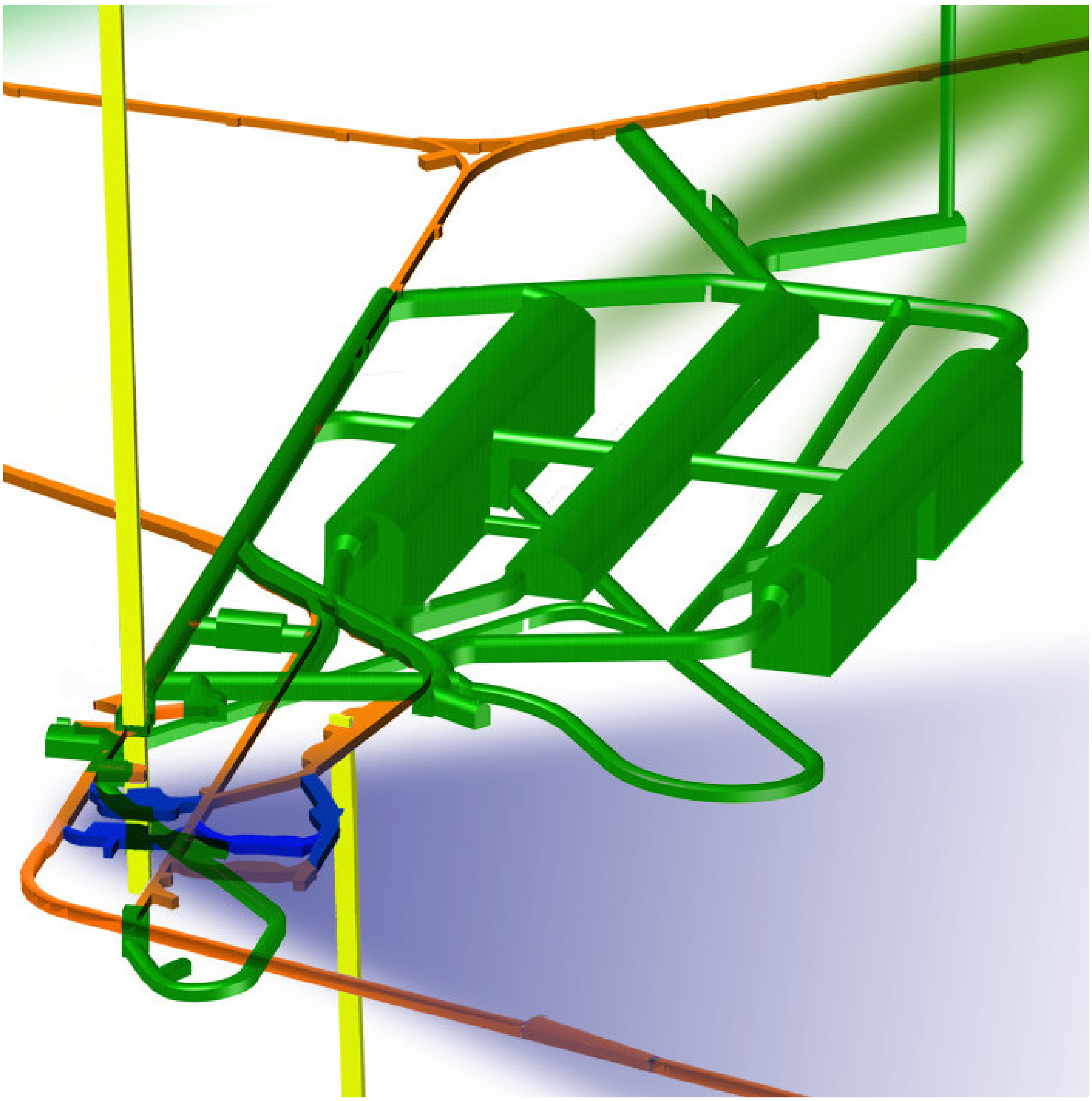
The Long-Baseline Neutrino Facility (LBNF) Far Site Conventional Facilities

Preliminary Design Report



October 12, 2015

1

Contents

List of Figures

List of Tables

Todo list

Chapter 1

Introduction

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1.1 The Long-Baseline Neutrino Facility for DUNE

ro-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.

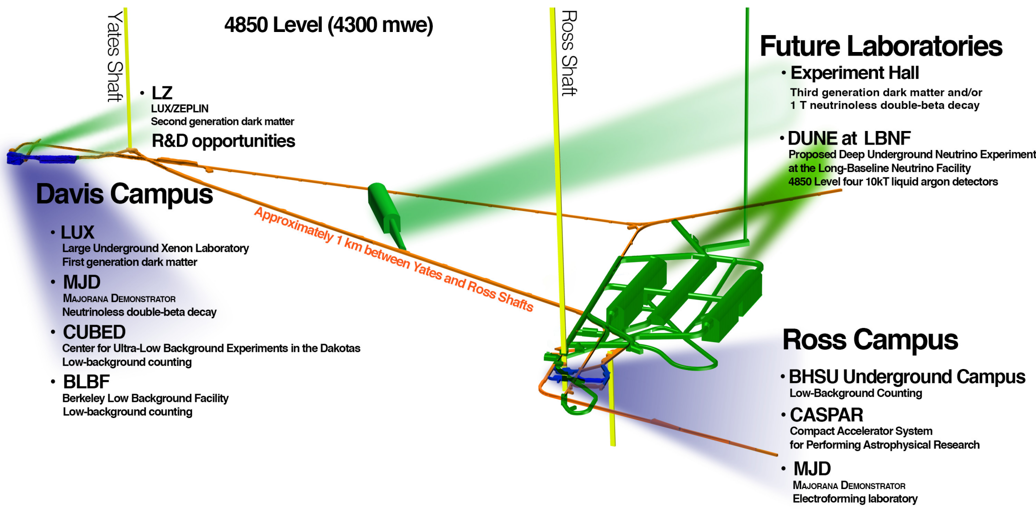

Figure 1.1: Underground cavern layout (SRK, Courtesy SURF)

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 deep-underground installation is required to shield the sensitive detector from cosmic rays, as detailed in the Report on the Depth Requirements for a Massive Detector at Homestake [6]. The 4850L is deeper than what is absolutely required, but is used because of existing access at this level. 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.

About 50 buildings and utilities exist above-ground at SURF, a few 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 [7, 8, 9, 10] 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 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 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 [11].

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.

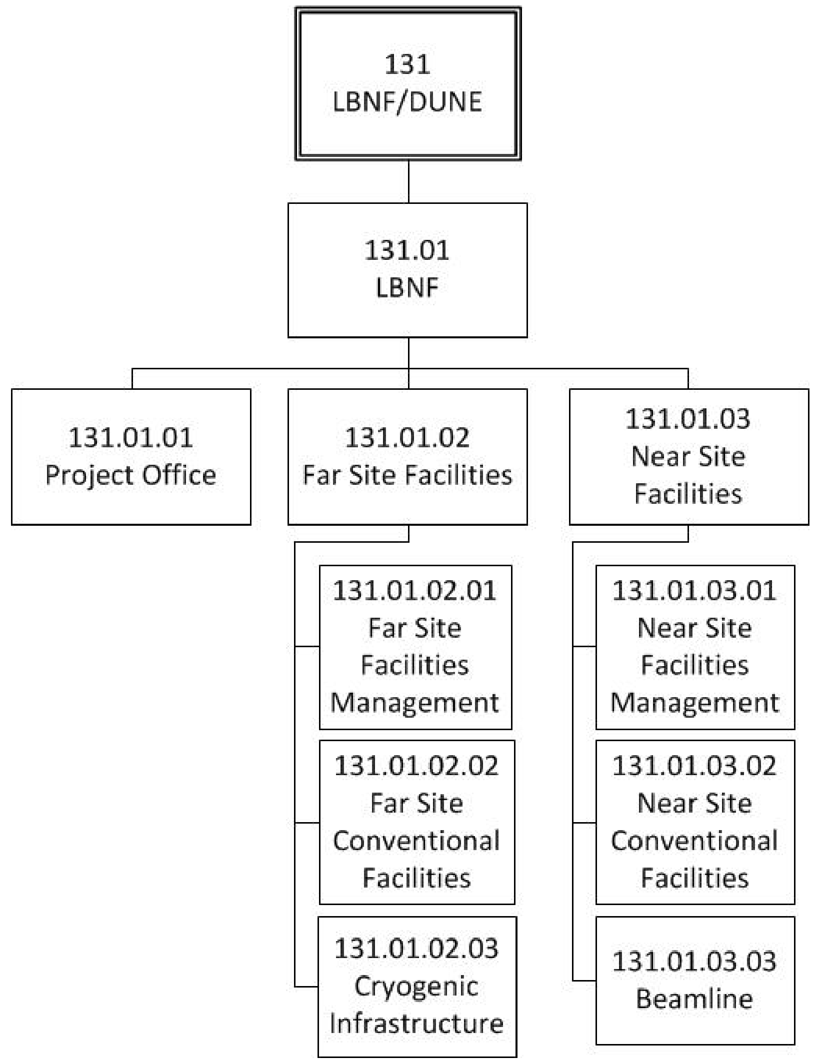

Figure 2.1: LBNF Work Breakdown Structure (WBS) to Level 3 (L3)

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.

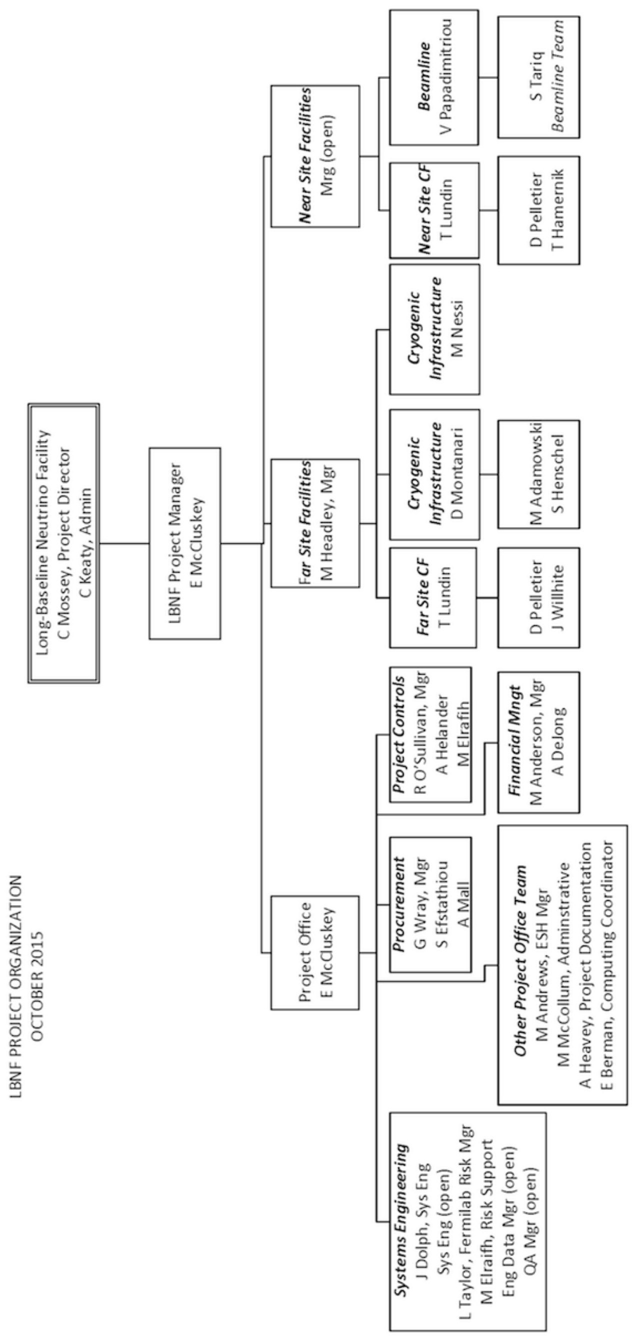

Figure 2.2: LBNF Organization

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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 Fermilab's 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 [11].

