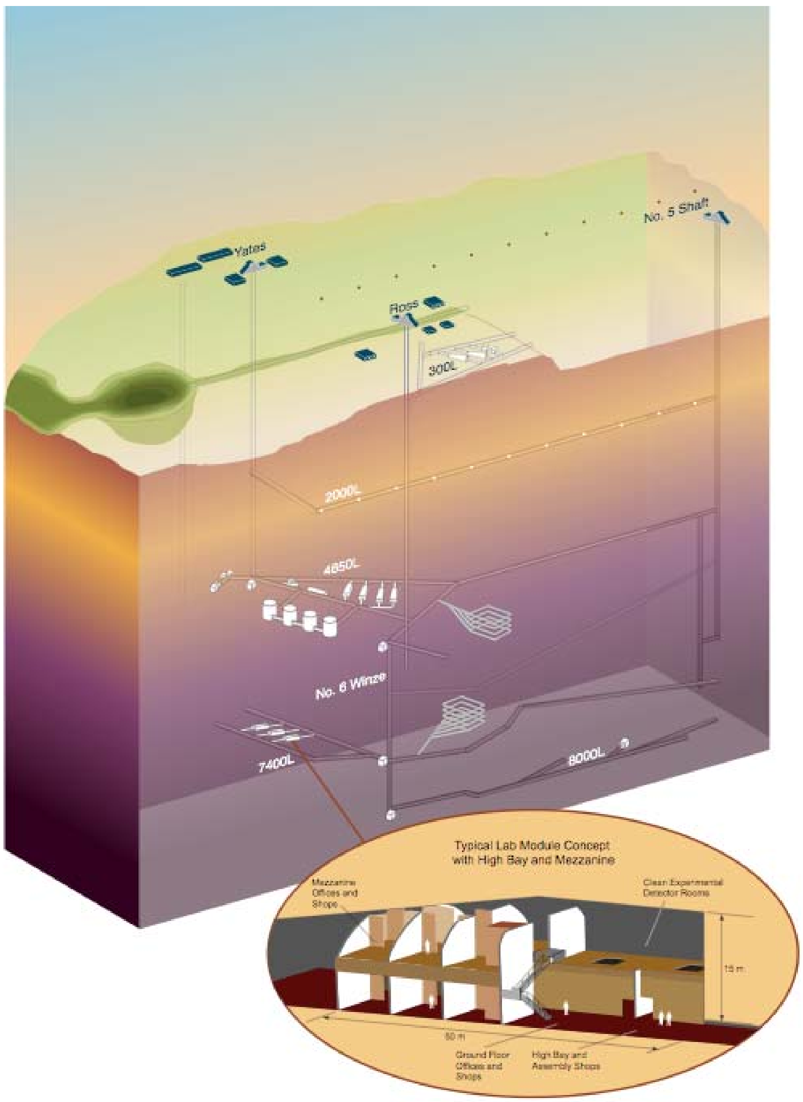
The Deep Underground Science and Engineering Laboratory at Homestake:

Conceptual Design Report



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Abstract: We propose the former Homestake mine as the site for the National Science Foundation's Deep Underground Science and Engineering Laboratory (DUSEL). Homestake offers many advantages over other possible sites for creating a dedicated, multidisciplinary laboratory. These advantages include well-characterized, varied, and interesting geology; expeditious access to great depths; significantly reduced technical risk; dedication to research without disruption from mining or other commercial uses; capacity to host a comprehensive, international, multidisciplinary suite of experiments; and ability to expand in capacity and depth as the science and education programs evolve in the coming decades.

Significant early work is already in progress. To acquire Homestake for scientific purposes, the State of South Dakota established the South Dakota Science and Technology Authority (the Authority) in 2004. Since 12 May 2006 the Authority has owned and occupied the property. In preparation for DUSEL, the Authority has also: 1) attended to indemnification and insurance requirements; 2) begun converting the site into a dedicated science and education facility, one without competition or interference from mining interests; 3) established a well-understood plan for rehabilitating the facility, re-establishing access to deep levels and dealing with the inflow accumulation of water; 4) established a management organization with critical environmental, safety and health functions as well as plans for transitioning into DUSEL; and 5) secured funds sufficient for five years of basic, safe operation of the infrastructure.

