SURF and LBNF/DUNE

Jaret Heise
SURF Science Director

Snowmass Community Summer Study
University of Washington, Seattle
UF + NF July 21, 2022

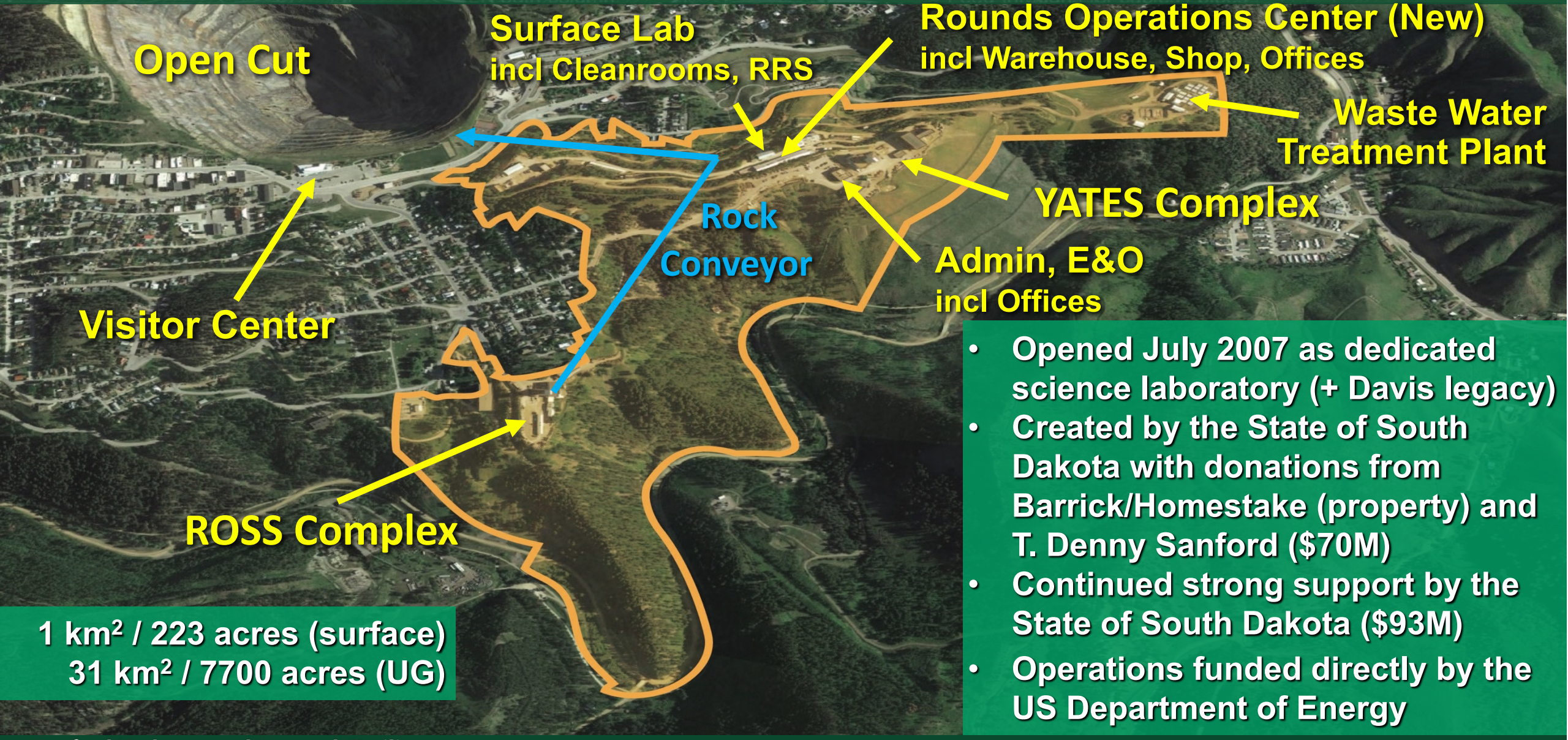
Sanford
Underground Research Facility
South Dakota Science and Technology Authority

Sanford Underground Research Facility

Where in the world is SURF?

Sanford Underground Research Facility

Nation's deepest underground lab, advancing multi-disciplinary research



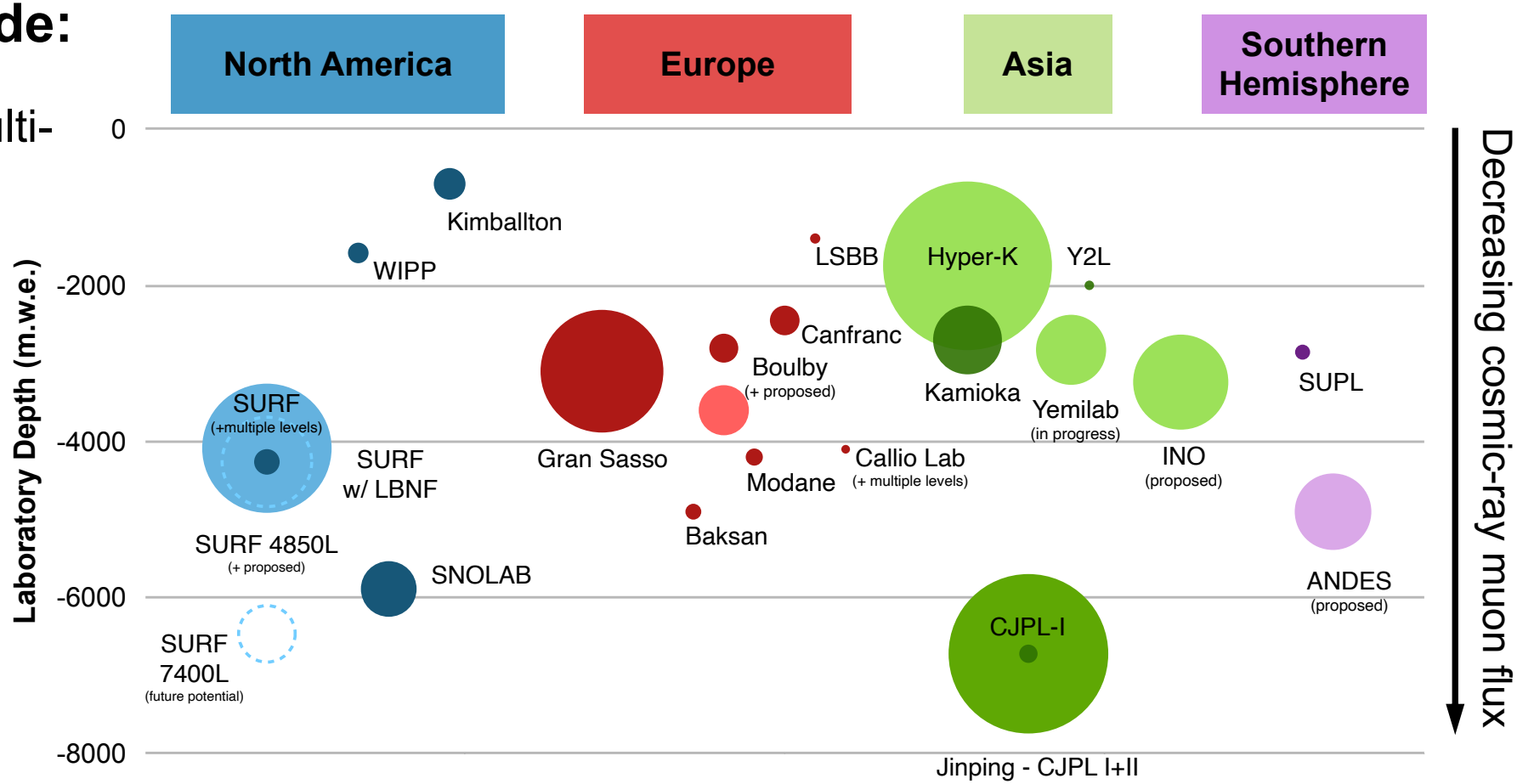
- Opened July 2007 as dedicated science laboratory (+ Davis legacy)
- Created by the State of South Dakota with donations from Barrick/Homestake (property) and T. Denny Sanford ($70M)
- Continued strong support by the State of South Dakota ($93M)
- Operations funded directly by the US Department of Energy

1 km² / 223 acres (surface)
31 km² / 7700 acres (UG)

Underground Facilities

UG Facilities can provide:

- Unique environments for multi-disciplinary research
  - Overburden protection from cosmic-ray muons
- Local radiation shielding
- Assay capabilities
- Material production/ purification
- Environmental control
- Implementation and operations support
- Community catalyst



Note: Circles represent volume of science space

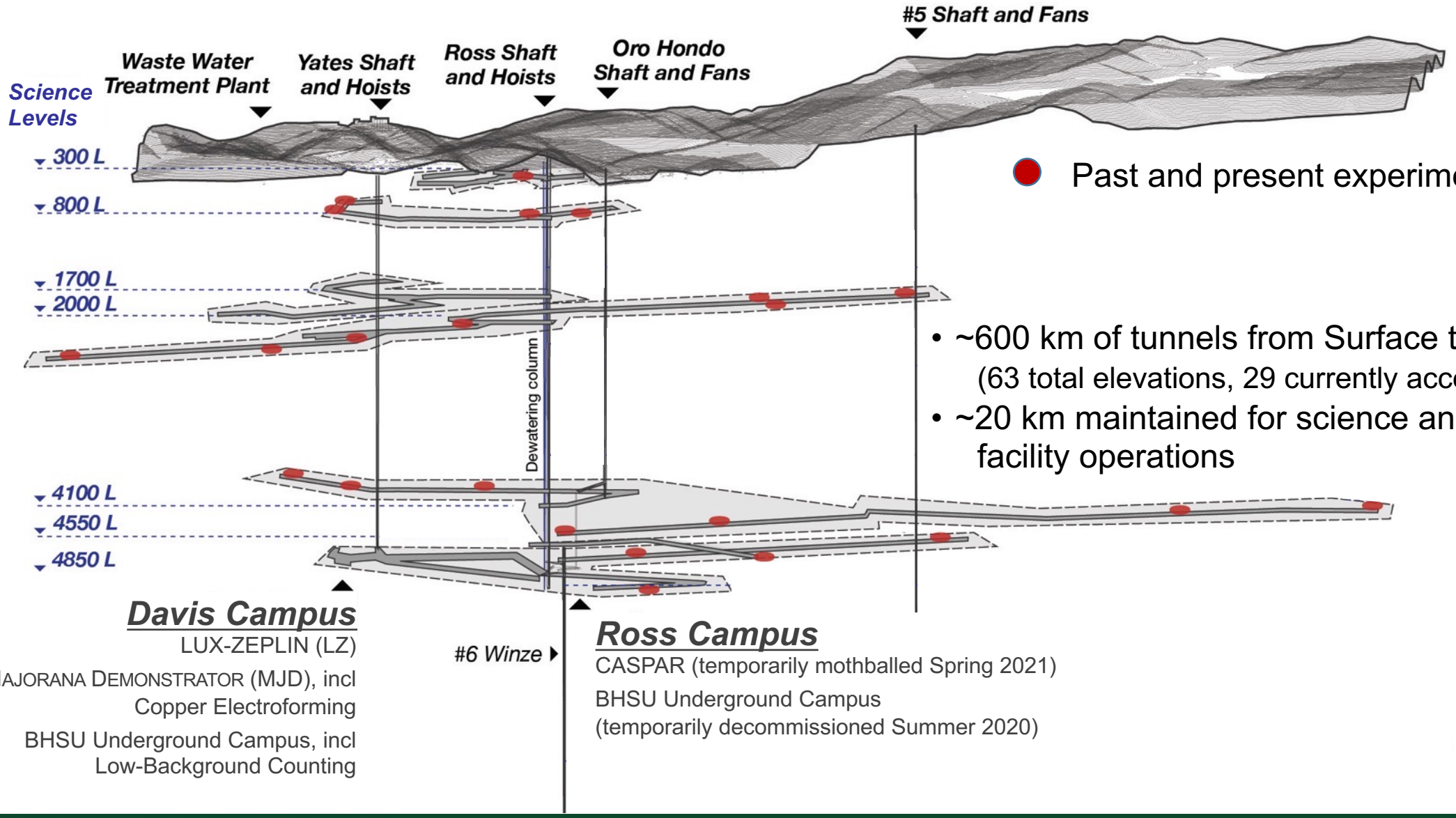
Underground Facilities – SURF

SURF can provide:

- **Unique environments for multi-disciplinary research:** SURF has attracted world-leading experiments and scientists from diverse scientific communities:
  - **Overburden protection from cosmic-ray muons:** SURF is the deepest underground lab in U.S., one of deepest in the world (1500 m, 4300 mwe). SURF has sufficient depth for next-generation experiments, but needs additional space – SURF is exploring options for more 4850L lab space as well as greater depth (2300 m, 6500 mwe)
- **Local radiation shielding:** Water tank and corresponding water purification system, steel shielding; also selection of low-activity facility construction materials (e.g., concrete, shotcrete).
- **Assay capabilities:** International-level screening for experiment materials (SURF expts + community).
- **Material production/purification:** One of only a few labs where UG Cu electroforming is performed.
- **Environmental control:** Cleanrooms with HEPA filtration, dehumidifier and Rn-reduction systems.
- **Implementation and operations support:** Robust organization with support for experiment planning, installation and operations. SURF has proven track record of delivering successful science.
- **Community catalyst:** User Association, incl Vision Workshop 2021. Science Program Advisory Cmttee. Both groups support upcoming SURF application to become DOE Office of Science User Facility.

SURF Underground Lab Geography

Yates & Ross Shafts + ventilation shafts, multiple levels for science



- Past and present experiment sites

- ~600 km of tunnels from Surface to 2.4 km deep
  (63 total elevations, 29 currently accessible)
- ~20 km maintained for science and facility operations

Davis Campus

LUX-ZEPLIN (LZ)

MAJORANA DEMONSTRATOR (MJD), incl Copper Electroforming

BHSU Underground Campus, incl Low-Background Counting

Ross Campus

CASPAR (temporarily mothballed Spring 2021)

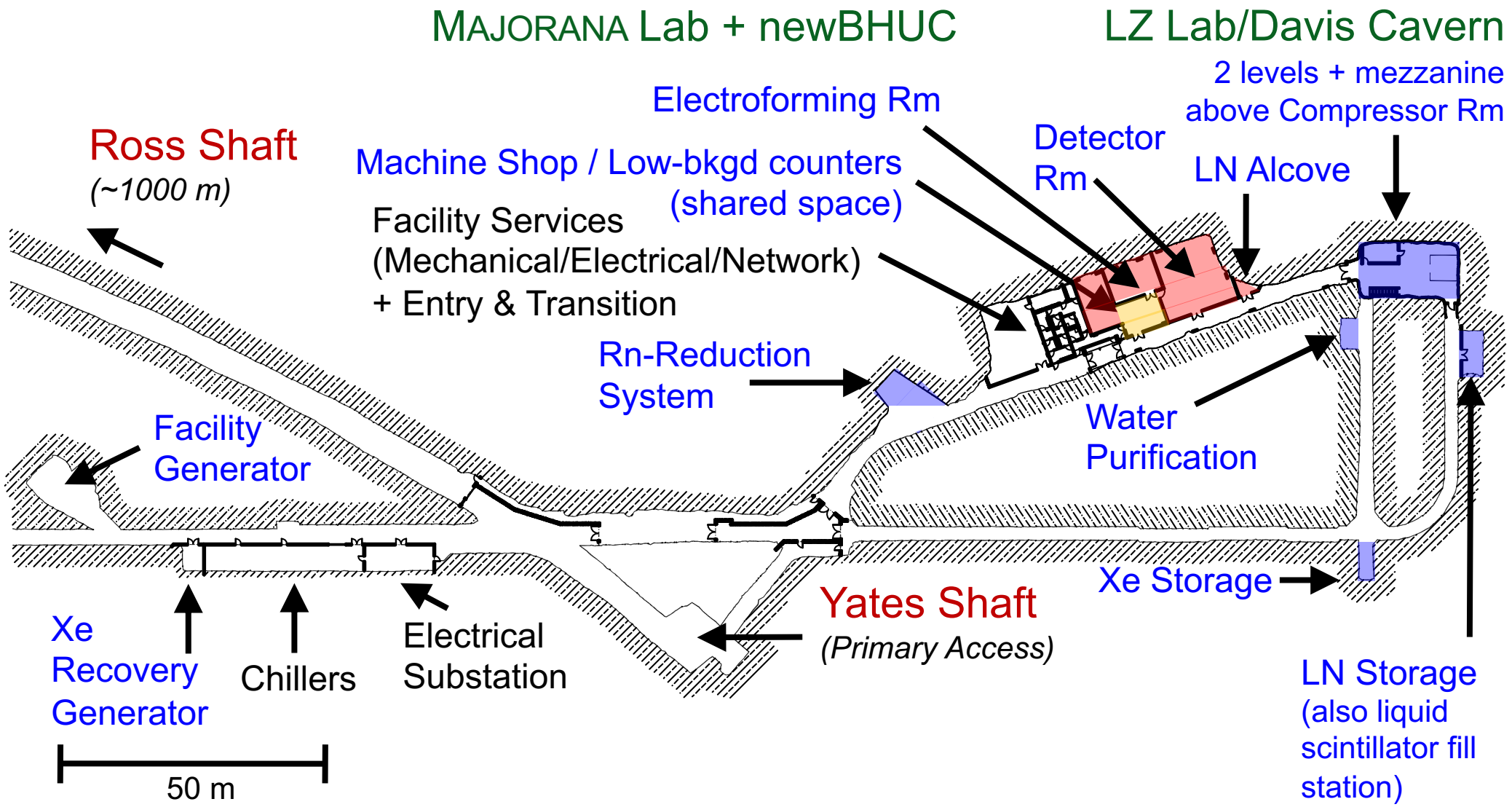
BHSU Underground Campus
(temporarily decommissioned Summer 2020)

4850L Davis Campus

Welcome!

4850L Davis Campus

3,017 m² (Total) / 1,018 m² (Science)



4850L Davis Campus

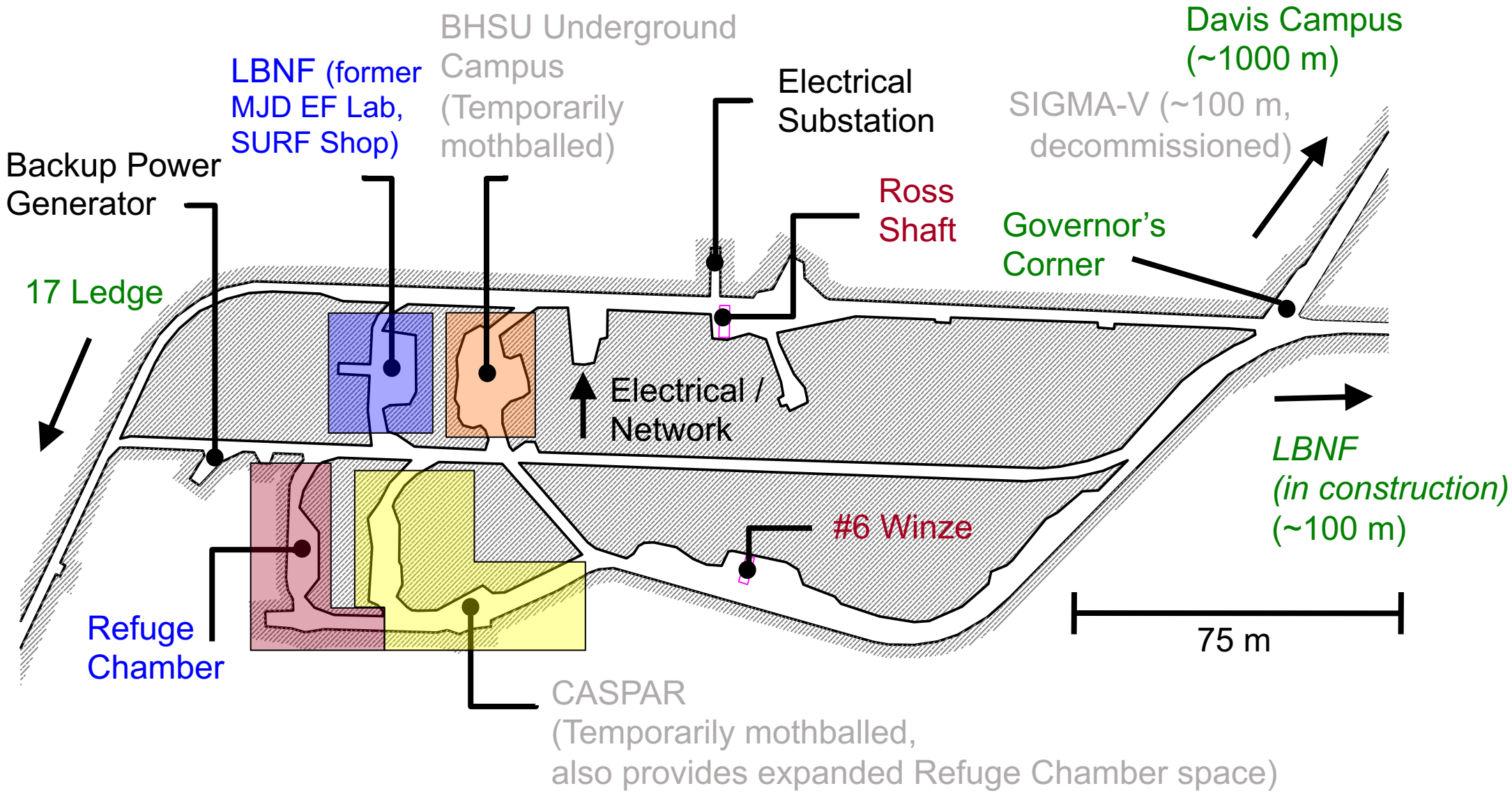
Examples of laboratory space

Detector Room (MJD):
Area =140 m^2, 11 m × 9.8-12.8 m × 2.7 m (H)
(raised section: 5.9 m × 5.8 m × 3.2 m (H))

Lower Davis Cavern (LZ):
Area =142 m^2, 13.7 m × 9.1 m × 6.4 m (H)
(incl tank: 7.6 m diameter × 6.4 m H)

4850L Ross Campus

2,653 m² (Total) / 920 m² (Science)



4850L Ross Campus

Examples of laboratory space

2010-2017

Copper Electroforming

2015-2020, resume FY24

Former MJD Electroforming:
Area = 228 m^2
(Cleanroom removed, future UG WWTP)

2015-2021, resume FY24

BHUC Cleanroom:
Cavern Area = 268 m^2,
Cleanroom = 12.1 m × 6.1 m × 2.4 m (H)

CASPAR Hall:
Area = 236 m^2,
30 m × 3 m (min) × 2.8 m (H)

SURF Science Program

Research activities ranging from the surface to 1500+m underground

Physics

LZ – *Dark matter, 2-phase Xe TPC*

MAJORANA DEMONSTRATOR / LEGEND – *Neutrinoless double-beta decay, Ge-76, Ta-180m, also Cu e-forming*

CASPAR – *Nuclear astrophysics with 1 MV accelerator*

LBNF/DUNE – *Neutrino properties, etc*

BHUC – *BHSU Underground Campus, mainly material screening*

Berkeley LBF – *Low-bkgd counter (x3);* also CUBED – *Low-bkgd counter (x1)* *(possibly future Crystal Growth)*

nEXO – *Low-bkgd counter (x1)*

LLNL – *Low-bkgd counter (x1)*

SDSMT Bkgds – *Neutron bkgds*

Total = 29 groups

21 Active Projects

60 Total Groups Since 2007

Significant interest from others **(17 groups in 2021)**

* Denotes proprietary group

Biology

Astrobiology/DeMMO – *In-situ cultivation, DNA isolation*

2D Best – *Biofilms*

Biodiversity – *Microbial communities*

Biofuels – *Extremophile bioprospecting*

BuG ReMeDEE – *Methane oxidation*

Carbon Sequestration – *Biology in core*

Chemistry – *Env characterization*

Liberty BioSecurity* – *Extremophiles*

Geology

SIGMA-V – *Geothermal*

3D DAS – *Seismic monitoring using fiber*

Core Archive* – *Mainly gold deposits*

Hydro Gravity – *Gravity for water tables*

BH Seismic – *Global monitoring*

Transparent Earth – *Seismic arrays*

Engineering

Xilinx, Inc* – *Chip error testing*

Thermal Breakout – *In situ stress*

Shotcrete – *Mining safety*

GEOX™ – *Env monitoring*

Caterpillar* – *Mining processes*

Blast Monitoring – *LBNF-related*

SURF Science Program – Current Physics Highlights

Strong and diverse program with exciting future

- **LZ:** Direct search for **dark matter** using 10 tonnes xenon within ultra-pure water shield + Gd liquid scintillator veto

  Status: Production data started Dec 2021. Detector working well, robust calibration program underway (incl DD generator). First WIMP-search results announced Jul 7, 2022, run for 5 years.

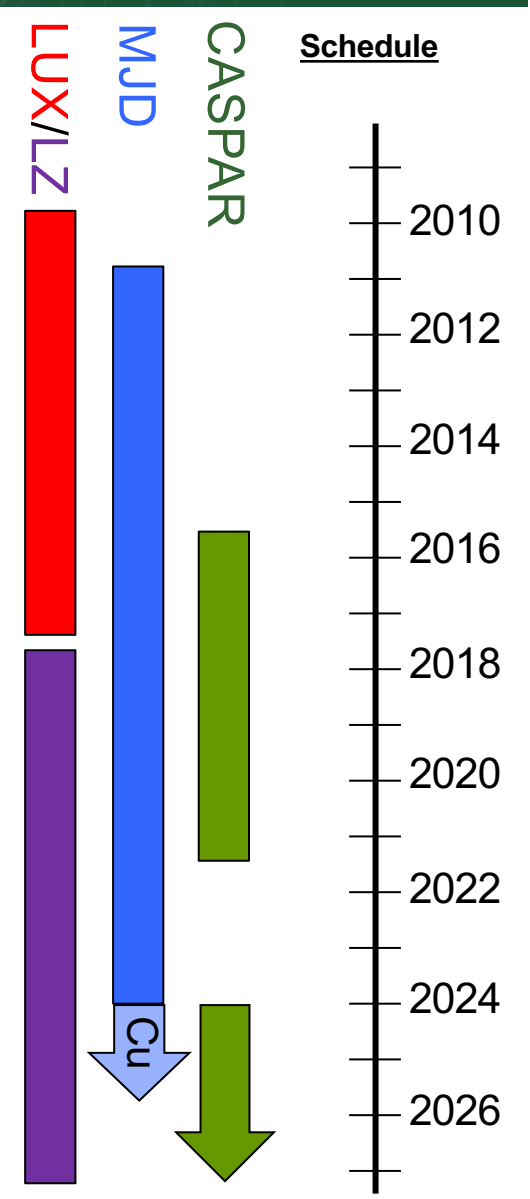
- **MAJORANA DEMONSTRATOR:** Investigate **neutrinoless double-beta decay** using 44 kg Ge in two cryostats, 30 kg enriched ^{76}Ge inside multi-layer compact shield

  Status: Data 2015-2021 (exposure goal achieved), final 0νββ result posted Jul 15, 2022. Ultra-pure electroformed Cu production continues, also LEGEND detector characterization and R&D. Rare decay search ^{180m}Ta underway, complete in 2023.

- **CASPAR:** Study of stellar nuclear fusion reactions, esp. neutron production for **slow neutron-capture nucleosynthesis** using 1-MV accelerator

  Status: Beam operation 2017-2021, targets incl ^{7}Li, ^{11}B, ^{14}N, ^{18}O, ^{20}Ne, ^{22}Ne (gas, solid), ^{27}Al. ^{18}O(α,γ)^{22}Ne PRL Apr 2022. Next phase starting FY24, incl ^{14}N (relevant for CNO solar neutrinos).