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[12]
- Risk Management Board, as described in the Fermilab Risk Management Procedure for Projects [13]

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.

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

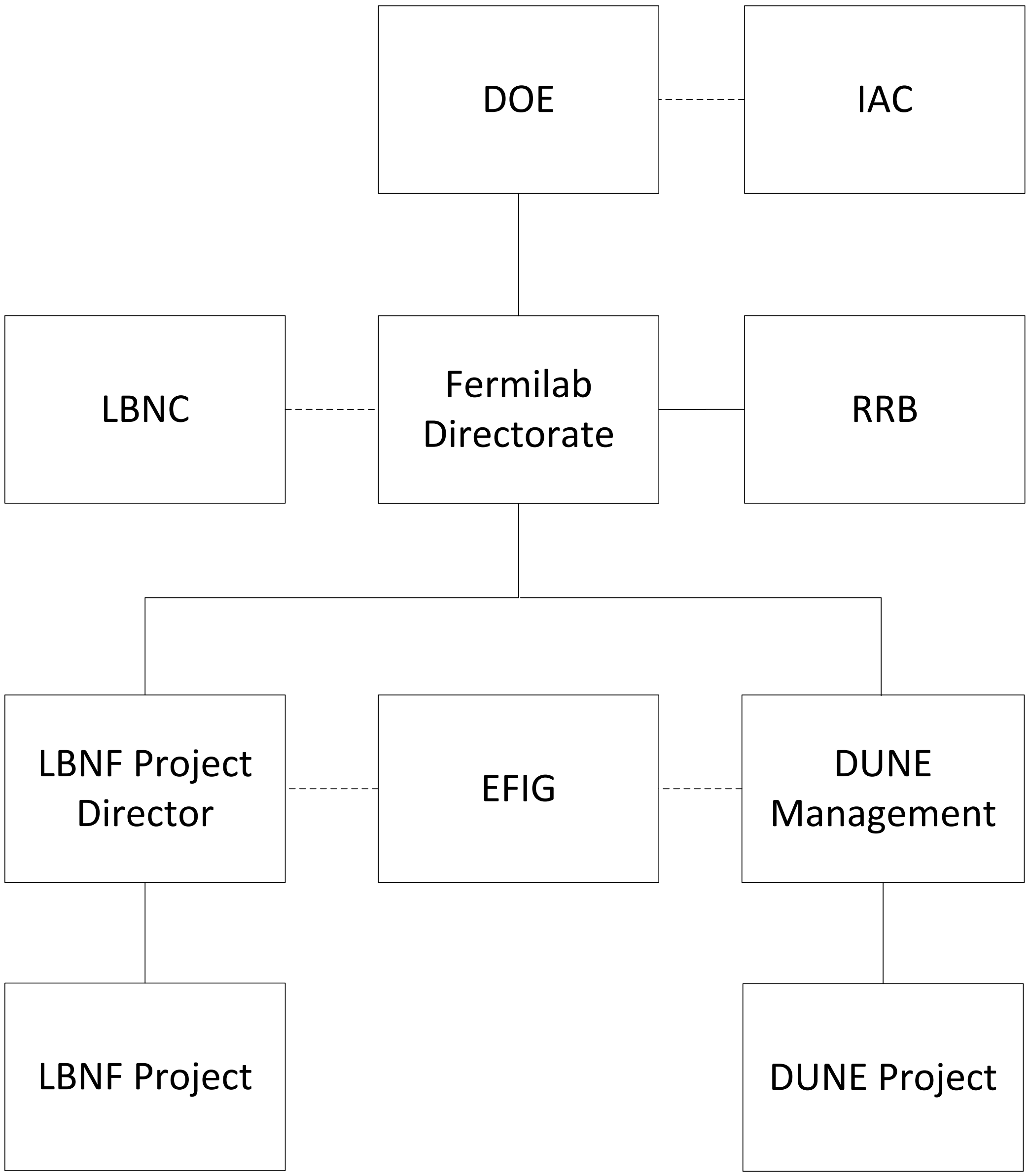

Figure 2.3: Joint LBNF/DUNE management structure

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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 "Common Projects" and "Common Funds" 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 Neu-

trino 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 independent of 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 donated the Homestake mine to the State of South Dakota in 2006 for use as a research facility.

3.1 Existing Site Conditions Evaluation

The facility conditions as of

year - I still think this year is important (this comment will be invisible in the final (non-draft) file)

were assessed by the architect/engineering firm 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 [14]. The portions of DUSEL's assessment pertinent to the LBNF Project are included here; they have been edited to reflect current activities

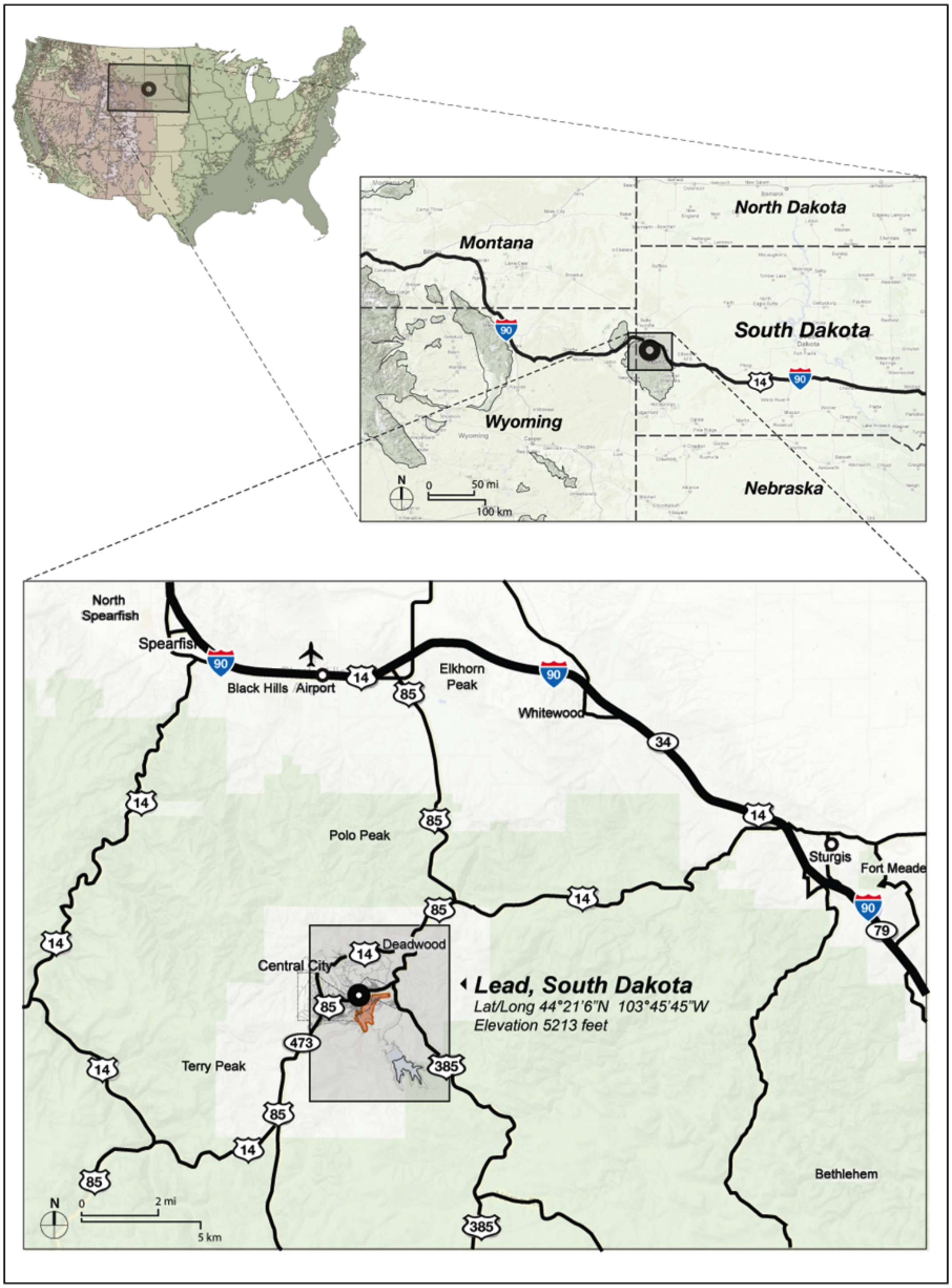

Figure 3.1: Regional context showing the city of Lead, South Dakota. (Dangermond Keane Architecture, Courtesy SURF)

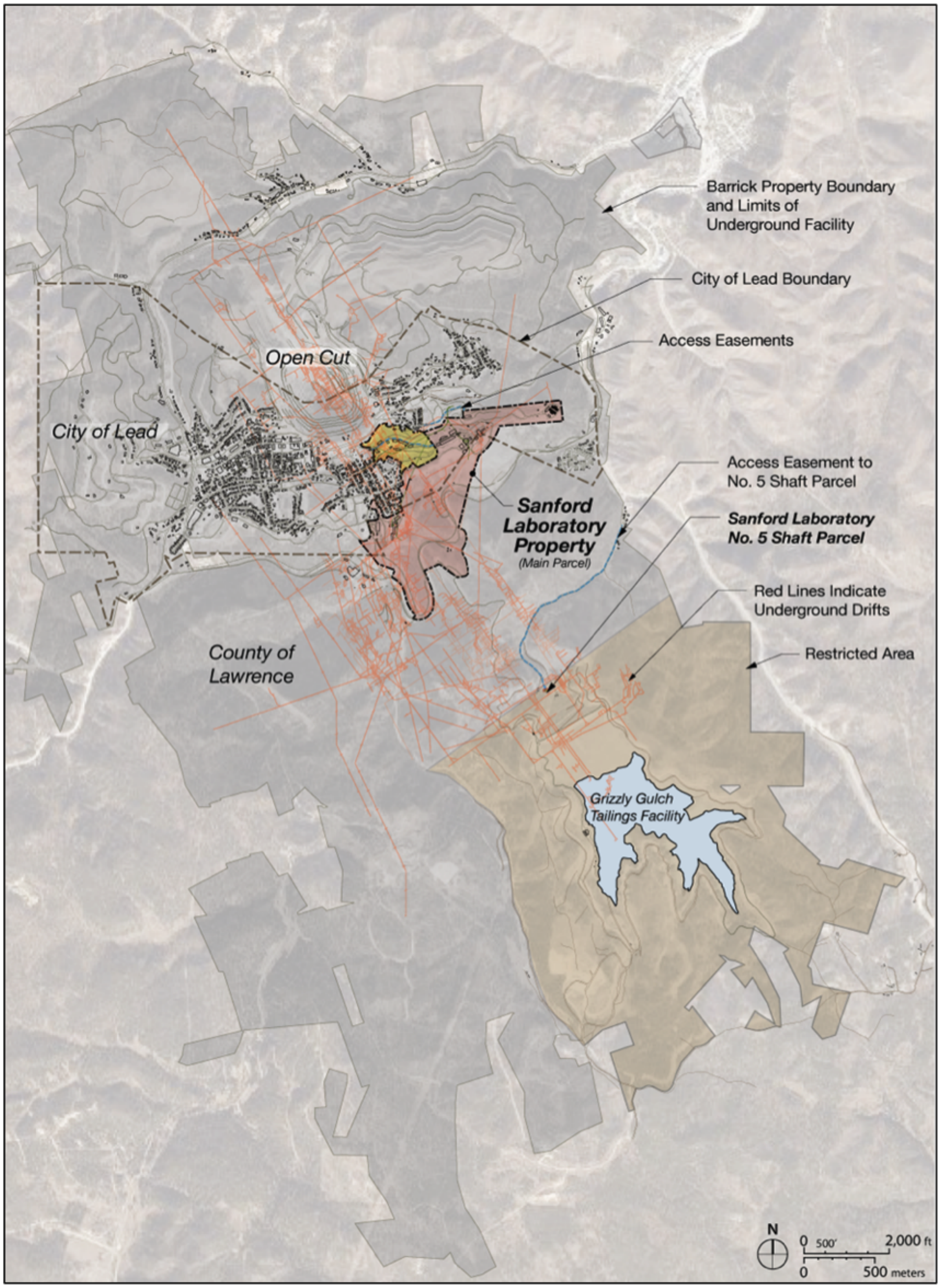

Figure 3.2: SURF Complex shown in the context of the city of Lead, South Dakota, and the property remaining under ownership of Barrick. Area shown in yellow is a potential future expansion of the SDSTA property. [Dangermond Keane Architecture, Courtesy of SURF]

fig:surf

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

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 for the DUSEL Preliminary Design and are described in detail in the DUSEL Preliminary Design Report [15, 14].

