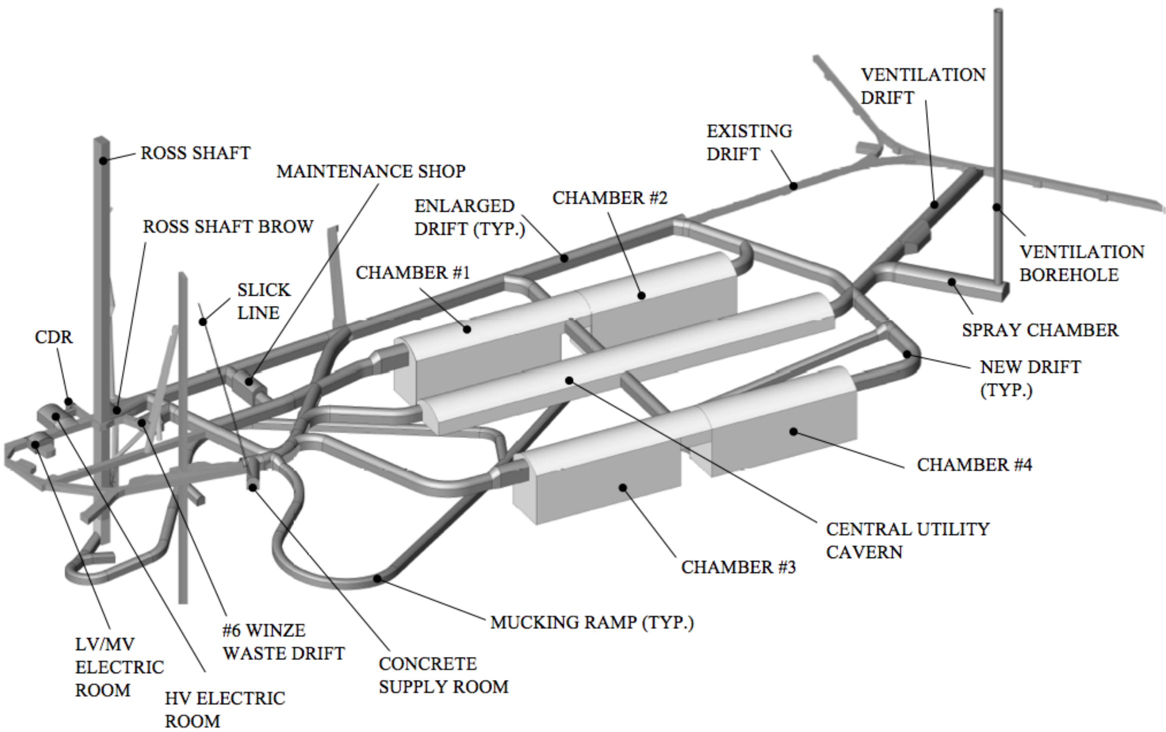


Figure 5.2: Dimensions of the main LBNF cavern excavations (final dimensions will be slightly smaller). (SURF)

Preliminary modeling of the proposed excavations included 2D and 3D numerical modeling. The intact rock strength and joint strength had the greatest impact according to the 2D modeling, and 3D modeling confirmed that the complex geometry is possible.

The far detector cavity and drifts will be supported using galvanized rock bolts/cables, wire mesh, and shotcrete for a life of 30 years. The floor of the cavity has been evaluated and does not require support. A groundwater drainage system will be placed behind the shotcrete in the arch and walls of the far detector cavity rock excavation. This drain system will collect groundwater (native) seepage and eliminate the potential for hydrostatic pressure build-up behind the shotcrete. Channels will be placed in the concrete invert to drain groundwater to the sump system.

5.1.2 Structure and Cranes

The LBNF caverns require monorail cranes to facilitate the construction of the detector components. Rock bolts will be coordinated with the excavation contractor to provide anchorage to support these monorails.

5.2 LBNF Central Utility Cavern

LBNF requires spaces for cryogenics equipment outside of the detector caverns. These requirements have been combined with that for the conventional facilities utilities in an independent Central Utility Cavern. This area will house the experiment's cryogen system, electrical equipment to supply power for facility and experiment needs, sump pump access and controls, fire sprinkler room, air handling units (AHUs), chilled water system, and ducting. The centralized location minimizes overall utility distribution costs. Isolating the utilities from the experiment simplifies electrical ground isolation to avoid interference with sensitive detector electronics, and also provides the opportunity to optimize ventilation to control heat emanating from the equipment in the Central Utility Caverns.

5.3 Access/Egress Drifts

In order to accommodate deliveries, the drift connections from the Ross Shaft to new excavations required for LBNF will be optimized to accommodate the maximum load size possible through the shaft plus the utilities required to service the facility. At the writing of this document, an assumed size of 5m wide by 6m tall is used for all access and egress drifts. All new excavations, or drifts enlarged for LBNF will be provided with a shotcrete wall (rib) and ceiling (back) and a concrete floor (sill).