- **BHUC:** 5x **low-bkgd assay** counters operating (~10s ppt sensitivity)



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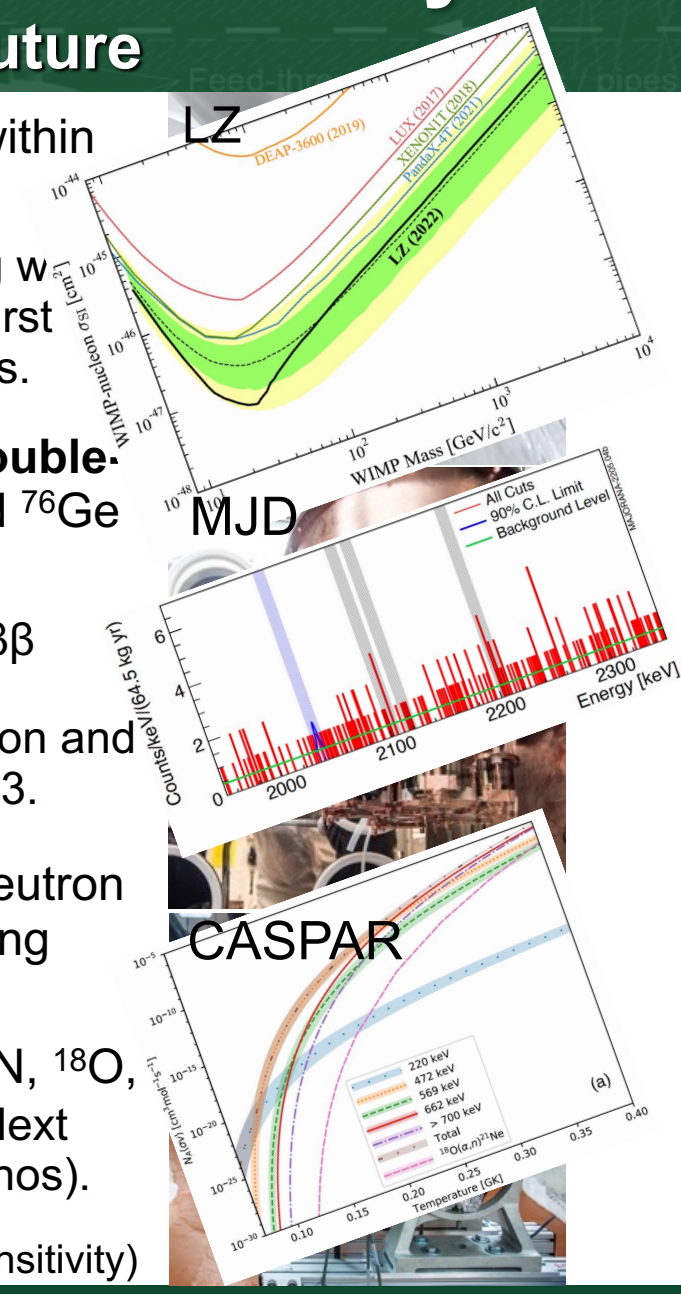
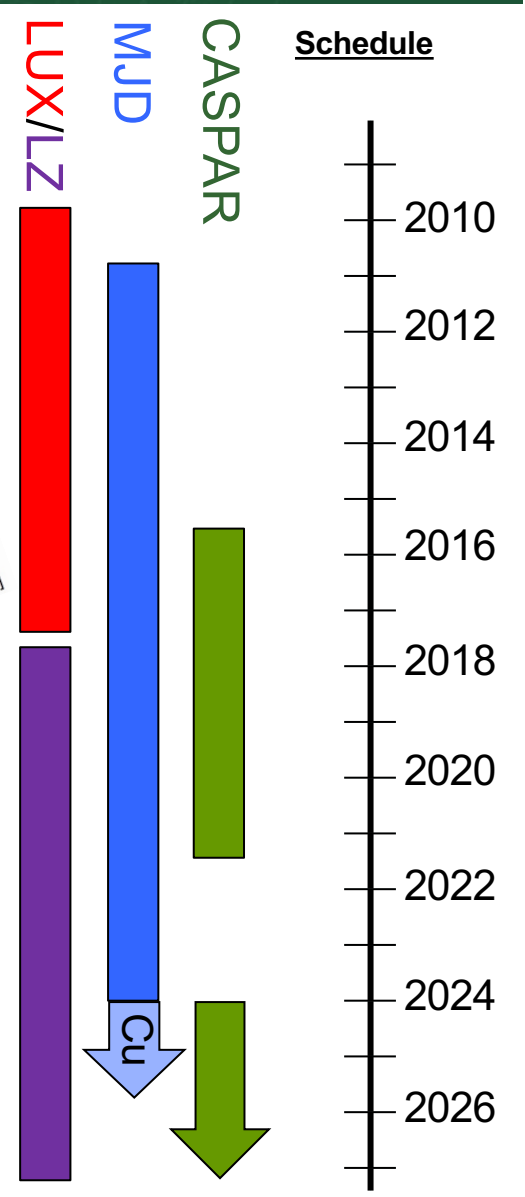




Long-Baseline Neutrino Facility (LBNF)

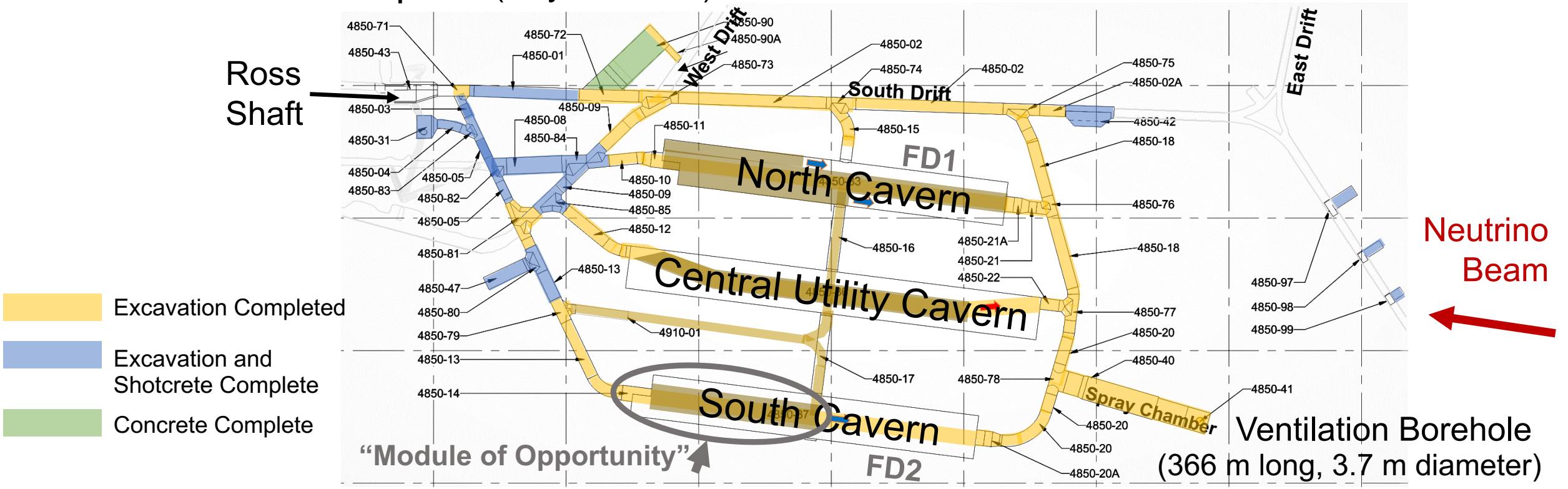
LBNF will host the Deep Underground Neutrino Experiment (DUNE)

- First internationally conceived, constructed, and operated project hosted by the Department of Energy in the United States. Significant **international** contributions (incl CERN).
- Two detector caverns to host 4 detectors (total of 70 kT/50M liter liquid argon) + utility cavern.
- **Reliability projects** rehabilitated some key SURF infrastructure 2016 – 2020.
- **Pre-excavation construction** at SURF in Jan 2019 – Feb 2021. Transportation system for excavated rock operational (first rock to Open Cut May 2021).
- **Excavation** initial phase started Jun 2020, focused on ventilation. Main excavation phase (caverns, access) started Apr 2021 and will last ~3 years (drill & blast expected to complete by ~Oct 2023).
- **Infrastructure outfitting** and **cryostat construction** expected 2024-2027, **science starts 2028**.

Long-Baseline Neutrino Facility (LBNF)

LBNF will host the Deep Underground Neutrino Experiment (DUNE)

Excavation 35% complete (July 20, 2022)



- Aug 2023: North Cavern excavation complete
- Mar 2023: Central Utility Cavern excavation complete
- Oct 2023: South Cavern excavation complete
- Mar 2024: All concrete complete
- May 2024: Infrastructure outfitting (~18 mths), cryostat construction starts (warm ~11 mths + cold ~12 mths)

Long-Baseline Neutrino Facility (LBNF)

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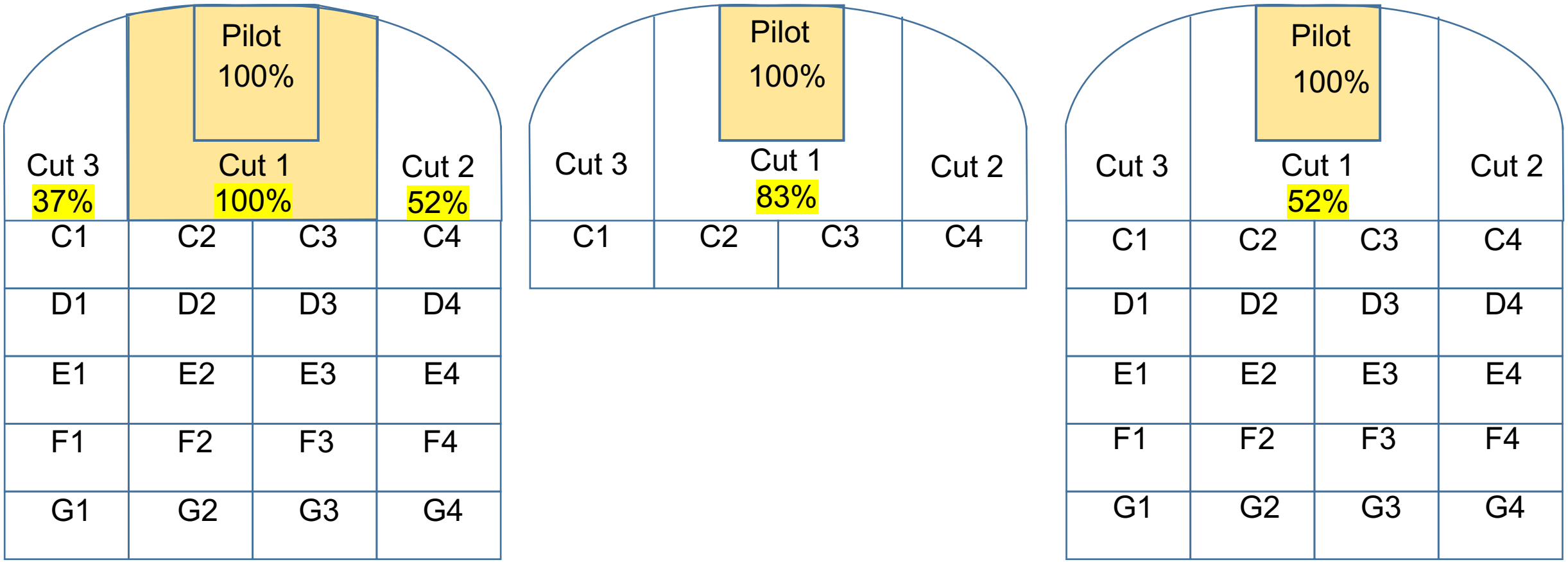
Cavern Excavation Completion Percentage

July 20, 2022



North Cavern CUC Cavern South Cavern

Long-Baseline Neutrino Facility (LBNF)

LBNF will host the Deep Underground Neutrino Experiment (DUNE)

Rock conveyer to Open Cut

Borehole reamer

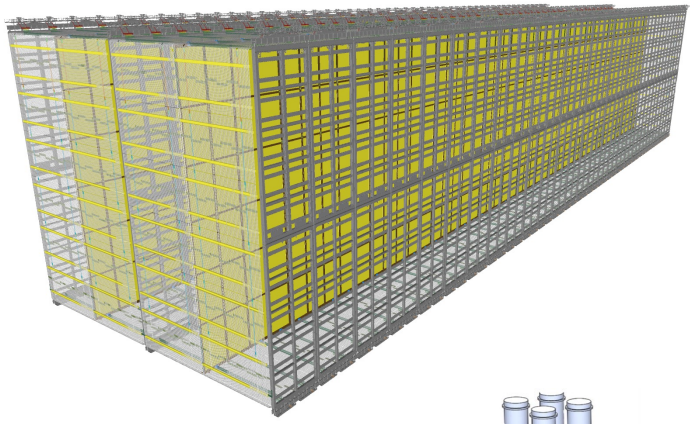
Excavation/bolting

SURF Science Program – Planned / Future

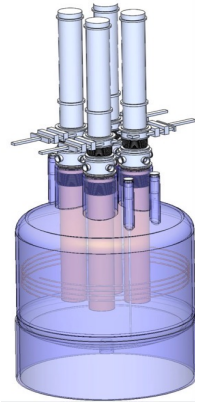
Strong and diverse program with exciting future possibilities

- **DUNE:** 4x 10 kT LAr detectors with horizontal/vertical drift for **neutrinos** (**CPV, MH, SN, proton decay**, etc). Excavation complete in 2024, science starts **2028.** Renewed discussions for "**Module of Opportunity**"
- **Neutrinoless Double-Beta Decay** (Ton+ Scale): Investigate **neutrino properties** using ~1-100-tonne enriched isotope, inverted hierarchy coverage
- **Dark Matter** (Generation-3): Search for WIMP **dark matter** to neutrino background "floor/fog" using ~50-100 tonne Xe (e.g., XLZD) or other target
- **Theia**: Water-based liquid scintillator (25-100 kT) using LBNF beam to investigate **neutrino** properties (**CPV, MH, CNO, DSNB**, etc)
- Low-Bkgd Module: **SoLAr** (nu), **SLoMo** (nu+DM), etc, targeting the "Module of Opportunity"
- Other:
  - Low-mass dark matter: **TESSERACT** (Al_2O_3, GaAs, LHe), **Hydro-X** (hydrogen), **CrystaLiZe** (solid)
  - Quantum Information Systems (QIS)
  - *Vertical facility (atom interferometry, etc)*

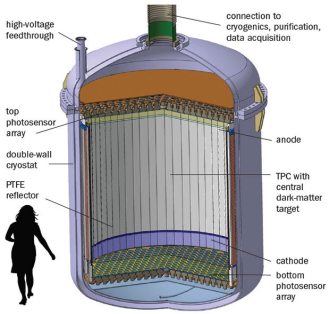
DUNE

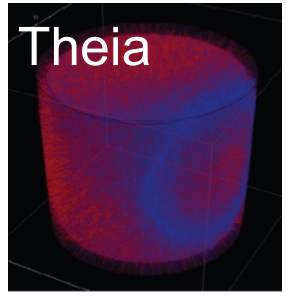


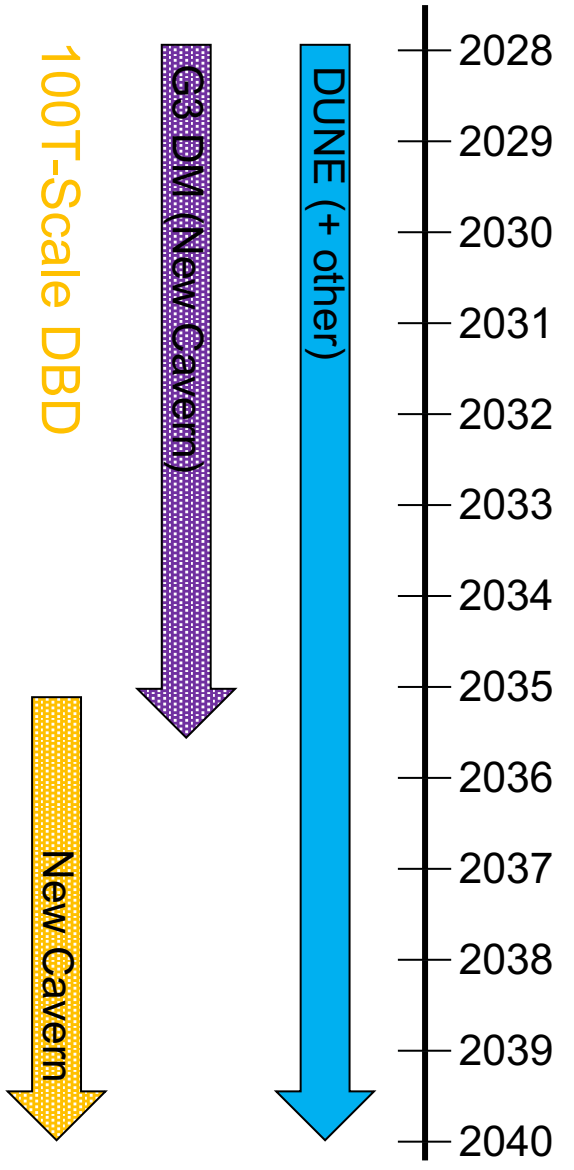
Ton+ Scale DBD



G3 DM







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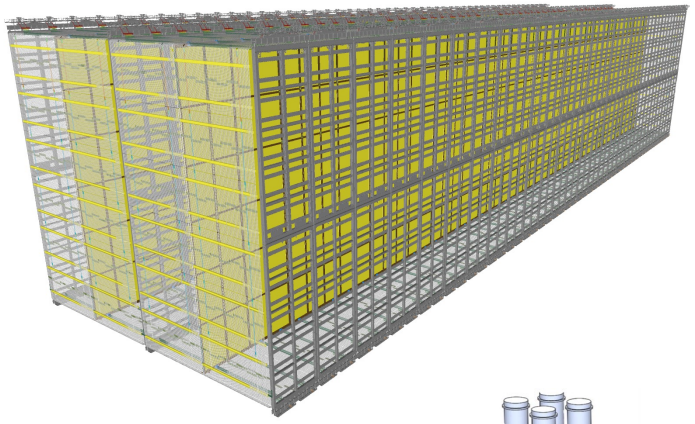
- …-based liquid scintillator (25-100 kT) using LBNF beam to investigate **neutrino** properties (**CPV, MH, CNO, DSNB**, etc)
- Low-Bkgd Module: **SoLAr** (nu), **SLoMo** (nu+DM), etc, targeting the "Module of Opportunity"
- Other:
  - Low-mass dark … GaAs, … (solid)
  - … Systems (QIS)
  - *… facility (atom interferometry, etc)*

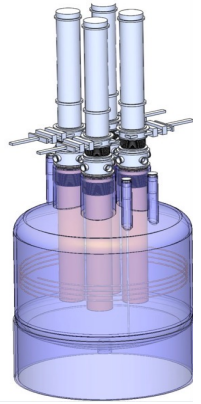
Non-DUNE Projects Require New Cavern (and/or "Module of Opportunity")

Vertical Facility Requires Feasibility Study (and design/development)

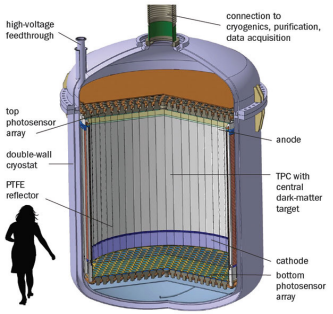
DUNE

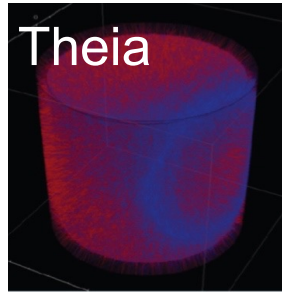


Ton+ Scale DBD



G3 DM





100T-Scale DBD

G3 DM (New Cavern)

New Cavern

DUNE (+ other)

2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040

SURF Science Strategic Planning

SURF Snowmass whitepaper reflects UG science community input

- Recommendations to DOE/NSF prioritizers:
  - Mission need for **additional deep laboratory space** in U.S. (incl depths > 6000 m.w.e.) in U.S. to support compelling future science
  - Mission need for a next-generation (~100 tonnes) **dark matter** and **neutrino** observatory in U.S.
  - Develop a process for allocating temporary use of a LBNF module (“**module of opportunity**”)
  - Endorse value of **multi-disciplinary underground science** at a dedicated laboratory in U.S.
- Additional underground space proposed:
  - **4850L** (1500 m, 4300 m.w.e), **7400L** (2300 m, 6500 m.w.e.)
  - Initial engineering designs completed
  - Excavation for **100-m cavern(s)** could begin as early as 2027, first cavern **complete by ~2030**
- Other:
  - Operational details (incl conveyance specs, storage/staging, etc)
  - Ross Campus occupancy resuming FY24

The Sanford Underground Research Facility

J. Heise

630 East Summit Street, Lead, SD 57754 USA

Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

Executive Summary

The Sanford Underground Research Facility (SURF) has been operating since 2007 supporting underground research in rare-process physics, as well as offering research opportunities in other disciplines. SURF laboratory facilities include a Surface Campus as well as campuses at the 4850-foot level (1500 m, 4300 m.w.e.) that host a range of significant physics experiments, including those studying dark matter, neutrino properties, and nuclear astrophysics topics. SURF is also home to the Long-Baseline Neutrino Facility (LBNF) that will host the international Deep Underground Neutrino Experiment (DUNE). SURF offers an ultra-low background environment, low-background assay capabilities, and electroformed copper is produced at the facility. SURF is proposing additional underground space on the 4850L and 7400L (2300 m, 6500 m.w.e.), and initial engineering designs have been completed. SURF is a dedicated research facility with significant expansion capability, and applications from new experiments are welcome.

As the nation’s primary underground laboratory and based on input from the underground science community, SURF advocates for the following Snowmass and P5 recommendations:

- Mission need for additional deep laboratory space (including at depths > 6000 m.w.e.) in the U.S. to support compelling future science
- Mission need for a next-generation (~100 tonnes) dark matter and neutrino observatory in the U.S.
- Develop a process for allocating temporary use of a LBNF module (“module of opportunity”)
- Endorse the value of multi-disciplinary underground science at a dedicated laboratory in the U.S.

1 Introduction

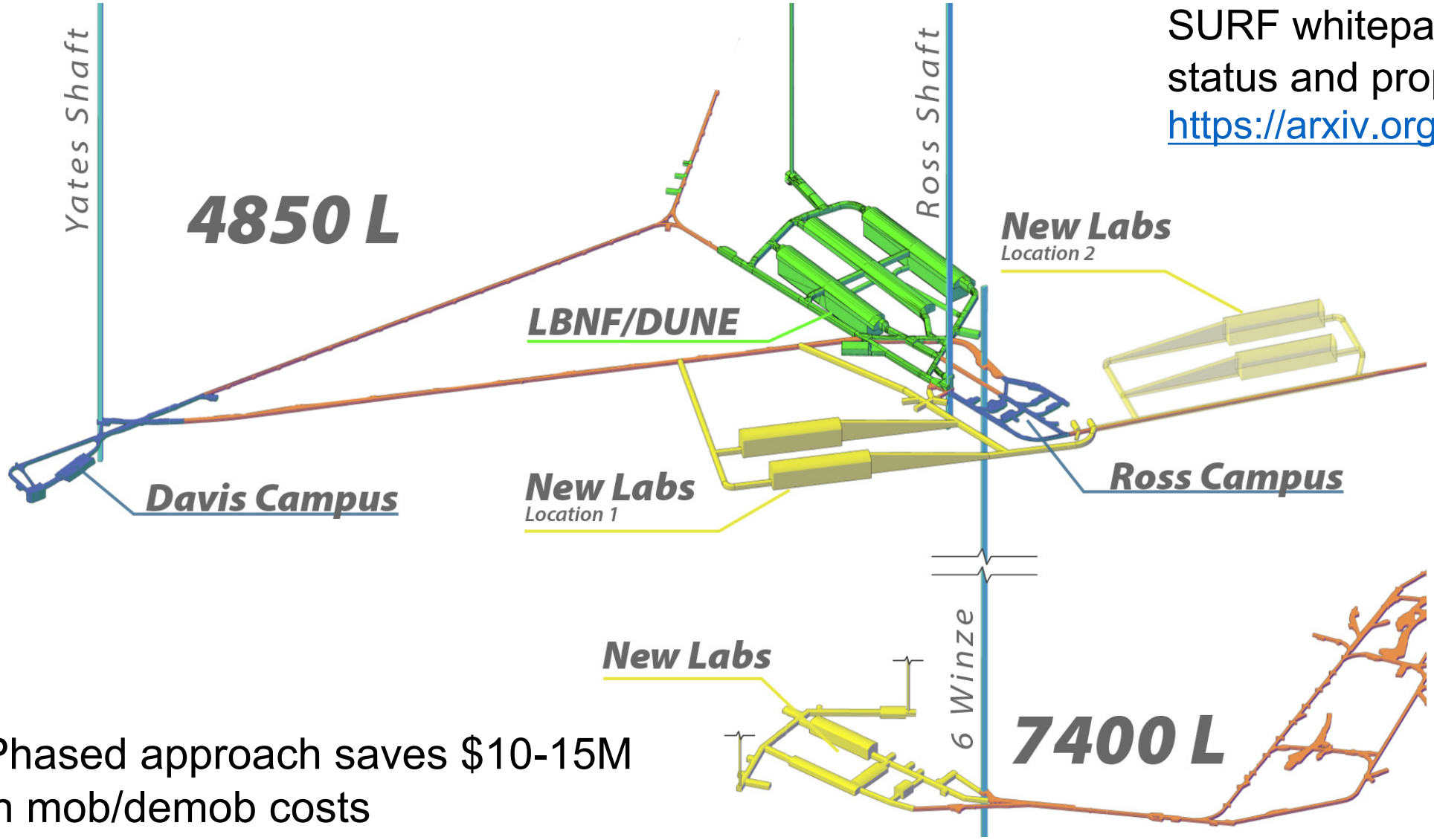
The Sanford Underground Research Facility (SURF) is an international facility dedicated to advancing compelling multidisciplinary underground scientific research, including physics, biology, geology and engineering [1, 2, 3]. The unique underground environment at SURF allows researchers to explore an array of important questions regarding the origin of life and its diversity, mechanisms associated with geologic processes as well as a number of engineering topics such as mining innovations and technology developments. A deep underground laboratory is also where some of the most fundamental topics in physics can be investigated, including the nature of dark matter, the properties of neutrinos and topics

1

UG science community input from SURF Vision Workshop held Sep 2021, https://indico.sanfordlab.org/e/Vision2021

SURF Current & Future Underground Facilities

Strategic plan incl additional 4850L labs + deeper access



SURF whitepaper describing current status and proposed future facilities: https://arxiv.org/abs/2203.08293

Phased approach saves $10-15M in mob/demob costs

SURF Current & Future Facilities

Summary for various science campuses, including timelines

Location	Laboratory	Existing/*Planned* Space		Available (CY)	Comments
		Area (m^2)	Vol (m^3)		
Surface	Surface Lab (+ RRS)	210	600	2021	LZ use ~complete, allowing use by others
Davis Campus (4850L)	LZ Lab – Davis Cavern (2 levels)	372	1,956	~2027	LZ data complete by ~2026 + decommissioning
	MJD Lab – 2 Rooms + BHUC share	300	1,279	~2024/2026	Initial scope completed 2021, Ta-180m data 2022-2023 + decommissioning; Cu e-forming through 2025+
	Cutout Rooms (4)	100	412	~2027	LZ timeframe for most spaces
Ross Campus (4850L)	Former E-forming	228	742	?	LBNF use now, SURF UG WWTP in next few years
	BHUC (BHSU cleanroom)	266	773	N/A	Mothballed, equip and systems relocated to Davis Campus; re-occupy FY24 after LBNF construction
	CASPAR	395	1,130	2029-2031	Mothballed, equip remains, re-occupy FY24 after LBNF construction. (Also expanded Refuge Chamber)
	Refuge Chamber	258	866	?	Long-term use TBD
LBNF (4850L)	*LBNF*	*9,445*	*191,863*	*~2024*	*Excavation complete in 2024, "module of opportunity"?*
4100L	Geoscience Lab	334	11 drill holes	Fall 2022	Leverage EGS/SIGMA-V infrastructure
4850L	*New Labs (2 proposed)*	*4,022*	*94,608*	*Earliest new: excavation 2027, complete ~2030*	*Each 20m (W) x 24m (H) x 100m (L)*
7400L	*New Labs (2 proposed)*	*4,178*	*42,440*		*Each 15m (W) x 15m (H) x 75m (L) + other supporting*

Summary

- SURF currently offers world-class service to the UG science community:
  - SURF has attracted world-leading experiments and scientists from diverse scientific communities
  - SURF has proven track record of enabling experiments to deliver high-impact science

- In addition to DUNE, SURF wants to host other future world-leading experiments:
  - UG science community input from SURF Vision Workshop 2021

- SURF is actively exploring options to increase underground laboratory space:
  - Engineering studies have been completed to build large caverns on the 4850L (1500 m, 4300 mwe)
  - Previous engineering studies exist for the 7400L (2300 m, 6500 mwe)
  - Discussions have been renewed for the LBNF/DUNE “Module of Opportunity”
  - Aggressively seeking funding: Recent briefings incl DOE-HEP and state officials, discussions with private investors planned in 2022. Optimistic regarding phased development.