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 PDR, 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

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

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 measurement capacity of the test instruments.

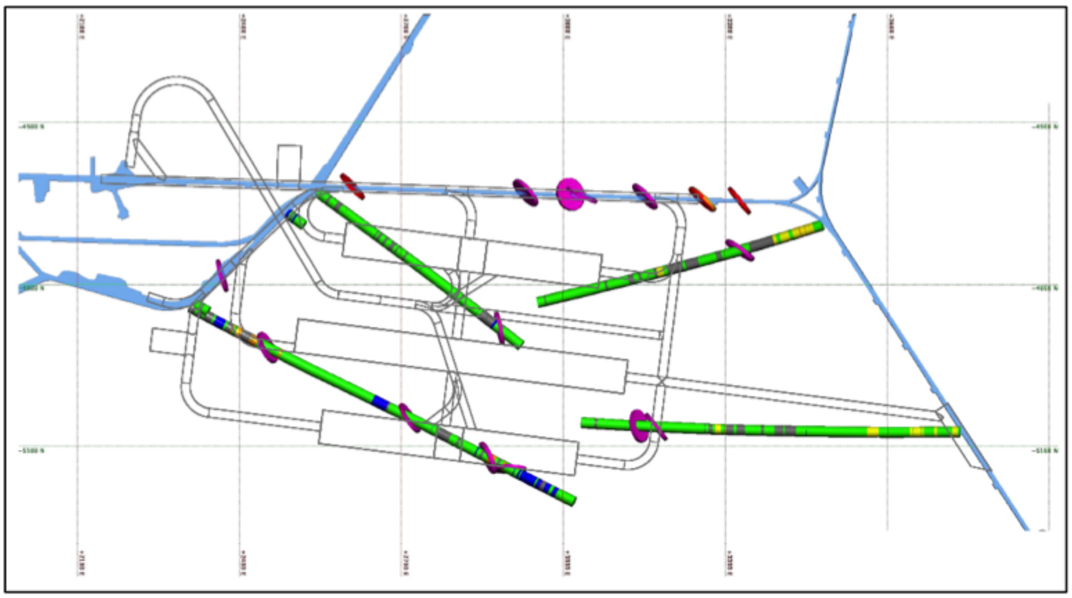

Figure 3.3: LBNF core locations and geological features

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.

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 [16].

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.

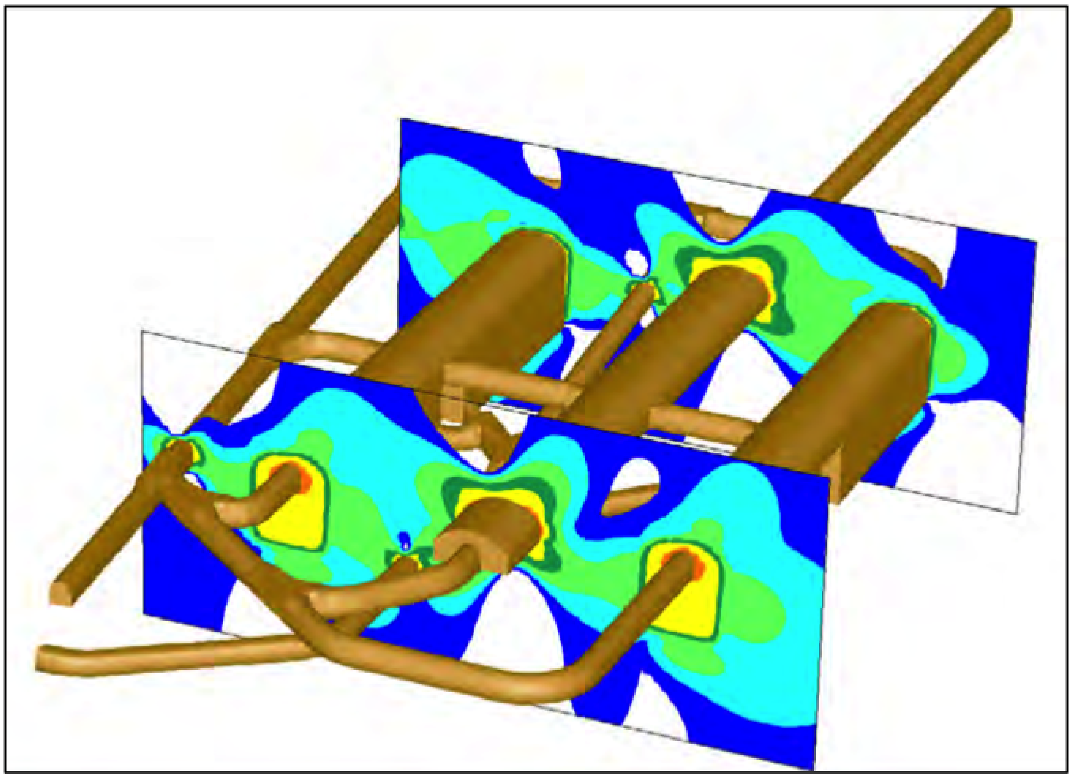

Figure 3.4: Contour of stress safety factor indicating influences between caverns

Chapter 4

Surface Facility

4.1 Existing Surface Facility

The SURF property of 186 acres includes steep terrain and man-made cuts dating from its mining history. There are approximately 50 buildings and associated site infrastructure on the surface to support the main access to underground area from either the Yates Complex or the Ross Complex; the latter will be the main LBNF access. A select few of these buildings at the Ross Complex will be upgraded and rehabilitated as necessary for use by LBNF, as will the main utilities. 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, the Command and Control Center for the experiment and facility and a new Cryogenics Compressor building, and will continue to house the SURF maintenance and operations functions. Layout of the surface facilities in the vicinity of the Ross Shaft is shown in Figure 4.2.

4.2 Surface Buildings

Surface buildings for LBNF, existing and planned, include those necessary for safe access and egress to the underground through the Ross Shaft and for office space. The existing buildings will be rehabilitated to comply to codes and to the experiment's requirements. The Ross Dry building will be modified to provide space for a surface control room (the Command and Control Center) and offices. The description in this section is excerpted from the 100% Preliminary Design Report [16] provided by Arup, USA.

A new building and surrounding concrete slabs are planned in order to provide space for the equipment required for conversion of liquid argon and liquid nitrogen to gaseous form and compression of the nitrogen gas for delivery through the shaft to the underground. The location of this building was selected based on proximity to the shaft and accessibility for trucks, as thousands of truckloads

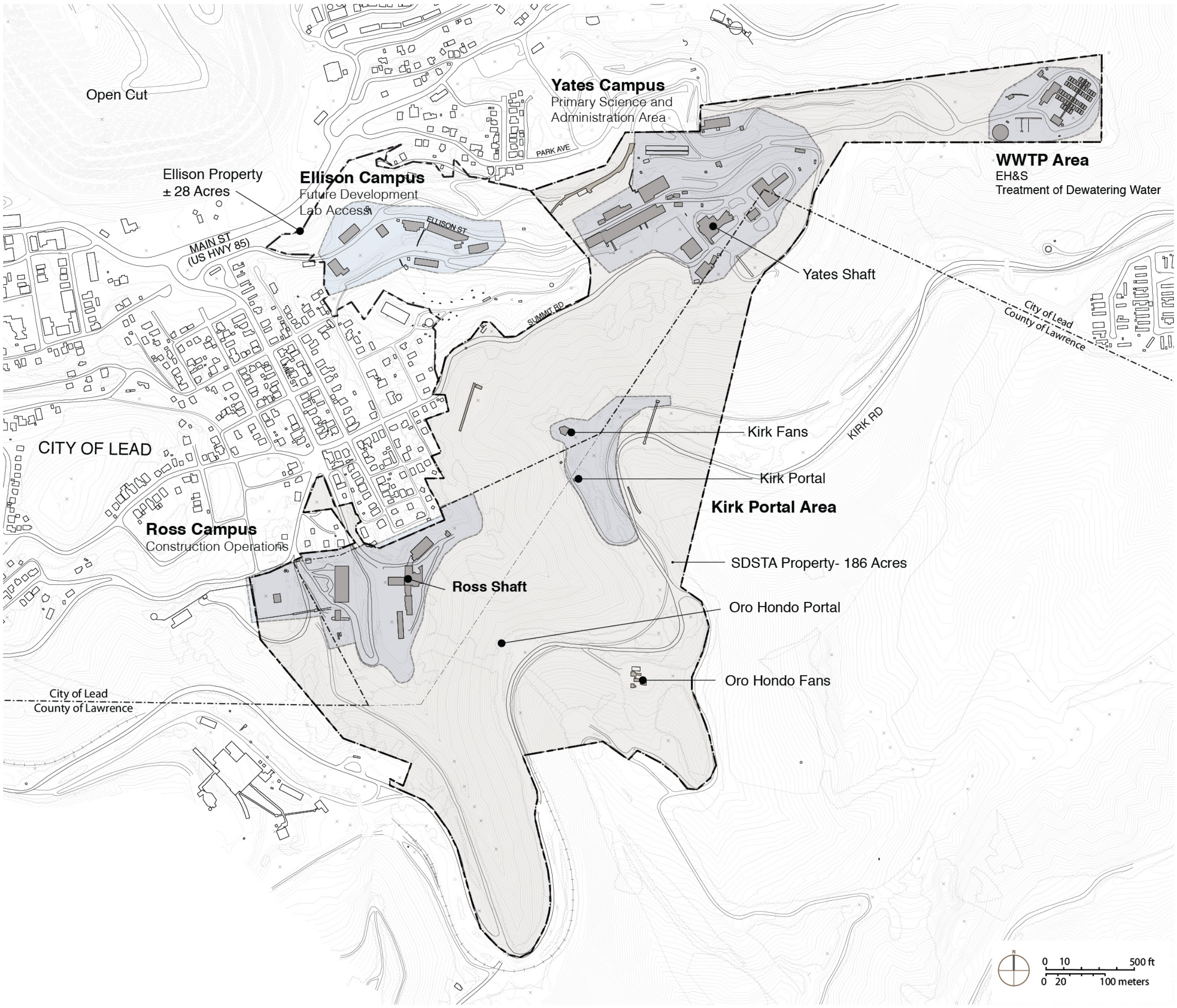

Figure 4.1: Architectural site plan; north points up (HDR)