5.4 Excavation Sequencing

A key goal of both LBNF and DUNE is to complete construction of one 10 kt detector as soon as possible. To facilitate this, the excavation will be sequenced to allow DUNE to begin installation of a cryostat in the first detector chamber while excavation continues. A temporary wall will be built in the detector installation laydown space between detector chambers to isolate one area from another. This wall must be of sturdy construction to withstand air shock waves associated with drill and blast type construction. Further evaluation of vibration limits and controls must be considered as the design advances to avoid damaging the cryostat during assembly.

In addition to controlling the impacts from blasting, logistical coordination is a key concern with a sequenced excavation allowing cryostat construction concurrent with excavation. Many experiment components will be delivered through the Ross shaft, competing with excavation and other construction. A logistics study[6] has been performed to evaluate whether this can be done without impact on either civil or experiment construction. This study confirmed that with good coordination, led by the construction manager, this single shaft can support all anticipated material and personnel deliveries. The Yates shaft can provide some relief during high intensity work periods as well, but this was not considered in the study to evaluate the most conservative approach.

Most excavated material will travel through a mucking ramp starting at the base of each detector pit and ending at the waste dump near the Ross Shaft. This route is completely independent of all other traffic and includes a separate ventilation stream to keep diesel exhaust from other occupied spaces. During times when excavation is establishing the upper sections of the caverns and developing a means of dumping excavated material to this lower elevation, material will need to be transported at the 4850L. To alleviate any potential interferences, the first phase of construction will establish a connection from the 4850L to the mucking ramp, as well as ventilation paths to avoid contaminating the air in spaces that have been turned over for cryostat construction.

Delivery of cryostat components to the individual pits can be accomplished in one of two ways. All materials are delivered through the shafts to the 4850L, which is 18m above the base of the pits. During construction of the first cryostat, while excavation continues in the other areas, all materials will be delivered to the detector installation laydown area between the first and second detector chambers and/or to the west end of the first detector chamber. An overhead crane will be used to lower this material into the pits. This crane is required for installation of detector component within the cryostat, so is not additional equipment. All excavation will be completed before any construction is required in the third and fourth detector pits, providing the opportunity to use the excavation mucking ramp for delivery of cryostat components. This ramp has been designed at an 8% grade to from the west side to allow for this possibility.

5.5 Interfaces between DUNE, Cryogenics and Excavation

There are several points at which the experiment and the facility interface closely. These are managed through discussions between DUNE design team, the Cryogenics Infrastructure design team, and the Conventional Facilities design team and design consultants.

- The LBNF cryostat is a freestanding structure requiring infrequent access for inspection around the vessel. Low tolerance control in excavation will impact the cost of providing access to inspect this vessel.

- The utility spaces to house the cryogen system are directly influenced by the size of the cryogen system equipment.

- The size and construction sequencing of the detector chambers are critical to the experimental strategy.

Chapter 6

Underground Infrastructure

The requirements for underground infrastructure for the LBNF Project will be satisfied by a combination of existing infrastructure, improvements to those systems, and development of new infrastructure to suit specific needs. The Project must consider the other tenants underground at SURF for which infrastructure is required, including both the existing Davis Campus experiments and the Ross Campus Experiments. The Ross campus experiments in particular are in relatively close proximity (∼150 m) to LBNF.

The systems must support the LBNF Conventional Facilities (CF) construction activities, Cryogenics Infrastructure, DUNE experiment installation, and operations of both CF Equipment and the experiment. These three scenarios were analyzed and the most demanding requirements chosen from each situation were used to define the requirements for design.

Some of the SURF infrastructure that requires upgrading for LBNF will be rehabilitated prior to the beginning of LBNF construction funding. This includes Ross Shaft rehabilitation, Yates Shaft focused maintenance and repair, and ground support activities at the 4850L between the Yates and Ross Shafts. Additional discussion of this work is included in section 3.5 .

The conceptual underground infrastructure design for LBNF has been performed by several entities. The primary designer referenced in this document is Arup, USA. Arup's scope includes utility provisions and fire protection- life safety (FLS) strategy, covering infrastructure from the surface through the shafts and drifts, to the cavity excavations for the experiment. Utility infrastructure includes fire/life safety systems, permanent ventilation guidance, HVAC, power, plumbing systems, communications infrastructure, lighting and controls, per the experimental utility requirements provided by DUNE and through coordination with LBNF, SURF and the excavation and surface design teams. The design is described in Arup's LBNF 100% Preliminary Design Report[5] and in the conceptual design drawings. This chapter summarizes the work done by Arup and utilizes information from that report.

Shaft rehabilitation and waste rock handling design were previously provided for the DUSEL PDR. This chapter uses excerpts from the DUSEL Preliminary Design Report, Chapter 5.4 [10]. The research supporting this work took place in whole or in part at the Sanford Underground

Laboratory at Homestake in Lead, South Dakota. Funding for this work was provided by the National Science Foundation through Cooperative Agreements PHY-0717003 and PHY-0940801. The assistance of the Sanford Underground Laboratory at Homestake and its personnel in providing physical access and general logistical and technical support is acknowledged.

