

The Sanford Underground Research Facility at Homestake

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Abstract

The Sanford Underground Research Facility (SURF) at Homestake is presented. The Davis campus is described in detail including the two laboratory modules at the 4850-foot level (4200 mwe). These modules house the LUX dark matter and MAJORANA DEMONSTRATOR neutrinoless double-beta decay experiments. The Long Baseline Neutrino Experiment plans to place their far detector at SURF. The facility is managed for the US Department of Energy (DOE) by Lawrence Berkeley National Laboratory. The South Dakota Science and Technology Authority (SDSTA) owns and operates the facility. SURF is a dedicated science facility with significant expansion capability.

Introduction

The initial concepts for SURF were developed with the support of the US National Science Foundation (NSF) as the primary site for the NSF's Deep Underground Science and Engineering Laboratory (DUSEL). With the National Science Board's decision to halt development of a NSF-supported underground laboratory, the US Department of Energy (DOE) now supports the operation of the facility. Both the NSF and DOE support experiments at SURF.

SURF is being developed in the former Homestake Gold Mine, in Lead, South Dakota. Barrick Gold Corporation donated the site to the State of South Dakota in 2003, following over 125 years of mining. Mining operations created over 600 km of tunnels and shafts in the facility, extending from the surface to over 8000 feet below ground. The mining levels are distributed ~150 feet apart and are referenced by the feet below the entrance to the facility.

The South Dakota philanthropist, T. Denny Sanford, gifted US\$70M, to convert the former mine into a research laboratory and develop a science education facility. With these funds and the State of South Dakota appropriations, access to the underground has been reestablished and the primary access rehabilitated and improved. The facility has been stabilized and the accumulated underground water has been pumped below the 6000L. The Davis Cavity at the 4850L has been enlarged and adapted primarily for current and next-generation dark matter experiments. A new laboratory has been excavated and outfitted adjacent to the Davis Cavity to host a neutrinoless double beta decay experiment. Additional science efforts are hosted throughout the facility, including an ultrapure detector development laboratory, multiple geophysics and geological efforts, and a public outreach program.

The science program for the coming ~ five years consists of the MAJORANA DEMONSTRATOR experiment, the Large Underground Xenon dark matter search, the Center for Ultralow Background Experiments at DUSEL (CUBED), and geoscience installations. Plans are being developed to host the Department of Energy's Long-Baseline Neutrino Experiment (LBNE), a nuclear astrophysics program involving underground particle accelerators, and second and third generation dark matter experiments.

Site Context, Geology and Local Conditions

The SDSTA operates and maintains the Sanford Laboratory at the Homestake site. The SDSTA property includes 186 acres on the surface and 7,700 acres underground. The Surface Campus

includes approximately 253,000 gross square feet of existing structures. Using a combination of private funds, South Dakota Legislature-appropriated funding, and a US Federal HUD Grant, the SDSTA has made significant progress in stabilizing and rehabilitating the facility to provide for safe access and prepare the site for experiments. These efforts include dewatering of the underground facility and mitigating and reducing facility and experimental risks. Elements of this article are drawn from the Homestake DUSEL Preliminary Design Report¹.

The geology of the site has been studied during mine operations and recently as part of the studies for the DUSEL Project. The three major units encountered in the underground are, from youngest to oldest: the Ellison Formation, Homestake Formation, and Poorman Formation. These rock units consist of interbedded schists, metasediments, and amphibolite schists. The Yates Member (Unit) is the lowest stratigraphic unit of the Poorman Formation. Exposed on the 4850L (in the triangle of drifts between the Yates and Ross Shafts) are the Yates Unit and the Poorman Formation, as well as Tertiary Rhyolite Dikes. Exposed on the 300L are the Ellison and the Northwestern Formations. The overall geology is a well-defined stratigraphic sequence of schists and phyllites. These rocks are of high strength and low deformability except when influenced by fracturing, folding, and (dike) intrusions.

The large-scale structural geology contains a series of interacting synclines and anticlines. This pattern of multiple, overlapping folding and deformation events occurs at all scales such that local folding can be seen in the rock fabric at the scale of inches, feet, and tens of feet. Fold deformations result in complex yet systematic variations in rock mineralogy and structure. Folding creates multiple repeats of the broad-scale formational geology. As a result, most areas close to the ore zones show multiple anticlines and synclines. Such structures occur right across the mine width at any given level. At the 4850L, the formations are apparently domed up over the main amphibolite body forming the core of the Yates Member, at least near the proposed cavity locations. The geology and age of the formations produce a rock mass substantially lower in uranium and thorium than found at other underground laboratories.