That second point—conversion into a laboratory—is an especially important advantage. South Dakota has committed \$46M in Authority controlled funds to create the Homestake Interim Laboratory, including surface infrastructure and underground space at the 2000 and 4850 Levels (measured in feet below ground). The Homestake Interim Laboratory is the starting point for DUSEL, which will expand these facilities and develop deep modules at the 7400 and 8000 Levels and ~11 (of 60) existing levels in the facility. Starting on 2 January 2007 the Authority commenced work to rehabilitate the shafts, refurbish the pumps, and preserve the 4850 Level. The three-phased plan will first restore the surface facilities including recommissioning the hoists and associated equipment. Phase two, scheduled to begin 15 April 2007, focuses on creating safe access down the Yates and Ross shafts. Phase three will operate the pumps from 15 September 2007 through 15 June 2008 and preserve the 4850 Level infrastructure.

In addition to the State's contributions, a philanthropic donation agreement between T. Denny Sanford and the Authority, has been executed and will provide an additional \$70M. These funds will complete the interim laboratory infrastructure, making it fully equipped and ready to host experiments; build a world-class Education and Outreach center; and provide funds for the creation of deep underground modules. In all, the Authority already controls a total of \$116M to create an underground laboratory at Homestake.

The initial steps in defining Homestake's scientific programs have also begun. The Homestake Scientific Collaboration and the Authority issued a call for Letters of Interest and received some 85 responses. A Program Advisory Committee (PAC) was established to evaluate them and to advise the Authority on the science program for the Homestake Interim Laboratory. These Letters of Interest and the PAC report assist us greatly in planning DUSEL development by establishing a realistic database of experimental requirements and by establishing preliminary research and development (R&D) roadmaps for the many disciplines interested in using DUSEL.

The scientific program of the Interim Laboratory is called the Early Implementation Program. It includes not only the R&D phases for many of DUSEL's Initial Suite of Experiments, but also several experiments that will be ready for deployment before the DUSEL Major Research

Equipment and Facilities Construction (MREFC) proposal is prepared. Following PAC guidance, several of the Letters of Interest are being developed into Memoranda of Understanding in preparation for the installation of these experiments and efforts.

Homestake's proposed DUSEL Initial Suite of Experiments, developed from the National Science Foundation's S-1 Report and the Letters of Interest, addresses many of today's most important scientific challenges, and spans a range of disciplines. Many of them place a premium on depth, and all benefit from the dedication to science available at Homestake. They include

— Searches for dark matter and neutrinoless double beta decay

— Searches for "dark life" and the limits of life on Earth

— Long-baseline neutrino oscillation research addressing CP-violation and nucleon decay

— A vast array of earth-sciences topics, including geochemistry, hydrogeology, coupled processes, rock mechanics, underground engineering, environmental, geoneutrino, and biological investigations

— Nuclear astrophysics research

— Experiments addressing high-profile societal issues including ground water, carbon sequestration, and geothermal energy.

As we will detail at length throughout this proposal, the Homestake site and our plans for its development are an excellent match for these experiments. Homestake can host them all, and, with its combination of depth and freedom from interference by mining and other activities, can do so under something approaching ideal circumstances. We also have plans to create a world-class education and public outreach center, providing unequalled opportunities from the start of the project for fully integrating those goals with our multidisciplinary science program.

Homestake is not only a scientifically near-ideal site for DUSEL, but also a cost-effective site entailing low risk of financial, technical, or procedural issues. It is well-characterized; most of the legal and permitting issues have been dealt with; and a significant portion of the infrastructure, facility upgrades, and initial access to deep underground are financed by the Authority. No new shafts, tunnels, or drifts will be needed, even to obtain access at great depths. All this allows a large fraction of future funding to be devoted to the experimental programs.

The Authority's plans include upgrades such as an automated, on-demand personnel lift, an enhanced freight lift, and a supply of radon-reduced air. Installation of many of the infrastructure upgrades will begin as early as 2007. Consequently, Homestake provides the best "time to science," with significant results in physics, earth science, biology, engineering, and education anticipated even while DUSEL is still being developed.

We present in this document our Preliminary Project Execution Plan, including initial risk assessments and mitigation plans. Included are several environmental assessment studies, and evaluations by South Dakota's Department of Environment and Natural Resources (which is the representative of the federal Environmental Protection Agency) of Homestake's status and potential environmental risks. No project-threatening risks have been identified, and plans for dealing with the remaining lesser issues are presented. The Project Execution Plan presents design concepts, plans and schedules for laboratory development, and a preliminary cost estimate for infrastructure requirements, as well as an estimate for the DUSEL Initial Suite of Experiments.