6.1 Fire/Life Safety Systems

Life safety is a significant design criterion for underground facilities, focusing on events that could impact the ability to safely escape, or if escape is not immediately possible, isolate people from events underground. Design for fire events includes both preventing spread of fire and removing smoke and/or cryogenic gasses through the ventilation system. The evaluation and establishment of requirements for cryogenic gas removal is performed by the cryogenics group and provided to CF.

Life safety requirements were identified and the design developed by Arup, utilizing applicable codes and standards, including NFPA 520: Standard on Subterranean Spaces, which requires adequate egress in the event of an emergency. Facility fire detection and suppression systems, as well as personnel occupancy requirements are defined in accordance with NFPA 101: Life Safety Code. The design was reviewed by Aon Risk Solutions and the recommendations documented in Fire Protection/Life Safety Assessment for the Conceptual Design of the Far Site of the Long Baseline Neutrino Experiment [16]. Due to the unique nature of the experiment and its location, a number of potential variances will require approval from the authority having jurisdiction (AHJ). Significant examples include use of elevators for egress and use of drifts as air *ducts*. The AHJ for Lead, SD is familiar with the facility and the project, and is expected to provide reasonable and timely feedback for proposed variances.

Based on data provided by SURF the maximum occupant load of the 4850L will be controlled 144 occupants following completion of the Ross Shaft Rehabilitation. This can support the anticipated 42 Underground Operations staff, 50 science staff for LBNF (during installation), and 20 science staff associated with the existing experiments. A logistics study[6] was completed by Arup evaluating the occupancy load during CF construction as well, confirming the adequacy of this number.

Compartmentation will be needed for egress routes to separate them from adjacent spaces to limit the horizontal and vertical spread of fire and smoke. Use of compartmentation will help to reduce the likelihood of fire and smoke spreading from the area of fire origin to other areas or compartments. Compartmentation will also help limit the spread of other materials such as cryogenic gases, leaks and spills. This results in design criteria of minimum 4-hour fire separation between the LBNF cavities and adjacent drifts, while all rooms that connect directly to the egress drift at 4850L, as well as the shafts, will have 2-hour minimum fire separation.

6.2 Shafts and Hoists

The Ross and Yates Shafts provide the only access from the surface to the underground, and are therefore critical to the function of the Facility. Both shafts provide service from the surface to the 4850L, though not every intermediate level is serviced from both shafts. The shafts also provide a path for all utilities from the surface to the underground.

The Ross and Yates Shafts were both installed in the 1930s and have operated since installation. These shafts, along with their furnishings, hoists, and cages, were well maintained during mining operations, but have experienced some deterioration as described in this section. A complete assessment of the Ross and Yates shafts was conducted for the DUSEL Project, and is documented in the Arup Preliminary Infrastructure Assessment Report (DUSEL PDR Appendix 5.M [10]).

6.2.1 Ross Shaft

The Ross Shaft will be used for facility construction, including waste rock removal, routine facility maintenance, and egress path for the finished underground campuses. It will also be used for LBNF experiment primary access. Excavation for LBNF cannot begin until the Ross Shaft is rehabilitated by SURF.

The Ross Shaft is rectangular in shape — 14 ft 0 in (4.27 m) by 19 ft 3 in (5.87 m), measured to the outside of the set steel. The shaft collar is at elevation 5,354.88 ft (1,632.17 m) and the 5000L is the bottom level at elevation 277.70 ft (84.64 m) above sea level. Service is provided to 29 levels and five skip loading pockets. The shaft is divided into seven compartments: cage, counterweight, north skip, south skip, pipe, utility, and ladder way. See Figure 6.1 below showing shaft layout.

The Ross Shaft was in operation until the Homestake Gold Mine closed in 2003. Deterioration through corrosion and wear on the shaft steel, including studdles (vertical steel members placed between steel sets), sets, and bearing beams, prompted a full *strip and re-equip* project being performed by SURF. The Ross Shaft layout will not be significantly modified from the existing configuration. The set spacing is being increased from 6 ft to 18 ft, but the general configuration is remaining the same to allow for emergency egress during rehabilitation. The shaft was installed with limited ground support, electing to utilize lacing to prevent spalled rock from reaching the personnel conveyances. The new design replaces this system with a pattern bolting system to control rock movement. The requirements for this shaft are safety, performance, and code driven and defined by the existing configuration. Shaft rehabilitation through calendar year 2016 has been executed by SURF with non-LBNF Project funds. The rehabilitation is just over 60% complete as of this report and is planned to be completed in 2017. Beginning in January 2017, the funding for the balance of the rehabilitation project will come from the LBNF project. This will also include rehabilitation of the skip loading pocket for waste rock handling, and replacement of skips, cage, and ropes..