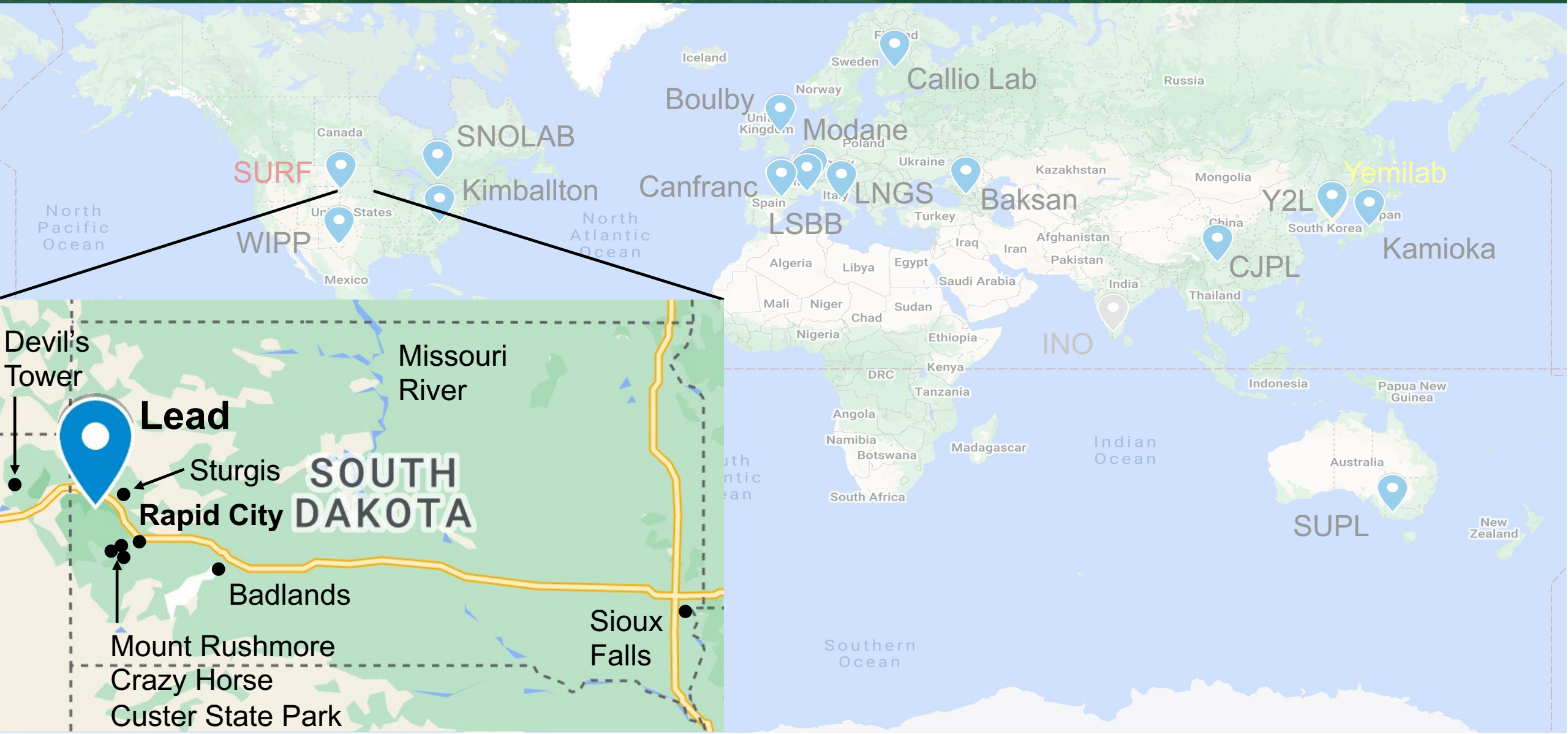
Sanford Underground Research Facility

Thank You!

Agency Acknowledgement: The Sanford Underground Research Facility (SURF) is a federally sponsored research facility under DOE-SC HEP Award Number DE-SC0020216 (cooperative agreement)

Sanford Underground Research Facility

Where in the world is SURF?

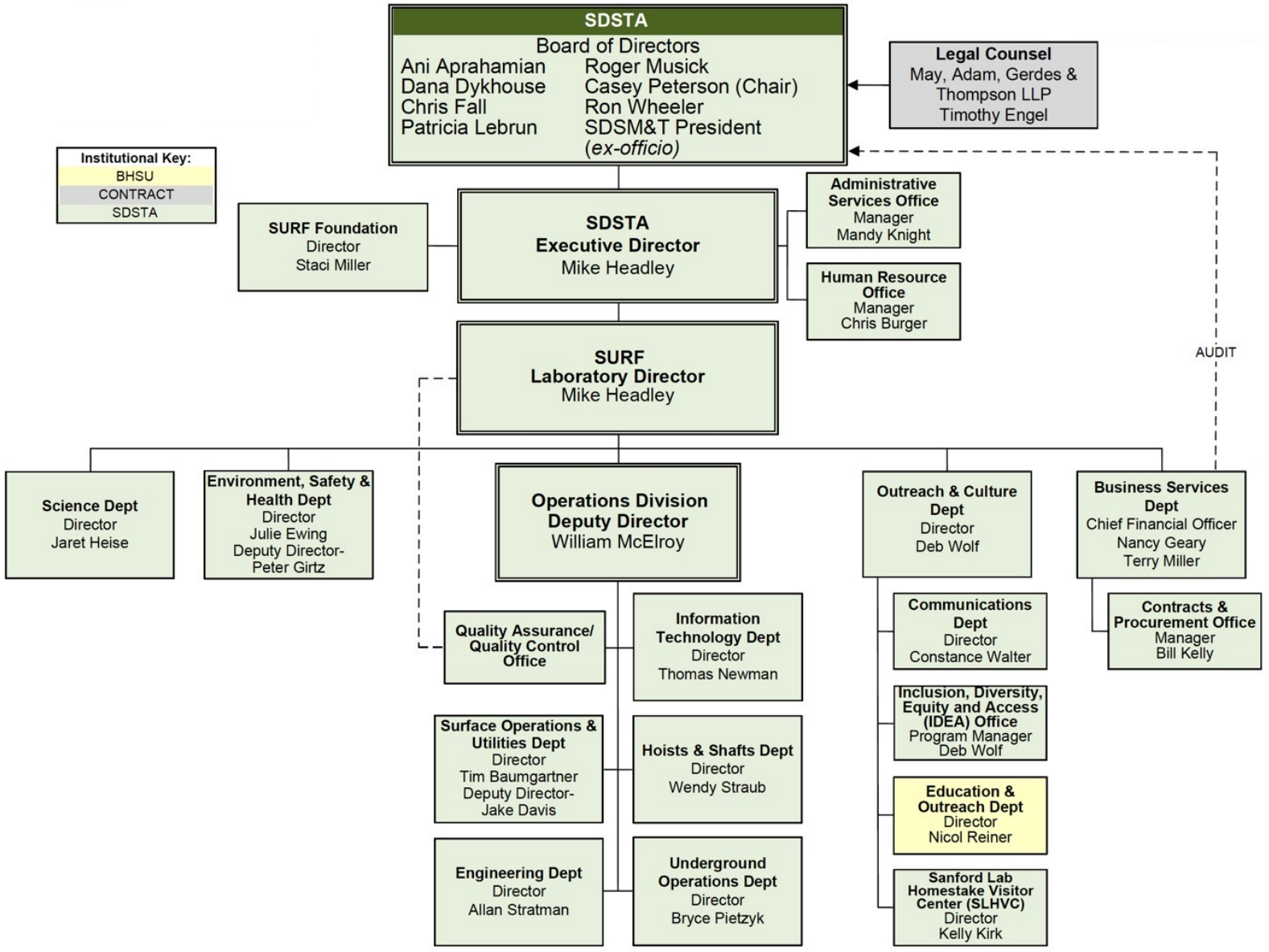


Sanford Underground Research Facility

Nation's deepest underground lab, advancing multi-disciplinary research

SURF Organization

Resources to enable safe and successful implementation of high-impact science

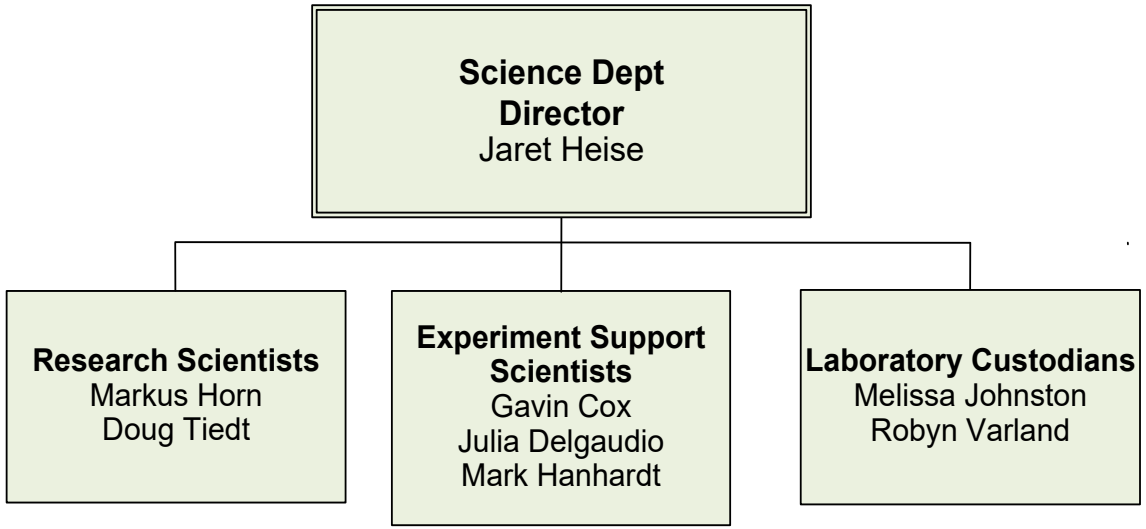


Staffing Area	Current FTE (%)	FY27 FTE (%)
Admin	34 (18%)	36 (17%)
Technical	125 (67%)	140 (67%)
Scientific	6 (3%)	11 (5%)
ESH	23 (12%)	23 (11%)
TOTAL	**187**	**209**

Science Organization and Scope

Resources to enable safe and successful implementation of high-impact science

- **Main point of contact** for experiments and researchers
- **Experiment implementation process** management, incl coordination of review and authorization processes
- **Scientific support,** incl participation as collaboration members and technical experiment support (e.g., low-background counter operations, specialized welding, other experiment procedures as needed)
- **Science facility** support, incl coordination and oversight (e.g., laboratory coordinators), specialized custodial support and management of cleanliness protocols, technical monitoring, development of some laboratory orientation training
- **Represent SURF** (facility and science) at venues ranging from public presentations to scientific conferences to DOE strategic planning



Cox, Delgaudio supported by LZ

+ budget support for portion of Maupin (Engineering Dept)

9 FTE

Science Staffing Overview

Resources to enable safe and successful implementation of high-impact science

Markus Horn (PhD)
Research Scientist
- Surface + UG Campuses

Charles Maupin (BSME, PE)
Expt Review Engineer
- Reviews, cryogen safety (0.15 DOE CA)

Jaret Heise (PhD) – *Director*
- Manage dept and experiment implementation program

Mark Hanhardt (MS)
Expt Support Scientist
- Surface + UG Campuses

Gavin Cox (MS)
Expt Support Scientist
- LZ Operations (not DOE CA)

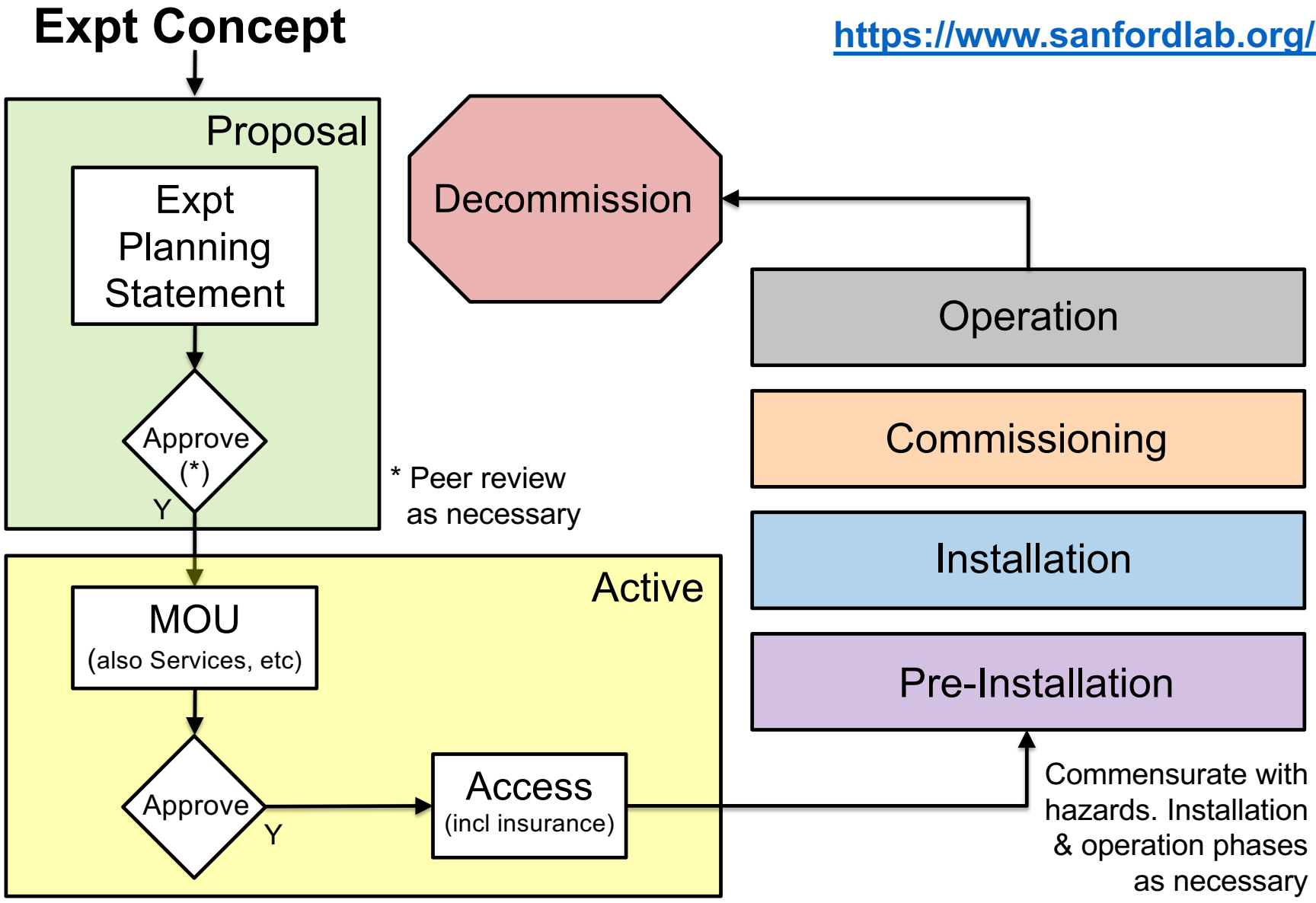
Robyn Varland - *Lab Custodians (Surface + UG)* - Melissa Johnston

Doug Tiedt (PhD)
Research Scientist
- Surface + UG Campuses

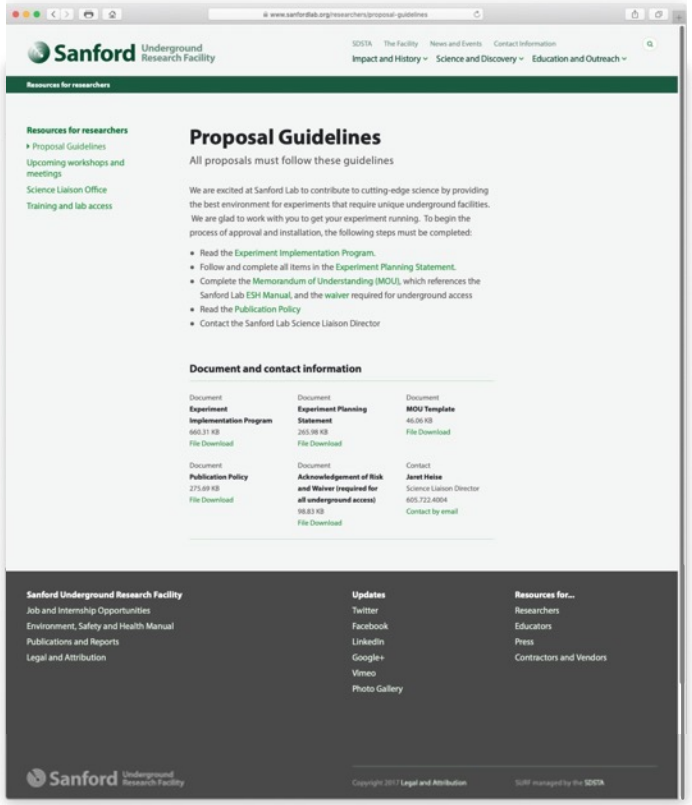
Julia Delgaudio (BS)
Expt Support Scientist
- LZ Operations (not DOE CA)

SURF Experiment Implementation Program

Identify interfaces and hazards within approval framework



https://www.sanfordlab.org/researchers/proposal-guidelines



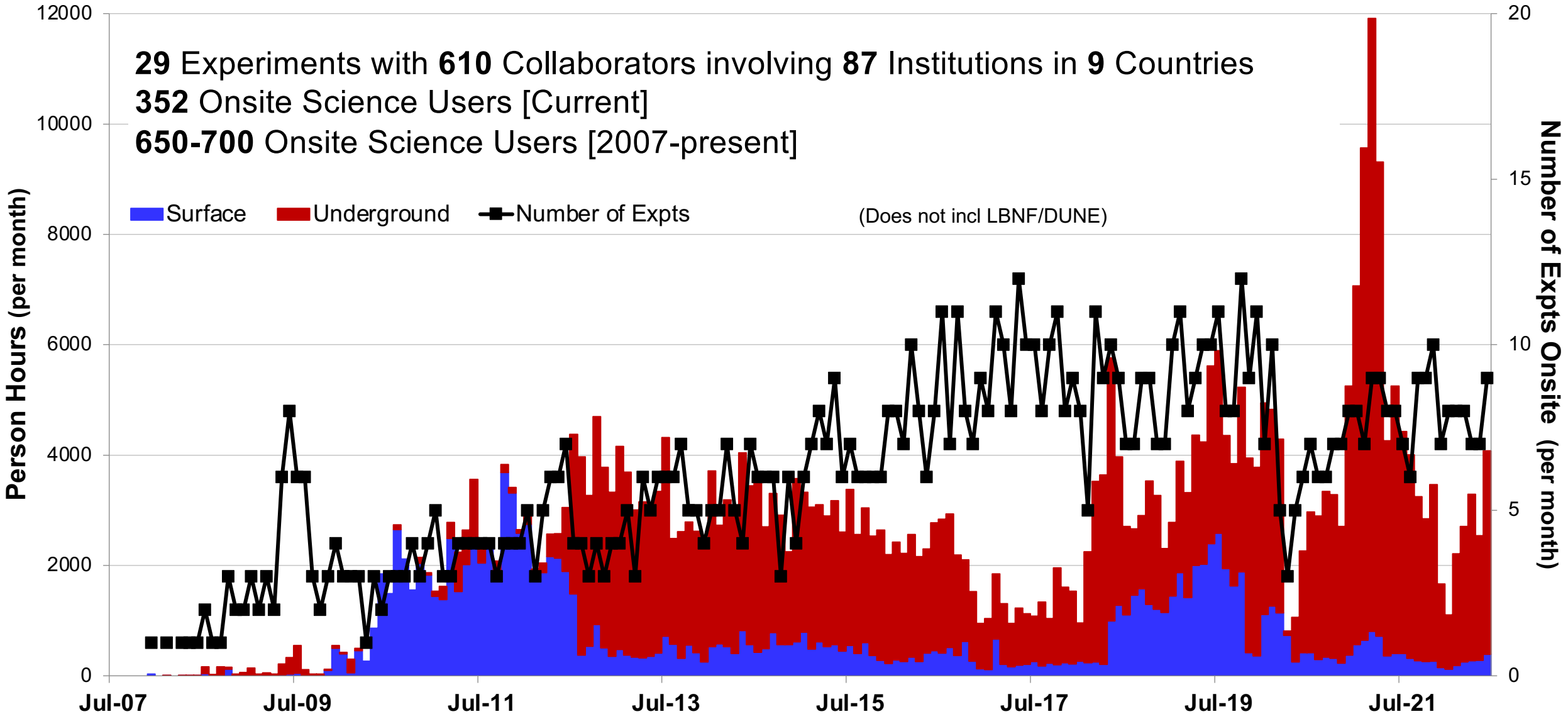
Experiment Implementation Program
DOE Cooperative Agreement Guidance

- **Basic Support for Non-Proprietary Experiments:**
  - General terms:
    - Provision of useable underground space that includes ventilation, power, water pumping;
    - Volume of underground space should be appropriate to scientific need;
    - Access to the underground for the installation, operation, decommissioning of experiments;
    - Communication and networking services;
    - Scientific and engineering liaison with users needed to help them meet the unique environment of SURF; and
    - Provision of usable above ground laboratory and setup space to prepare experiments.
  - Needs beyond basic support billed on cost-recovery basis (via contract or GSA)

- **Full Cost Recovery for Proprietary Experiments:**
  - Fee structure based on SURF budget (surface / UG) relative to non-proprietary researcher access & space footprint (updated annually, via contract or GSA):
    1. **Project access** (per experiment person, per hour, based on location)
    2. **SURF personnel** acting on behalf of a project (per SURF person, per hour)
    3. **Space occupancy and operations** (monthly, based on annual budget and location)
  - Unattended operation: cost recovery based on space occupancy, specific support by SURF personnel
  - No equipment installed: cost recovery based on access, specific support by SURF personnel

SURF Science Program

Research activities ranging from the surface to 1500+m underground



SURF Science Program

Researchers from 87 institutions (Pre-DUNE), active in bold (61)

United States

- **Black Hills State University, Spearfish, SD**
- **Brandeis University, Waltham, MA**
- **Brookhaven National Laboratory, Upton, NY**
- **Brown University, Providence, RI**
- Caltech, Pasadena, CA
- **Caterpillar Global Mining, LLC, East Peoria, IL**
- Colorado School of Mines, Golden, CO
- **Department of Energy (EERE), Washington, DC**
- **Desert Research Institute, Las Vegas, NV**
- **DTRC, Lead, SD**
- **Duke University / TUNL, Durham, NC**
- **Fermi National Accelerator Lab, Batavia, IL**
- **Golder Associates, Inc., Redmond, WA**
- **Idaho National Laboratory, Idaho Falls, ID**
- **Indiana University, Bloomington, IN**
- Jet Propulsion Laboratory, Pasadena, CA
- **Lawrence Berkeley National Lab, Berkeley, CA**
- **Lawrence Livermore National Lab, Livermore, CA**
- Liberty BioSecurity, LLC, Arlington, VA
- **Los Alamos National Lab, Los Alamos, NM**
- **Mattson Hydrology LLC, Victor, ID**
- McClure Geomechanics, Palo Alto, CA
- **Montana State University, Bozeman, MT**
- National Energy Technology Lab, Albany, OR / Morgantown, WV
- National Renewable Energy Lab, Golden, CO
- **North Carolina State University, Raleigh, NC**
- **Northwestern University, Evanston, IL**
- **Oak Ridge National Lab, Oak Ridge, TN**
- **Pacific Northwest National Lab, Richland, WA**
- **Pennsylvania State University, State College, PA**
- **Primo, Lead, SD**
- **RE/SPEC, Rapid City, SD**
- Rensselaer Polytechnic Institute, Troy, NY
- **Rice University, Houston, TX**
- Rutgers University, Piscataway Township, NJ
- **Sandia National Laboratories, Albuquerque, NM**
- **South Dakota School of Mines & Technology, Rapid City, SD**
- **Spearfish School District, Spearfish, SD**
- **SLAC National Accelerator Lab, Menlo Park, CA**
- **Stanford University, Stanford, CA**
- Tennessee Tech University, Cookeville, TN
- Texas A&M University, College Station, TX
- US Geological Survey, Rapid City, SD / Tucson, AZ

US – continued

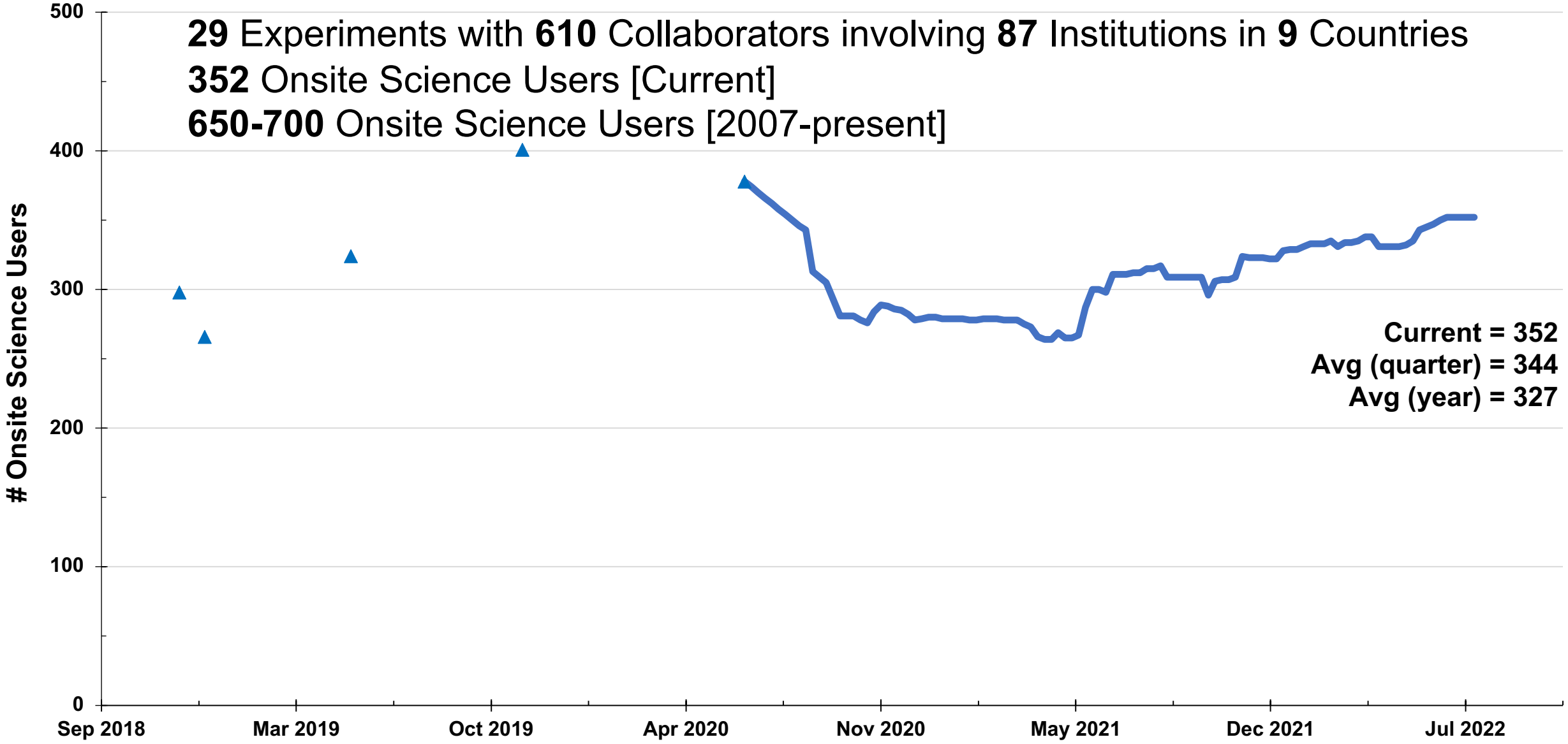
- **University at Albany/SUNY, Albany, NY**
- **University of Alabama, Tuscaloosa, AL**
- **University of California Berkeley, Berkeley, CA**
- **University of California Davis, Davis, CA**
- **University of California Los Angeles, Los Angeles, CA**
- **University of California Santa Barbara, Santa Barbara, CA**
- **University of Kentucky, Lexington, KY**
- **University of Maryland, College Park, MD**
- **University of Massachusetts, Amherst, MA**
- **University of Michigan, Ann Arbor, MI**
- **University of North Carolina, Chapel Hill, NC**
- **University of Notre Dame, Notre Dame, IN**
- **University of Oklahoma, Norman, OK**
- **University of South Carolina, Columbia, SC**
- **University of South Dakota, Vermillion, SD**
- **University of Southern California, Los Angeles, CA**
- **University of Rochester, Rochester, NY**
- University of Tennessee, Knoxville, TN
- University of Utah, Salt Lake City, UT
- **University of Wisconsin – Madison / Physical Sciences Lab, Madison, WI**
- **University of Washington, Seattle, WA**
- USDA NCAUR, Peoria, IL
- WD Masonry, Rapid City, SD
- Williams College, Williamstown, MA
- Xilinx, Inc., San Jose, CA
- Yale University, New Haven, CT

World (Non-US)

- **Center for Underground Physics (IBS), Daejeon, Korea**
- Joint Institute for Nuclear Research, Dubna, Russia
- **Imperial College London, London, England**
- **LIP Coimbra, Coimbra, Portugal**
- NRC Institute for Theoretical and Experimental Physics, Moscow, Russia
- Osaka University, Osaka, Japan
- Queen's University, Kingston, Canada
- **Royal Holloway and Bedford New College, Egham, England**
- **Rutherford Appleton Laboratory, Didcot, England**
- Technische Universitat Munchen / Max Planck Institute, Munich, Germany
- **University College London, London, England**
- **University of Bristol, Bristol, England**
- **University of Edinburgh, Edinburgh, Scotland**
- **University of Liverpool, Liverpool, England**
- **University of Oxford, Oxford, England**
- **University of Sheffield, Sheffield, England**

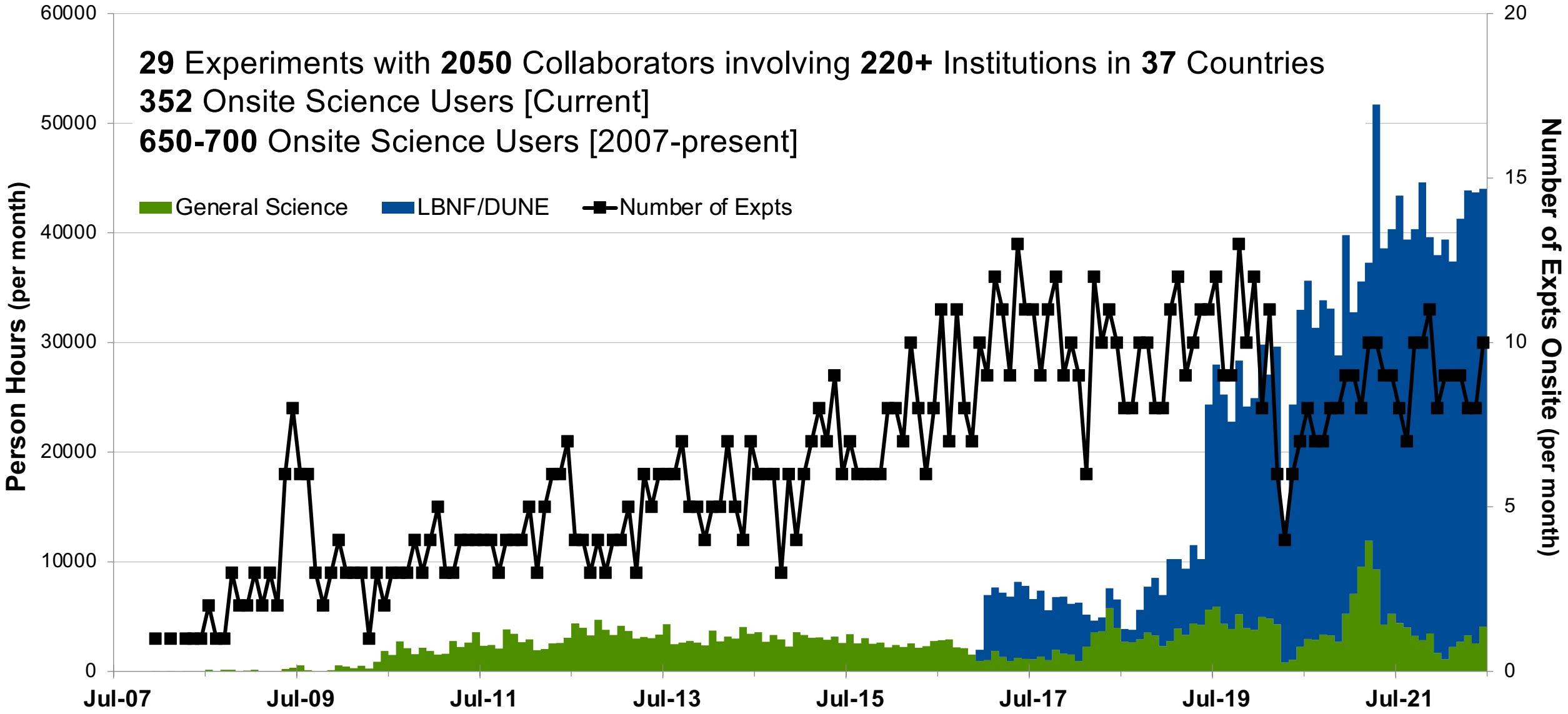
SURF Science Program

Research activities ranging from the surface to 1500+m underground



SURF Science Program

Research activities ranging from the surface to 1500+m underground



SURF Science Guidance

User Association

- Established Dec 2020: 9-10 members spanning breadth of SURF science: physics, biology, geology, engineering.
- Scope: reinforce two-way communication, foster sense of community, promote scientific case for UG science.
- SURF Long-Term Vision Workshop held mid-Sep 2021. First General Meeting Sep 2021, next meeting Oct 2022.