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1 Introduction and Document Definition

This Conceptual Design Report proposes, discusses the suitability of, and reports our progress toward establishing a Deep Underground Science and Engineering Laboratory at the Homestake Mine in South Dakota. The scope for this Conceptual Design Report is established by the National Science Foundation Solicitation 06-614 [1] and more generally by the NSF's Major Research Equipment and Facility Construction Account Guidelines (NSF-03-049) [2]. These documents are included as Appendices A1 and A2 of this report.

This Conceptual Design Report responds to all the elements listed in those guidelines at an appropriate level of rigor.

1.1 Collaboration Goals for Homestake DUSEL

We propose to develop a dedicated, multidisciplinary laboratory for underground science. The Homestake facility will provide significant laboratory and research space at levels of 8000, 7400, 4850, 2000, and 300 feet (2438, 2256, 1478, 610, and 91 m) below ground, as well as providing extensive support facilities on the surface. Integrated into the science program and research facility will be a world-class education and public outreach program.

The proposed facility will support the DUSEL Initial Suite of Experiments. Those experiments run the gamut from physics (measuring or searching for dark matter, neutrinoless double beta decay, solar neutrinos, and geoneutrinos, as well as establishing facilities for nuclear astrophysics measurements); earth sciences (geology, rock mechanics, hydrology, coupled processes, seismology and extensive sensor arrays, geomicrobiology, ecology and environmental studies, and bioprospecting), and engineering (geotechnical studies, large cavities, and research into underground excavations). The Homestake facility will foster future investigations and research efforts by providing extensive capabilities to a wide range of fields.

The design of the Homestake facility is adaptable and readily expandable. Additional laboratory modules can be added to the facility with a minimum of impact on existing efforts.

We present our current plans for underground laboratory and common space at these levels in Table 1.3. Additionally, surface support buildings include a 50,000 square foot (4600 m^2) education science center and 100,000 square feet (9300 m^2) of support buildings, assembly buildings and shops. The support buildings will be, in some cases, adapted from existing structures.

Table 1.1 Underground laboratory space for the DUSEL Initial Suite of Experiments and future expansions. Estimates do not include the access drifts or underground connecting tunnels, nor do they include the many other drifts or former mining areas that could be made available for nomadic research purposes. The term "mwe" means "meters of water equivalent" and describes the cosmic-ray attenuation value of the Homestake rock formations [3].

Level below ground	Laboratory Floor Space (m^2)	Laboratory Volume (m^3)	Common Space (m^2)	Common Space Volume (m^3)
300ft (91m, ~233 mwe)	640	6800	150	1,500

Level below ground	Laboratory Floor Space (m^2)	Laboratory Volume (m^3)	Common Space (m^2)	Common Space Volume (m^3)
4850ft (1478m, ~4100 mwe)	7200	65,000	2800	40,000
7400ft (2256m, ~6400 mwe)	4500	40,500	1500	15,000
8000ft (2438m, ~7000 mwe)	100	1000	-	-

In this report we also discuss management structures that will oversee maintenance and operations of the facility and its multidisciplinary scientific program. Of the highest importance will be a fully integrated environmental, health, and safety program. This program will involve many of the elements developed during Homestake Mine's 126 year record of safe operation. However, the safety program must involve many new elements required by the scientific program. It will stress the safe integration of many new users, including students, visitors, and scientists, as well as the personnel traditionally associated with underground excavation.

1.2 Homestake's Approach

Our approach to creating DUSEL is to acquire and adapt the existing and closed Homestake Gold Mine in Lead, South Dakota. Our approach defines a dedicated laboratory that has no interfering or competing uses for its infrastructure.

To host our proposed DUSEL Initial Suite of Experiments, we have defined initial research campuses at levels 300, 4850, 7400, and 8000 feet below ground. We target several long transverse drifts (tunnels) for specific earth-science applications, including seismic arrays (on levels 2000 and 3900 below ground, as well as the extensive ramp system). The principal levels in the Homestake facility that are of interest to research are described in Chapter 7, Section 7.5.

For the DUSEL Initial Suite of Experiments, we will rehabilitate and modernize the conveyances that provide access from the surface to 8150 feet underground. Upgrades and improvements to the conveyances, drifts (tunnels), ventilation, and communications are included. We will make use of existing excavations, as well as providing new customized laboratory and research space. Surface support buildings will also be customized to provide necessary services for users.