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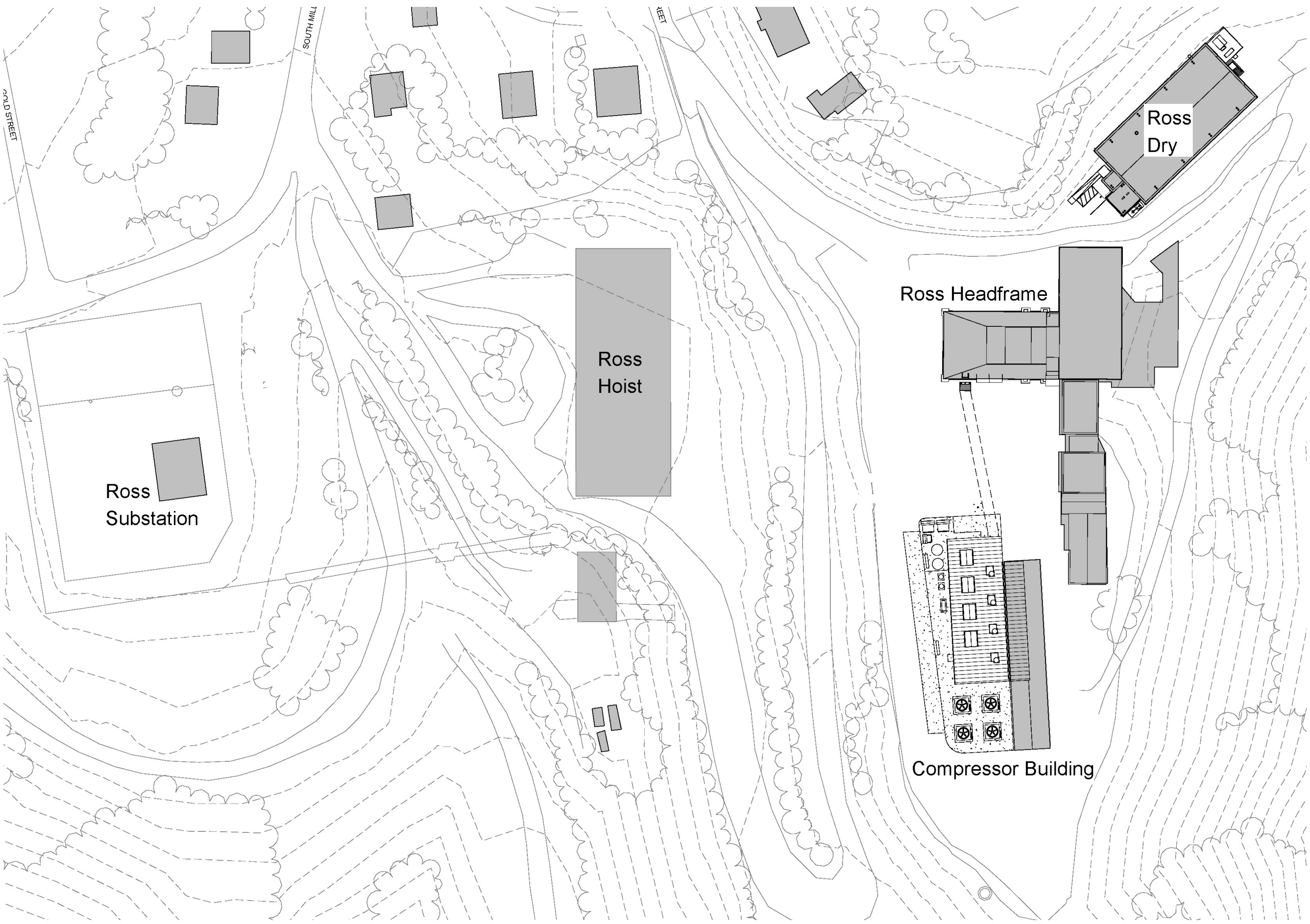

Figure 4.2: Ross Complex architectural site plan (Arup)

fig:ross

of argon will be required to fill the detectors underground.

In addition to housing nitrogen compressors inside the building, concrete slabs will be placed around the building for installation of argon and nitrogen receiving dewars (into which the trucks will unload), vaporizers to boil the liquids into gas, an electrical transformer to supply power to the four 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 LBNF Cryogenics Infrastructure [17]. The architectural layout of this building and surrounding equipment is provided in Figure 4.3.

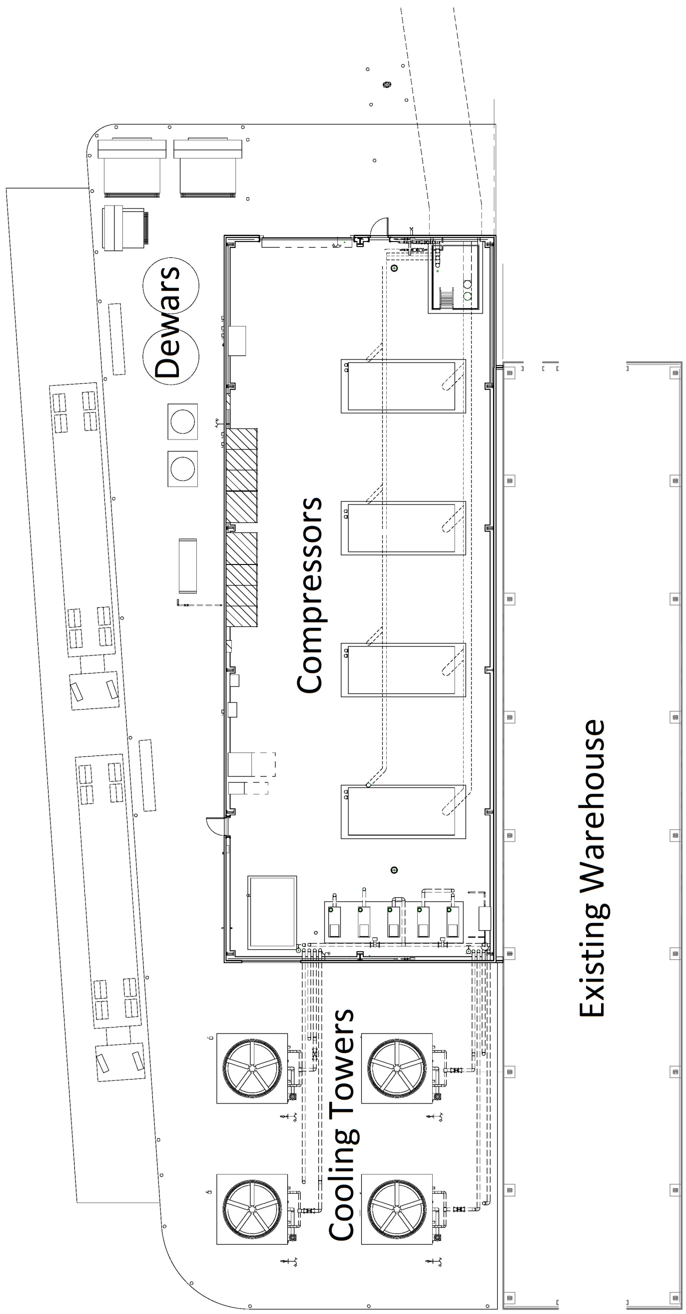

Figure 4.3: Architectural layout of LBNF Cryogenics Compressor Building

4.2.1 Ross Dry Building

The Ross Dry building is in use by SURF to provide office and meeting space in addition to men's and women's locker room (or *dry*) facilities and emergency response capabilities. As a scope option, the design includes a complete renovation of this building to upgrade these existing capabilities and to add space for an above-ground Control and Command Center. (This control center itself is not a scope option; it could be placed in a different location.) This design includes flexible space that can be tailored to evolving needs as the project transitions from construction to operations.

The proposed renovations to the Ross Dry Building are shown in Figures 4.4 and 4.5.

4.2.2 Ross Headframe

The Ross Headframe Building will be the main entry point for construction activities and for ongoing operations and maintenance functions. In addition, gas pipes from the LBNF Cryogenics Compressor Building will pass through this building on the way to the shaft.

Following shaft rehabilitation, the LBNF Project will include structural reinforcement of the Ross Headframe to meet current codes and standards. The headframe will also be modified to accommodate loads with dimensions longer than it can currently accommodate. This project will occur concurrently with other site preparation activities planned to be performed outside of the CD-3a scope, as described in Chapter 7.

4.2.3 Yates Headframe Building

The Yates Shaft, which terminates in the headframe building at the Yates Campus, will be used for delivery of personnel and materials underground during construction and operation of LBNF/DUNE. The building and shaft will in fact be critical to LBNF during the installation of gas piping through the Ross Shaft, during which time the Ross Shaft will be restricted to that activity plus emergency egress. The LBNF Project will therefore include structural reinforcement of the Yates Headframe to meet current codes and standards, to be completed prior to the installation of gas piping through the Ross shaft. Installation of a redundant fiber optic backbone through the Yates Shaft will provide a means to transfer DUNE data in the event of disruption of the fiber optic connection in the Ross Shaft, as well as for communications.

4.2.4 Ross Crusher Building

The existing Ross Crusher Building is a high-bay space that contains rock-crushing equipment used for construction operations. The exterior of the building will be repaired so that people can comfortably work inside. 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.

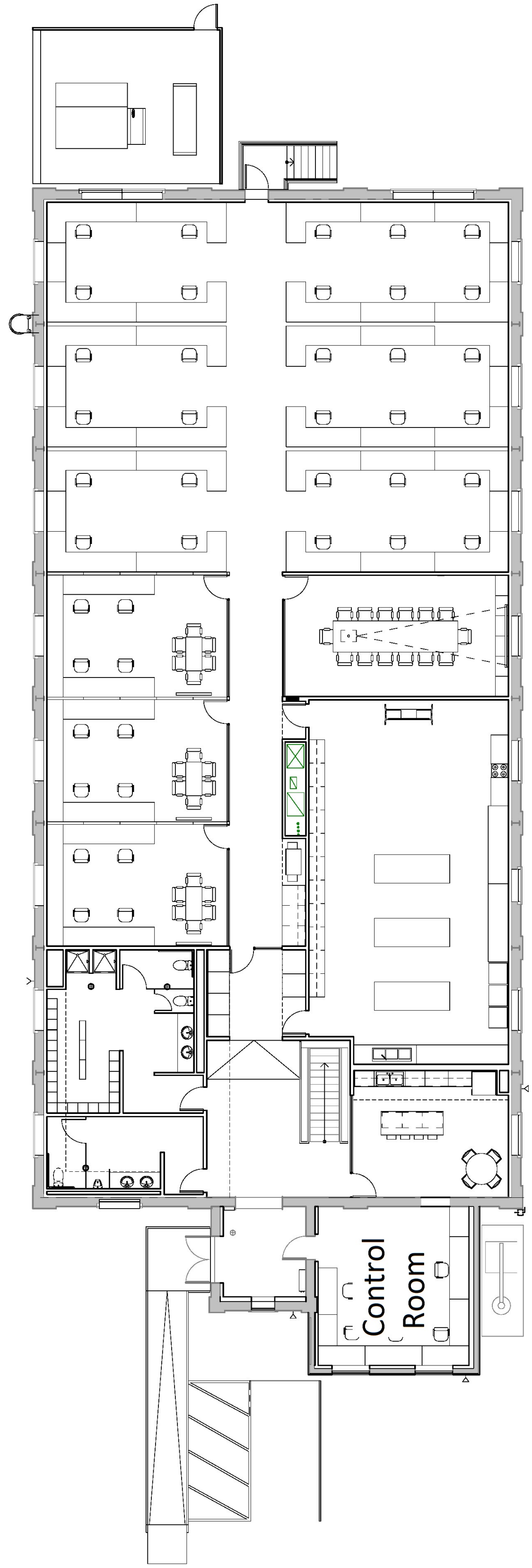

Figure 4.4: Ross Dry Building renovation, main floor, showing the planned location for the control room (Command and Control Center).