1. Brittany Kruger (DRI/**Chair**)
2. Megan Smith (LLNL/**Secretary**)
3. Mark Hanhardt (SDSTA)
4. Kevin Lesko (LBNL)
5. Rachel Mannino (Wisconsin)
6. Ralph Massarczyk (LANL)
7. Sam Meijer (LANL)
8. Brianna Mount (BHSU)
9. Frank Streider (SD Mines)
10. Wenqin Xu (USD)

Science Program Advisory Committee

- Established Sep 2021: 14 members, national & international experts spanning breadth of SURF science with strategic and synergistic influences.
- Scope: Review science program, support and facilities. Peer review per DOE User Facility.
- First meeting held Jan 2022, next meeting in Fall 2022.

1. David MacFarlane (SLAC/**Chair**)
2. Ed Blucher (Chicago)
3. Derek Elsworth (Penn State)
4. Joseph Formaggio (MIT)
5. Hunter Knox (PNNL)
6. Magdalena Osburn (Northwestern)
7. Federica Petricca (Max Planck)
8. Lance Roberts (SD Mines)
9. Hamish Robertson (Washington)
10. William Roggenthen (SD Mines)
11. Kate Scholberg (Duke)
12. Barbara Szczerbinska (TAMU-CC)
13. Mary Voytek (NASA)
14. TBD

Also:

- SDSTA Board of Directors (SD Mines President *ex-officio*)
- SURF Strategic Advisory Committee
- SURF is looking to strengthen administrative and academic relationships with SD universities

SURF User Association

https://www.sanfordlab.org/researchers/surfuserassociation

Purpose

- **Two-way communication** on topics important to researchers.
- Promotes a **sense of community** amongst SURF experiments and researchers.
- Articulates and promotes **scientific case for UG science** and significance to society, provides channel for **advocacy.**

Organization

- **Membership** open to Underground Science Community (initially was limited to active SURF researchers). General meetings held at least annually.
- **Executive Committee** consists of 9 individuals across scientific disciplines, incl early career. Two-year terms (with term overlap), limits per experiment and institution. Quarterly meetings held with SURF Mgmt.

1. Brittany Kruger (DRI/**Chair**)
2. Megan Smith (LLNL/**Secretary**)
3. Mark Hanhardt (SDSTA)
4. Kevin Lesko (LBNL)
5. Rachel Mannino (Wisconsin)
6. Ralph Massarczyk (LANL)
7. Sam Meijer (LANL)
8. Brianna Mount (BHSU)
9. Frank Streider (SD Mines)
10. Wenqin Xu (USD)

Status

- **Established** Dec 2020, operating well. Two rounds of **Executive Committee** elections conducted successfully (2020, 2021).
- **Charter** updated in Aug 2021 to broaden membership to **global underground science community**. Subcommittee ratified new registration process in Apr 2022, form linked on SURF website and advertised to community. Expanded membership will increase SURF's prominence and leadership in global UG science community.
- **Charter** update in progress to reflect SPAC recommendation to increase **minimum representation** from various disciplines. Change ratified by Executive Committee in Apr 2022 (SURF to formally adopt).
- Association organized SURF **Vision Workshop** Sep 2021. First **General Meeting** Sep 2021, next meeting Oct 26-27, 2022.

SURF Science Program Advisory Committee

Purpose

- **Science Program:** Provide guidance on overall SURF scientific program (incl current, planned/proposed experiments), as well as direction and breadth of program. Peer review per DOE User Facility.
- **Science Support:** Advise on SURF experiment implementation program and organizational capacity to support experiments.
- **Science Facilities:** Advise on capability and capacity of the SURF facility necessary to support the SURF scientific program.

Organization

- SPAC consists of up to **14 members,** representing breadth of SURF research disciplines with strategic and synergistic influences (SDSTA Laboratory and Science Directors *ex-officio*).
- Members: **Two-year** terms (extendable). Chair: **One-year** term (extendable).
- Selection of new members made by SDSTA Laboratory + Science Directors in consultation with SDSTA IDEA Office.

1. David MacFarlane (SLAC/**Chair**)
2. Ed Blucher (Chicago)
3. Derek Elsworth (Penn State)
4. Joseph Formaggio (MIT)
5. Hunter Knox (PNNL)
6. Magdalena Osburn (Northwestern)
7. Federica Petricca (Max Planck)
8. Lance Roberts (SD Mines)
9. Hamish Robertson (Washington)
10. William Roggenthen (SD Mines)
11. Kate Scholberg (Duke)
12. Barbara Szczerbinska (TAMU-CC)
13. Mary Voytek (NASA)
14. TBD

Status

- **Established** Sep 2021, operating well.
- **First meeting held** (remotely) Jan 2022, tracking 17 recommendations (incl conducting planning workshops to strengthen SURF's posture for attracting new science). Next meeting planned for Fall 2022 (hopefully, in-person!).

SURF Designated APS Historical Site

Announcement Sep 2020, Dedication May 2022

www.interactions.org/press-release/aps-designates-sanford-lab-morgan

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A communication resource from the **world's particle physics laboratories.**

APS designates Sanford Lab, Morgan State University as historic physics sites

14 September 2020 - Sanford Underground Research Facility

The pioneering neutrino research done by Ray Davis over nearly three decades forever changed our understanding of the Standard Model of Physics

The American Physical Society (APS) today announced it has designated SURF one of two Historic Sites in physics. The other, Morgan State University in Baltimore, Maryland, is recognized as the birthplace of the National Society of Black Physicists (NSBP).

DATE ISSUED:
September 14th, 2020

SOURCE:
Sanford Underground Research Facility

CONTENT:
Press Release

CONTACT:
Constance Walter
Communications Director
cwalter@sanfordlab.org

LUX-ZEPLIN (LZ)

Large Underground Xenon - ZonEd Proportional scintillation in Liquid Noble gases

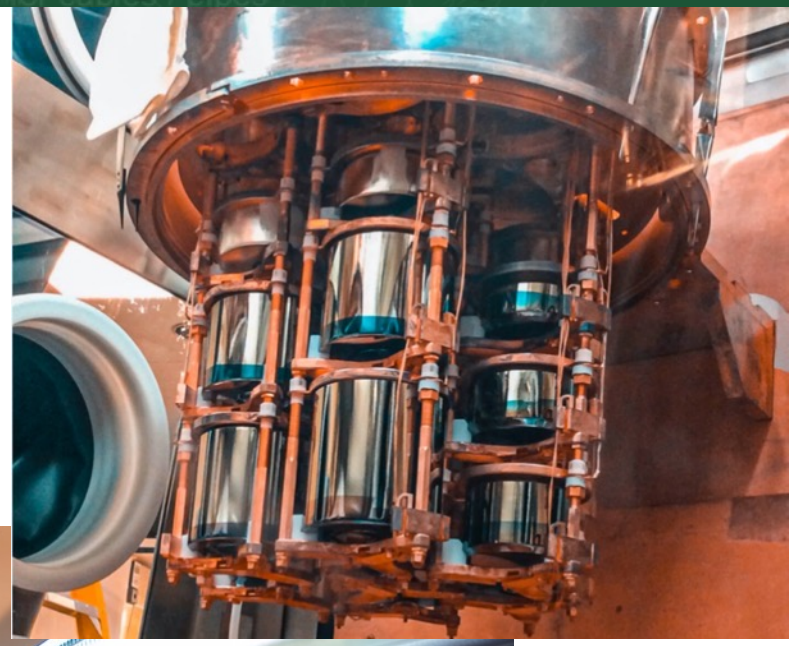
- **Science Goal:** Direct dark matter search using dual-phase xenon (10 tonnes) in Ti cryostat inside ultra-pure water + Gd liquid scintillator veto
- **Collaboration:** 245 members, 35 institutions, lead = LBNL (DOE HEP)
- **Status:**
  - Onsite since Jul 2017 (as LUX since Nov 2009).
  - Detector assembly 2018-2019 at Surface Laboratory supported by radon-reduction system.
  - Production data started Dec 2021. Detector working well, robust calibration program underway (incl DD generator).
  - First WIMP-search results announced Jul 7, 2022: https://lz.lbl.gov (also https://arxiv.org/abs/2207.03764).
- **Future:**
  - Complete science data ~2026, decommissioning ~2027.
  - Meetings held with advocates for next-generation liquid Xe observatory for dark matter and neutrino physics (LZ and European) collaborators: http://arxiv.org/abs/2203.02309. Proposing up to ~100 tonnes Xe, site TBD.
  - Other low-mass dark matter projects being considered as follow-ons to LZ (e.g., Hydro-X, CrystaLiZe).


https://vimeo.com/368551340
PODIUM

MAJORANA DEMONSTRATOR (MJD)

Also Large Enriched Ge Experiment for Neutrinoless ββ Decay (LEGEND)

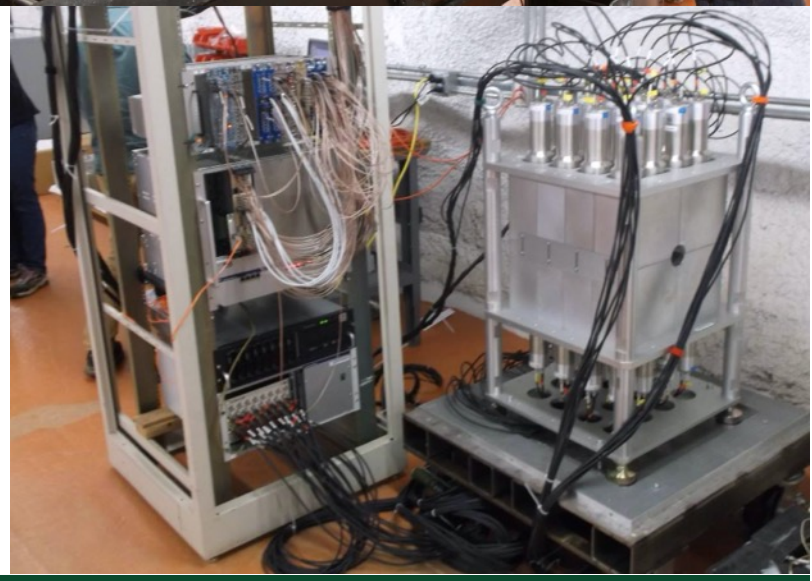
- **Science Goal:** Neutrinoless double-beta decay using 44 kg Ge in two cryostats, 30 kg enriched ^{76}Ge inside compact shield (poly + Pb + Cu); also LEGEND R&D and more recently rare decays (^{180m}Ta)
- **Collaboration:** 67 members, 20 institutions, lead = ORNL (DOE NP)
- **Status:**
  - Onsite at SURF since Nov 2010
  - Achieved 65 kg-yr exposure (2015-2021), ^{enr}Ge to LNGS for LEGEND-200. Bkgd studies with ^{nat}Ge May-Nov 2021
  - Tantalum-180m rare-decay search started May 2022.
  - Cu e-forming at Ross Campus using 10 baths (2011-2016, decommissioned in 2017). Davis Campus e-forming since 2018, now 3 baths (4th operating soon).
- **Future:**
  - Ta-180m search goal is 12 kg-year exposure (~1 year).
  - May expand to ~8 Cu e-forming baths for LEGEND.
  - Double-Beta Decay Summit Oct 2021: Agreement (in principle) for 1 ton-scale expt in each of North America and Europe: nEXO (Xe) and LEGEND-1000 (Ge). Only SURF option is LBNF “module of opportunity”.



CASPAR

Compact Accelerator System for Performing Astrophysical Research

- **Science Goal:** Study of stellar nuclear fusion reactions, esp. neutron production for slow neutron-capture nucleosynthesis using 1-MV electrostatic accelerator for protons or alpha particles
- **Collaboration:** 16 members, 5 institutions, lead = SD Mines (NSF MPS/PHY)
- **Status:**
  - Onsite at SURF since mid-2015, beam since 2017.
  - Data collected 2017-2021 with targets: ^{7}Li, ^{11}B, ^{14}N, ^{18}O, ^{20}Ne, ^{22}Ne (gas, solid), ^{27}Al.
  - Bkgd characterization, incl liquid scintillator neutron detectors (ORNL), ^{3}He and NaI arrays (Notre Dame).
  - Laboratory mothballed Apr 2021 due to LBNF construction.
- **Future:**
  - 9 scientific papers planned: 2 published (incl PRL), 2 submitted. Also: 3 students graduated, 3 in queue.
  - Meeting planned for Aug 2022, incl prep for NSF proposal.
  - Planning for next phase of operation starting ~FY24 (4850L Ross Campus lab), targets incl ^{14}N (for CNO solar neutrinos).



EGS Collab / SIGMA-V

Stimulation Investigations for Geothermal Modeling Analysis and Validation

- **Science Goal:** Study enhanced geothermal system (EGS) effects on 10-meter scale. Pressure systems used to isolate sections of holes and flow water between holes; also biology sampling
- **Collaboration:** 128 members, 23 institutions, lead = LBNL (DOE Office of Energy Efficiency and Renewable Energy (EERE), Geothermal Technology Office (GTO))
- **Status:**
  - Onsite since Oct 2017 (as kISMET since Jun 2016).
  - 4850L: 8x holes drilled (each 60 m), stimulation/flow studies completed, site decommissioned (in future, possibly re-use 2 EGS holes, also 5x kISMET holes).
  - 4100L: 2x initial holes plus 9x holes completed Jan-Aug 2021 (180-265 m long). Some SURF prep (incl modest excavation). Stimulation/flow tests underway.
- **Schedule:**
  - Final tests summer 2022, mothball by Oct 2022 due to funding.
  - Other funding proposals being pursued (incl international Geothermica/DOE starting ~mid-2023). DOE call for proposals?

SIMFIP tool installed on 4100L

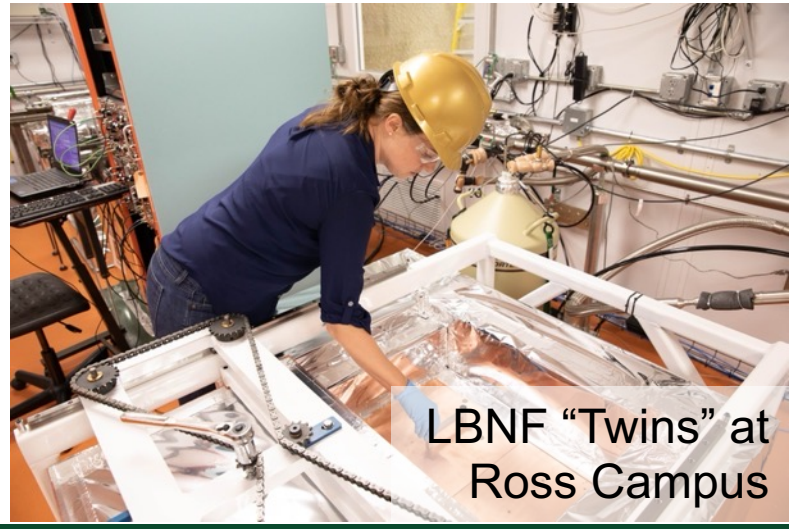
DOE-SC BES program manager visit

SURF Material Assay at BHUC

Black Hills State University Underground Campus

- **Science Support Goal:** Characterize radiopurity of experiment components; also multi-disciplinary science support at Ross Campus
- **Collaboration:** 14 members, 7 institutions, lead = BHSU (institutional funding, some DOE support via experiments like LZ)
- **Status:**
  - Onsite since Sep 2015 (previous low-bkgd efforts with CUBED starting Apr 2013 at Davis Campus).
  - Ross Campus operations Sep 2015 – Jul 2020. Laboratory temporarily mothballed Mar 2021 due to LBNF construction.
  - Initial operations at Davis Campus starting Nov 2020 after SURF-supported cooling upgrades. Samples resumed Mar 2021.
  - Five of six counter systems operating, incl LLNL dual-crystal system. Recent samples incl protoDUNE, also IceCube and CUPID.
- **Schedule:**
  - Operation of all six detector systems. Possible addition of 7th detector (Ge-V).
  - Limited space for expansion at Davis Campus. Return to Ross Campus in ~FY24 following LBNF construction.

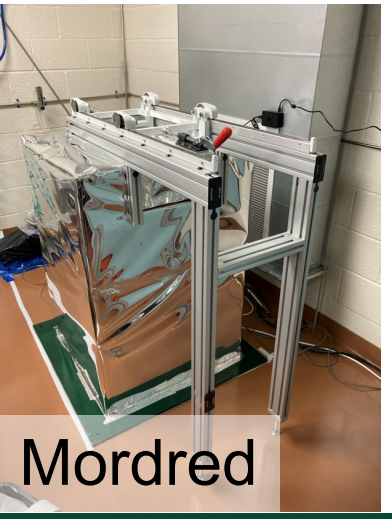
LLNL detector commissioning at Davis Campus

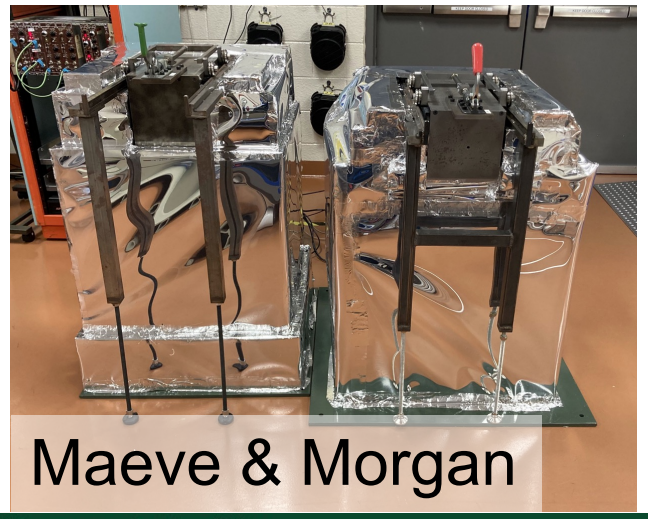


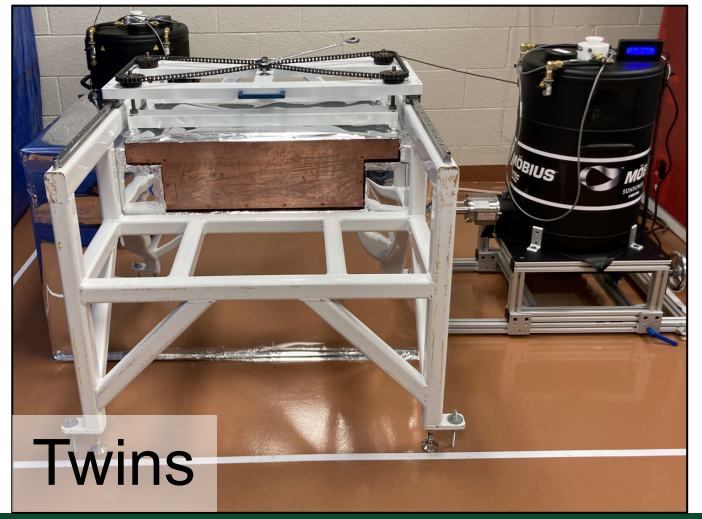
LBNF “Twins” at Ross Campus

SURF Material Assay at BHUC: Davis Campus

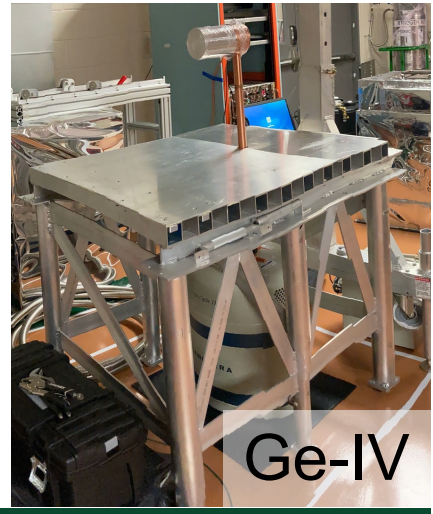
Low-background counting capabilities serving national & international community


Mordred


Maeve & Morgan


Twins


RHYM/RESN


Ge-IV

SURF Material Assay at BHUC

Low-background counting capabilities serving national & international community

Detector	Crystal		[U] mBq/kg	[Th] mBq/kg	Install Date	Status	Comments
	Type	Size					
Maeve (BLBF)	p-type (85%)	2.2 kg	**0.1** (10 ppt)	**0.1** (25 ppt)	Davis Campus: Nov 2020 (Ross Campus: Nov 2015; Davis Campus: May 2014)	Production assays	Relocated from Oroville. Old Pb (200-yr old) inner shielding. Cooling system upgrade 2020.
Morgan (BLBF)	p-type (85%)	2.1 kg	**0.2** (20 ppt)	**0.2** (50 ppt)	Davis Campus: Nov 2020 (Ross Campus: Nov 2015; Davis Campus: May 2015)	Production assays	Low-bkgd upgrade 2015. Cooling system upgrades 2020.
Mordred (USD/CUBED, BLBF)	n-type (60%)	1.3 kg	**0.7** (60 ppt)	**0.7** (175 ppt)	Davis Campus: Nov 2020 (Ross Campus: Jul 2016; Davis Campus: Apr 2013)	Production assays	Low-bkgd upgrade 2015-2016, shield access upgrade. Cooling system upgrades 2020.
Dual HPGe ("Twins") (BLBF, BHSU, UCSB)	p-type (2x120%)	2x 2.1 kg	**~0.01** (~1 ppt)	**~0.01** (~1 ppt)	Davis Campus: Sep 2020 (Ross Campus: Mar 2018, Jul 2017 (initial))	Operating	Low-bkgd upgrades 2016-2017; flexible shield. Cooling system upgrades 2020.
Ge-IV *(Alabama, Kentucky)*	*p-type (111%)*	*2 kg*	***0.04*** *(3 ppt)*	***0.03*** *(8 ppt)*	*Davis Campus: Summer 2022?, Nov 2020 (initial) (Ross Campus: Jul 2018, Oct 2017 (initial))*	*Installation underway*	*Vertical design, requires gantry + hoist. Cooling system upgrades 2020.*
Dual HPGe ("RHYM+RESN") (LLNL)	p-type (2x65%)	2x 1.1 kg	**<0.1** (<10 ppt)	**<0.1** (<25 ppt)	Davis Campus: Feb 2022, Sep 2020 (initial)	Operating	Cryocooler, low-E ^{210}Pb (<2 mBq/kg).

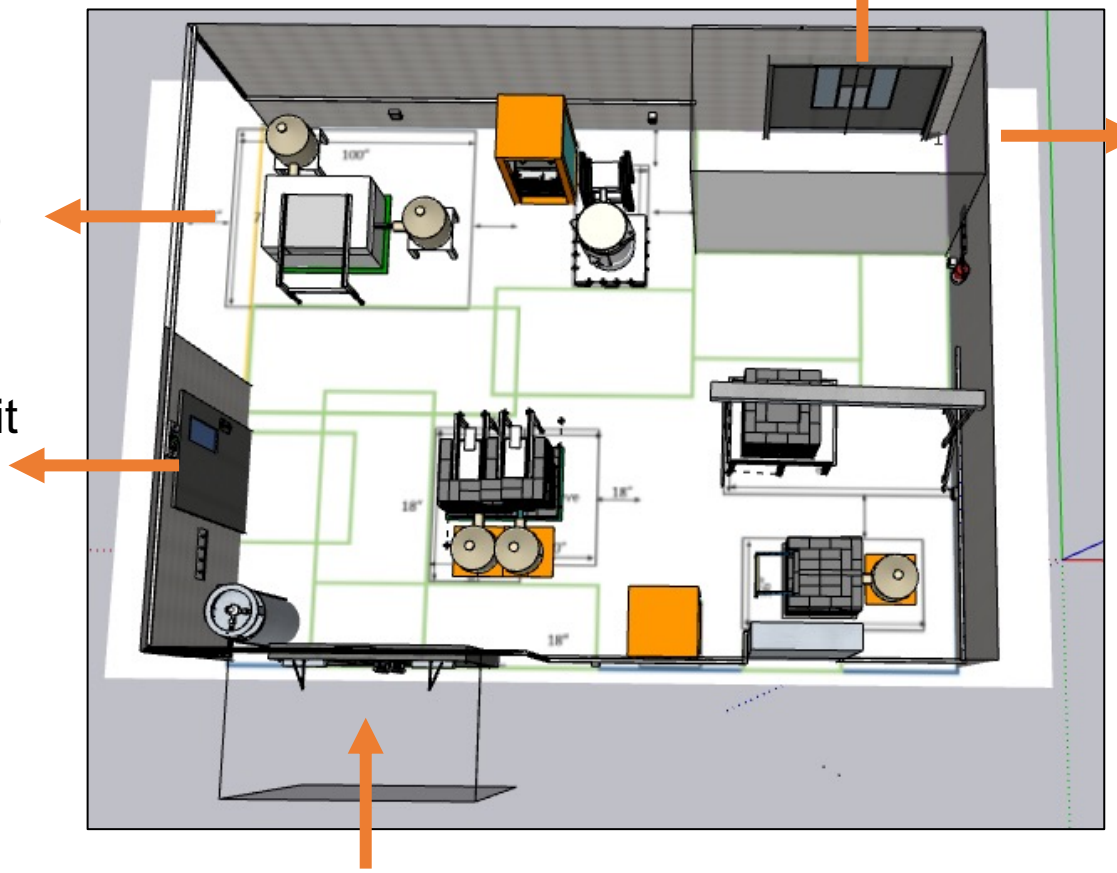
Also see: LZ Assay Paper https://arxiv.org/pdf/2006.02506

Local universities have some additional material screening capabilities: **HPGe** (SOLO [0.6 kg]/BHSU, [0.2-0.4 kg]/SD Mines), **ICP-MS** (BHSU), **Rn emanation** characterization (0.1 mBq/SD Mines), **Alpha** (1 mBq/m^2 ^{210}Po/SD Mines; XIA UltraLo-1800/LZ purchased)

SURF Material Assay at BHUC: Davis Campus

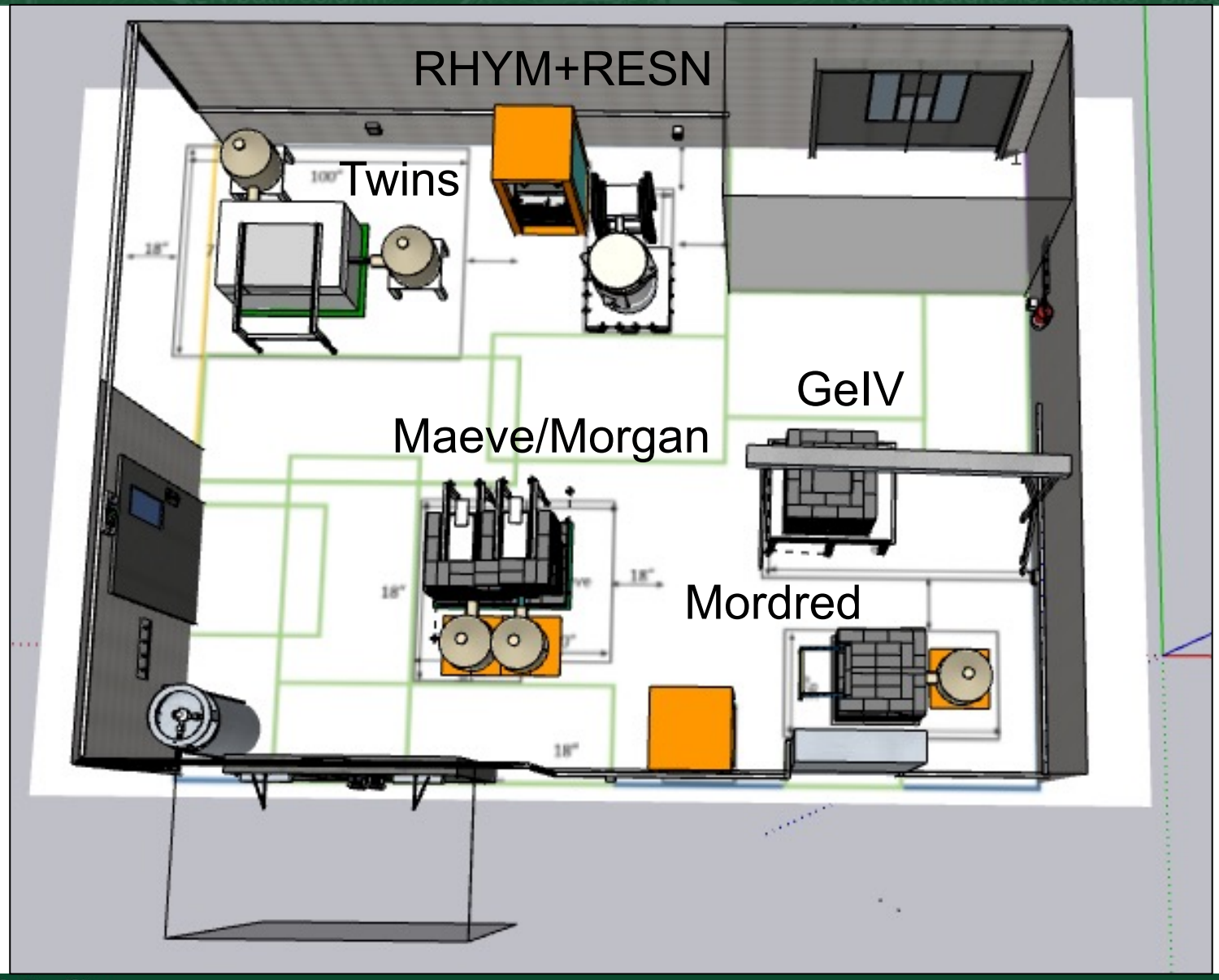
Low-background counting capabilities serving national & international community

Detectors now have Mobius Coolers, no need for regular LN Fills!