We propose a phased approach to the development of the laboratory. Initially we will focus on the surface and 4850 Level campuses. Then we will focus on the development of additional laboratory modules at the 300, 7400 and 8000 Levels and further enhancements to the higher-level campuses. In total, Homestake DUSEL has the potential to expeditiously access over 30 km^3 of rock with existing drifts, ramps, and shafts.

To design and propose the Homestake laboratory, we have assembled an experienced and diverse scientific collaboration, the Homestake Scientific Collaboration, and coupled this to a state entity, the State of South Dakota Science and Technology Authority (the Authority). The Authority was established in 2004 to provide means to take title of the Homestake Property and to promote its use for science and engineering research [4] (see Appendix A3). The Homestake Scientific Collaboration is primarily tasked with defining the scientific, engineering and educational goals along with the scientific roadmaps and the laboratory requirements. The Authority is responsible for the acquisition of the facility, including the necessary antecedents of liability and indemnification statues, insurance, title, and the rehabilitation of the infrastructure. The DUSEL project team is comprised of members of these two bodies.

Through the combined efforts of the Homestake Scientific Collaboration and the Authority, the Homestake site will host scientific, engineering and educational efforts in advance of the NSF-supported DUSEL. We refer to this Authority-supported laboratory as the “Homestake Interim Laboratory.” This early phase provides essential underground laboratory space and environments for the research and development of many components of the proposed DUSEL Initial Suite of Experiments. More-advanced experiments in the next phase, the NSF-supported DUSEL, will benefit from the much-needed underground space.

1.3 Homestake Key Characteristics

We list here some of Homestake’s key characteristics. These and others are presented in greater detail in subsequent chapters, particularly Chapter 5.

The Homestake site encompasses over 30 km^3 of rock with depths accessible to 8150 feet below ground using existing shafts, drifts, and ramps. The site is capable of hosting a comprehensive suite of experiments. The full complement of S-1 identified fields of science and aligned research would be hosted at Homestake DUSEL. (The S-1 Report, Deep Science [5], is included in Appendix A4.) The DUSEL Initial Suite of Experiments would include all of the proposed experiments requiring extremely low backgrounds and very large detectors in particle and nuclear physics. Homestake DUSEL would also host a rich, diverse multidisciplinary variety of deep subsurface studies in geosciences, geoengineering, and microbiology. As noted in the S-1 report, certain earth-science experiments requiring sedimentary or granitic rock would be conducted in those rock types at separate sites, as no single site can readily provide all basic rock types. Science uses and access to the facility will be unimpeded by other activities.

Homestake DUSEL will be situated in competent, well-characterized rock. Existing large-scale excavations, including large caverns at the 4850 and 7400 Levels, demonstrate long-term stability of excavations at significant depths. Several independent geotechnical studies support the suitability of the Homestake formations for the creation of underground laboratories and research space. The site will accommodate an evolving science program of great longevity—at least 30 years.

The diverse and scientifically interesting geology provides for a rich geosciences program. There exists over a century of operations and safety records, maintenance logs, and geologic information, already being organized and made available for scientific purposes.

Homestake DUSEL benefits from extremely strong state and local backing, including financial, technical and logistical support. With the Authority funding and the Sanford donation, the Authority controls $116M allocated for the creation of Homestake DUSEL. Title to the entire facility is now held by the Authority. Issues regarding indemnification and insurance have been defined and resolved.

We are following a professionally prepared and externally reviewed plan for re-opening the mine, focusing on underground safety, rehabilitation, dewatering, and providing safe access to levels greater than 8000 feet below ground. Regaining underground access and dewatering the entire facility is anticipated to cost ~$50M and require ~18 months. We plan on beginning the rehabilitation in Spring 2007. On 10 June 2006 a camera system was lowered down the Yates shaft and recorded the good condition of the entire shaft and infrastructure. On 7 December

2006, cameras were sent down the Ross shaft and similarly recorded its good condition.

The Authority is initiating this plan to preserve and rehabilitate the Homestake mine and consequently create the Homestake Interim Laboratory. The Authority's plan includes providing five years of operating support and access for science, from the surface to the 4850 Level. The Authority has expanded its staff to prepare for the reentry plan and to oversee detailed engineering. There exists an available experienced, trained and knowledgeable workforce in the area. The management entity, including critical Environment, Health and Safety (EH&S) components, is being developed for the Homestake Interim Laboratory, and includes many individuals with years of experience in the Homestake mine.