fig:cmd-

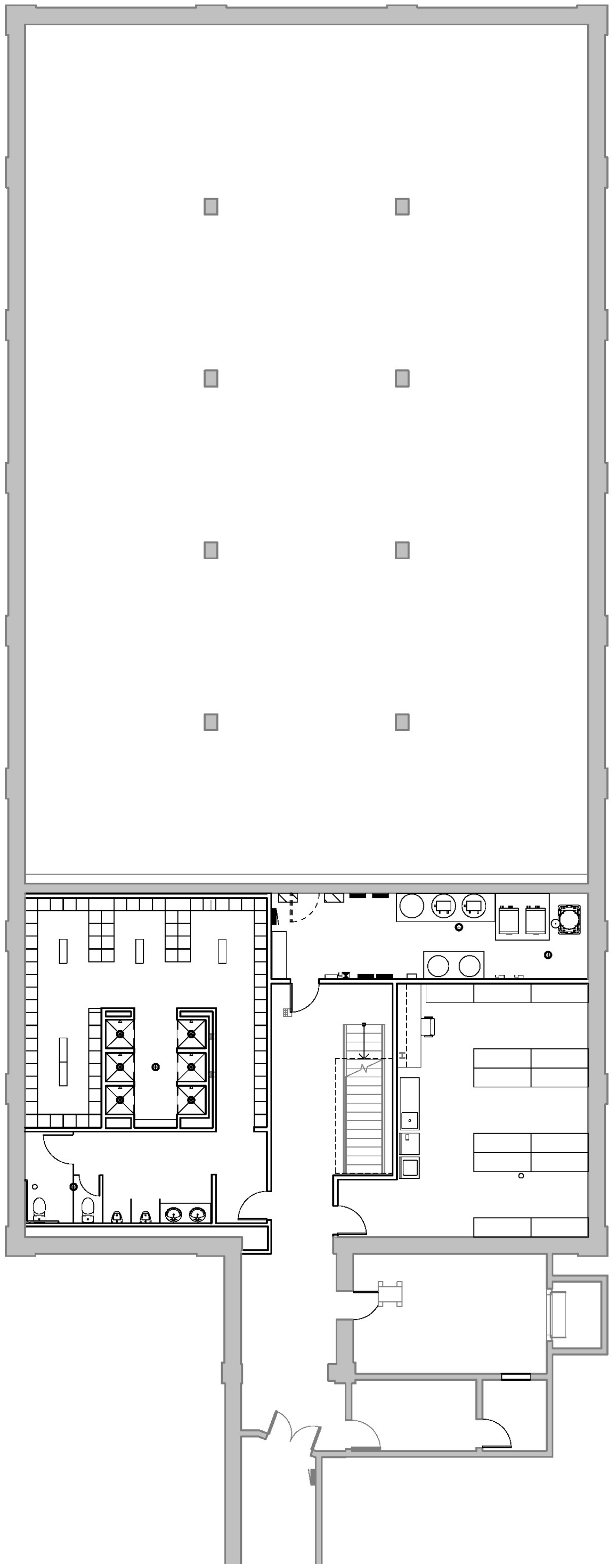

Figure 4.5: Ross Dry Building renovation, basement.

fig:cmd-

4.3 New Surface Infrastructure

Surface infrastructure includes items such as retaining walls and parking lots, as well as utilities to service both buildings and underground areas. Existing infrastructure planned for use by LBNF requires both rehabilitation and upgrades to meet code and LBNF requirements.

No new roads or parking lots are required for LBNF at SURF. However, the Ross Complex site will require minor demolition of power lines and a fire hydrant that are no longer used in order 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 Section 5.4.

Chapter 5

Underground Excavation

The LBNF and DUNE design teams have worked together to define the excavated spaces required at the 4850L for the DUNE far detector. These spaces include caverns to house the detector modules, drifts for access and utility routing, a cavern to house utilities and the cryogenics infrastructure (the Central Utility Cavern) and extra spaces to support construction and installation. Mucking drifts connected to the Ross Shaft for waste-rock handling and a shop area for underground assembly and maintenance of excavation equipment will likely be required. In addition, a spray chamber is planned to provide 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 in Figure 5.1.

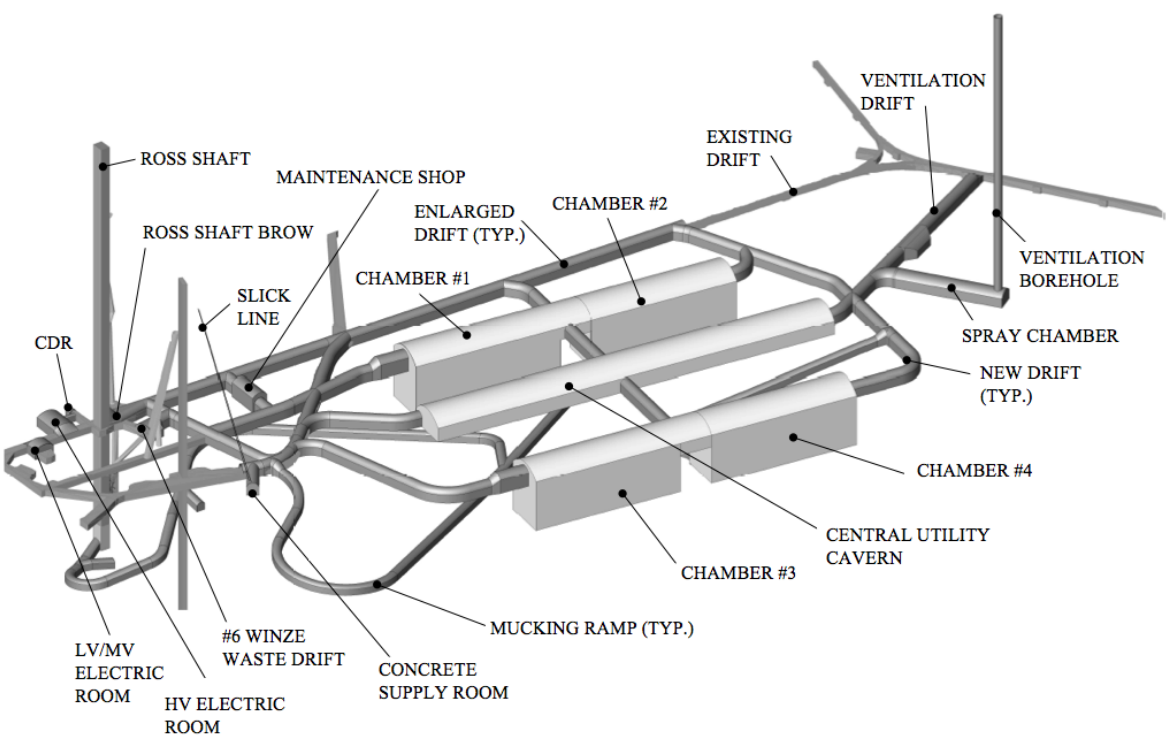

Figure 5.1: Spaces required for LBNF at 4850L (SURF)

5.1 LBNF Caverns

5.1.1 Detector Caverns

The requirements from the Cryogenic Infrastructure and Far Detector subprojects on the caverns are mainly related to the dimensions of the space, and are documented in [4]. The overall dimensions of the main caverns are shown in Figure 5.2. The DUNE detector modules will be housed in four chambers within two main caverns at the 4850L.

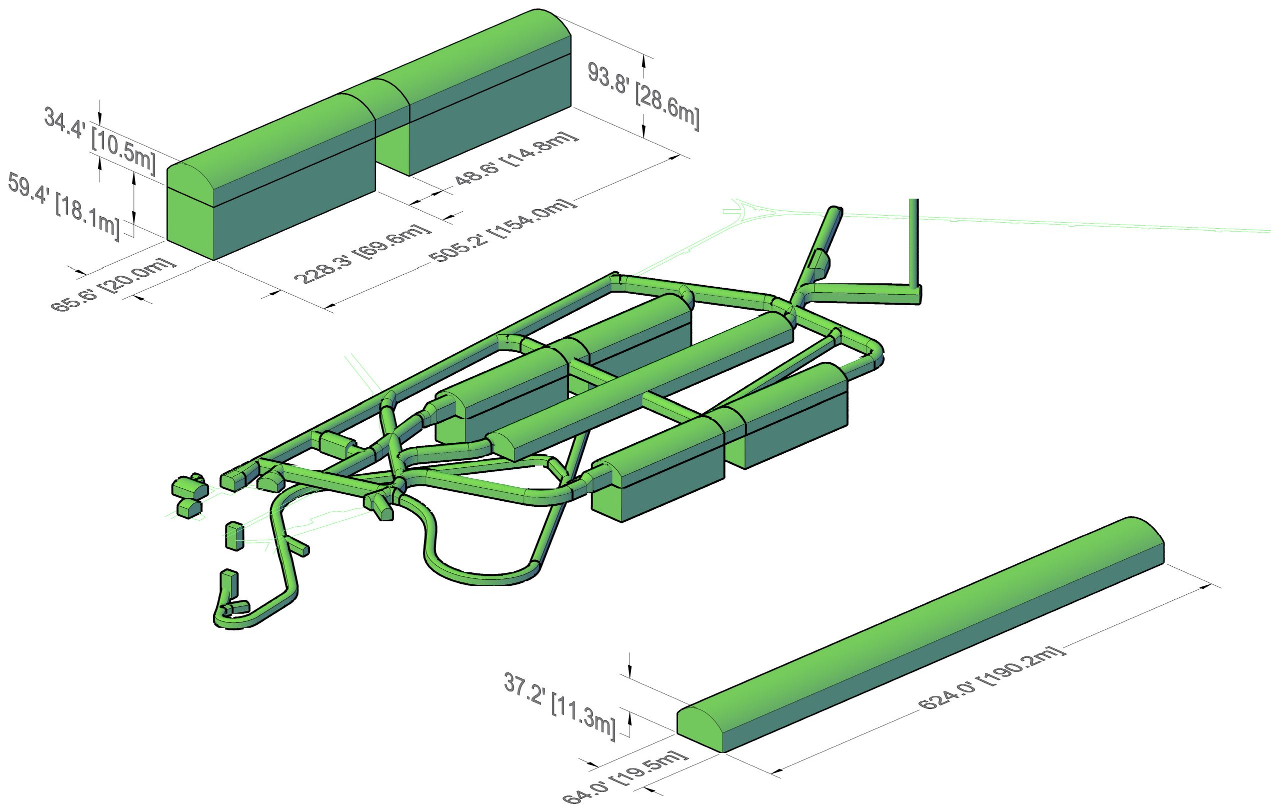

Figure 5.2: Dimensions of the main LBNF cavern excavations (final dimensions will be slightly smaller). (SURF)

The size of a detector module is limited by both rock strength and the maximum dimensions of anode and cathode plane arrays that can be produced, lowered through the shaft and installed. Space occupied by the free-standing steel structure, the vessel's insulating liner, and an intentional exclusion zone reduce the total volume of the detector to less than the volume of the excavation; the fiducial volume is consequently reduced, as well. Current assessment of rock quality for this formation indicates that caverns of the sizes indicated in Figure 5.2 are reasonable.