SURF Material Assay at BHUC: Davis Campus

Low-background counting capabilities serving national & international community



SURF Science Strategic Planning

Capabilities and future plans responsive to community's needs

- SURF strategic plan addresses need for additional space
  - Several module options studied and designed over past decade+, 4850L well characterized (incl recent LBNF + other research efforts)
  - **4850L lab expansion** – Feasibility study completed Feb 2022, DOE-HEP briefed
  - **Surface assembly/staging** – Initial planning requirements complete

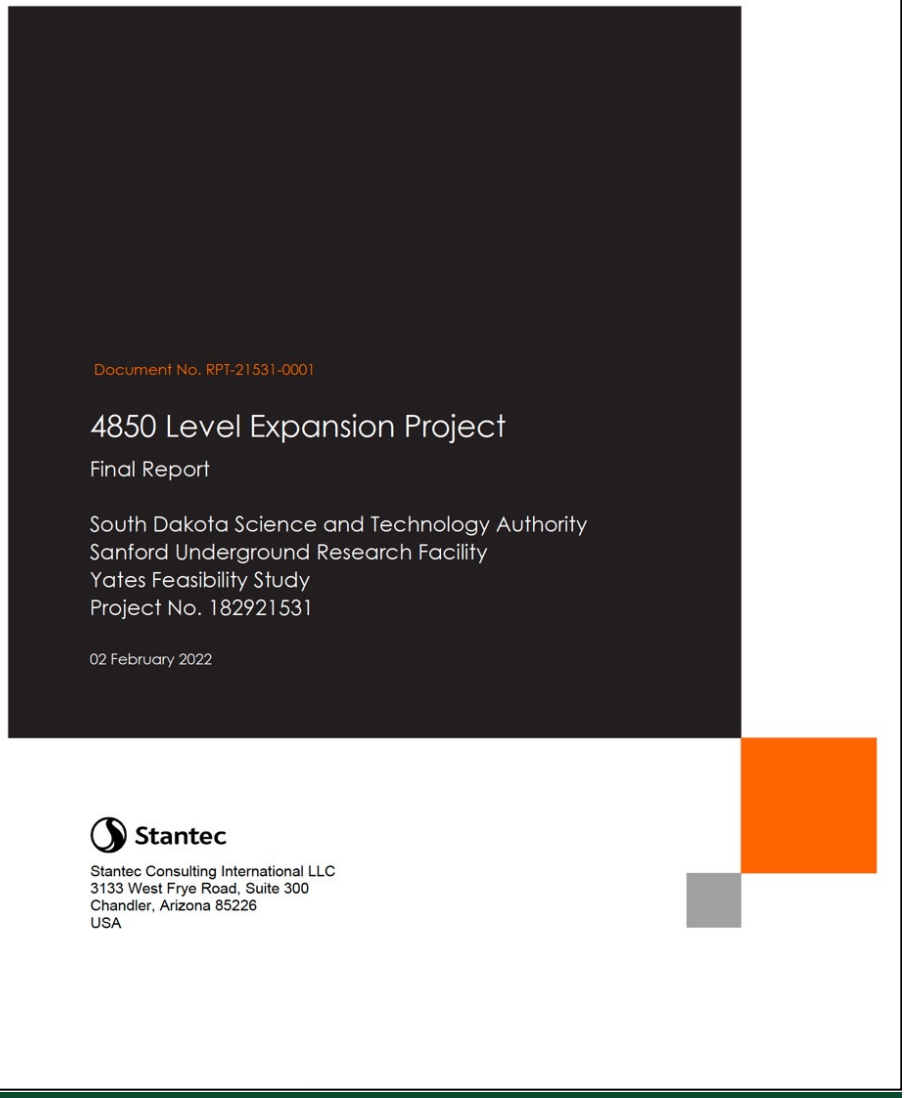
- SURF Long-Term Vision Workshop (User Association Sep 2021)
  - Very successful: 18 talks, 9 hours of presentations and discussions, 88 participants https://indico.sanfordlab.org/event/26/
  - Support for additional space for all disciplines, cavern dimensions appropriate for future experiments, possible new directions

- "Snowmass" (Physics HEP community planning/strategic planning)
  - Snowmass LOI submitted for Underground Facilities Frontier: https://www.snowmass21.org/docs/files/?dir=summaries/UF/
  - Snowmass whitepaper submitted for Underground Facilities Frontier: https://arxiv.org/abs/2203.08293

SURF Underground Facility Expansion

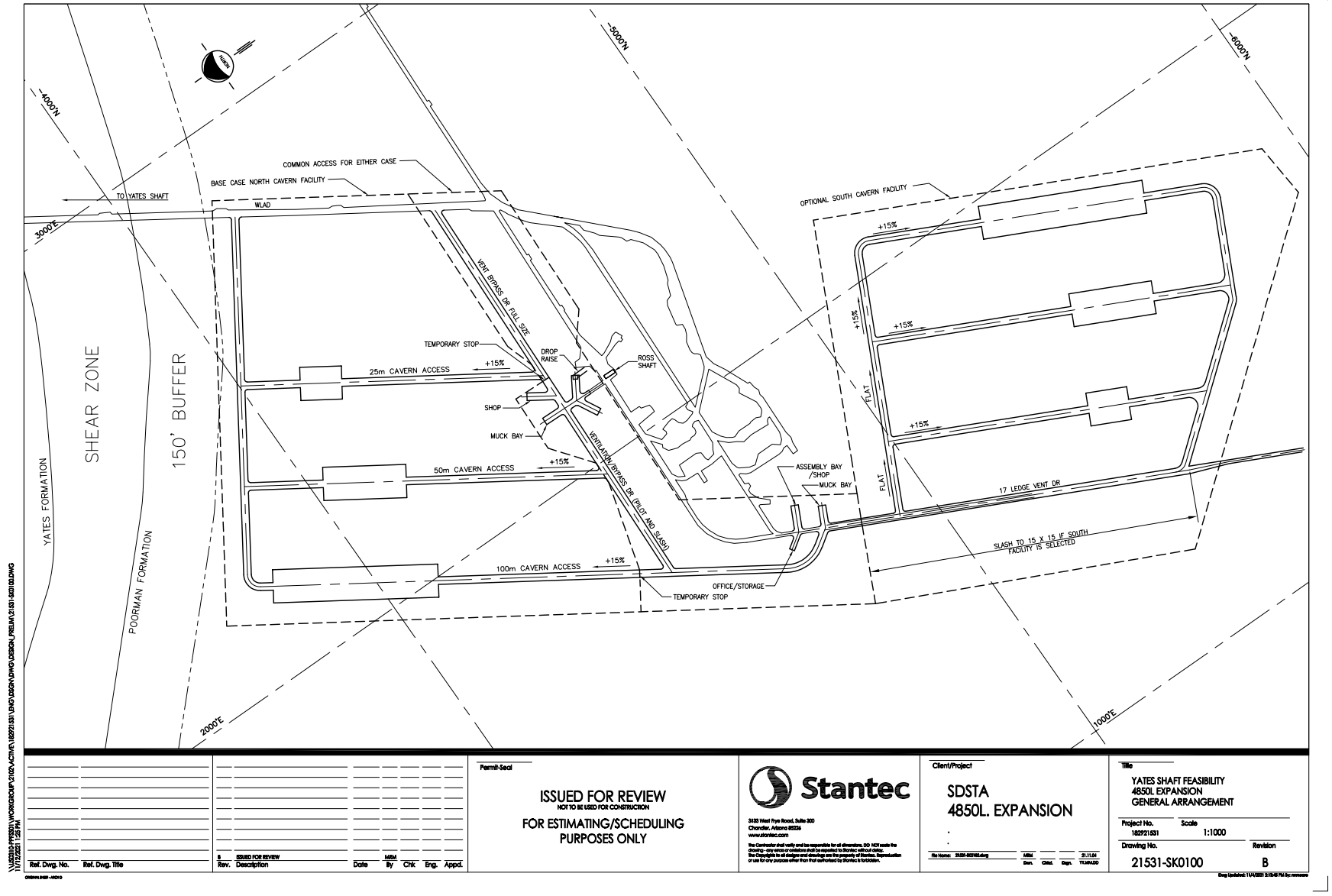
Feasibility design considerations for 4850L cavern(s)

- Geotechnical conditions
- Ventilation (intake and exhaust)
  - *Excavation, outfitting, operation*
- Access to existing operations
  - *Rock handling near Ross Shaft*
- Separation from existing facilities (LBNF, Ross Campus)
  - *Isolate researchers from construction (dust, equipment, etc)*
- Ability to excavate, construct, expand in phases
  - *Maximize flexibility at expense of efficiency (e.g., single heading only)*
- Adequate cavern space availability (25m, 50m, 100m lengths)
  - *15% grade to reach top of cavern*
  - *Room to install bridge crane/monorail*
- Misc alcoves, etc
  - *No rock in West Drift (!)*



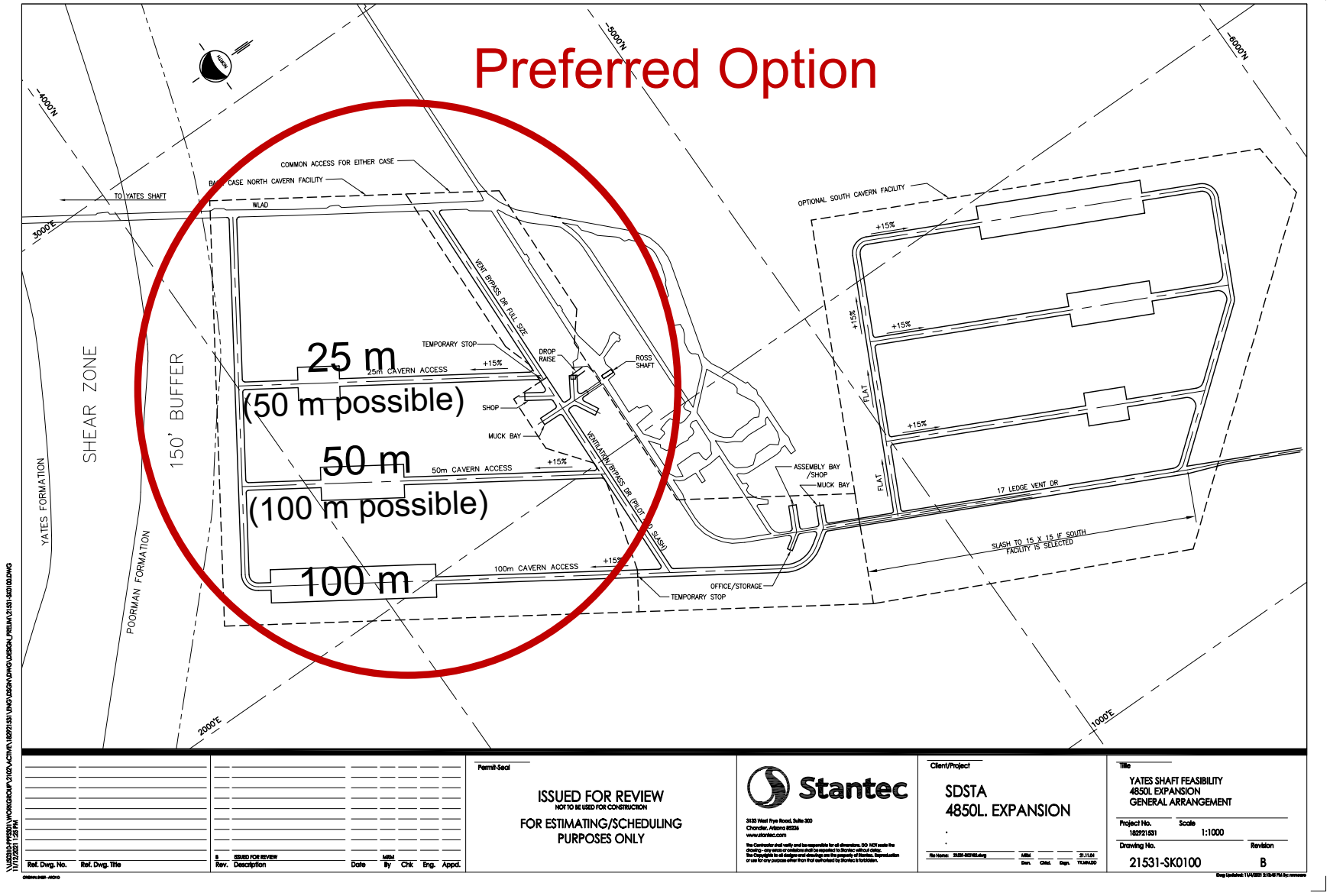
SURF Underground Facility Expansion

Feasibility concept



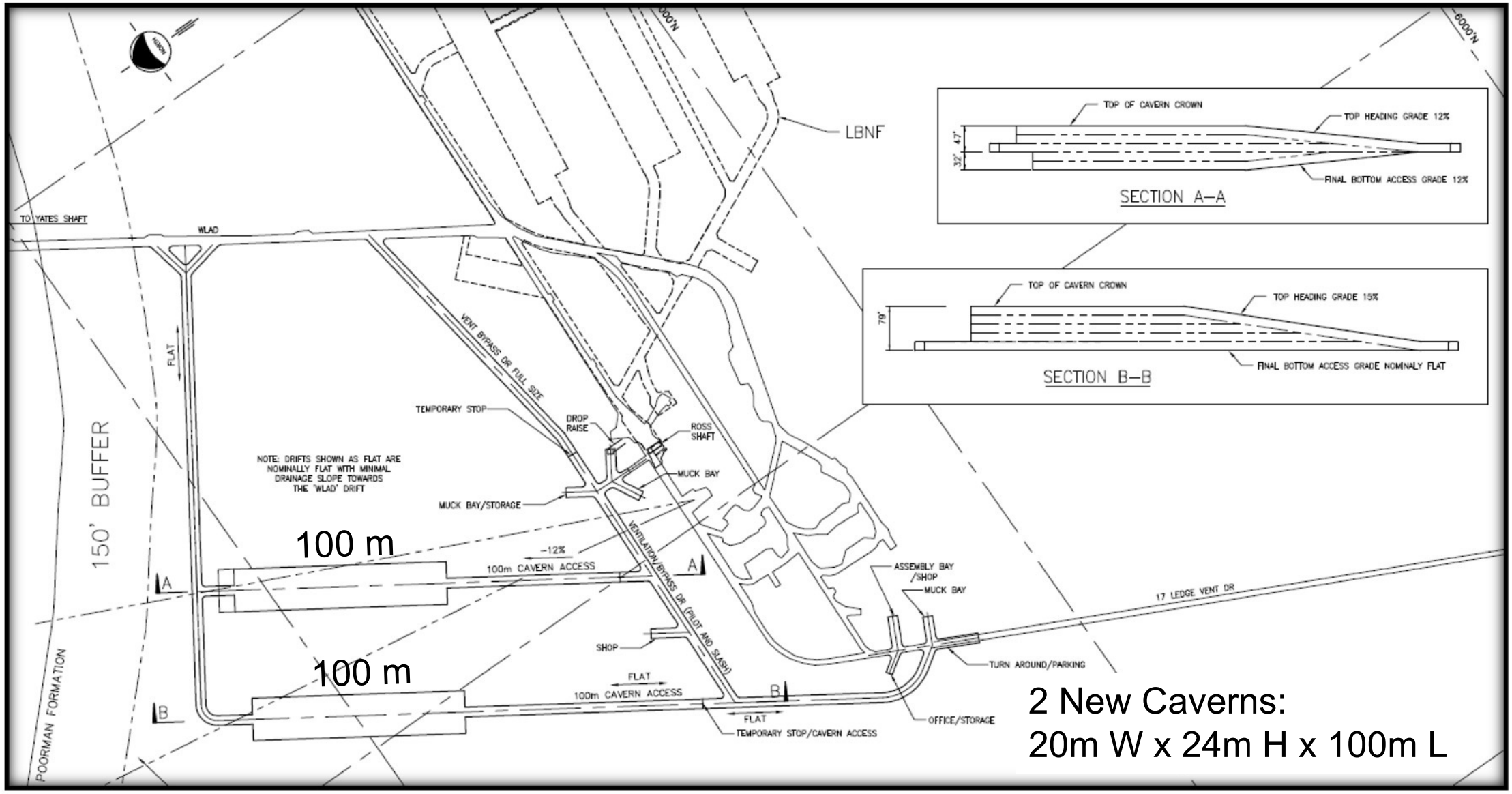
SURF Underground Facility Expansion

Feasibility concept



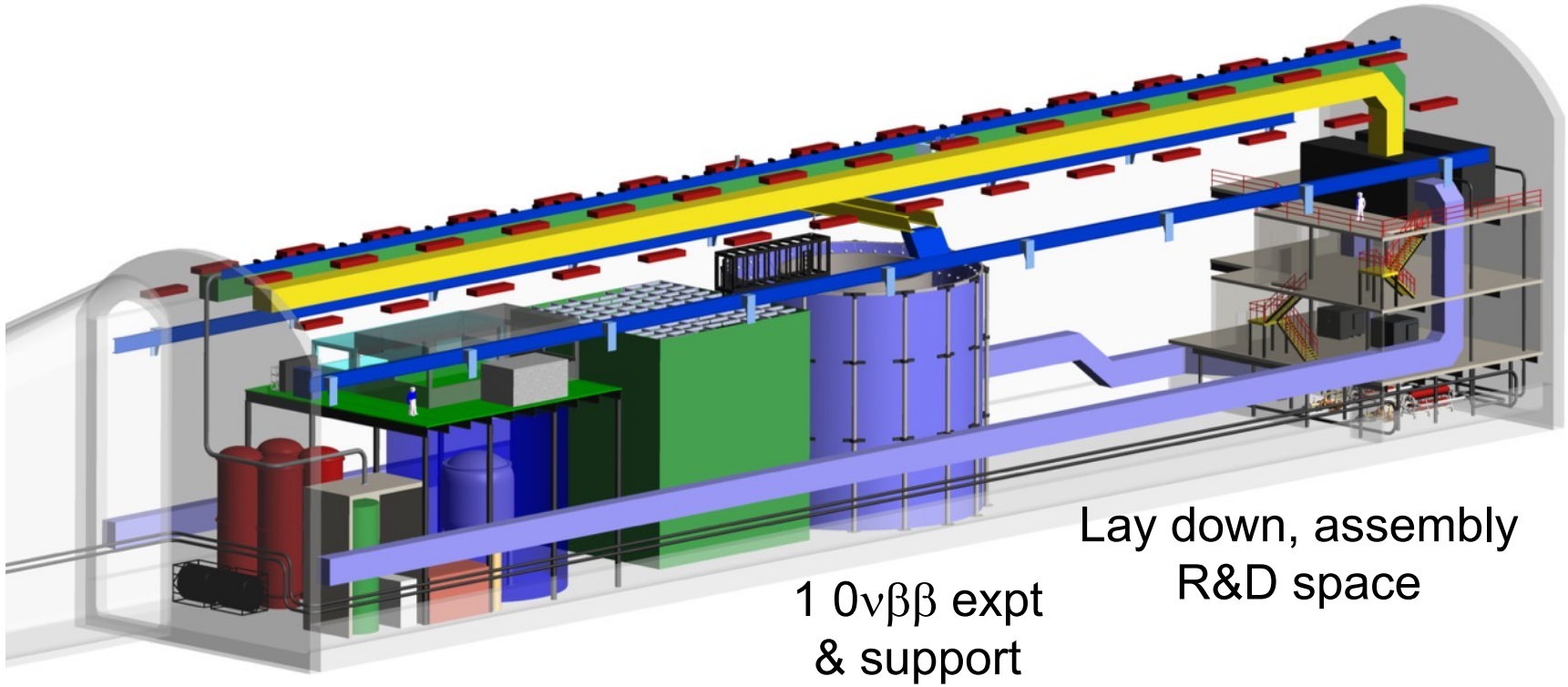
SURF Underground Facility Expansion

Feasibility concept



SURF Underground Facility Expansion

Example 4850L experiment hall layout

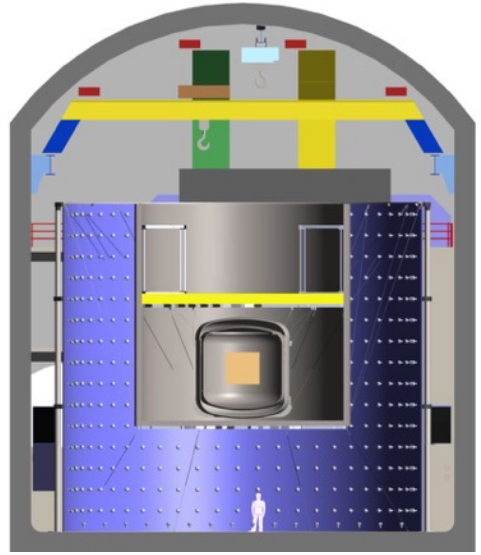


Mechanical
& electrical

Lay down, assembly
R&D space

1 $0\nu\beta\beta$ expt
& support

1 dark matter expt

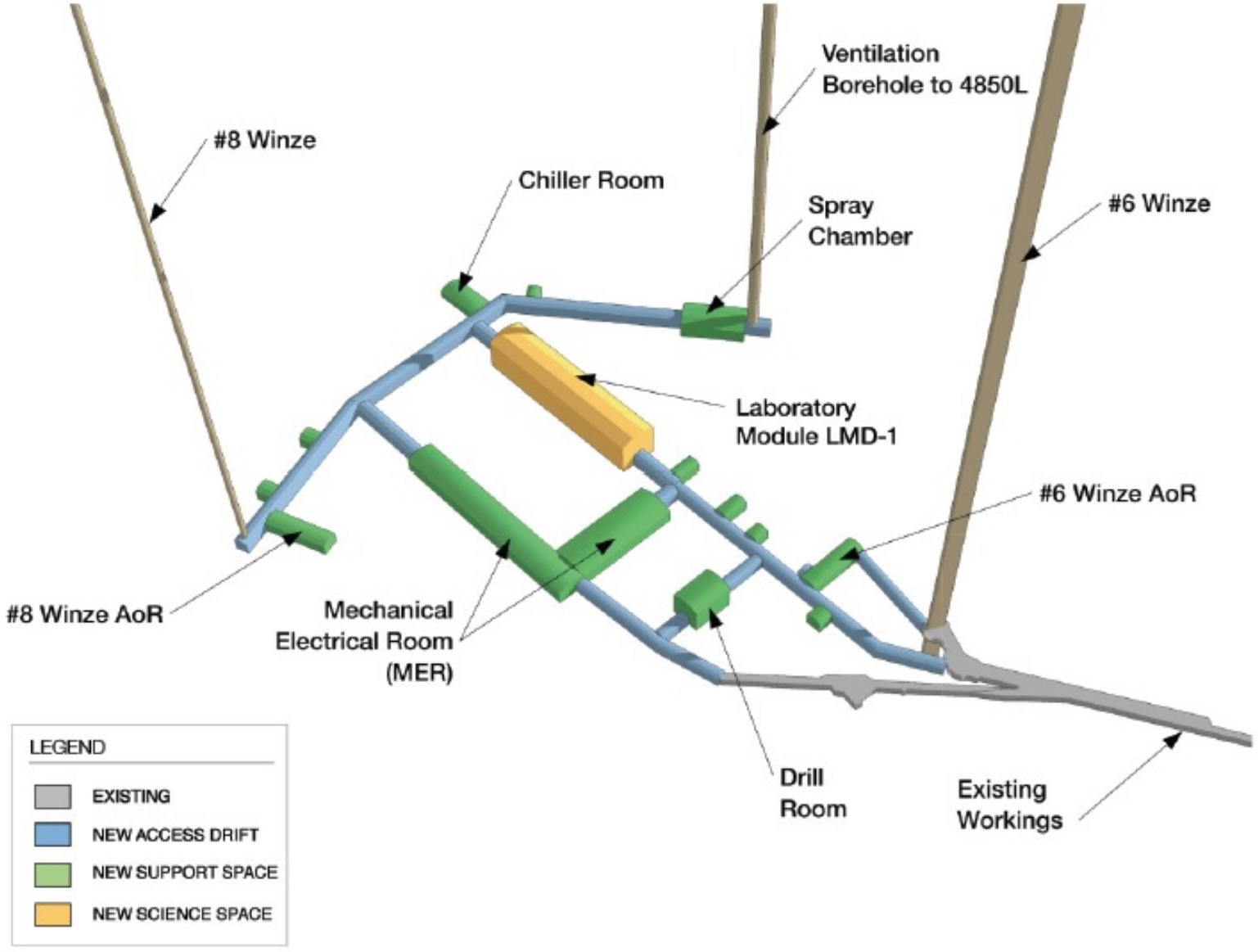


Cavern Size 20m (W) x 24m (H) x 115m (L)

(current design is 100m with additional space for utilities)

SURF Underground Facility Expansion

Example 7400L experiment hall layout



SURF Facility Expansion

Planning requirements for surface storage/assembly/staging

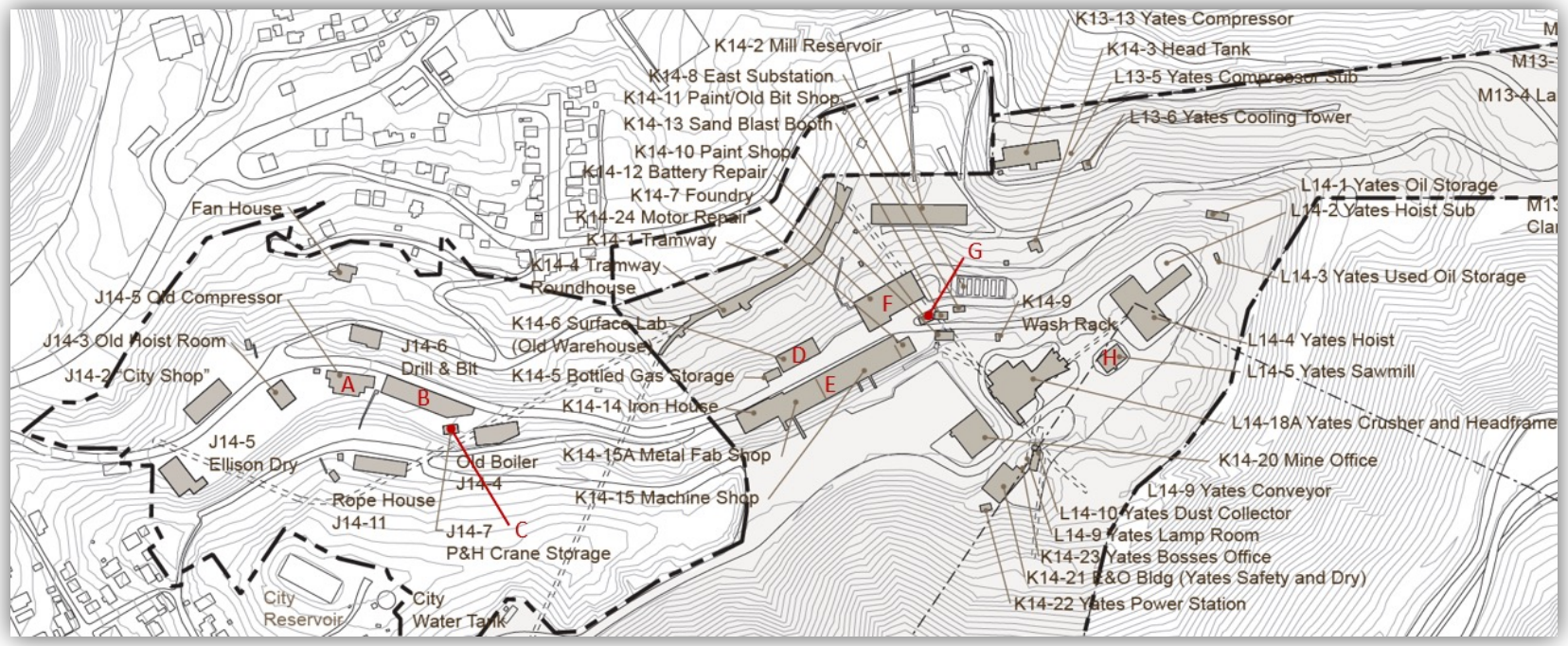


Table 2: Existing surface storage, staging and assembly space at SURF. Some staging areas can be used for non-cleanroom light assembly work.