The production and service hoists at the Ross Shaft are located on the surface in a dedicated hoistroom west of the shaft. The service hoist operates the service cage and the production hoist

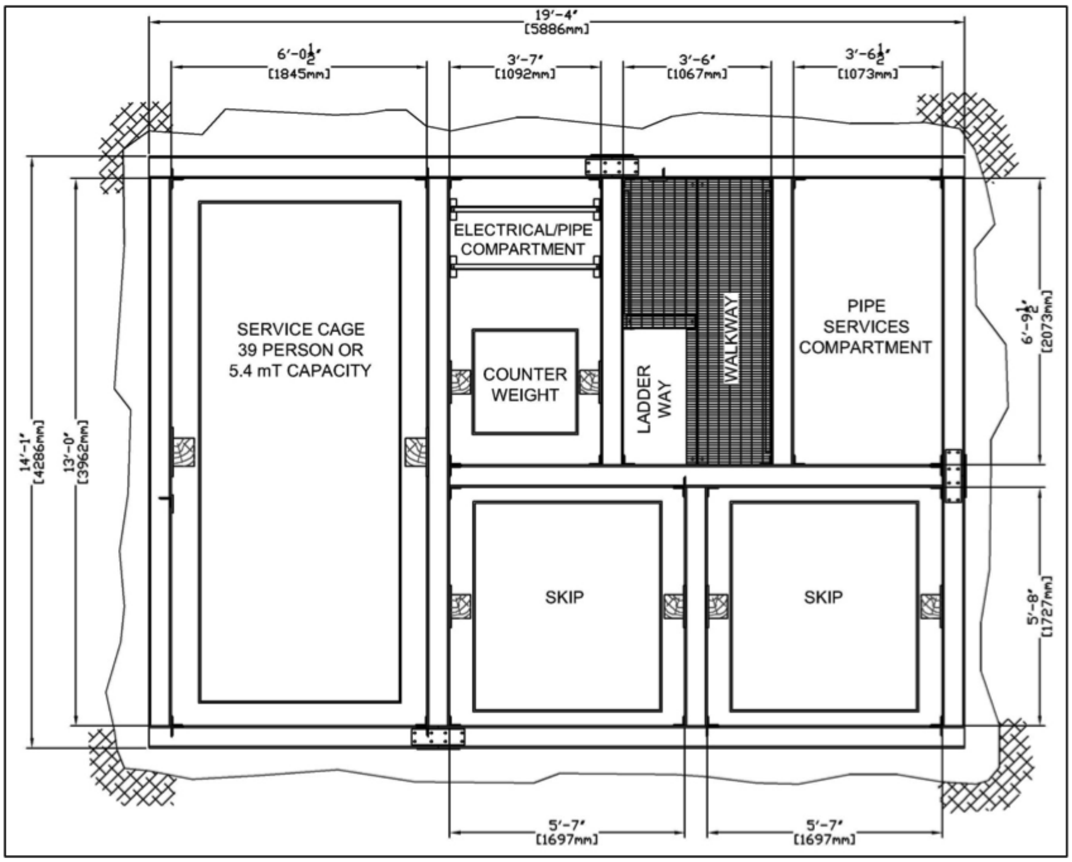


Figure 6.1: Ross Shaft, typical shaft set (SRK, Courtesy SURF)

operates the production skips. The DUSEL PDR describes the condition assessment of the electrical and mechanical hoisting systems which are described in detail in the Arup Preliminary Infrastructure Assessment Report (DUSEL PDR Appendix 5.M [10]). These electrical and mechanical systems will have standard maintenance performed on them to make them in like new condition, but will not be modified from the existing design. The Ross Headframe steel requires some strengthening and modifications to meet code requirements. All of this work is captured in the LBNF scope.

6.2.2 Yates Shaft

The Yates Shaft is rectangular in shapeâĂŤ15 ft-0 in (4.572 m) by 27 ft-8 in (8.433 m) measured to the outside of the set timbers. There are two cage compartments and two skip compartments as shown in Figure 6.2. In addition to the cage and skip compartments, there are two other compartments in which shaft services are located. The shaft collar is at 5,310.00 ft (1,618.49 m) elevation and the 4850L is the bottom level at elevation 376.46 ft (114.75 m) above sea level. Service is provided to 18 levels plus four skip-loading pockets. Sets are made up of various length and size timbers located to maintain compartment spaces. The Yates Shaft is timbered except for a fully concrete-lined portion from the collar to the 300L. Recent repairs include full set replacement from the concrete portion to the 800L and additional set repair below this level where deemed critical.

The Yates Service Hoist and Production Hoist are planned to be used as existing, with maintenance performed to bring them into like new condition. Further details regarding the condition of the Yates Hoists' electrical and mechanical condition can be found in Section 2.2 of the Arup Preliminary Site Assessment Report (DUSEL PDR Appendix 5.M) [10].