Preliminary modeling in both 2D and 3D of the proposed excavations has been done. The 2D models indicated that the intact rock strength and joint strength have the greatest impact on the design and the 3D results confirmed that the complex geometry of the design, that includes multiple drifts and caverns, is possible.

The far detector caverns and drifts will be supported using galvanized rock bolts/cables, wire mesh, and fiber-reinforced shotcrete to allow a lifetime of 30 years. The area of the cavern floors has been evaluated and does not require support.

Groundwater is another factor to consider when planning the excavations. All experience, analysis, and field testing at the 4850L of SURF indicate that the volume of water to be encountered will be very minor ($\ll$1 lpm), but that the locations of these small seeps are unpredictable. A groundwater drainage system will be placed behind the shotcrete in the arch and walls of the far detector cavern rock excavation to collect the 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 cryostats and detector components. Placement of rock bolts will be coordinated with the excavation contractor to provide anchorage to support these monorails.

5.2 LBNF Central Utility Cavern

LBNF requires space for cryogenics equipment outside the detector chambers. Space is also required for conventional facilities utilities. It is planned to excavate an independent central cavern, called the Central Utility Cavern, to house the experiment's cryogenics systems, the electrical equipment to supply power for both facility and experiment needs, sump pump access and controls, fire sprinkler room, air handling units (AHUs), a chilled-water system and ducting. The centralized location minimizes overall utility distribution and the associated costs. Furthermore, isolating the utilities from the experiment simplifies electrical ground isolation, making it easier to avoid interference with sensitive detector electronics. Finally, it provides the opportunity to optimize ventilation; the heat emanating from the equipment can be controlled in this one cavern.

5.3 Access/Egress Drifts

All the equipment that comes down the Ross Shaft must also pass through the drift connections to get to the new LBNF excavations. The drift therefore needs to accommodate not only the largest possible load from the shaft but also utilities installed in the drift itself. The drift connection sizes will be optimized accordingly. At the writing of this document, an assumed size of 5 m wide by

6 m 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 LBNF and DUNE is to complete construction and start operation of the first 10-kt detector as early as possible. To this end, the excavation will be sequenced such that LBNF can begin installation of a cryostat in the first detector chamber while excavation continues into the second chamber in the same cavern. A temporary wall will be built in the detector installation laydown space (this is the area between detector chambers that is not as deep as the chambers themselves, sometimes called the ''rock pillar") to isolate one from the other. This wall must be sturdy enough to withstand the air shock waves associated with drill-and-blast type excavation. Vibration limits and controls must be further evaluated as the design advances to avoid damaging the cryostat as it is assembled next-door to the excavation of the second chamber.

In addition to controlling the impacts from blasting, logistical coordination is a key concern with a sequenced excavation schedule in which cryostat construction is concurrent with excavation. Cryostat and detector components will need to be delivered through the Ross Shaft, which will also be used for loads associated with excavation and other construction activities. A logistics study [18] 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 transport. The Yates shaft can provide some relief during high-intensity work periods, but this was not factored into in the study; therefore the results are conservative.

Most excavated material will travel through a mucking ramp starting at the base of each detector chamber and ending at the waste dump near the Ross Shaft, as illustrated in Figure 5.1. This ramp is completely independent of all other traffic and is outfitted with a separate ventilation stream to keep diesel exhaust from the 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 (at the top of the detector modules) to the mucking ramp (at their base, the ∼4905L), 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 chambers can be accomplished in one of two areas. All materials are delivered through the shafts to the 4850L, which is ∼18m above the base of the chambers. 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 chambers. Excavation in chambers 3 and 4 will be accomplished in parallel and will be complete before cryostat construction begins.

5.5 Interfaces between DUNE, Existing Facilities, Cryogenics and Excavation

terfaces

There are several points at which the experiment and the facility interface closely. These are coordinated between the design teams for DUNE, LBNF Cryogenics Infrastructure and LBNF Conventional Facilities, and design consultants. Sizing of spaces and components, and sequencing of construction figure among the key issues, listed here, that interfaces must address.

- The LBNF cryostats are freestanding structures requiring infrequent access for inspection around the structures' perimeters.
- The utility spaces to house the equipment for the cryogenics system are directly influenced by the size of the equipment.
- The size and construction sequencing of the detector chambers are critical to the DUNE experiment strategy.

In addition to these interfaces, the LBNF excavation requires coordination with existing facilities and activities, in particular, with experiments located in relatively close ($\sim$100 m) proximity to the planned excavation. A test blast program has been designed to study the actual response of the rock mass in this area due to vibrations and air-blast overpressure created by drill-and-blast excavation techniques. This test blast program is currently being coordinated closely with the existing experiments and the test itself will be completed within the first quarter of FY16. The results of this test will either confirm that the planned excavation approach is appropriate, or indicate where modifications to the plan must be made.

Chapter 6

Underground Infrastructure

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

The infrastructure must support (1) the FSCF construction activities, (2) installation of the Cryogenics Infrastructure and the experiment, and (3) operation of all the the equipment and the experiment. After analysis of these activities, the most stringent requirements that they impose were used to define the requirements for design.

Among the requirements is the need to reduce the risk of existing infrastructure failure to be able to adequately support LBNF construction activities. This work will be completed as Site Preparation: Ross Shaft rehabilitation, maintenance and repair focused on the Yates Shaft, and ground-support activities at the 4850L between the Yates and Ross Shafts. Additional discussion of this work is included in Section 3.1.

The preliminary design for LBNF underground infrastructure has been produced collaboratively, the primary designer being Arup, USA. The scope of this design covers infrastructure from the surface down through the shafts and drifts, to the excavations for the detector modules. Arup's design was produced in coordination with LBNF, SURF and the excavation and surface design teams.

The utility infrastructure includes fire/life safety systems and strategies, permanent ventilation pathways, HVAC, power, plumbing systems, communications infrastructure, lighting and controls. The design is fully documented in Arup's LBNF 100% Preliminary Design Report [5] and in the preliminary design drawings. This chapter includes a summary of that report.

Shaft rehabilitation and waste-rock handling design were previously provided for the DUSEL PDR in 2011 and LBNF will follow this design. This chapter uses excerpts from the DUSEL Preliminary

Design Report, Chapter 5.4 [14]. The research supporting this work took place in whole or in part at SURF, which was then called 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 evacuate personnel, or if evacuation is not immediately possible, isolate personnel from potentially dangerous situations underground. Design for fire events includes both preventing the spread of fire and removing smoke and/or cryogenic gases through the ventilation system. The evaluation and establishment of requirements for cryogenic gas removal is performed by the Cryogenics Infrastructure project team and provided to FSCF.

Arup identified the life safety requirements and developed the design, 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* [19]. 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 limited to 144 following completion of the Ross Shaft Rehabilitation. This limit is based on both the ability of the shafts to provide egress within one hour and the capacity of the existing refuge chamber. This chamber 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 [18] completed by Arup that evaluated the occupancy load during CF construction confirms the adequacy of this number.

To limit the horizontal and vertical spread of any fire or smoke, egress routes will be separated from adjacent spaces via compartmentalization. This will also help limit the spread of any cryogenic gas leaks, or other leaks and spills. A minimum four-hour fire separation is required between the LBNF caverns and adjacent drifts, and a minimum two-hour fire separation for all rooms that connect directly to the egress drift at 4850L, as well as the shafts. Fire and life safety systems designed to meet these requirements are described in the following sections.

6.2 Shafts and Hoists

The Ross and Yates Shafts provide the only access/egress between the surface and the underground levels, and are therefore critical to the function of the facility. Both shafts provide service down to the 4850L, though not every intermediate level is serviced from both shafts. The shafts also provide a path for all utilities between the surface and 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 experienced some deterioration in the years after the mine closed. A complete assessment of the Ross and Yates Shafts was conducted for the DUSEL Project in 2011, and is documented in the Arup Preliminary Infrastructure Assessment Report (DUSEL PDR Appendix 5.M [14].

6.2.1 Ross Shaft

The Ross Shaft will be used for facility construction, including waste rock removal, routine facility maintenance, and as an egress path for the finished underground campuses. It will also be used for primary access to the DUNE experiment. 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. Figure 6.1 shows the shaft cross sectional layout.

The Ross Shaft was in operation until the Homestake Gold Mine closed in 2003, and was put back in operation when the Sanford Laboratory reopened the site in 2008 without major repairs. 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 presently being performed by SURF. The set spacing is being increased from 6 ft to 18 ft, but the general configuration of the shaft will remain the same to allow it to remain in service for emergency egress during rehabilitation. The shaft was installed with limited ground support in the surrounding walls, 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 constrained by the existing configuration; they are driven by a focus on safety, performance, and codes. Shaft rehabilitation through calendar year 2016 is being executed by SURF with non-LBNF Project funds. The rehabilitation is just over 60% complete as of this report and completion is planned for 2017. Beginning in January 2017, the funding for the balance of the rehabilitation project will come from the LBNF Project as part of site preparation (Chapter 7). This will also include rehabilitation of the skip loading pocket for waste rock handling, and replacement of skips, cage, and ropes.

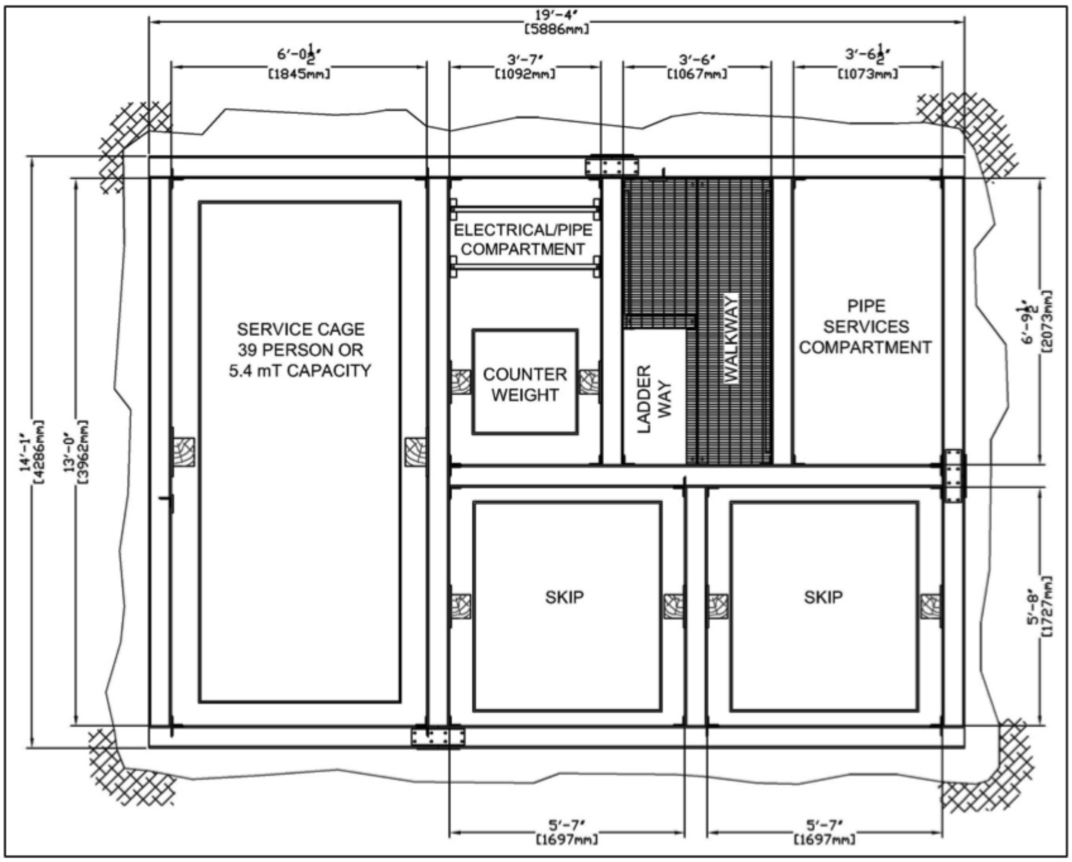

Figure 6.1: Ross Shaft, typical shaft set (SRK, Courtesy SURF)

fig:ross

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 operates the production skips. The DUSEL PDR [14] 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). These electrical and mechanical systems will have standard maintenance performed on them to restore them to like-new condition, but will not be modified from the existing design. All of this work is captured in the LBNF scope as part of site preparation (Chapter 7).