Facility Description

SURF consists of surface and underground campuses and supporting infrastructure at the Homestake site. The Ross Surface Campus will be used primarily for construction and operations support, while the Yates Surface Campus will support science and administrative activities, education and public outreach functions, and the Waste Water Treatment Plant. The Ross and Yates shafts provide redundant underground access.

Yates Campus

The scientific users and facility administration are supported using three repurposed buildings: The Administration building, the Yates Education and Outreach building, the LUX warehouse and the Waste Water Treatment Plant. The Administration building provides space to support the facility administration, the scientific and facility staff, conference rooms and IT. The Yates E&O building supports the active outreach program and provides additional meeting space. The LUX warehouse provides an assembly and prototyping space for experiments. Additional buildings provide for receiving, cold storage, and the rock core archive. Scientific access to the Davis campus is primarily provided through the Yates shaft. Utilities including power, IT, ventilation and water are routed down the Yates shaft. The Yates shaft has recently been upgraded. The shaft is maintained regularly and provides 24/7 access to the 4850L and intervening levels.

Ross Campus

This campus supports facility maintenance and construction activities including skipping rock, pumping water, and general facility maintenance. Utilities including power, IT, ventilation and water are routed down the Ross shaft. The Ross shaft is in the process of undergoing a major rehabilitation replacing all the shaft furnishing, updating ground control and utilities.

The Davis campus is presented in Figure 1. Experiments are housed in the Davis Cavity (9m x 10m x 17m) and the Transition Area (15m x 5m x 41m). Photographs are presented in Figure 2.

Three experiments will move into the Davis Campus in 2012/2013. The LUX and CUBED experiments share the Davis Cavity. The MAJORANA experiment in the Transition Area maintains a minimum of class 10,000 cleanliness standards throughout the experimental space, including a dedicated machine shop and future electroforming room. A class 1000 clean room and glove box provide even higher standards of cleanliness to prevent contamination of the ultra-pure copper and germanium used in this experiment.

Services provided within the Davis Campus include fire sprinklers and alarms throughout the area, potable and non-potable (industrial) water, lighting, emergency lighting, ventilation, and air conditioning. A building management system provides controls throughout the Campus. No heating is required at this level due to natural rock temperatures, auto-compression of air as it travels through the shaft, and heat generated from the services at the level. Cooling is provided with two redundant 50-ton (633 M-Joule) chillers supplying chilled water to three air handling units that provide ventilation to separate Campus spaces. Chilled water is also available for experiments to connect equipment directly.

A dedicated 1500 kVA substation provides sufficient capacity for the experiment and facility needs, with margin for future expansion. Emergency power for lighting is provided with batteries in the lighting system to provide immediate light, while a standby diesel generator near the campus provides up to 24 hours of power to all safety systems in the campus. This includes water pumps in the nearby Yates shaft to prevent water from rising into the campus spaces.

Davis Campus

Occupancy in the Davis Campus is presently limited by applicable codes to a total of 48 persons: 25 in the Davis Cavity, and 23 in the Transition Space. Shared restrooms are provided in the transition space for both campuses, as well as shower facilities for access to the clean spaces. A “cart wash” area provides the ability to clean items beyond the less clean general spaces, but prior to entry into the laboratories.

Doors and walls are installed to provide at least two isolated means of egress from any space in the event of a fire or other emergency. A system of sumps and pumps provide the ability to store grey water (not sewer water) and allow testing to ensure environmental compliance prior to pumping to the facility dewatering system. A dedicated compressor provides 100 cfm of compressed air capacity for general use.

Existing and planned experiments in the Davis Campus use liquid nitrogen to provide cooling and/or radon purging. The two primary spaces each have their own alcoves for the storage of these cryogenes. The LUX experiment uses liquid xenon as the target material, requiring dedicated storage capacity, as well as an emergency storage reservoir. LUX also uses an 8 m diameter water shield to shield residual neutron and ionization radiation from the surroundings. The water for the shield is purified underground with a dedicated reverse osmosis system.

The SURF’s goal has always been to provide the lowest possible radioactivity environment for experiments hosted within the facility. This commitment had been integrated into the site

preparation process from the early days of the facility design, and carried over to the realization of the 4850 Level Davis Campus laboratories. We have drawn extensively from our experiences gained from SNOLab, Gran Sasso, Kamioka, and other underground research facilities to optimize the environment for the experiments. These efforts are summarized in a recent article². These efforts include site and environmental characterization including rock radioactive measurements, use of low radioactivity construction materials, and regular monitoring of environmental factors including air-borne radon. Table I presents some of the assay results, obtained by direct gamma counting for rock samples from the mine, including those collected on and close to the 4850L³.