To guide science planning for DUSEL and in particular for the Homestake Interim Laboratory, a diverse, international user pool was established with a call for Letters of Interest. As a result, ~85 responses were received. These Letters of Interest [6] (see Appendix A5) have been peer reviewed by an external Homestake Program Advisory Committee composed of independent experts in physics, geoscience, engineering and biology. Their advice and the S-1 working group's reports strongly influenced our preliminary plans and designs for the Homestake Interim Laboratory and help us in establishing a roadmap for developing DUSEL at the Homestake site.

Establishing the Homestake Interim Laboratory provides reduced project risks, accurate schedules, and lower DUSEL capital costs. Additional attractive Homestake DUSEL features include: a) expeditious, safe, deep underground access and research space provided by existing shafts and drifts with no competing uses; b) an agency and organizational structure to make the best use of this dedicated access; c) existing surface facilities at the site to support and foster the scientific and outreach programs; and d) identified and accessible rock and water disposal sites adjacent to the facility.

Homestake DUSEL further benefits from well-established characterization of a) the rock mass established from the existing drill core repository and mining/geologic database; b) the water inflows and sources; and c) the levels of intrinsic radioactivity in the rock mass and levels of radon in the entire facility. The levels of uranium, thorium and potassium in the Yates metamorphic formation, based on several existing core samples, are an order of magnitude lower than in typical granitic formations such as the Canadian Shield, Cascade Range, etc.

An integral part of the Homestake Interim Laboratory's program is effective use of existing efforts to foster education and public outreach programs at the historic site. These efforts are connected to existing NSF-funded South Dakota programs and will continue to be developed as an integral part of DUSEL.

2 DUSEL Science

It is obvious why researchers in the earth sciences would be interested in a laboratory thousands of feet underground. But what would microbiologists, particle physicists, or— most counter intuitively of all—astrophysicists be doing down there?

For physicists some exciting ways to study the universe involve neutrinos and other rarely interacting particles rather than photons. Neutrinos are nearly massless, hardly interactive at all, and moving as close to the speed of light as any particle could; neutrinos are often described as "ghostly." They are best observed not from atop a mountain but in the deep recesses of a mine, where the background noise of radiation is at a minimum and a large mass of detector material can be accommodated.

Biologists, as well, have discovered much of interest in the deep underground; even thousands of feet below the surface, profoundly isolated from the world of air and light, there are microbes. But are they like the microbes at the surface? Studying them might explain the evolution and survival of life as we know it and even give us a glimpse into possibilities for life, as we don't know it. New fields of science could emerge as scientists from many different disciplines meet and collaborate.

In this chapter, we give an overview of why a Deep Underground Science and Engineering Laboratory is of interest to so many different kinds of scientists. These scientific objectives are based on the report from the NSF site-independent study ("S-1"). Physics and astrophysics, biology, geoscience, and geoengineering are discussed, together with the anticipated synergy among them.

Later chapters (particularly Chapter 4) give details, with attention to why Homestake has advantages that are unique in the world as a site for DUSEL: its combination of depth, infrastructure, types of rock, freedom from the physical interference and competing priorities of a working mine, and outstanding community support.

2.1 Underground Universe (Physics and Astrophysics)

In 1514, Copernicus sparked a revolution when he demoted planet Earth from its position at the center of the universe and relegated it to the status of a planet revolving around a star. As observation technologies and interpretations continued to evolve, the Sun was found to be a quite average star, one of billions in the Milky Way galaxy, and rather far from the center at that; later still it was learned that the Milky Way is an ordinary spiral galaxy, one of millions. For centuries, this succession of discoveries seemed to signal the loss of any privileged position in the universe for Earth and its creatures. Recently this view of our tiny and undistinguished place in a tremendous universe has taken another leap: the kind of matter we can see is only perhaps one-fifth of all the matter that exists.

Atoms are vastly outnumbered by ghost-like neutrinos and photons (particles of light) by a factor of about one to a billion. In terms of weight, the mystery substance called dark matter outweighs atoms five to one (Figure 2.1). Furthermore, a mysterious force called dark energy that pushes the universe apart at ever-increasing speed fills the empty space of the universe. For that matter, why atoms and anti-atoms did not mutually annihilate as the universe cooled from the Big Bang is so mysterious that it will take another revolution in physics, as profound as the Copernican version, to explain it.