6.2.2 Yates Shaft

The Yates Shaft is rectangular in shape – 15 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, two other compartments accommodate shaft services. 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 so as 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 they are, with maintenance performed to bring them into like-new condition as part of site preparation (Chapter 7). 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 [14]).

6.3 Ventilation

The ventilation system for LBNF/DUNE 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 caverns 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, the primary function of which is rejecting heat from the LBNF chilled water system (see Section 6.5.3). In this chamber the exhaust and heat are directed into a new borehole that connects to the 3500L at a point near the Oro Hondo shaft. The mixture is routed to the shaft, and pulled directly up by the fan at the surface.

The design calls for a ventilation rate for heat extraction of 230,000 cfm of which 27,500 cfm passes through each detector cavern and 21,500 through the Central Utility Cavern; the balance of the air required for heat rejection will come directly from the shafts through connections to existing drifts. The environmental design criteria for LBNF underground spaces are shown in Table 6.1.

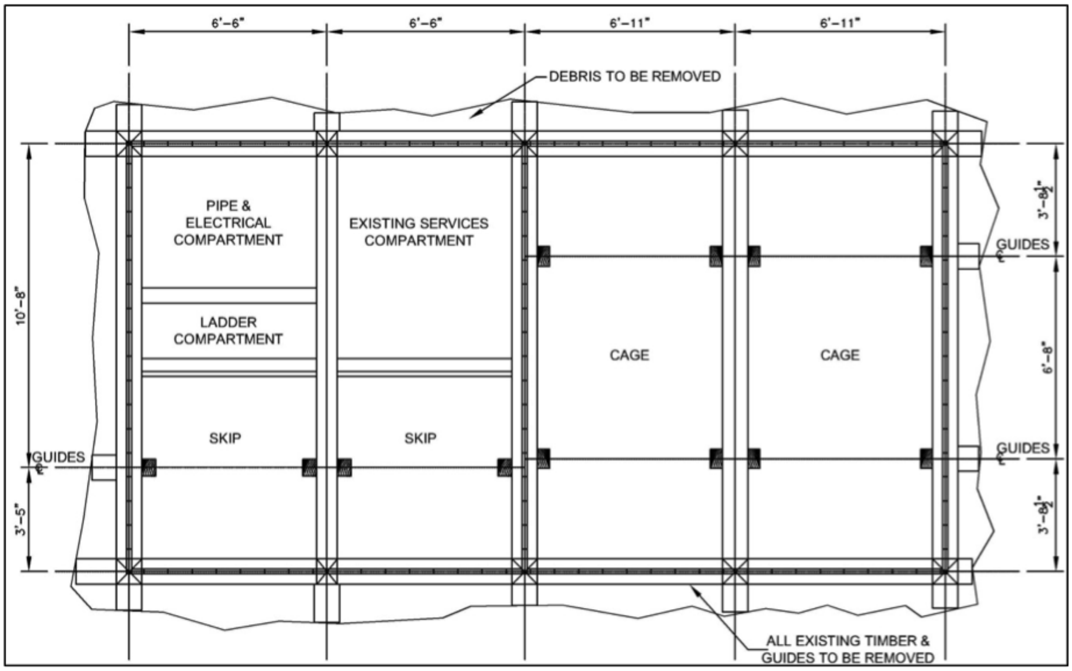

Figure 6.2: Existing Yates Shaft layout (Adapted from SRK, Courtesy SURF) fig:yate

Table 6.1: Environmental design criteria (Arup)

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

ign-crit

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 cryogenics systems surface compressors can be used for energy savings to heat the intake air.

6.4 Electrical

6.4.1 Normal Power

The estimated electrical loads for both the far detector and the underground infrastructure serving the detector spaces are included in the facility load determination and design; the loads are listed in Table 6.2.

Power for the far detector will originate from the Ross substation and be routed down the Ross Shaft to the 4850L. One set of 15-kV mining cables will be installed down the Ross Shaft to the 4850L. These will be cable-rated for mine use, highly flame retardant, have low smoke toxicity, high tensile strength and be self-supporting. At the 4850L, the 15-kV mining cables will terminate in a 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

Standby power is necessary for emergency evacuation of personnel and circulation of cryogens (to avoid rapid boil-off and loss of argon) when surface power is inoperable.

A 300-kW emergency/standby diesel generator will be provided in the Central Utility Cavern with 48 hours worth of diesel fuel to operate it. This duration aligns with the stored LN for controlling argon boil off; these figures satisfy requirements 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 also occur at a very low rate. The following electrical loads are anticipated to be installed to the emergency/standby power system at the 4850L:

- Security

[1] During operations, occupancy of the LBNF cavities is 20. 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 unless specific requirements that differ from this are provided by LBNF/SURF or the lab experiment design teams.

Table 6.2: Underground Electrical Loads

Underground Electrical Load by Area	kW
Cryostat 1&2 Detector Electronics	450
Cryostat 1&2 Argon Pumps	98
Cryostat 1&2 CF	350
Total Cryostat 1&2	898
Cryostat 3&4 Detector Electronics	450
Cryostat 3&4 Argon Pumps	98
Cryostat 3&4 CF	342
Total Cryostat 3&4	890
Central Utility Cavern - Detector Cryogenics	956
Central Utility Cavern - DAQ	36
Central Utility Cavern - CF	753
Total Central Utility Cavern	1745
Spray Chamber	165
Maintenance/Assembly Shops (2)	84
Drifts	152
Total (other spaces)	401
Total non-CF	2088
Total CF	1846
Total	**3934**
Aggregate Demand Factor	0.736
Total × Aggregate Demand Factor	**2894**

ec-loads

Table 6.3: Surface Electrical Loads

Surface Electrical Load	kW
Cryogen Building	5000
Control Room	250
Emergency/Standby Generator	50
Total Surface Load	**5300**

ec-loads

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

6.4.3 Fire Alarm and Detection

The 4850L will have notification devices installed to alarm the occupants in case 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 detector chambers and every 400 ft along the access drifts to communicate with the Command and Control Center at the surface.

An air-sampling and gas-detection system will be installed in the drifts and detector chambers for 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 at the affected levelâĂŹs fire alarm panel and at the Command and Control Center at the surface. Specific sounds and strobe colors will be identified with and used for specific types 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 for the lights is to be coordinated with conduit and supports of other systems running overhead. An average illumination of approximately 24 lux (2.4 foot candles) at floor level will be maintained throughout the drifts. Lighting control in drifts will be accomplished via low-voltage occupancy sensors and power packs suitable for high-humidity environments. Emergency lights will be provided in all areas, with a 90-minute backup power supply. Note that all occupants are required by SURF policy to have cap lamps readily available for emergency use as well.

6.4.5 Grounding

The grounding system will be designed to enable protective devices for electrical equipment to operate within a specified period during fault conditions, and to limit touch voltage under such conditions. The grounding system will be designed for a maximum resistance of 5 Ω, 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.

Josh: detector grounding reqs? Maybe we can get a reference later; Josh says graphic in doc 285 but print may be too small

6.5 Plumbing

LBNF scope includes plumbing for the DUNE detector and the infrastructure that services it. This is the plumbing for cooling systems and gas piping for nitrogen and argon delivery from the Cryogenics Compressor Building (on the surface) to the Central Utility Chamber. It also includes 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 water service. It is not feasible to run an uninterrupted main water supply line from grade level down to 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 purify industrial water sufficiently to 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 during operations that will be removed by LBNF-provided chillers. Three chillers that each run at 50% capacity 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 detector caverns immediately before exhausting into a new borehole providing a direct connection to the exhaust shaft to surface. See Section 6.3. 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 exhaust air temperature to no more than 95 degrees F.

6.5.4 Fire Suppression

The source of water for fire suppression will be the existing 4-inch industrial water main at the 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. This will provide 90 minutes of capacity even if the water supply were completely cut off. The fire protection system at the 4850L Campus will be gravity-fed. There will be a connection to an existing 6-in industrial water main in the west drift fed from the Yates Shaft, where a similar, but slightly larger (50,000 gallons), sump has been built by SURF. This provides a redundant supply from the surface. All new and/or enlarged excavations created for LBNF, with the exception of excavation-specific mucking ramps, will be provided with fire-suppression systems. In the detector caverns, pre-action type systems, which require two indications of fire before activating, will be provided.

6.5.5 Drainage

Drainage from the drifts, mechanical electrical rooms (MERs), and from 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 in which each pump discharges 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 being discharged 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 Ross 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 for the cyberinfrastructue will be based on uniform cable distribution with a star topology. New fiber connections will be extended to the 4850L from the Ross Dry Building, and will be dedicated to the use of LBNF/DUNE. The design provides one (1) 96-strand single-mode armored fiber optic cable from the DUNE Control and Command Center at the surface. A second 96-stand single mode armored fiber optic cable has been identified as a scope option and, if included, will be routed through the Yates shaft to provide redundancy for data systems. Figure 6.3 shows the fiber distribution network for LBNF/DUNE.

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. The leaky feeder is planned as a scope option. 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 Excavated Material Management

Prior to the commencement of any excavation activities, it will be necessary to establish an excavated-material management system and repository. The capacity of this system will be equivalent to what was in place during mining operations. There are a number of components to the management system, including refurbishing the Ross Shaft hoisting system and crushers, and constructing a new conveying system. As of this report, two options have been identified for final repositories of the material.