Existing Use

Use	Footprint (m^2)	Comment
Storage, Cold	1385	Including drill core repository (1015 m^2)
Storage, Heated	220	Heated space, including some formal HVAC
Staging	71	HVAC environment
Assembly	284	HVAC environment, some cleanroom space

SURF Facility Expansion

Planning requirements for surface storage/assembly/staging

Projected Use

- Estimate based on DUSEL Lab Modules and current SURF experiments
  - Medium-scale expt: 185 m^2 (2000 ft^2) assembly
  - Large-scale expt: 370 m^2 (4000 ft^2) assembly
- Several options exist to renovate existing SURF buildings, new construction also possible

Surface Assembly Space Planning		
4850L	**50m Length**	**100m Length**
Module 1 Experiments	1 Lg or 2 Med	2 Lg or 4 Med
Module 2 Experiments	1 Lg or 2 Med	2 Lg or 4 Med
Assembly Sq. Ft.	8,000	16,000
7400L	**50m Length**	**100m Length**
Module 1 Experiments	1 Lg or 2 Med	2 Lg or 4 Med
Module 2 Experiments	1 Lg or 2 Med	2 Lg or 4 Med
Assembly Sq. Ft.	8,000	16,000
Total Sq. Ft.	**16,000**	**32,000**

M. Michael Rounds Operations Center (ROC)

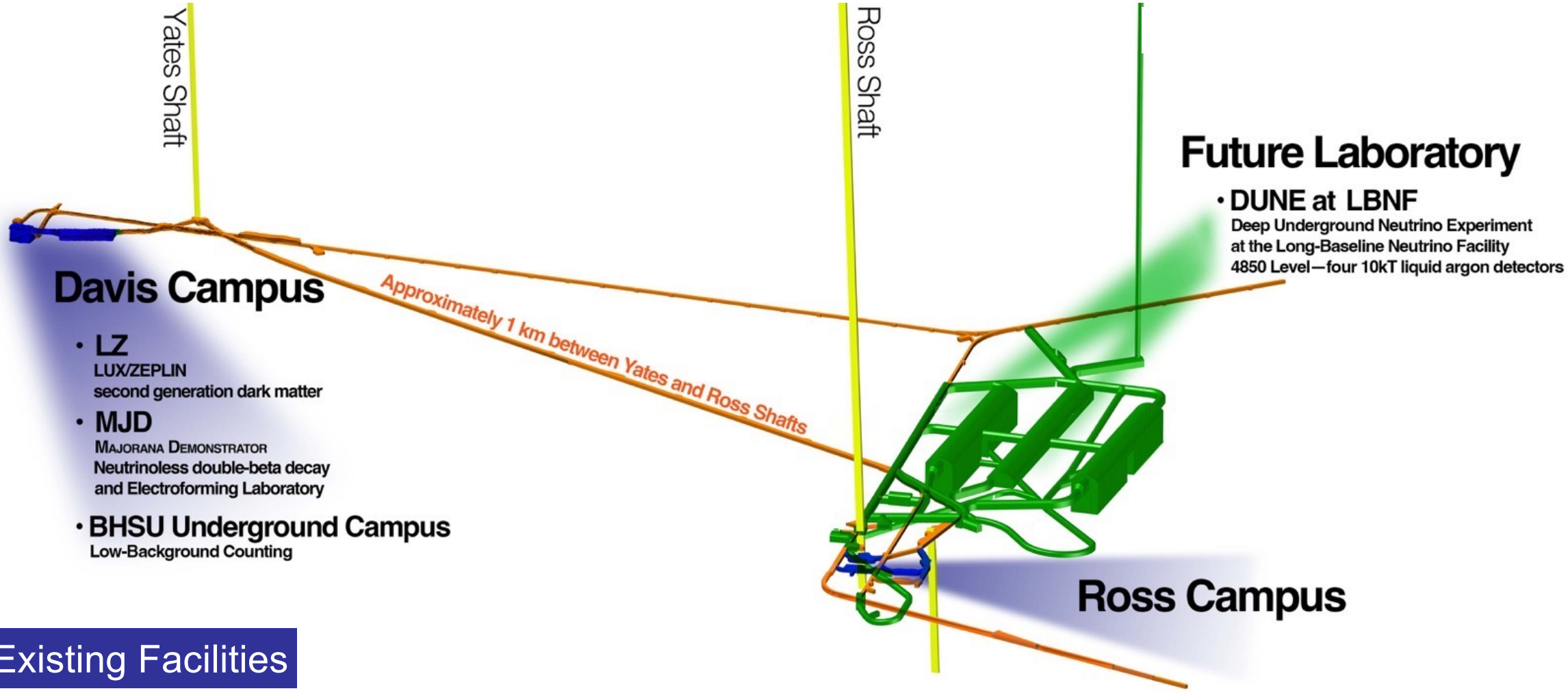
- $6.5M South Dakota commitment
- 26,000 sq.ft. (2415 m^2) total footprint
- Includes warehouse, machine shop, ops/engineering office space
- Dedicated Aug 20, 2021

Sanford Lab Homestake Visitor Center

SDSTA acquired building and land on Jan 7, 2022. Acquisition and ops funded by SDSTA.

Current & Future Underground Facilities

SURF research through 2050 and beyond

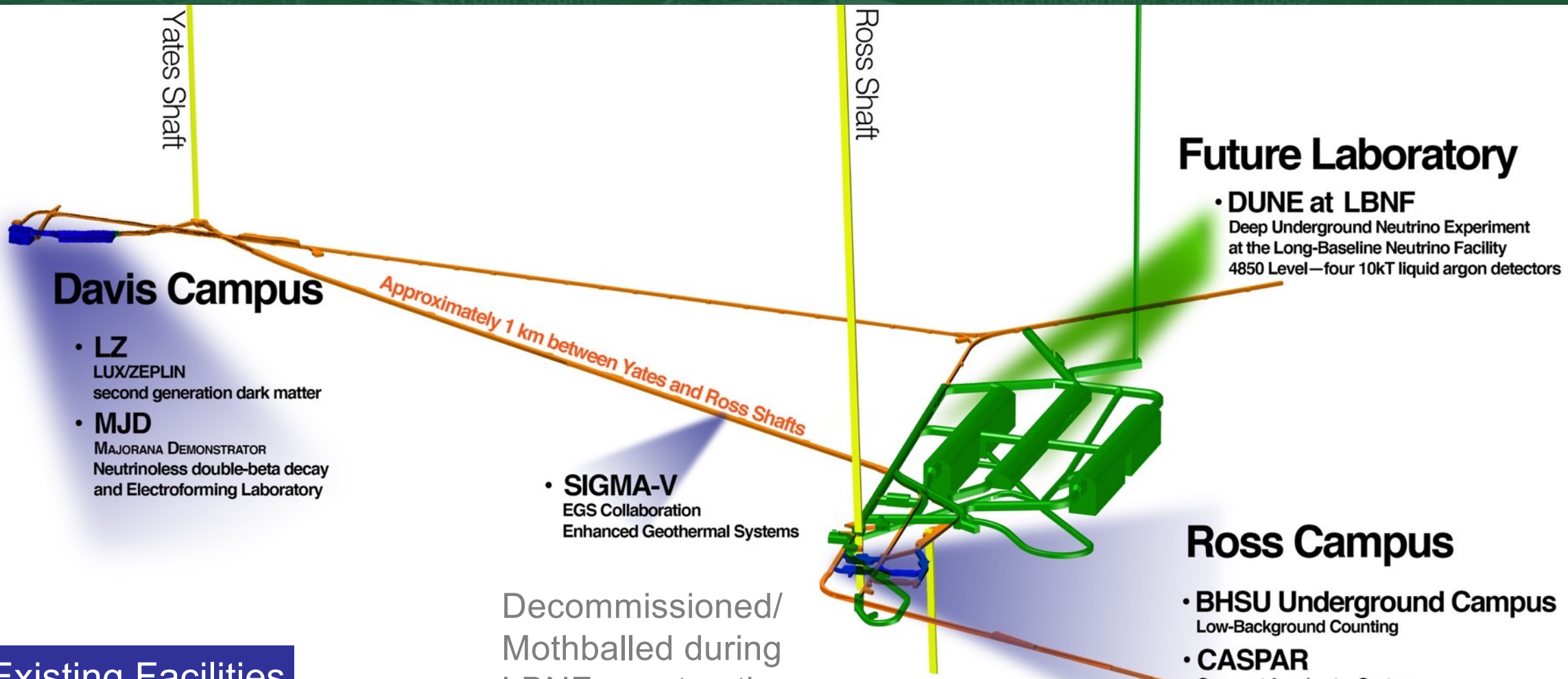


Existing Facilities

Future Facilities

Current & Future Underground Facilities

SURF research through 2050 and beyond



Existing Facilities

Future Facilities

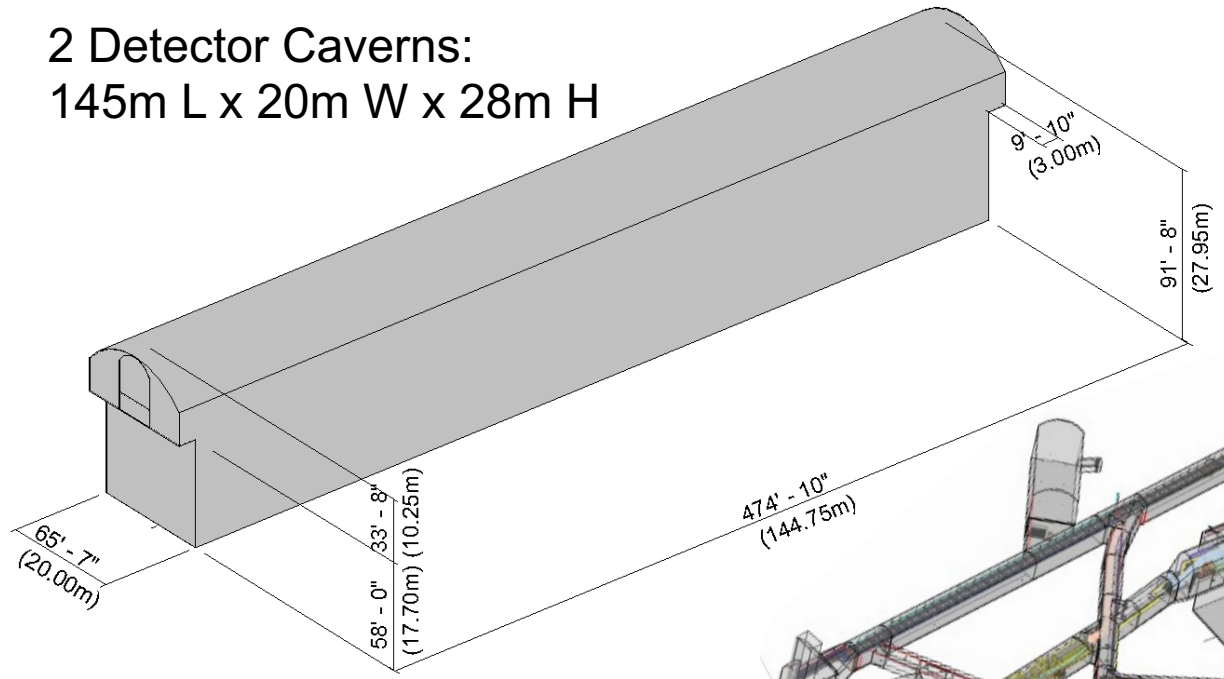
Decommissioned/
Mothballed during
LBNF construction

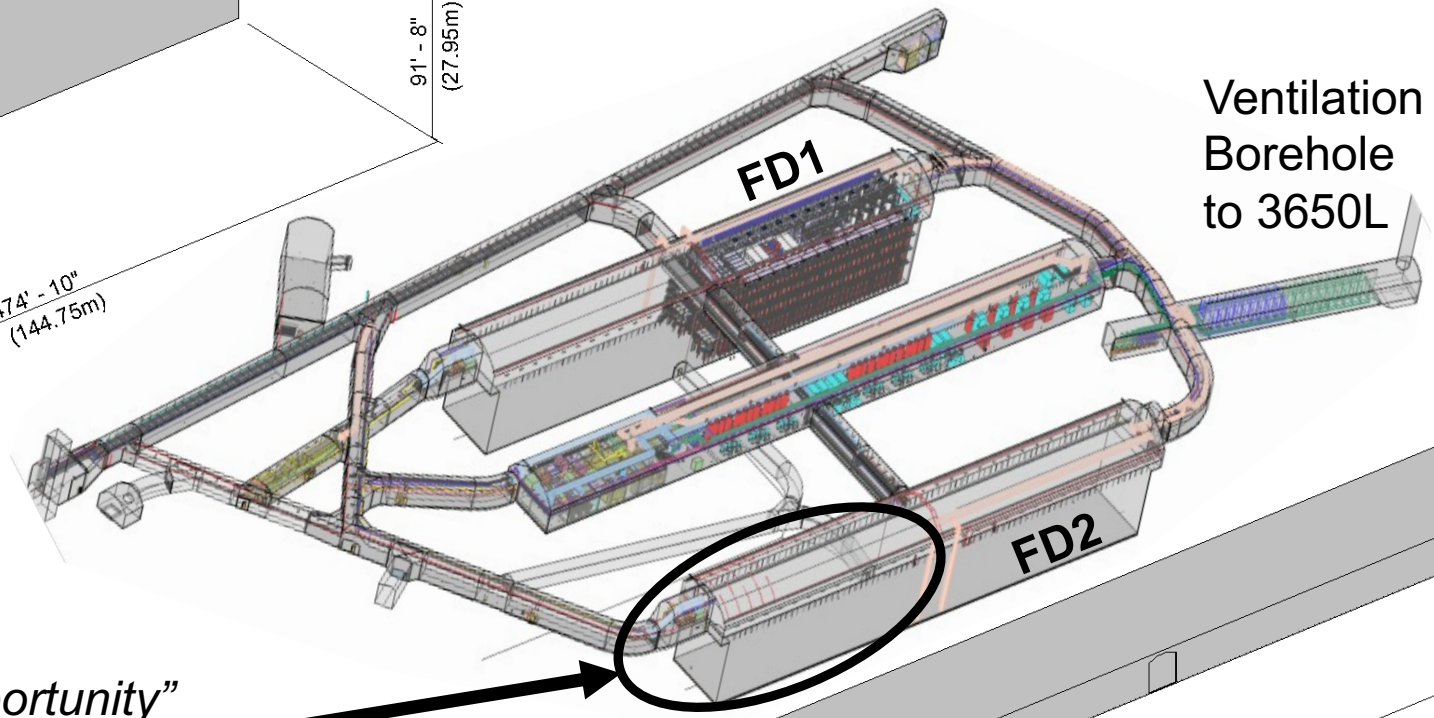
Mothballed during
LBNF construction

Long-Baseline Neutrino Facility (LBNF)

LBNF will host the Deep Underground Neutrino Experiment (DUNE)

2 Detector Caverns:
145m L x 20m W x 28m H



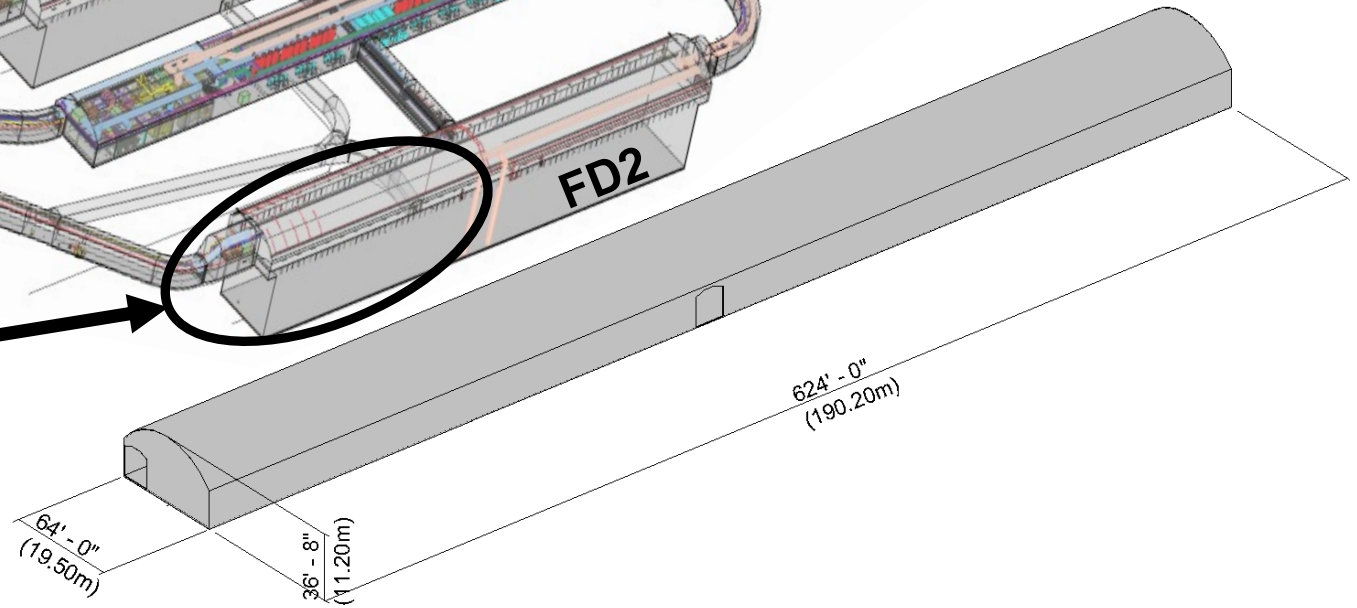


Neutrino Beam

Ventilation Borehole to 3650L

"Module of Opportunity"
(73m L x 20m W x 28m H)

1 Utility Cavern:
190m L x 20m W x 11m H



LBNF Excavation Process

1. Drill Blast Holes

2. Remove Explosive from magazine

3. Charge Face

4. Evacuation

5. Close Blast Doors

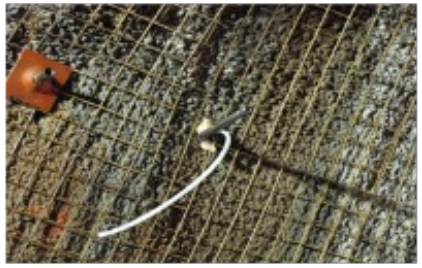
6. Initiate Blast

7. Ventilate

8. Scaling

9. Mucking

10. Geological Mapping



11. Ground Support

Drill and Blast Cycle

Long-Baseline Neutrino Facility (LBNF)

LBNF will host the Deep Underground Neutrino Experiment (DUNE)

Explosive Magazine

Shotcreting in South Cavern for Monorail

Excavation to full section in North Cavern

SURF Radon Reduction System – Surface

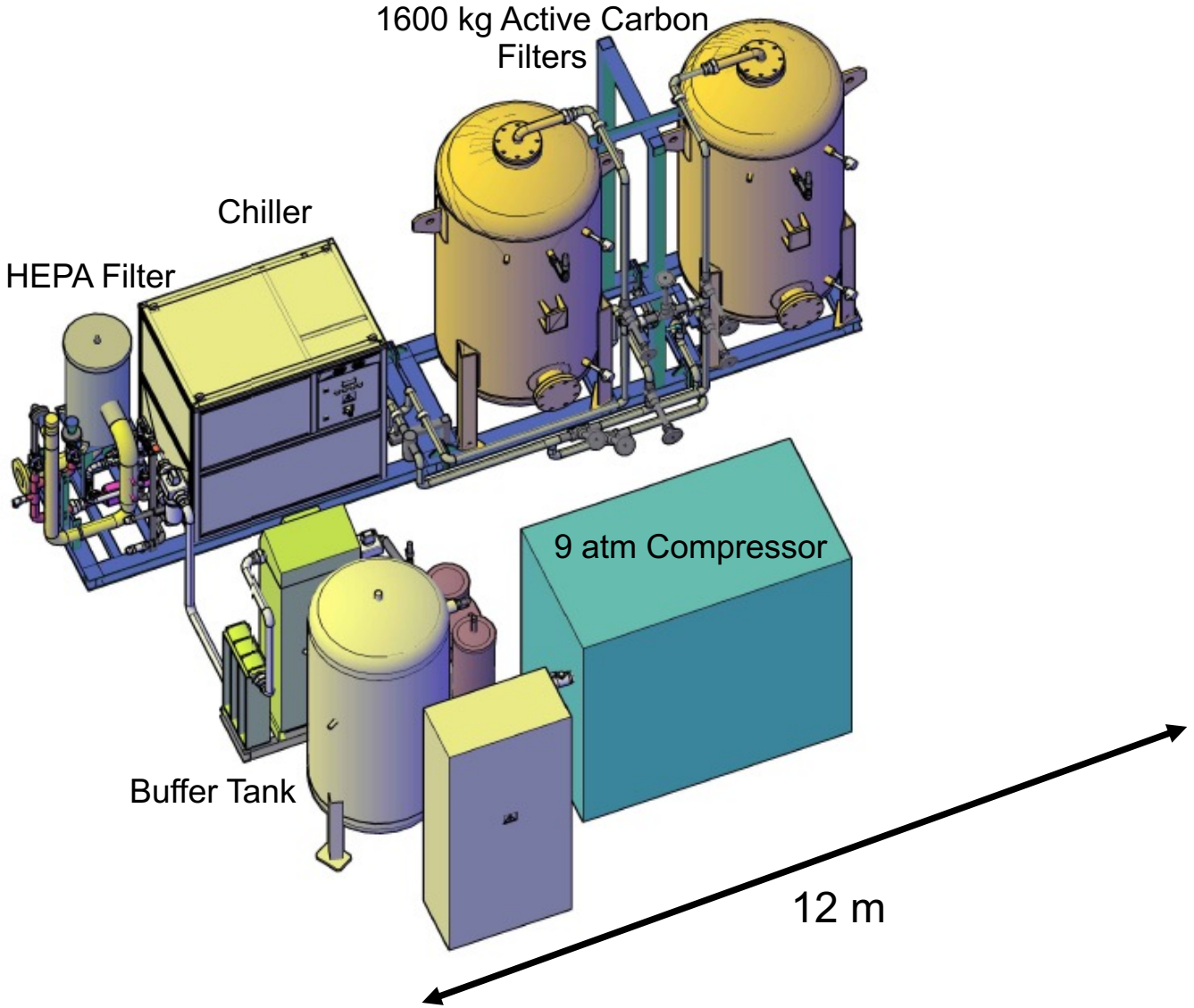
Commercial continuous-cooled Rn mitigation system

- **Specs:** 1000x Rn reduction, 300 m^3/hr
- **Supplier:** Ateko, Czech Republic (same as Y2L, Gran Sasso, etc)
- **Design:** Compress air to 9 bar, cool to -60C dew point, flow air through carbon adsorption columns, reduce pressure, reheat as desired
- **Space:** Dedicated bldg, 74 m^2
- **Status:** Operating, 2200x Rn output reduction

- **Specs:** Design/protocols support Class 100
- **Supplier:** SBB Inc., Syracuse, NY
- **Design:** Metal panels (Al) with careful sealing, balancing differential pressures, special entry ports (air shower, soft-wall for materials, etc)
- **Space:** 54 m^2, 240 m^3
- **Status:** Operating as Class 100, **770x Rn reduction** inside cleanroom

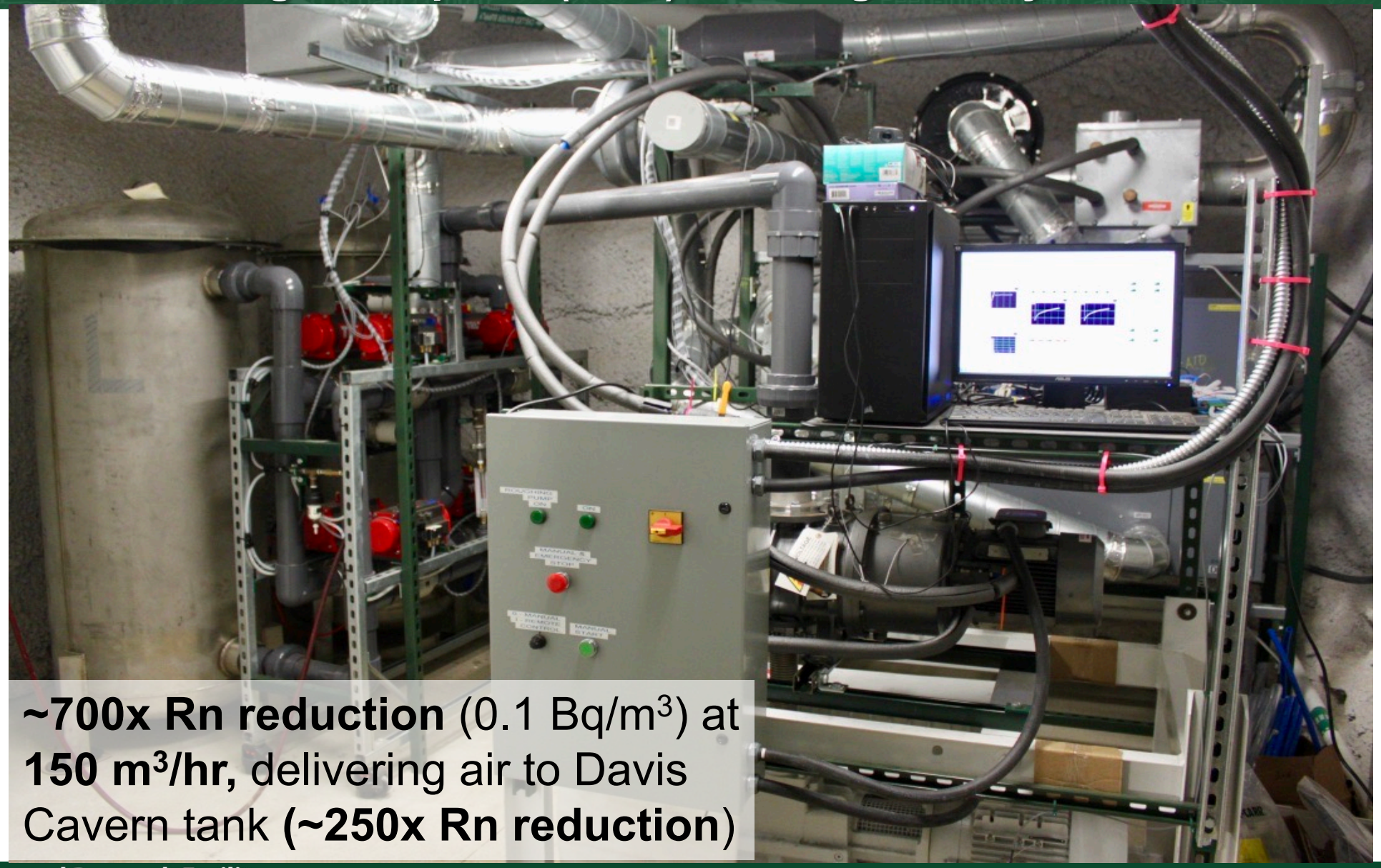
SURF Radon Reduction System – Surface

Commercial continuous-cooled Rn mitigation system



SURF Radon Reduction System – Underground

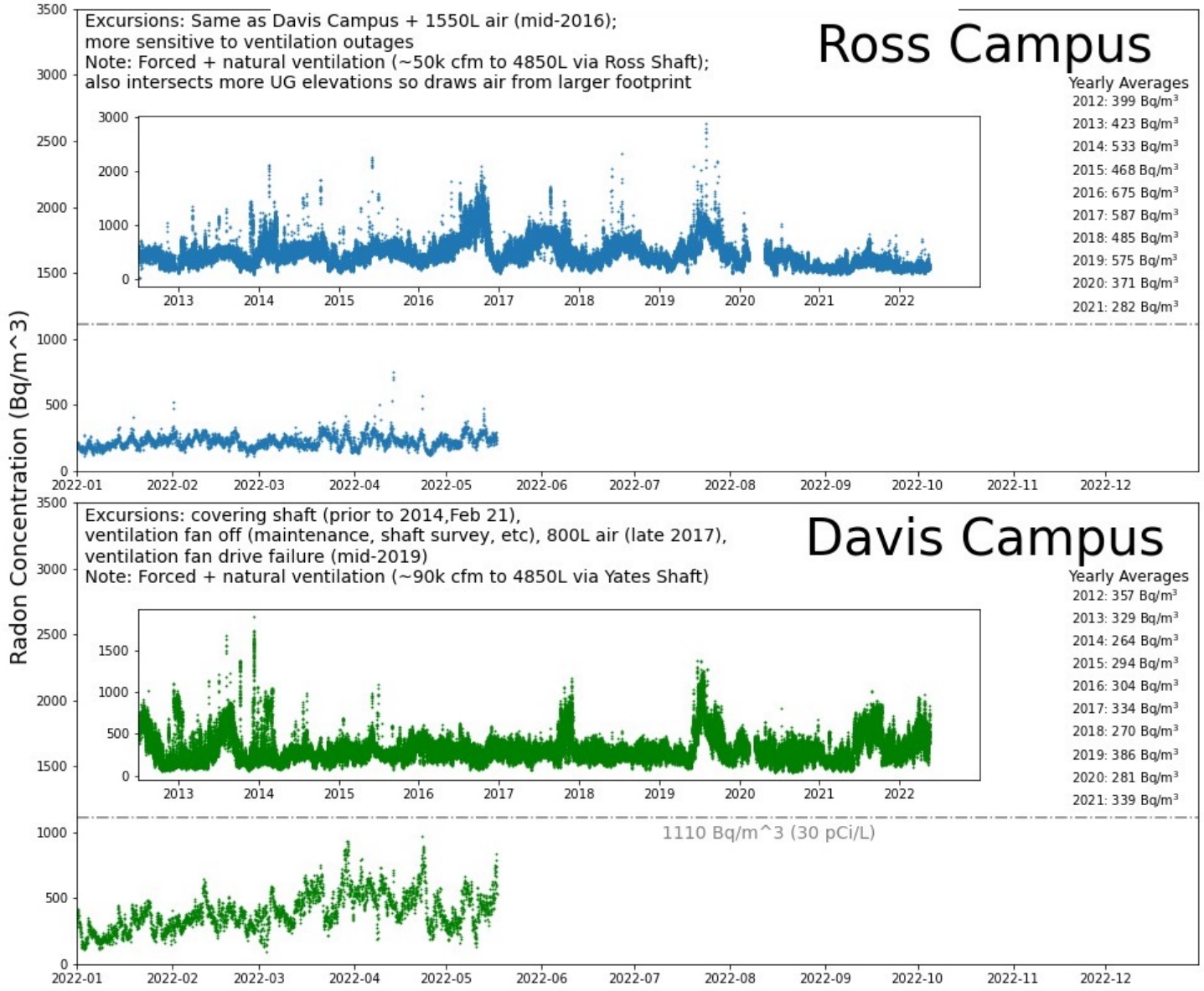
SDSMT vacuum-swing adsorption (VSA) Rn mitigation system