6.3 Ventilation

The ventilation system will utilize the existing mine ventilation system for most of the distance to the surface, with modifications made near the LBNF caverns to improve capacity. Fresh air for the LBNF cavities and the utility drifts will be provided by pulling air directly from the existing drifts, which is supplied from the Yates and Ross Shafts. Air will be exhausted from the LBNF cavities and utility drifts through a spray chamber rejecting heat from the LBNF chilled water system into new borehole connecting to the 3500 level of the facility, a short distance from the Oro Hondo shaft, which provide direct connection to the fan at the surface. 230,000 cfm design is required for heat extraction. 27,500 cfm passes through the each main experimental areaand 21,500 through the central utility cavern, with the balance of the air required for heat rejection coming directly from the shafts through connections to existing drifts. The environmental design criteria for LBNF underground spaces are shown in Table 6.1. [1]

[1] During operations, occupancy of the LBNF cavities is 10. Temperature, humidity and filtration requirements in localized areas of these spaces may differ, dependent on requirements. This will be provided by the experiment installation design team. The internal conditions stated above will be used to inform the design of plant and services for each space

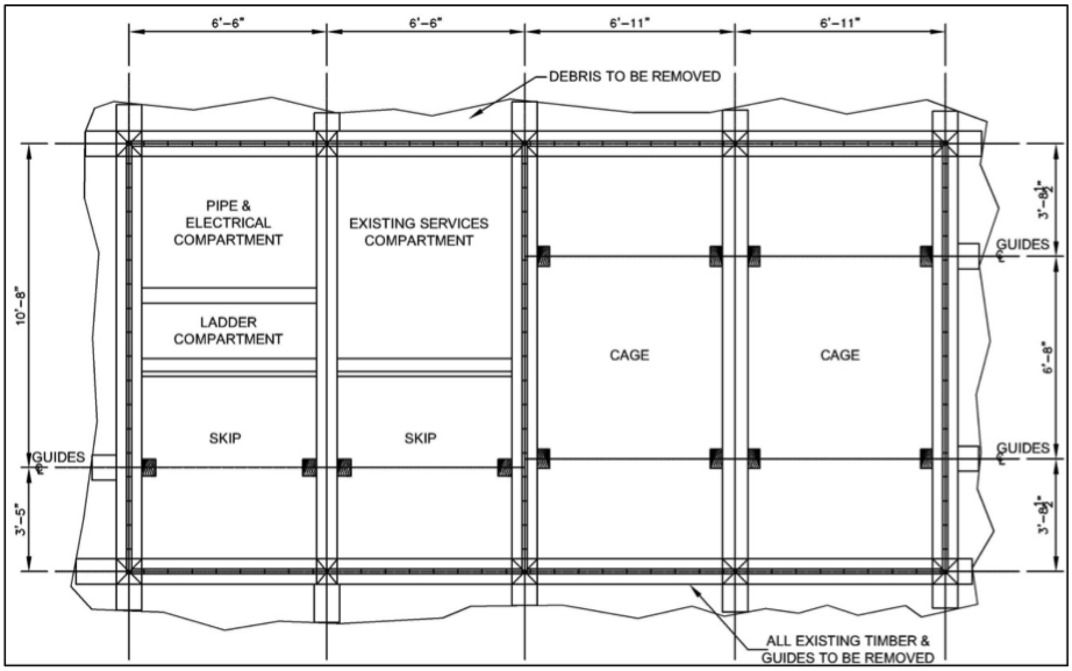


Figure 6.2: Existing Yates Shaft layout (Adapted from SRK, Courtesy SURF)

Table 6.1: Environmental design criteria (Arup)

Room	Internal Temperature	Humidity Range	Min. Vent. Rate/ Fresh Air Changes	Occupancy (during assembly)
LBNF Cavities	$40-82\,^{\circ}$F ($10-28\,^{\circ}$C)	$15-85\%$	1	20(50)
Access Drifts	Min $50\,^{\circ}$F ($10\,^{\circ}$C)	Uncontrolled		Transient space
Utility spaces / Electrical rooms	$50-95\,^{\circ}$F ($10-35\,^{\circ}$C)	Uncontrolled	1	
Storage Rooms	$59-104\,^{\circ}$F ($15-40\,^{\circ}$C)	Uncontrolled	Min 15 cfm/person	Room-dependent

Per historical data, outdoor temperatures can drop below −20 °F; therefore, the intake air requires heating to prevent ice build-up in the shafts which could potentially disrupt hoisting operations and damage shaft support members, cables and piping. The existing shaft heaters are expected to be adequate for normal operation, but temporary supplemental heating may be necessary during excavation due to higher demands. A study will be performed during final design to determine if waste heat from the cryogenic systems surface compressors can be used for energy savings to heat the intake air.

6.4 Electrical

The underground facilities at the 4850L will have electrical power for normal operations as well as standby power for emergency occupant evacuation. LAr experiment power requires standby power for circulation of cryogens to avoid rapid boil-off and loss of argon.

6.4.1 Normal Power

The estimated electrical loads for both the far detector experiment and the underground infrastructure serving the experimental spaces are included in the facility load determination and design.