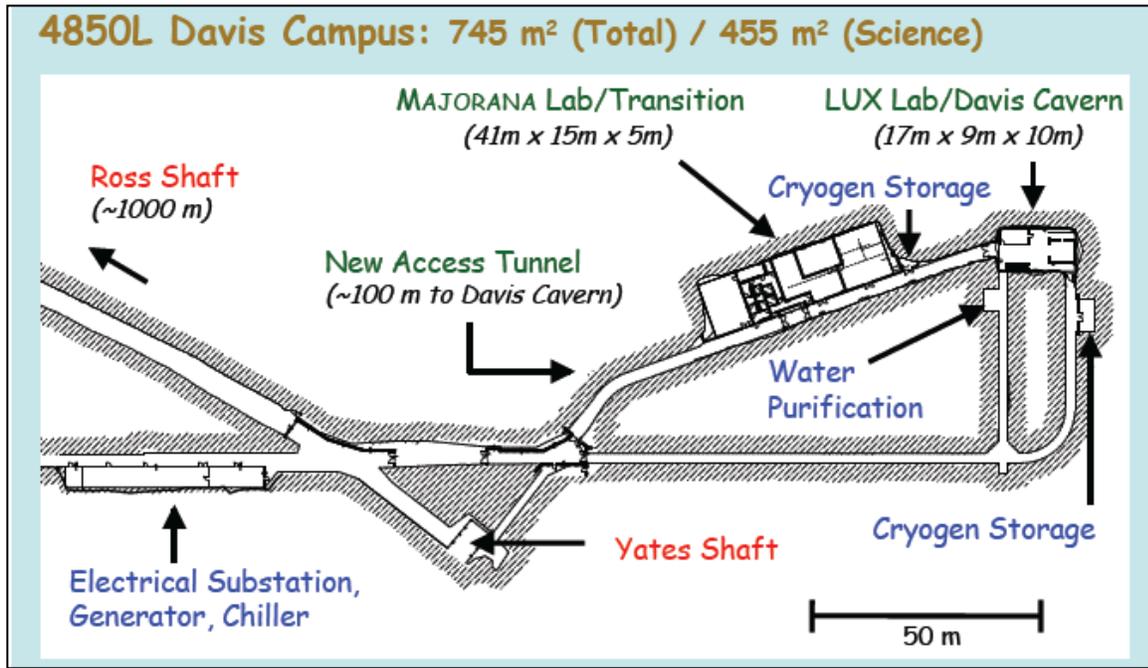


Figure 1. The Davis Campus at the 4850L. The Davis Lab in the upper right houses the LUX experiment and low background counting detectors. The Majorana Lab houses the MJD experiment as well as mechanical and HVAC equipment. Access is from the Yates shaft ~100 m from the research campus.

It was found that the U/Th/K radioactivity for the underground bedrocks at Homestake is in general very low; some samples are in the sub-ppm levels. However, samples from Rhyolite intrusions, a very small fraction of the total, show a relatively high content of U, Th, and K more typical of the levels found in other laboratories, in particular those in granitic formations. Regions of potential Rhyolite intrusions have been identified and documented. In some cases local shielding significantly mitigates the impact of the Rhyolite intrusions.

The use of shotcrete for ground stabilization is a common practice for long-term occupancy of underground facilities; however low-radioactivity shotcrete is costly to create. The introduced construction materials have also been assayed and typical results are presented in Table 1. We have documented the distribution and thickness of the shotcrete using laser scans prior to and post application of shotcrete to provide input for detailed experimental models.

In addition to the direct gamma counting of the rock and construction materials, measurements of airborne radon are ongoing and *in situ* measurements of gamma rays at the 4200 mwe depth, neutrons and cosmic ray muons have been published⁴.



Figure 2. The Davis Campus at completion of laboratory outfitting. Top-left Majorana Transition Area; top-right utilities leading into the Davis campus; bottom-left LUX detector; bottom-right Davis Cavity 8 m diameter water shield. Pictures courtesy of LBNL.

	Uranium (ppm) Ave. [Range]	Thorium (ppm) Ave. [Range]	Potassium (%) Ave. [Range]
U/G Country Rock	0.22 [0.06-0.77]	0.33 [0.24-1.59]	0.96 [0.10-1.94]
Shotcrete	1.89 [1.74-2.23]	2.85 [2.00-3.46]	0.88 [0.41-1.27]
Concrete Blocks	2.16 [2.14-2.18]	3.20 [3.08-3.32]	1.23 [1.27-1.19]
Rhyolite Dike	8.75 [8.00-10.90]	10.86 [8.60-12.20]	4.17 [1.69-6.86]

Table I. Partial U/Th/K assay results for Homestake rock samples. Overall errors estimated to be ~10-20%. Also shown are results for various construction materials (shotcrete/concrete).