~700x Rn reduction (0.1 Bq/m^3) at **150 m^3/hr,** delivering air to Davis Cavern tank **(~250x Rn reduction**)

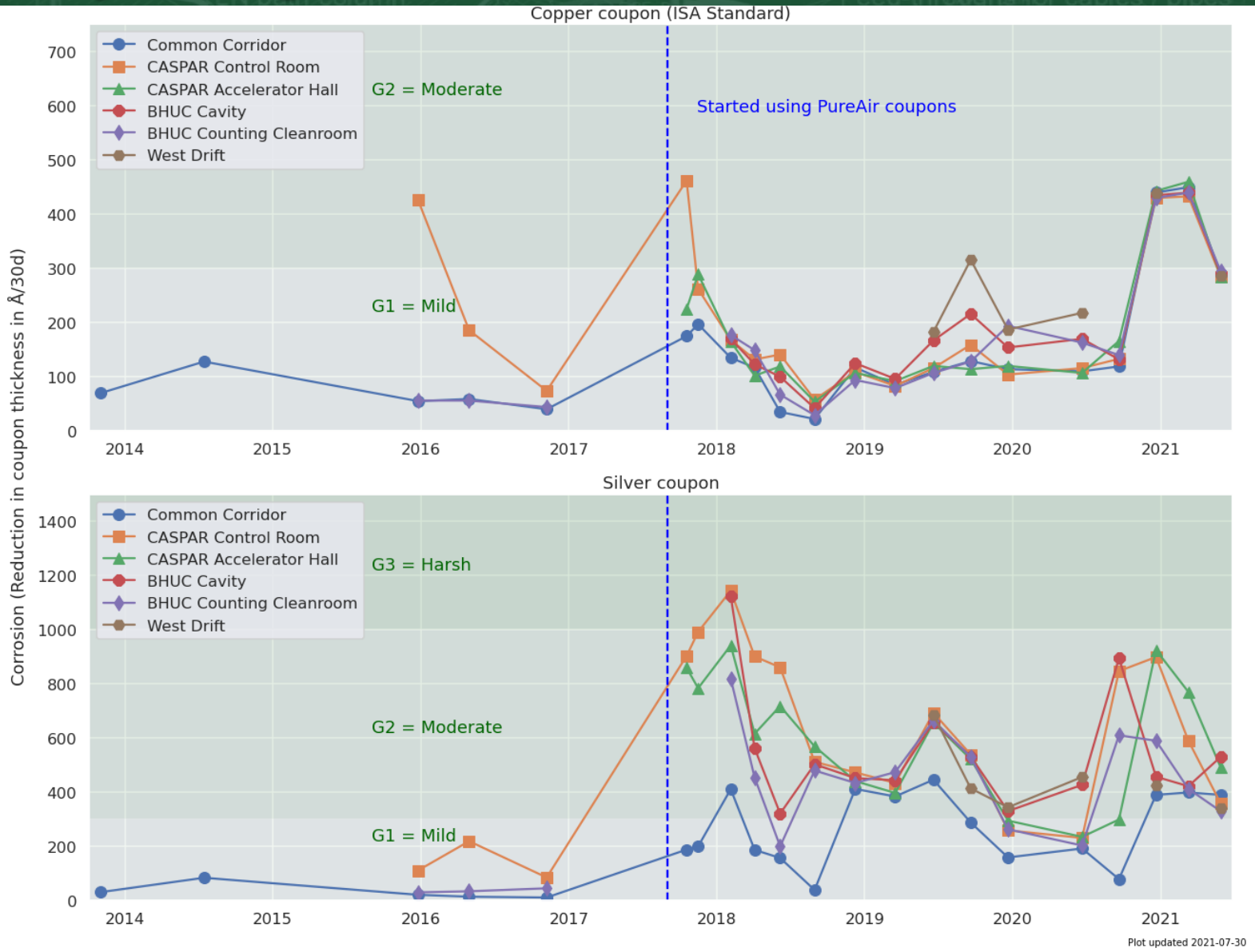
SURF Science Support – Monitoring

Radon concentrations in 4850L laboratories since 2012



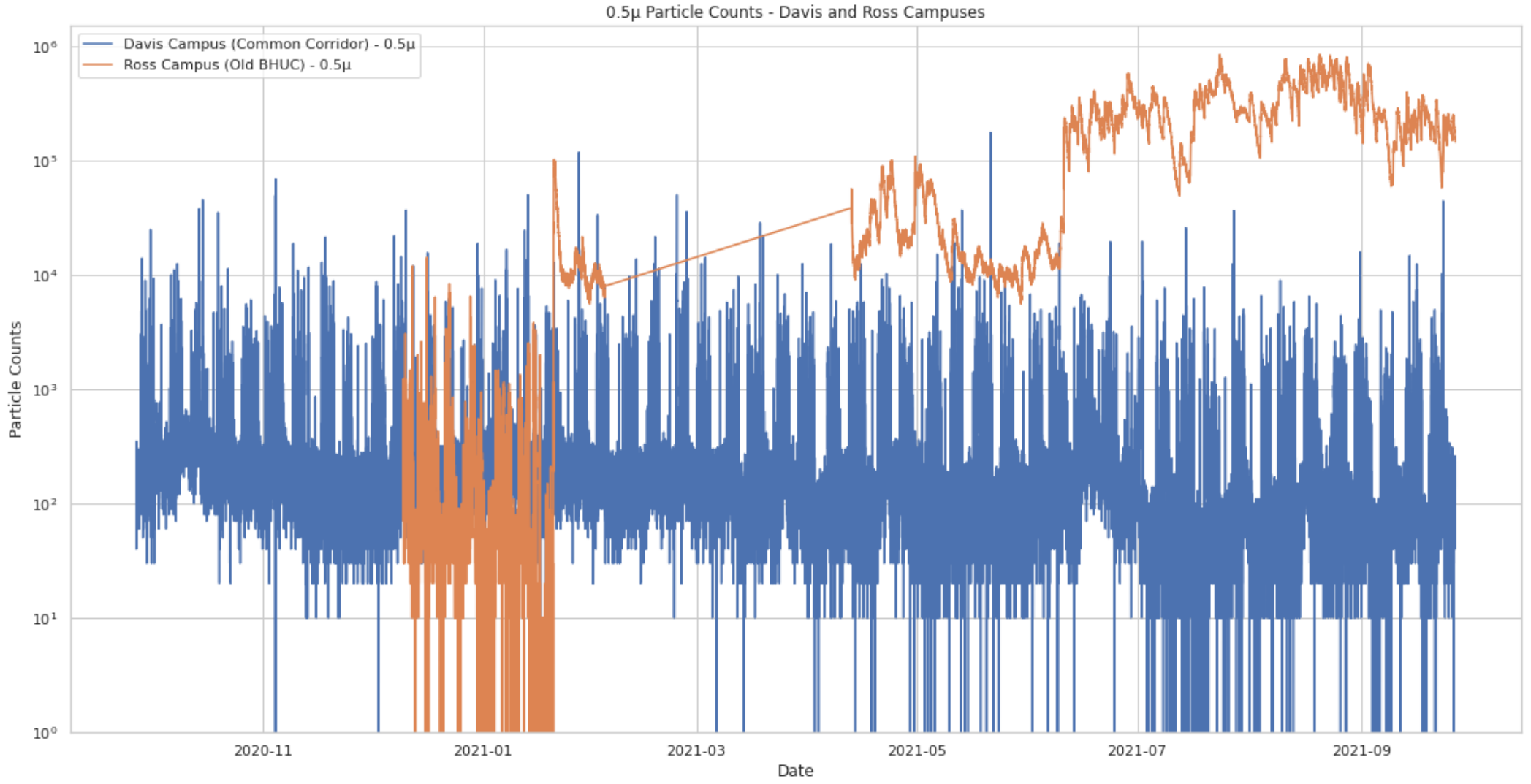
SURF Science Support – Monitoring

Corrosion/reactivity testing in 4850L laboratories since 2013



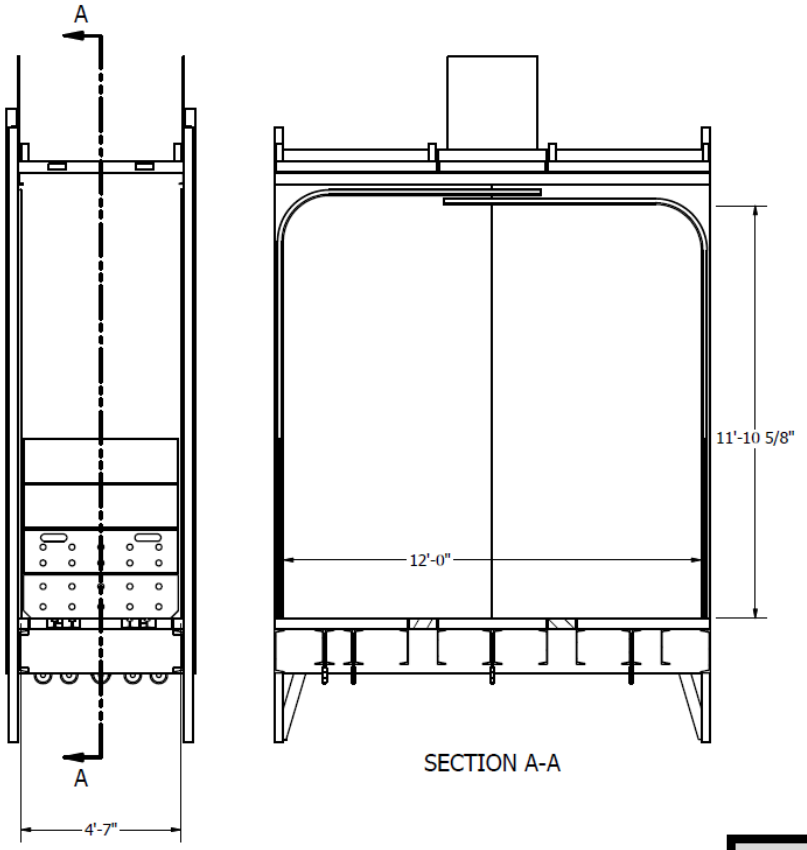
SURF Science Support – Monitoring

Particle counts in 4850L laboratories since 2013 (past year indicated)



SURF Cage Conveyances

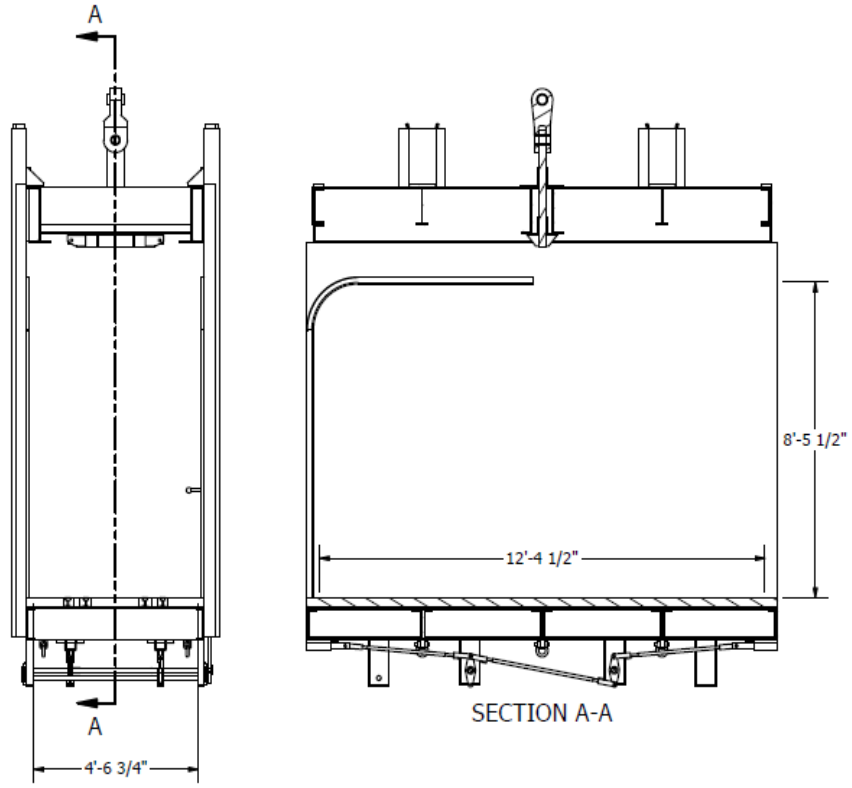
Cargo Load Limits



Ross Cage Load Limit Dimensions

Limits for Cage Loads

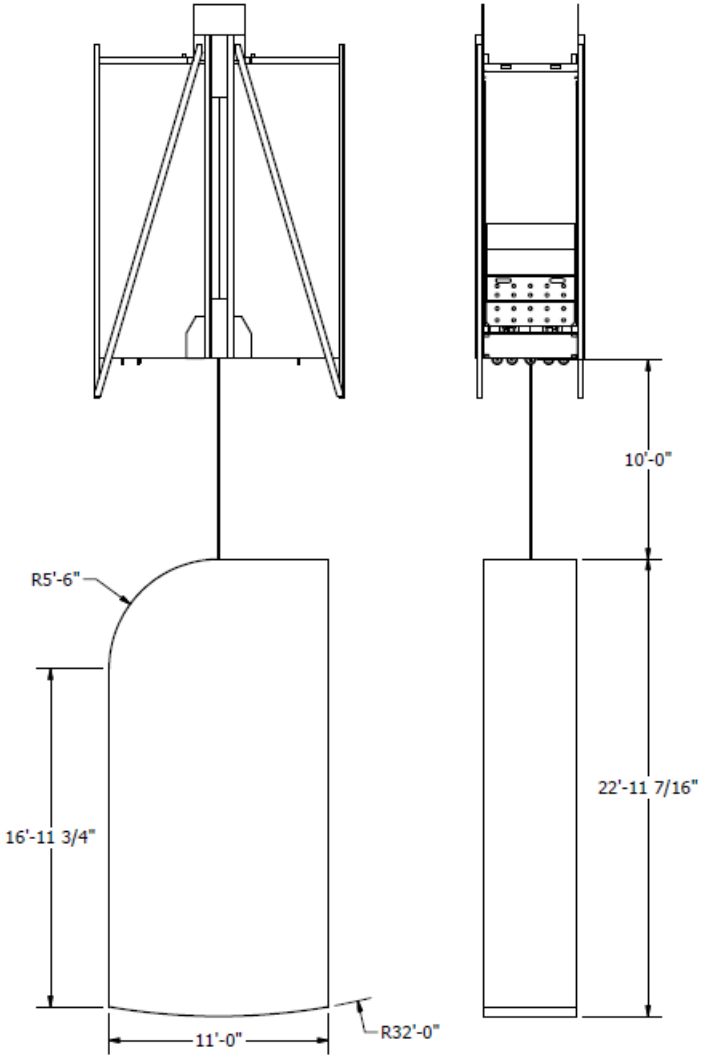
	Weight	Maximum Dimensions Length	Height	Width
Ross	13,500 lbs (6,123 kg)	12'-0" (3.66m)	11'-10 5/8" (3.62m)	4'-7" (1.4m)
Yates	10,600 lbs (4,808 kg)	12'-4 1/2" (3.77m)	8'-5 1/2" (2.58m)	4'-6 3/4" (1.39m)



Yates Cage Load Limit Dimensions

SURF Cage Conveyances

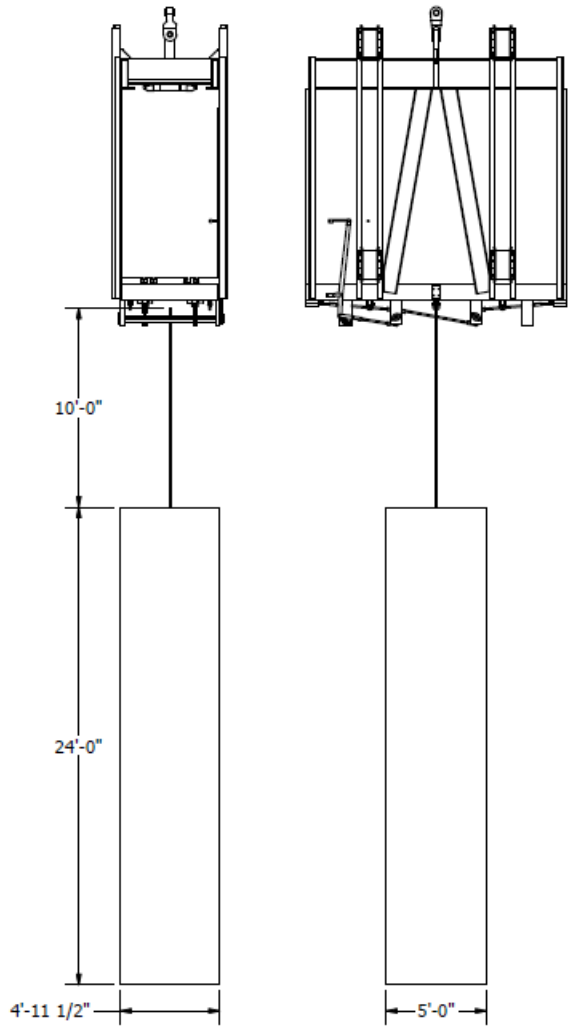
Slung Load Limits



Ross Cage Slung Load Dimension Limits

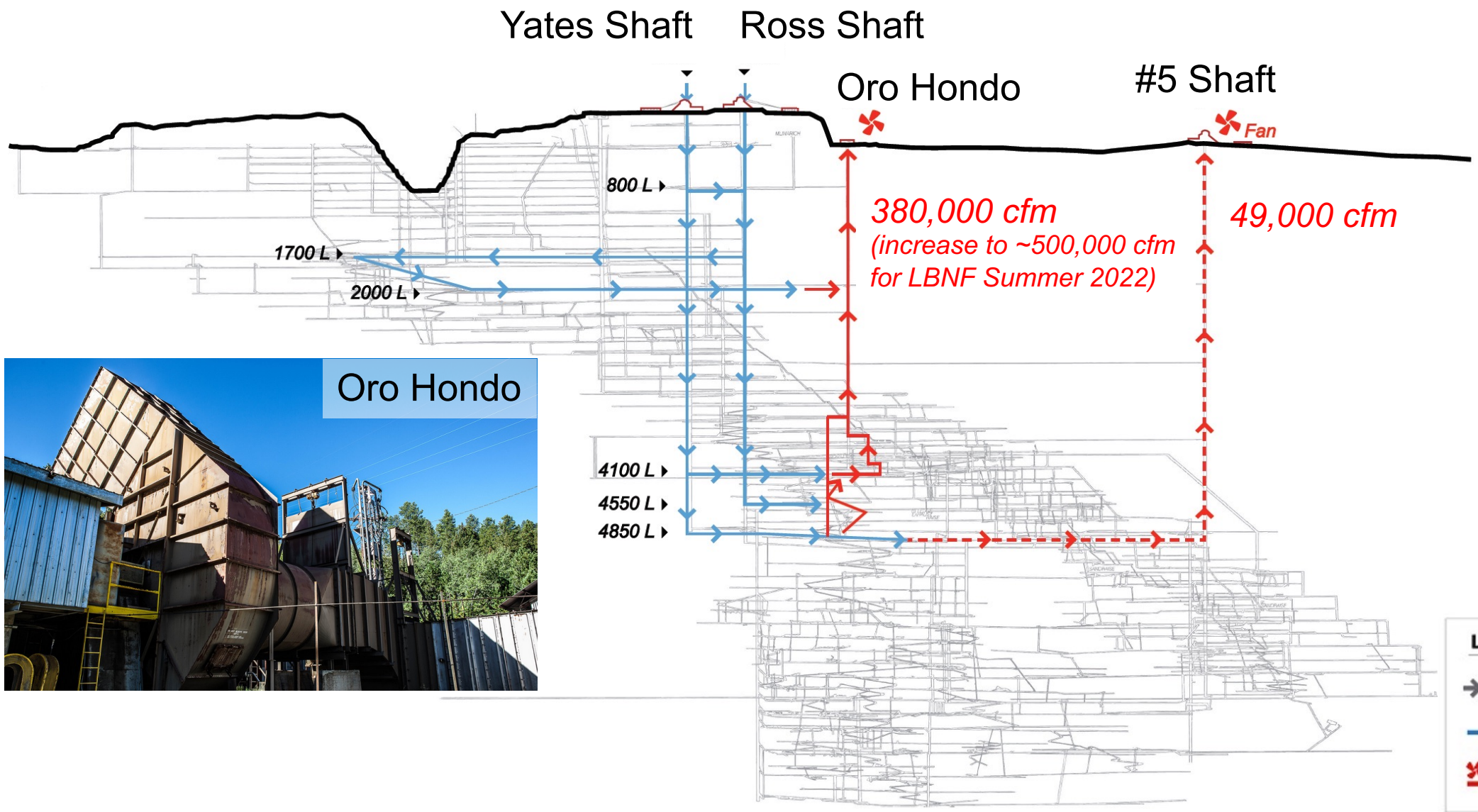
Limits for Slung Loads

	Weight	Maximum Dimensions		
		Length	Height	Width
Ross	13,500 lbs (6,123 kg)	11'-0" (3.35m)	22'-11 7/16" (7.0m)	4'-8" (1.42m)
Yates	10,000 lbs (4,536 kg)	5'-0" (1.52m)	24'-0" (7.32m)	4'-11 1/2" (1.51m)



Yates Cage Slung Load Dimension Limits

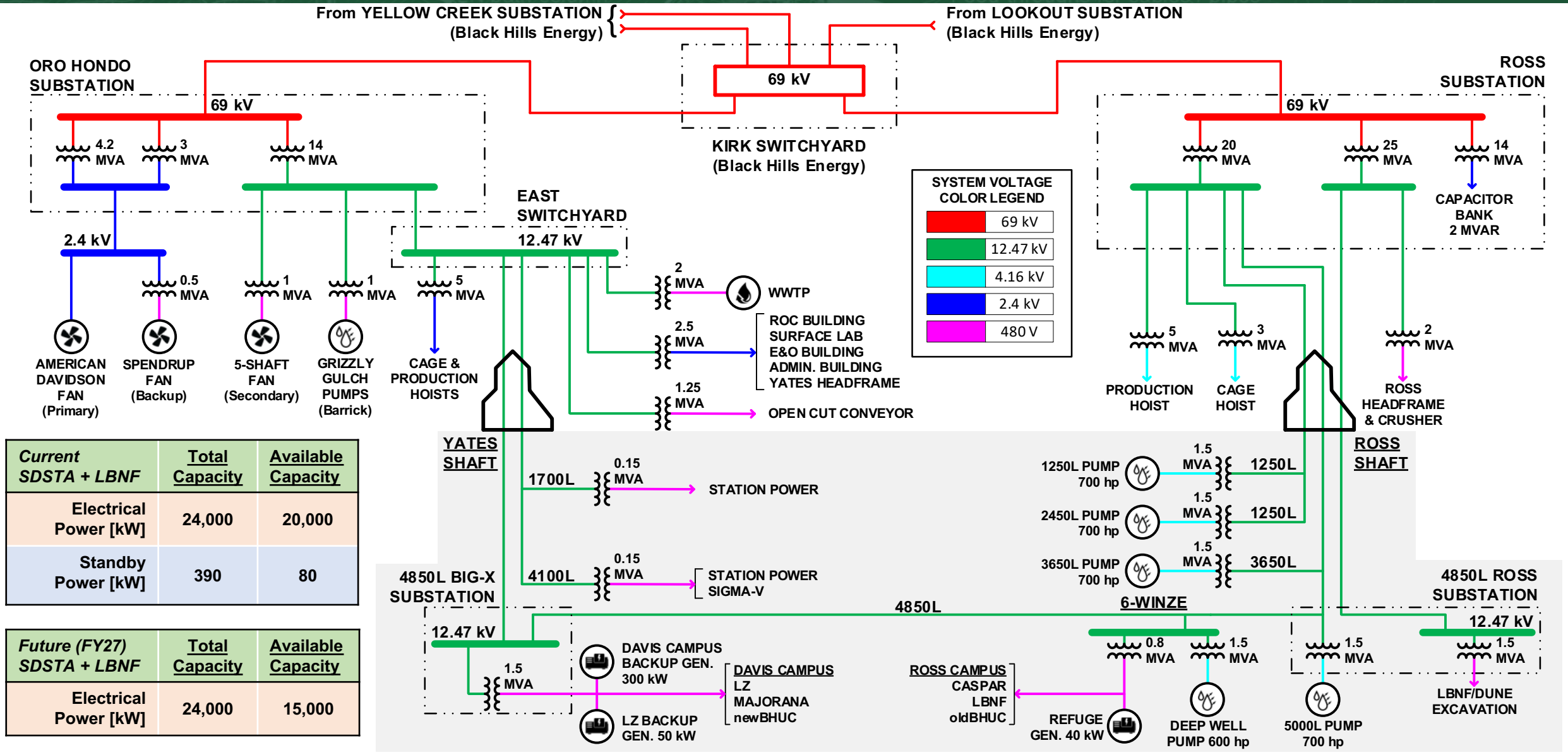
SURF Facility Ventilation



LEGEND

- VENTILATION FLOW DIRECTION
- INTAKE AIR
- EXHAUST AIR

SURF Electrical and Standby Power



Current SDSTA + LBNF	Total Capacity	Available Capacity
Electrical Power [kW]	24,000	20,000
Standby Power [kW]	390	80

Future (FY27) SDSTA + LBNF	Total Capacity	Available Capacity
Electrical Power [kW]	24,000	15,000

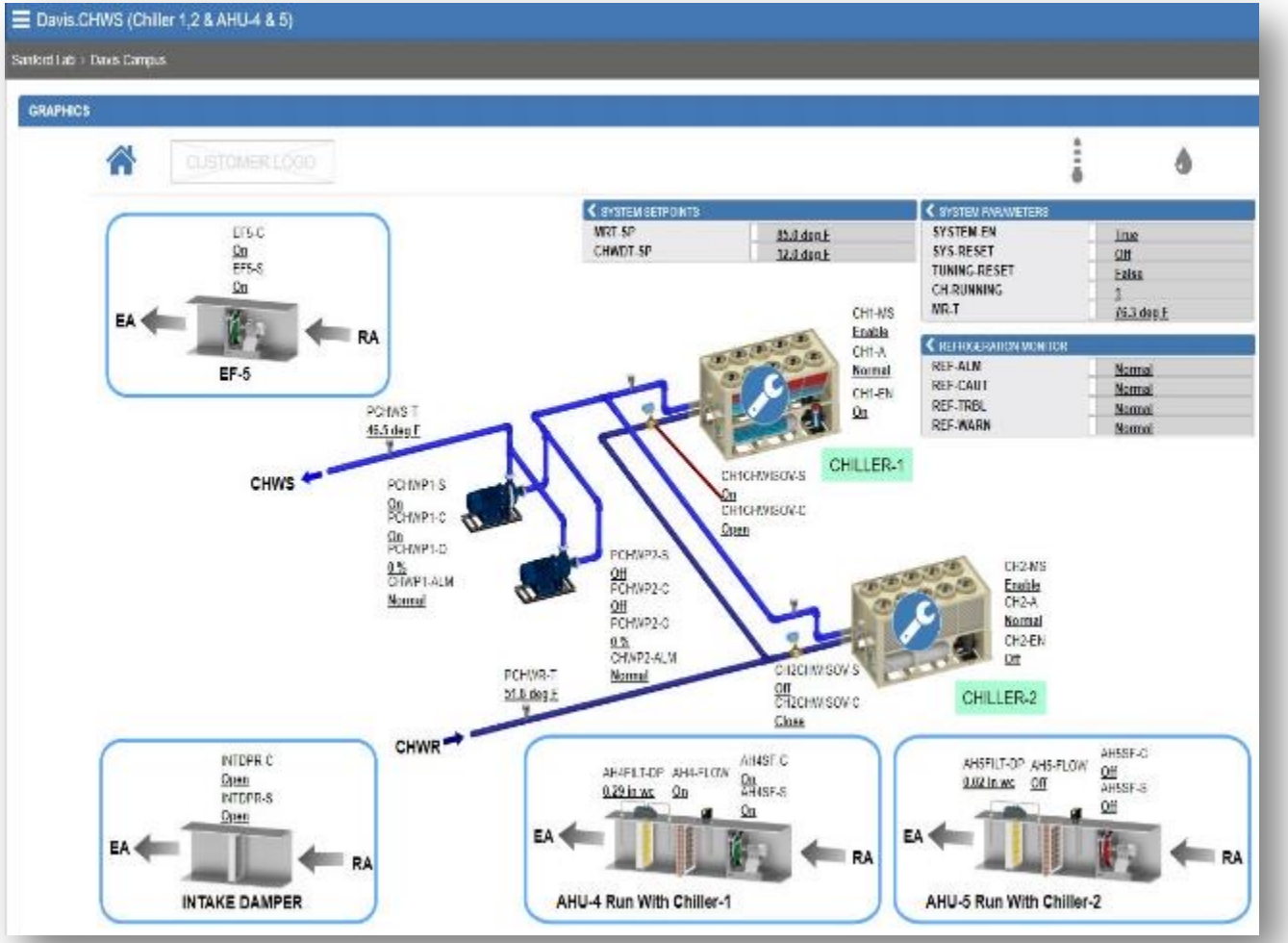
Industrial Water and Compressed Air

- Ross Complex (Surface)
  - Industrial/Non-Potable water from surface to 4850L, 400 GPM capacity, 75% available capacity.
  - Compressed air, 100 psi from surface to 4850L: Primary compressors – 1000 SCFM, 50% available capacity; Backup compressor – 740 SCFM.
- Yates Complex (Surface)
  - Industrial/Non-Potable water from surface to 4850L, 400 GPM capacity, 75% available capacity.
  - Compressed air from surface to 4850L, 100 psi: 528 SCFM, 25% available capacity.
- 4850L – Davis Campus (Underground)
  - Standalone compressed air system, 100 psi, 100 CFM, 50% available capacity.