Power to serve the far detector experiment will originate from the Ross substation and be routed down the Ross Shaft to the 4850L. One set of 15-kV mining cables shall be installed down the Ross Shaft to the 4850L and shall be cable rated for mine use, highly flame retardant, low smoke toxicity with high tensile strength and self-supporting. At the 4850L, the 15-kV mining cables will terminate in 15-kV switchgear located in a new Ross underground substation. This will be provided early in the construction process to allow it to be used for construction.

6.4.2 Standby and Emergency Power

A 300kW emergency/standby diesel generator will be provided in the Central Utility Cavern to serve standby and emergency loads. 48 hours of diesel fuel will be provided to operate the generator when surface power is inoperable. This duration aligns with the stored LN for controlling argon boil off, both of which were derived from historical power outages at the facility. Note that the facility is fed by the local utility provider in a loop infrastructure, and therefore power to the site has historically been very reliable – on the order of a few hours down per year. Within the facility, power outages due to maintenance or unforeseen events are also at a very low rate. The following 4850L electrical loads are anticipated to be installed to the emergency/standby power system:

- Security

unless specific requirements that differ from this are provided by LBNF/SURF or the lab experiment design teams.

- IT System for communications
- Smoke control fans
- Mono rail
- Cryostat system controls

6.4.3 Fire Alarm and Detection

The 4850L will have notification devices installed to alarm the occupants of a fire. Notification devices will consist of speakers and strobe lights. Manual pull stations will be provided within 200 ft of egress. Phones will be installed in the liquid argon chambers and every 400 ft along the access drifts to communicate with the surface level command center.

An air sampling and gas detection system will be installed in the drifts and liquid argon detector chamber as an early detection of a fire condition. The air sampling system will be connected into the fire alarm system.

The fire alarm system will also interface with the oxygen deficiency hazard (ODH) system to activate the fire alarm system and initiate an alarm at the respective level fire alarm panel and at the surface level command center. Specific sounds and strobe colors will be identified based on the type of alarm (fire, ODH, etc.).

6.4.4 Lighting

Suspended lights mounted at a height just below the lowest obstruction will be provided for all drifts and ramps. Mounting is to be coordinated with conduit and supports of other systems running overhead. Maintained average illumination of approximately 24 lux (2.4 foot candles) at floor level will be provided throughout the drifts. Lighting control in drifts will be via low voltage occupancy sensors and power packs suitable for high humidity environments.

6.4.5 Grounding

The grounding system will be designed to provide effective grounding to enable protective devices to operate within a specified time during fault conditions, and to limit touch voltage under such conditions. The grounding system will be designed for a maximum resistance of 5 ohms where possible based on Mine Safety and Health Administration (MSHA) recommendations for ground resistance in mines. Ground beds, consisting of an array of ground rods, will be installed at each substation to provide low impedance to ground.

Electrical separation between the cryostat detectors and cavern utilities will be achieved by separating the metal components (rebar, structure support, etc.) from each other. Inductors will be installed between grounding systems to control noise between systems while also controlling touch potential for safety.

6.5 Plumbing

Plumbing provided by CF, but specific to DUNE, includes plumbing for the cooling systems and gas piping for nitrogen and argon delivery from the Cryogenics Compressor Building on surface to the Central Utility Cavern. Beyond this the facility requires supplies of both potable and industrial water, as well as a means to remove water inflows.

6.5.1 Industrial Water

An existing 4-inch industrial water riser will be used for construction and as a secondary fire service. It is not feasible to run an uninterrupted main water supply line from grade level down to serve the lower levels due to the extremely high hydrostatic pressure that would occur in the system. A series of pressure reducing stations are located at regular intervals in intermediate levels and at the 4850L in order to maintain the pressure within the capability of readily available piping.

6.5.2 Potable Water

Potable water is not required in large quantities for LBNF. The SURF experience has been that plumbing potable water through the shafts for low volumes is not effective, as the pressure reducing systems have the potential to introduce biological contaminants that result in the water no longer meeting drinking water standards, especially in low flow situations. To address this, local filters and ultraviolet treatment is done at the 4850L to make industrial water meet drinking water standards. This system has been used successfully for several years at SURF.

6.5.3 Chilled Water

The DUNE equipment will produce a significant amount of heat which will be removed by LBNF-provided chillers. Three chillers at 50% each have been selected to provide N+1 redundancy to allow for maintenance. Heat from the chillers and various process loads will be rejected using a spray chamber located at the east end of the 4850L LBNF caverns immediately before exhausting into a new borehole providing a direct connection to the exhaust shaft to surface. The ventilation air is a mixture of air from the Yates and Ross Shafts at approximately 68 degrees F. This volume of air is such that the total heat rejected (2.9 MW or 822 Ton) will raise the air temperature to no more than 95 degrees F.