Proposed Experiments

Long-Baseline Neutrino Experiment (LBNE) (Fermilab, Illinois)

The DOE is developing plans to house a ~10 kt liquid argon detector at SURF to conduct searches for CP violation physics coupling Fermilab's powerful neutrino beams to a far detector at Homestake; comprehensive and precision measurements of neutrino mixing and oscillations; and a wide spectrum of non-beam related research including proton decay, and astronomical neutrino observations. Both surface and underground options are being developed to comply with DOE's request to establish a phased approach to the LBNE program. The surface option would be located in the Kirk Canyon to the southeast of the Ross campus. Underground options are located on the 4850L. LBNE is further described in {ref 5}

Generation-2 Dark Matter Experiments

The DOE and NSF have plans to develop Generation-2 Dark Matter experiments, with masses ~ several tonnes. The LUX-ZEPLIN (LZ) Collaboration has submitted a proposal to develop a G-2 experiment in SURF using the existing infrastructure in the Davis Campus. SURF is open to working with all interested collaborations to develop proposals for G-2 experiments⁵.

Generation-3 Dark Matter Experiments

The DOE has discussed developing a “roadmap” for Dark Matter searches including Generation-2 and Generation-3 Dark Matter experiments beginning ~ FY17. Initial efforts to develop the Generation-3 collaboration are advancing⁶.

Dual Ion Accelerators for Nuclear Astrophysics (DIANA) (University of Notre Dame, Indiana)

As part of the NSF support for the development of underground physics experiments {<http://www.nsf.gov/pubs/2012/nsf12043/nsf12043.pdf>} a proposal has been developed to create an underground accelerator facility for low energy nuclear astrophysics experiments. An existing excavation at the 3950L within SURF has been identified to potentially house DIANA⁷.

Summary

SURF is a deep underground research facility, dedicated to scientific uses and is not compromised by competing uses such as mining, transportation, or tourism. The Davis campus was recently completed and the LUX and MJD experiments are being installed at the 4850L in state-of-the-art facilities. The site benefits from the naturally low background rock and effective efforts during construction to control the introduction of trace amounts of radioactivity. The transition of the support of the facility operation from NSF to the DOE is well advanced. Stable operations of the facility were achieved in FY12, including a variety of facility improvement programs further customizing the infrastructure. SURF welcomes collaborations seeking deep underground facilities to host additional instruments and experimental efforts.

¹ Lesko, K.T., et al., “Deep Underground Science and Engineering Laboratory - Preliminary Design Report”, [arXiv:1108.0959](https://arxiv.org/abs/1108.0959), (2012)

² Chan, Y.D., “The Low-Background Construction of Laboratories at the 4850-ft Level Davis Campus”, <http://dusel.org/html/early-science-progress.html>, (2012)

³ W. Roggenthen and A.R. Smith, White Paper: U, Th, K contents of materials associated with the Homestake DUSEL site, Lead, South Dakota. (Private Communication); A.R. Smith, Homestake Samples: Results of Radiometric Analyses at LBNL (Private Communication)

⁴ Barker, D. and Mei, D.M., “Muon-Induced Background Study for an Argon-Based Long Baseline Neutrino Experiment”, Nucl.Instrum.Meth.A638:63-66,2011 [arXiv:1202.5000](https://arxiv.org/abs/1202.5000); Zhang C., Thomas, K., Gray, F., “Early Results on Radioactive Background Characterization for Sanford Laboratory and DUSEL Experiments”, [arXiv:0912.0211](https://arxiv.org/abs/0912.0211), (2012) BAPS.2007.DNP.DA.78, and BAPS.2010.DNP.HD.5

⁵ http://science.doe.gov/grants/pdf/SC_FOA_0000597.pdf, <http://www.nsf.gov/pubs/2012/nsf12043/nsf12043.pdf>

⁶ Salamon, M., "Second Generation Dark Matter Experiment Program", http://science.energy.gov/~media/hep/hepap/pdf/march-2012/Salamon_HEPAP_Talk_G2_DM_March_2012.pdf (2012); Sadoulet, B., "DUSEL and the US Dark Matter program", <http://www.physics.ucla.edu/hep/dm10/talks/sadoulet1.pdf> (2010)

⁷ “Dual Ion Accelerators for Nuclear Astrophysics”, <http://www.jinaweb.org/underground/DIANA/>