Underground Chilled-Water System
Davis Campus

- System Configuration
  - Two redundant refrigerant-to-water chillers (246 kW each)
  - Two redundant water circulation pumps
  - Fully integrated, remotely controllable & monitorable control system
- Current Total Online Capacity = 246 kW
- Current Allocated Capacity = ~176 kW
  - Davis Campus Infrastructure: Heating ventilation air conditioning (HVAC) systems
  - MAJORANA DEMONSTRATOR
  - LZ: Cryocooler (x2), Xenon circulation compressor (x2)
- Current Available Capacity = ~70 kW

Additional cooling capacity available through use of industrial water



SURF Water Purification Systems

Surface

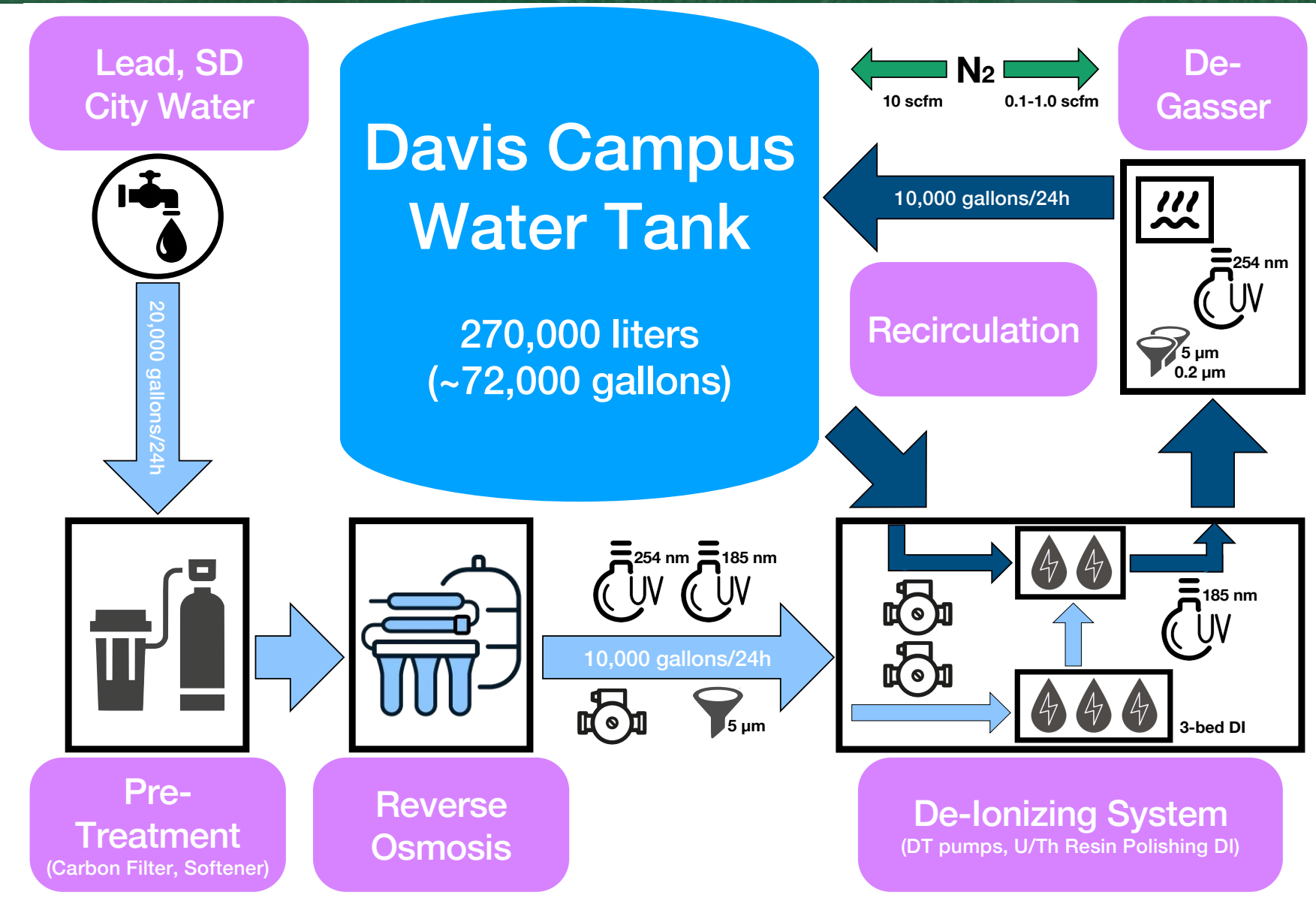
- Located In Surface Assembly Laboratory
- Provides Purified Water To Reduced Radon Cleanroom
- Configuration
  - Reverse Osmosis Water Purification System
  - De-Ionized Water Purification System

Underground

- Located Adjacent To Davis Cavern
- Provides Purified Water To Davis Cavern
- Configuration
  - Reverse Osmosis Water Purification System
  - De-ionized Water Purification System
- Capacity
  - Production Mode – 31 Liters Per Minute
  - Circulation Mode – 38 Liters Per Minute

SURF Water Purification System

Davis Campus



SURF Laboratory Design

Element	4850L Laboratory		
	Davis Campus	Ross Campus	LBNF
Development	Existing cavern, drifts + new excavation	Existing caverns, drifts	New excavation
Rock Characteristics	Amphibolite + rhyolite, drill core, GSI 70	Poorman + Homestake	Poorman schist, drill core, GSI 85, avoid rhyolite dike shear zone
Coatings Floor	Urethane, some low-activity concrete, single pour for MJD lab	Latex, macropoxy in BHUC, existing concrete + new pad for BHUC	Standard concrete
Walls	Some low-activity shotcrete, some trowel finish, mainly latex paint, Minova Tekflex in water purification	Standard shotcrete, standard finish, macropoxy in BHUC	
Chiller System	Redundant 246-kW, water to air heat rejection (closed loop)	Single 40-ton, water heat rejection	
Backup Systems	300 kW diesel generator for fire/life safety, 50 kW for LZ Xe recovery. Battery backup lighting, UPS for network incl phones	Battery backup lighting, UPS for network incl phones	
Alarm System	Heat/smoke, low-O2, wet fire suppression, low airflow	Smoke/some heat, low-O2, dry (pre-action) fire suppression	

SURF Laboratory Design
4850L Davis Campus

- **Key Design Requirements**
  - Environmental Conditioning: 21C, 50% RH
    - Working in clean room garb resulted lowering the temperature, leading to higher relative humidity and HV breakdown, corrosion concerns – this illustrates the importance of challenging requirements.
  - Chilling System: Air cooled chilled water system (closed loop)
  - Cleanliness:
    - AHU1: Nominal Class 1000 (5,250 cfm, ~150 air changes per hour)
    - AHU2: Nominal Class 10,000 (8,590 cfm, ~6 air changes per hour)
    - AHU3: Nominal Class 2000 (7,250 cfm, ~18 air changes per hour)
  - Power: 1500 kVA, backup for life safety, incl comm, AHUs, exhaust fans, egress lighting
- **Ground Support**
  - 1” dia. x 10’ long resin-grouted threaded rebar
  - Standard- and low-activity aggregate shotcrete (7.5 cm thick)
- **Monitoring**
  - Single- and multi-point extensometers for ground movement
  - Life safety: smoke/heat/low O2, also CO
  - Radon, particle counts
- **Special Considerations**
  - Shielding: 6-m high x 8-m diameter water shielding tank (72,000 gallons), iron plates below
  - Water purification system (commercial RO/ultra-filtration)
  - Internal detector stand
  - Material transport from shaft station to lab (air bearings), via decline/stairs (electric dolly)

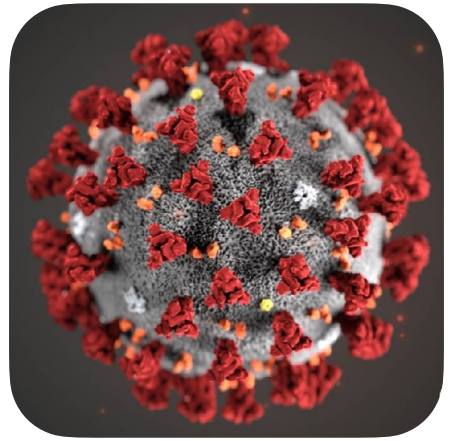
SURF Laboratory Design
4850L Ross Campus

- **Key Design Requirements**
  - Environmental Conditioning: 20–25C, 20–50% RH
  - Chilling System: water heat rejection (~40 gpm, not closed loop)
  - Cleanliness:
    - BHUC Counting Cleanroom: Nominal Class 1000 (2,400 cfm, ~30 air changes per hour)
    - BHUC Multi-Use Cleanroom: Nominal Class 10,000 (600 cfm, ~23 air changes per hour)
    - CASPAR: No cleanliness class (1000 cfm, ~1.3 air changes per hour)
  - Power: 300 kVA (CASPAR+BHUC), E-Forming = 75 kVA (not incl filter fan), emergency = egress lighting (no generator for AHUs, etc)
- **Ground Support**
  - 6’ - 8’ long resin-grouted threaded rebar, 12’ long cement-grouted cable bolts
  - Standard-activity aggregate shotcrete
- **Monitoring**
  - Life safety: smoke/heat/low O2, also CO
  - Radon, particle counts
  - Radiation (gamma, neutron)
- **Special Considerations**
  - Reduce radon emanation from rock walls using special coatings, macropoxy/TSL’s
  - Radiation shielding from CASPAR accelerator (doors, utility mazes)

SURF COVID-19 Response

Effective measures limiting COVID spread at SURF

- **Protocols**
  - SURF COVID-19 response and control requirements documented (currently version 11)
- **Initial**
  - Brief period of minimal essential operations:
    - Three levels of reduced operation established based on staffing in key areas and PPE supplies
    - Mar 25 – May 6, 2021: Access limited, critical monitoring/maintenance, consumable supplies (e.g., LN) still supported; some surface activities resumed in April
  - Monitored data in 100-mile region, scrutiny on travel
  - Controls developed based on CDC, OSHA:
    - Masks required in buildings/labs, respirators required on conveyances
    - Reduced #s on conveyances & meeting rooms, telework encouraged
    - Wellness checks at site entrances
  - Significant collaboration institutional travel restrictions
  - Large in-person events canceled or virtualized (e.g., Neutrino Day 2020 & 2021)

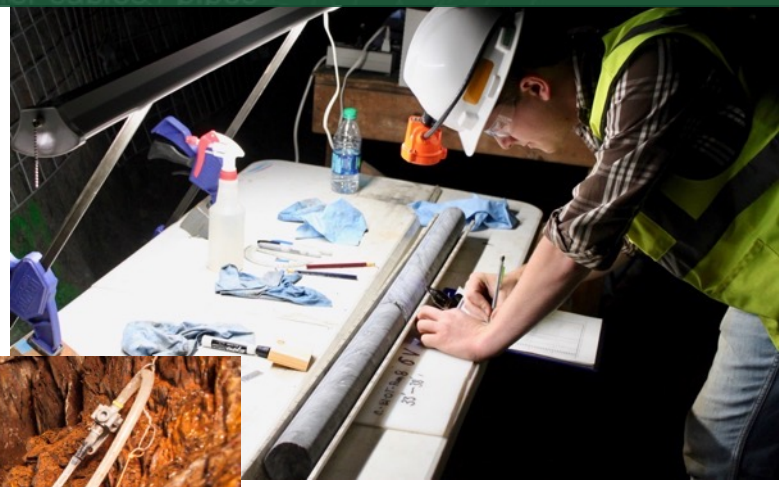


- **Current**
  - Masks and distancing per CDC based on county Community Levels (cases, hospitalizations).
  - As of Jul 14, 2022, masks and distancing required in all enclosed spaces occupied by multiple people, incl cages and laboratories.

Underground Facilities

UG Facilities serve a diverse community:

- Physics
  - Low-background environment to study rare processes
- Biology
  - Isolation from surface microorganisms
  - Variety of environmental conditions (temperature, humidity, etc)
  - Variety of niches (materials/rock geochemistry, water from different locations, trace gases, etc)
- Geology
  - Variety of geologic environments / rock formations (permeability, porosity, chemistry); also drill core archive
- Engineering
  - Real-world environments for technology development, mining, etc

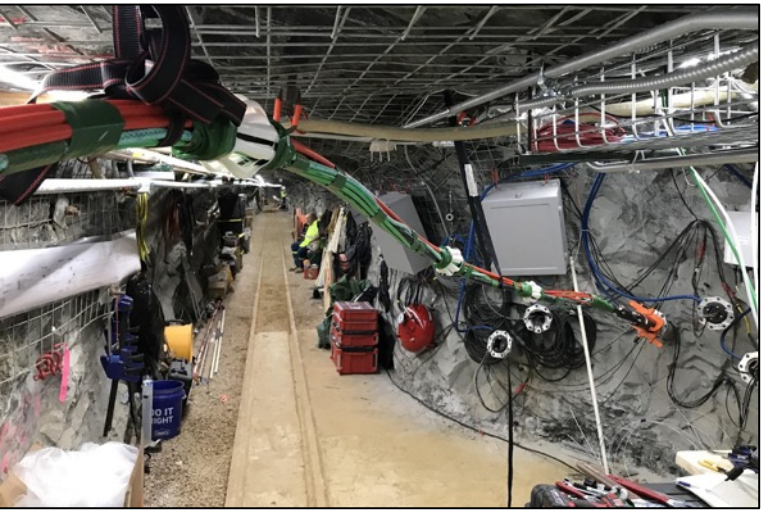


SURF Science Program

Biology / Geology / Engineering (Multiple Levels)

Life Science:

- Explorations into the diversity and extent of life, practical applications such as biofuels. Testing equipment for future Mars mission.
- **Status:** 800L, 1700L, 2000L, 4100L, 4850L.



Earth Science:

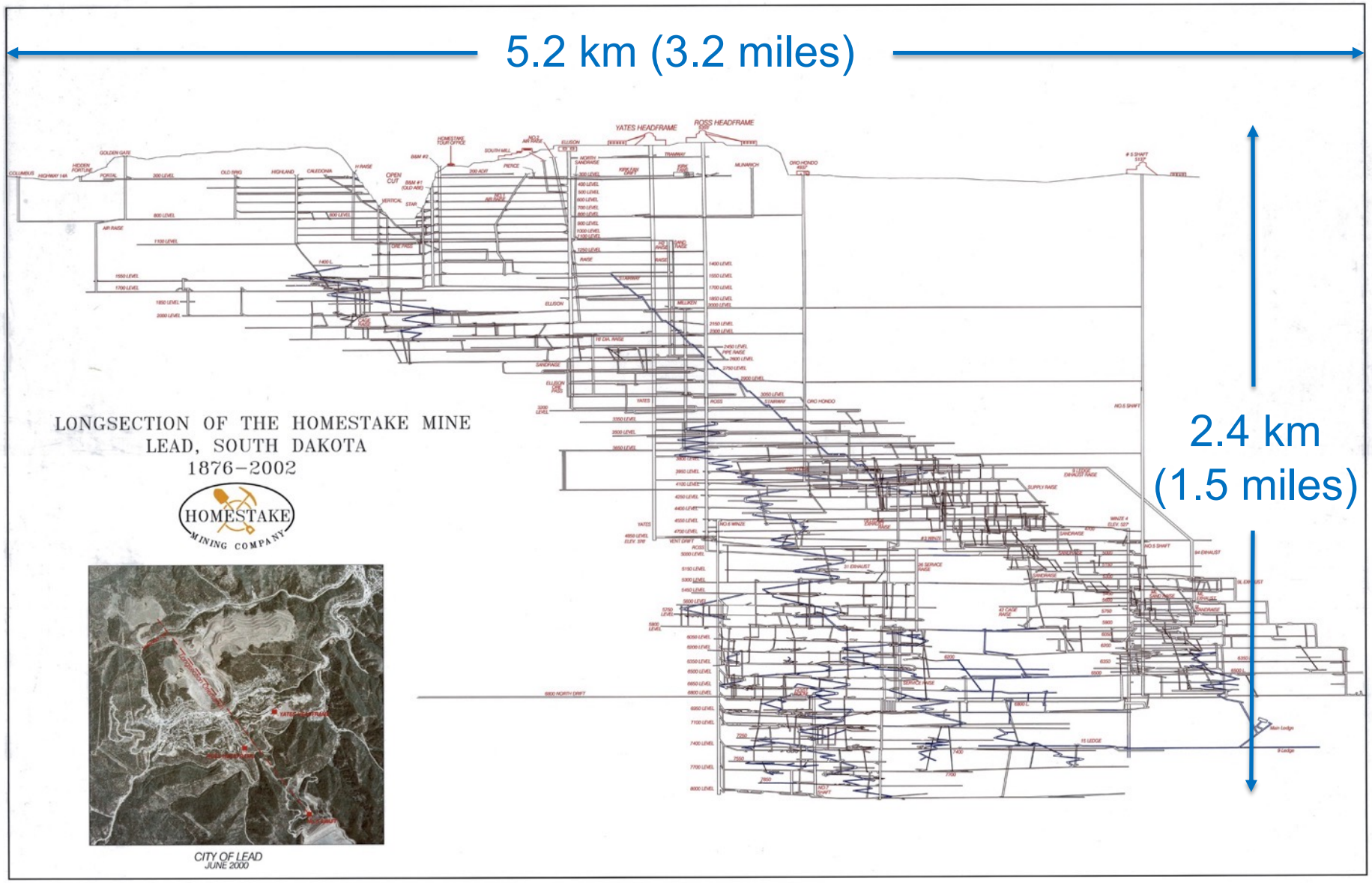
- Topics include seismic studies, UG monitoring, geothermal testing, mineral deposit studies
- **Status:** Surface, 800L, 1700L, 2000L, 4100L, 4850L.

Engineering:

- Topics include soft error rate chip testing, thermal applications, UG hazard monitoring, reinforced shotcrete, technology R&D
- **Status:** Surface, 1700L, 4100L, 4850L.

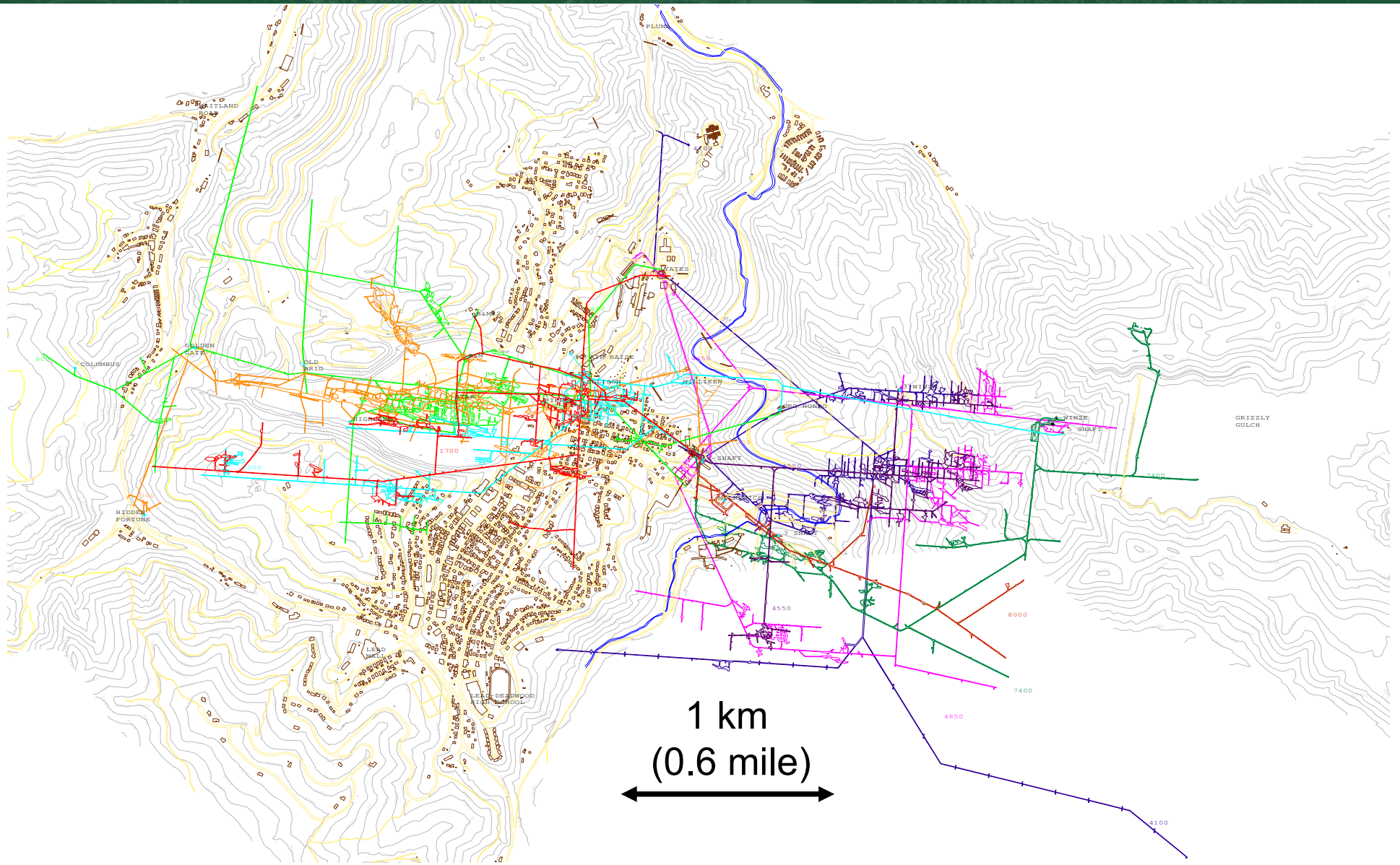
SURF Underground Lab Geography

Significant underground science footprint



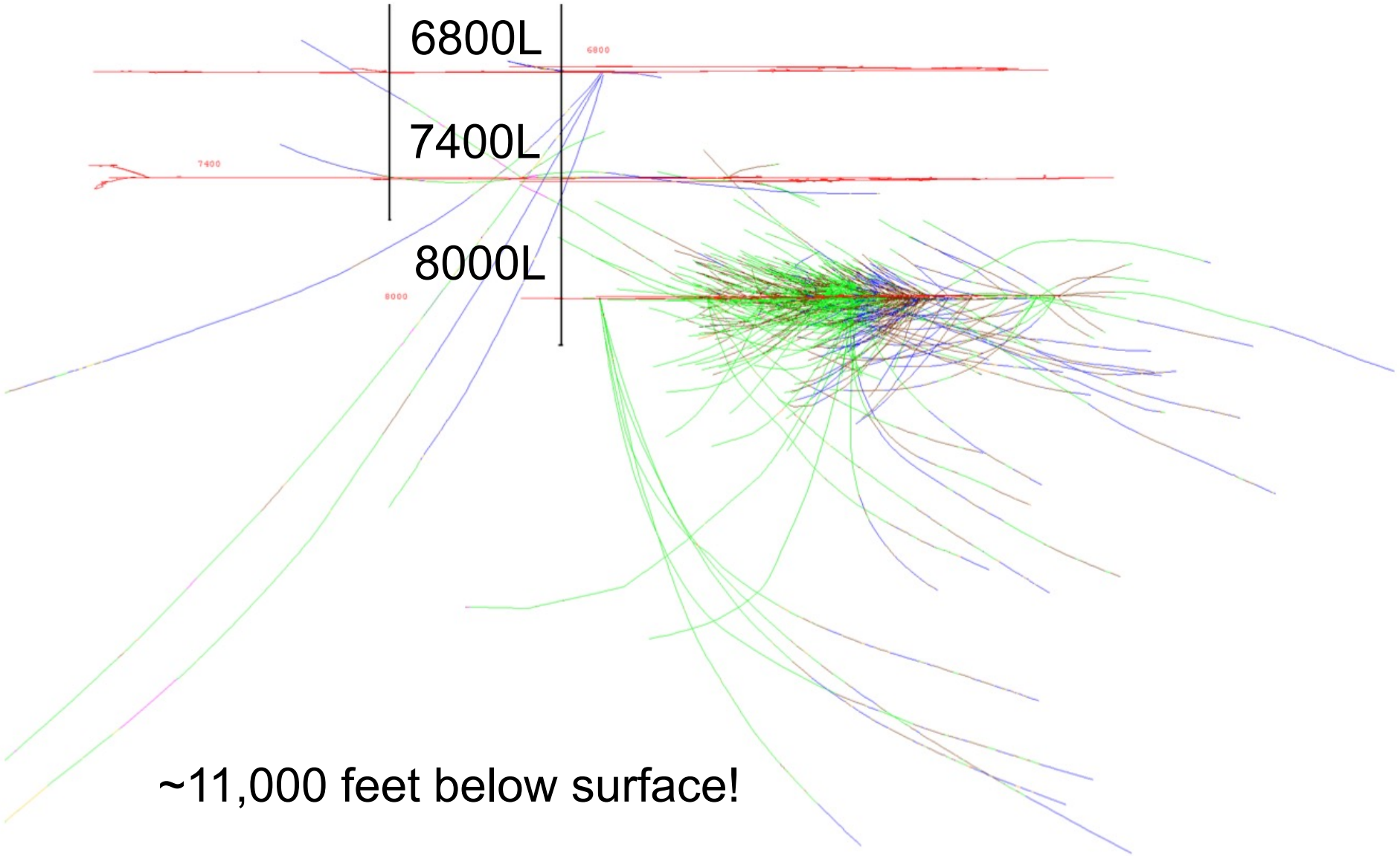
SURF Underground Lab Geography

Significant underground science footprint



SURF Underground Lab Geography

Future Possibilities to Access Existing Deep Holes?



~11,000 feet below surface!

Sanford Underground Research Facility

SURF Mission:

We advance world class science and inspire learning across generations.

SURF Vision:

The world's preferred location for underground science and education.

SURF serves the **entire underground science community**

SURF welcomes and encourages research from all disciplines that are able to take advantage of the unique attributes of our laboratory