6.5.4 Fire Suppression

The source of fire water main will be the existing 4-inch industrial water main at Ross Shaft. The connection to this line will be at the 4100L, where a new sump with at least 27,000 gallons capacity will be built using sump walls in an existing drift to provide 90 minutes of capacity even if the supply were cut off. The fire protection system at the 4850L Campus will be a gravity fed system. There will be a connection to an existing 6-in industrial water main in the west drift fed from Yates Shaft, where a similar, but slightly larger at 50,000 gallons, sump has been built by SURF. This provides redundant supply from surface.

6.5.5 Drainage

Drainage [17] from the drifts, mechanical electrical rooms (MERs), and any areas where spillage is likely to occur will be collected locally in sumps. Sumps will be located every 500 feet in any areas where drainage to the drifts is not practical. Sumps will be equipped with sump pumps in a staged configuration where each pump discharging to the adjacent sump until water is discharged to the #6 Winze, where it flows to the primary facility pool approximately 1,000 feet below the 4850L. From there, the existing SURF dewatering system pumps the water in stages to the surface where it is treated before discharge into a nearby stream.

6.5.6 Sanitary Drainage

No sanitary drainage is included in the requirements for LBNF. Existing SURF facilities are planned to be used.

6.5.7 Nitrogen and Argon Gas Piping

Two 16-in and three 8-in mild steel pipes are provided by CF from the surface Cryogenics Compressor Building to the shaft, through the shaft, and across the 4850L to the Central Utility Cavern west entrance. The design and specifications of this piping are the responsibility of the Cryogenics Infrastructure Project team. The supply and installation within the Cryogenics Compressor Building and the central Utility Cavern is also the responsibility of the Cryogenics Infrastructure Project.

6.6 Cyberinfrastructure

The Structured Cable System design will be based on uniform cable distribution with a star topology. New fiber connections will be extended to the 4850 level from the Ross Dry Building, and will be dedicated to the use of LBNF experiments at the 4850 level.The design provides one (1) 96-strand single mode armored fiber optic cable from the DUNE Control room dedicated to the experiments. A second 96 stand single mode armored fiber optic cable will be routed through the Yates shaft to provide redundancy for data systems. Figure 6.3 shows the fiber distribution network for LBNF.

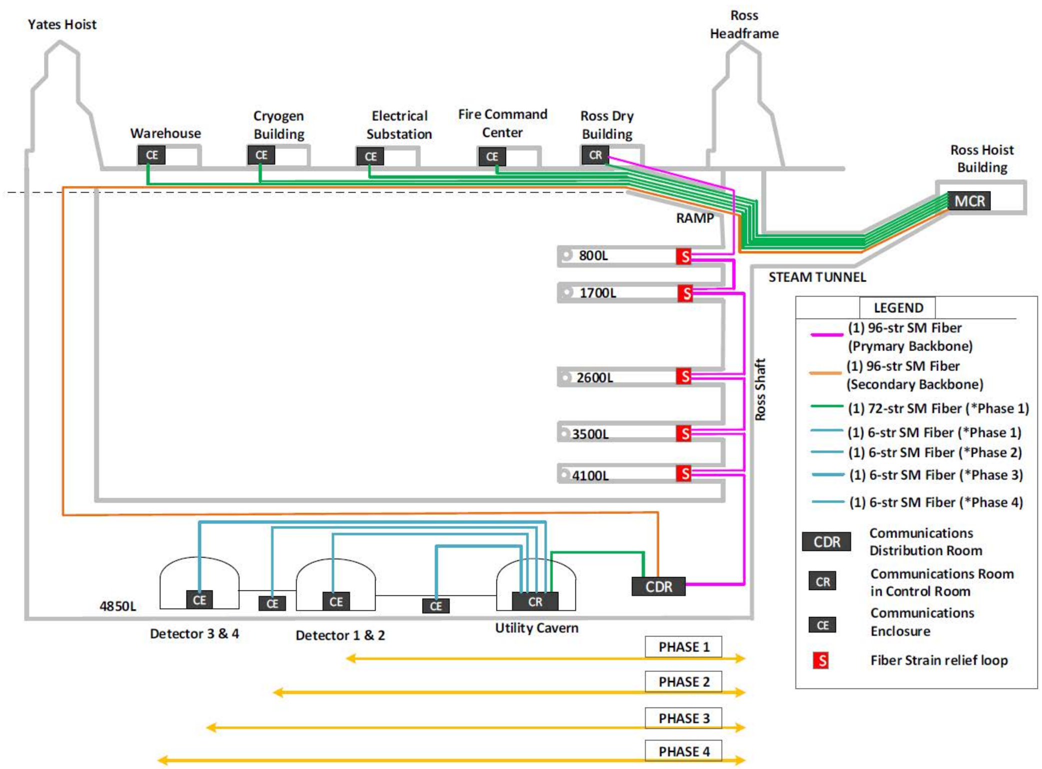


Figure 6.3: Fiber distribution system for LBNF (Arup)

Voice communications are provided via two-way radios and phones distributed throughout the underground spaces (in every room as well as every 500 ft in drifts). Two-way radios and cellular phones utilize a leaky feeder system to ensure communications over long distance without line of site. These leaky feeders are cables that act as antennas installed the length of all drifts and shafts. Standard phones utilize Voice over Internet Protocol (VoIP) to provide communication though the fiber optic data backbone.