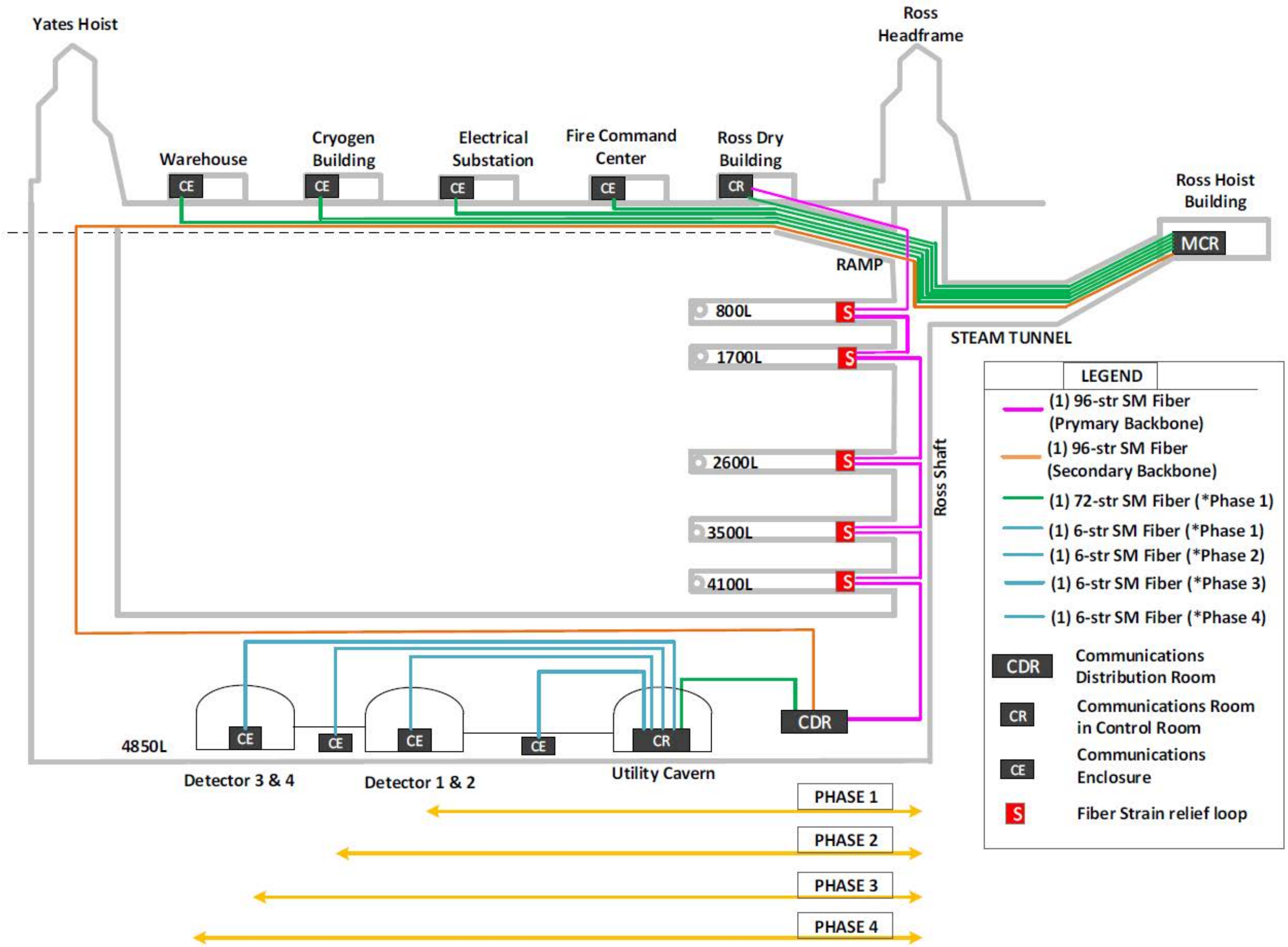

Figure 6.3: Fiber distribution system for LBNF/DUNE (Arup)

fig:fibe

The former Gilt Edge mine is located approximately seven miles from the SURF property and would require truck haulage as a component of the transportation system. In this option, a new conveyor is provided to transport rock downhill to Kirk Road, as seen in Figure 6.4. This is considered the reference design as of the date of this report.

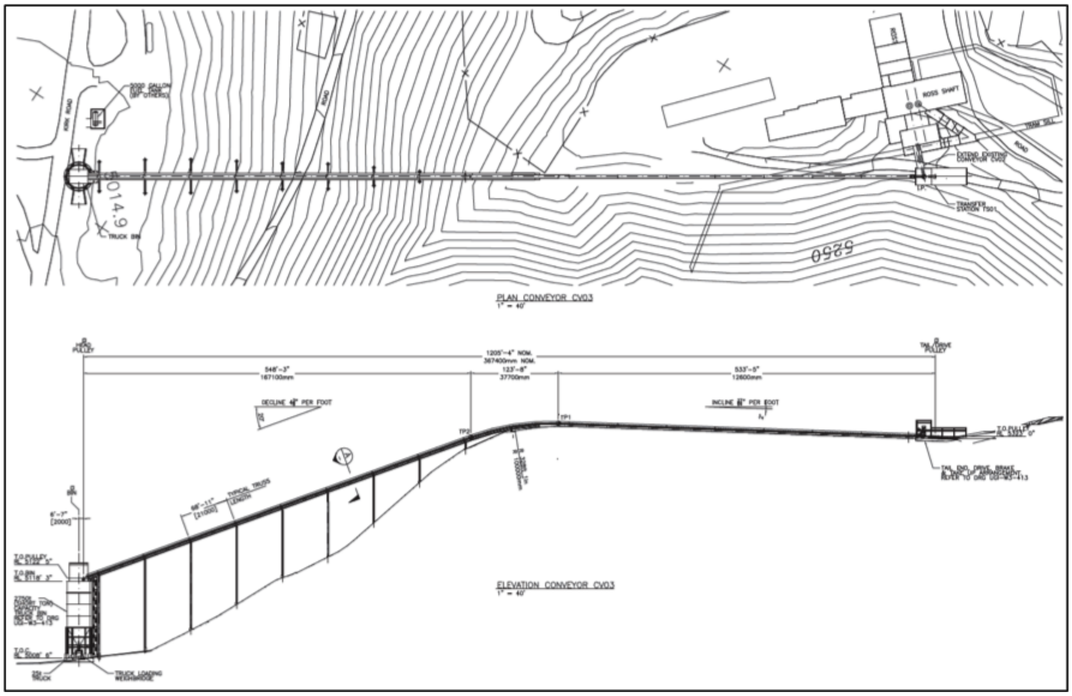

Figure 6.4: Excavated material handling system route (SRK, Courtesy SURF)

The alternative repository is the Homestake Open cut, located less than 1 mile from the SURF property. In this option it is possible to transport material directly to the final location, avoiding the need for over-the road transportation. The conveying system would be designed to follow a route formerly used to transport material from the open cut to the former Homestake mills.

A final decision on which repository to use will be made prior to the CD-3a approval. Both options have been evaluated in detail and are not significantly different in cost or installation schedule.

The systems utilize experience and equipment from the former Homestake Mining Company, 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 finely as it was during the mining period, and therefore some components of the system may not be re-used.

Chapter 7

SURF Site Preparation Activities

7.1 Overview

A number of activities at the SURF site that focus on maintenance or restoration of capabilities have been identified by the LBNF and SDSTA team as required for risk mitigation and/or construction preparation. These tasks are planned to be completed before or during the LBNF Project and are included as part of the overall LBNF project cost and schedule due to their potential impact on the construction and operation of LBNF and DUNE. They are, however, outside of the CD-3a request since they are not viewed as construction.

7.2 Ross Shaft Rehabilitation

The SDSTA has been in the process of rehabilitating the Ross Shaft since 2013. This rehabilitation includes removal of all existing steel structural elements, installation of ground support (rock bolts and welded wire mesh), and installation of new structural steel. Beginning in 2016, the funding for this project will be tied to the LBNF Project, but the actual implementation will not change. When the rehabilitation completes in 2017, the *cage*, or personnel conveyance, will be replaced with a new conveyance; this will restore the load capability of two decks, thereby improving personnel access. Both of the *skips*, which are buckets used to remove excavated material from the underground, will also be replaced with new ones to restore full functionality of the skips to remove rock for LBNF.

7.3 Oro Hondo Fan Upgrade

The primary ventilation fan for the entire underground facility was installed at the Oro Hondo Shaft in the mid-1980s to support mining efforts at various levels underground. This fan was designed for much larger air volumes than will be necessary for LBNF/DUNE construction or operation, and uses less than 25% of the 3000-HP motor's capacity. The variable-speed drive for this fan is obsolete, with little to no availability of parts. To reduce the likelihood and impact of failure, this fan will be evaluated for efficiency and either a new motor/drive combination or a completely new fan will be installed prior to LBNF construction.

7.4 Refuge Chamber Additions and Upgrades

SURF currently has small refuge chambers at two of the four dewatering pump locations in the Ross Shaft, and a large refuge chamber near the Ross Shaft at the 4850L. Refuge chambers are designed to provide food, water, breathable air, and sanitary facilities for individuals trapped underground. In preparation for the LBNF Project, two additional pump room refuge chambers will be procured and installed, and the 4850L chamber will be modified to accommodate the additional capacity made possible by the Ross Shaft rehabilitation. Underground occupancy is defined by the maximum number of individuals that can be transported to the surface in one hour. With the improvements to the shaft, that number will approximately double (see Section 6.1).

7.5 Resupport of Drifts at the 4850L

The drifts (tunnels) connecting the Yates and Ross Shafts at the 4850L were excavated for mining purposes with ground support (rock bolts) installed only as deemed necessary at that time (roughly 1876 to 2002). This ground support was submerged in water when the mine shut down, accelerating corrosion. The LBNF Project will provide supplies to re-support these drifts with full coverage in preparation for significantly increased traffic during construction and operation of LBNF and DUNE.

7.6 Water Inflow Control

While the SURF facility is generally very dry compared to most underground facilities, the vast expanse of the underground space both vertically and horizontally provides the opportunity for many small water inflows to aggregate, resulting in a total inflow of over 700 gallons per minute integrated over the 350+ miles of drifts. The surface mining of the open cut aggravates this during large inflow events (rain or snow melt) by acting as a direct funnel to the upper levels of the facility. This water migrates to either pump rooms or the *pool*; at ∼1,000 feet below the 4850L, the pool provides enough reserve capacity to prevent flooding of the 4850L even if the dewatering system were shut down for nearly a year. A system of walls and boreholes controls the flow of water, keeping it away from the occupied footprint. These controls were installed throughout the 125-year history of mining, however, and cannot all be accessed for evaluation. To prevent failure of an inaccessible control system, a project to capture and direct water from the upper levels to a known route is planned.

7.7 Adit Repairs

rep-adit

A number of adits (tunnels that connect underground areas to the surface) will be rehabilitated to prevent their failure. Specifically, two adits connecting at the 300L and two connecting at the *tramway* level are included in the LBNF budget. These adits support power, fiber, sewer, and water utilities, any of which could halt construction if a failure occurred. Repairs are primarily focused on the first 60 – 100 feet of the tunnels from the entrance at the exterior, with some repairs in the tunnels themselves.

7.8 Ross Crusher Roof Reinforcement

rossroof

As part of previous design efforts, many of the existing structures at SURF were evaluated for compatibility with current codes and standards. The SDSTA has already repaired many of the substandard roofs throughout the facility, with the Ross Crusher building lagging due to lack of immediate use. In preparation for use of this building by the LBNF project, the roof will be reinforced to ensure reliable support of snow loads.

7.9 Hoist Motor Rebuilds

ep-motor

All of the hoist motors at both the Yates and Ross Shafts were evaluated by consultants through the SDSTA and found to require rebuilds for reliable operation. The SDSTA started this process by rebuilding the motors at the Yates shaft, which currently provides primary access to the underground spaces while the Ross Shaft is rehabilitated. After the shaft rehabilitation completes, but before excavation can commence, all of the motors at the Ross Shaft will be removed, cleaned, and re-insulated (effectively rebuilt) to reduce the risk of failure during the heavy construction utilization.

7.10 Parking Lot Repairs

-parking

The surface facilities at SURF are located in steep and rugged terrain in Lead, SD. The headframes and supporting buildings were constructed at the top of a hill, with cut-and-fill techniques used to provide flat and level areas for buildings, roads and parking lots beginning in the 1930s. One of these parking lots, adjacent to the SURF administration building and near the Yates Shaft, experienced subsidence in the 1990s while the mine was still operational. To temporarily manage this, a number of limestone blocks were placed in the area of concern. In recent years, following significantly higher-than-normal precipitation, this area has again exhibited signs of movement. To address this issue, a permanent retaining wall system has been designed by a local engineering firm contracted by the SDSTA. The LBNF Project has included budget to implement this design to ensure that access to the Yates shaft is not compromised.

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