The data system is designed to provide 10-Gigabit Ethernet in the backbone and 1-Gigabit Ethernet to connected systems (computers). This system is intentionally left at a lesser level of design due to the continuous progression and advancement of technology that will almost certainly result in more advanced technologies than are currently available being utilized at the time of construction.

6.7 Waste Rock Handling

Prior to the commencement of any excavation activities, it will be necessary to establish a waste rock handling system

Josh says: Need to determine whether this terminology is acceptable from Pepin

. The capacity of this system will be equivalent to what was in place during mining. There are a number of components to the waste rock handling system, including refurbishing the Ross Shaft hoisting system, the Ross Shaft crushers, and a new conveying system to transport rock downhill to the Kirk Road, as seen in Figure 6.4.

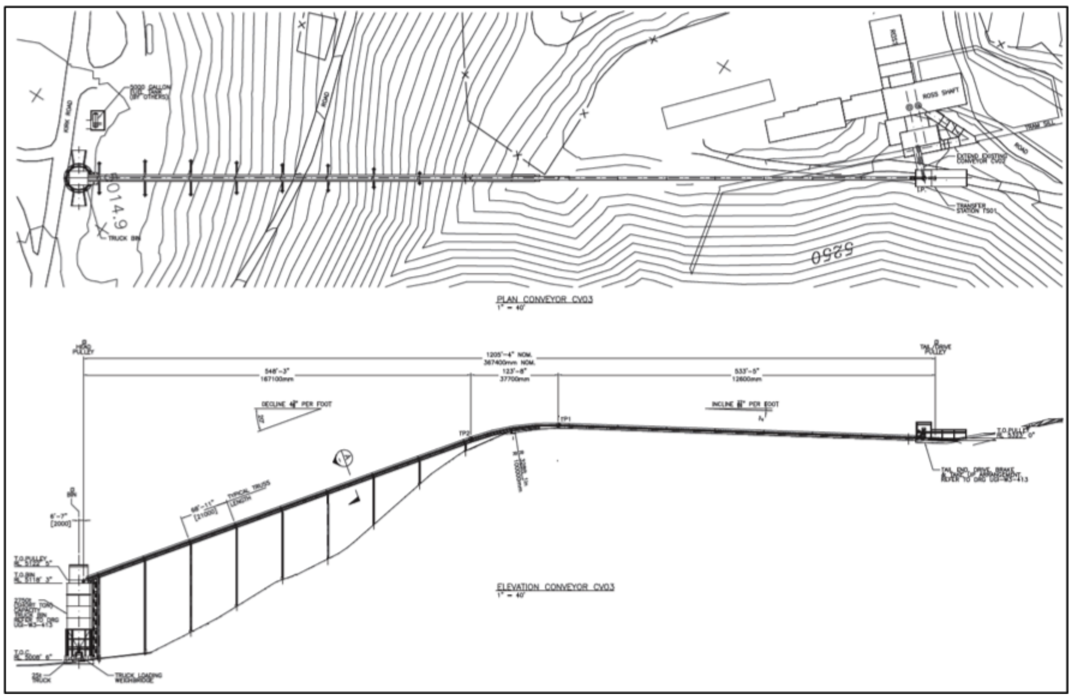


Figure 6.4: Waste rock handling system route (SRK, Courtesy SURF)

The systems utilize experience and equipment from the former Homestake Mining Company legacy, where rock was removed to the surface using skips in both the Yates and Ross Shafts. At the headframe of each shaft, the material was crushed to a nominal 3/4 in, passed through ore bins, and was transported via underground rail to the mill system. All systems from the underground to the crushers will be rehabilitated from the original systems, though the material may not be required to be crushed as fine as it was historically, and therefore some components of the system may not be re-used.

References

[1] LBNF/DUNE, "LBNF/DUNE Conceptual Design Report (CDR)," tech. rep., 2015. DUNE Doc 180-183.

[2] Particle Physics Project Prioritization Panel, "Building for Discovery; Strategic Plan for U.S. Particle Physics in the Global Context," 2014. http://science.energy.gov/~/media/hep/hepap/pdf/May%202014/FINAL_P5_Report_Interactive_060214.pdf.

[3] CERN Council, "The European Strategy for Particle Physics, Update 2013," 2013. http://council.web.cern.ch/council/en/EuropeanStrategy/ESParticlePhysics.html.

[4] LBNF/DUNE, "LBNF/DUNE Science Requirements," tech. rep., 2015. DUNE Doc 112.

[5] Arup, "LBNF FSCF 100% Preliminary Design Report ," tech. rep., 2015. DUNE Doc 136.

[6] LBNF, "LBNF Draft Comprehensive Logistics Report," tech. rep., 2015. DUNE Doc 423.