These are truly some of the most compelling questions in science today. In order to understand what the universe is made of, we need to see dark matter directly. To understand why we exist, we need to know why anti-matter disappeared from the universe, leaving the tiny bits of normal matter that we are made of. Underlying these mysteries, yet-unknown laws of physics explain the Big Bang and the evolution of the universe since. Many believe that the kind of unified theory of which Einstein dreamed will require these new laws of physics waiting to be uncovered. In many of these questions, neutrinos, the most ubiquitous form of matter in the present-day universe, must have played important roles.

The answers reveal themselves through signals that are in many cases extremely subtle. Trying to detect them on the ground is like trying to listen to a whisper in the middle of Manhattan street traffic. On the ground, sensitive devices in physics experiments are completely deafened by the chatter of cosmic rays. Coming from supernovae exploded millions of years ago in our galaxy, high-energy protons constantly bombard the atmosphere of the Earth. They create showers of particles that eventually decay to muons and neutrinos. In fact, thousands of muons go through our bodies every minute. They do not cause much harm to humans, but are a serious problem for a physicist who is trying to discover a phenomenon that happens maybe once a year. A deep underground laboratory offers a shelter from cosmic rays. Depth means fewer cosmic ray muons, hence a better place to "hear the sound of the universe."

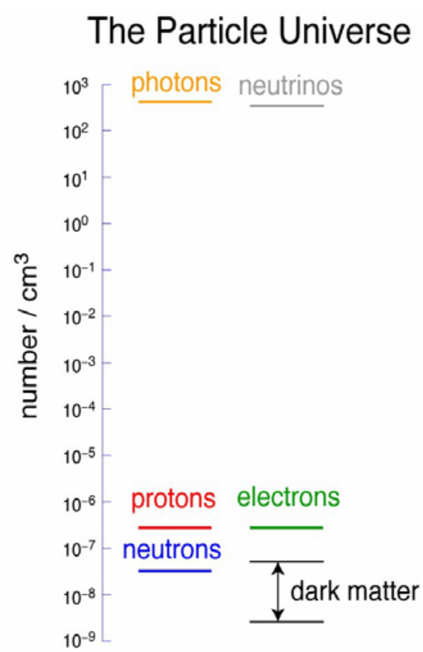
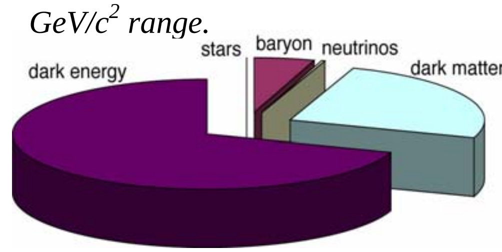


Figure 2.1 The number of various particles in the Universe, and their contributions to the energy budget of the Universe. It assumes a dark matter particle with a mass in the 10-1000 GeV/c^2 range.



2.1.1 What is dark matter?

Not only does dark matter outweigh ordinary matter five to one, but it also holds the galaxy together. Dark matter particles float around the galaxy, providing a gravitational pull strong enough to prevent the solar system from wandering out into intergalactic space. Dark matter particles are so elusive, even more so than the ghostly neutrinos, that they practically do not interact with atomic matter, and thus far have been revealed only indirectly (Figure 2.2).

In DUSEL, physicists hope to reveal the secret of dark matter particles by placing an ultrasensitive high-tech device in a quiet location deep underground. Undisturbed by human activities and cosmic rays, the detector will watch for the feeble signals of dark matter particles sneaking easily through thousands of feet of rock to give a tiny telltale *kick* in the device. By observing this subtle signal, physicists could directly establish the presence of dark matter that astronomical observations have identified in the Milky Way galaxy. Combined with the search for astrophysical signals of dark matter annihilation in the sky and with the direct production of dark matter particles at high-energy accelerators, underground dark matter observations would establish the true character of dark matter.

2.1.2 What are neutrinos telling us?

Neutrinos are the most ubiquitous matter particles in the universe, and they must have played important roles in shaping the universe today. Yet we are still learning much about them. This has been an extraordinarily difficult task because they interact hardly at all with ordinary matter. Trillions of them go through our body every second and we do not feel them at all. We need the largest feasible detectors in a quiet deep underground location to boost the chance of seeing these elusive particles.

Only very recently have physicists learned that neutrinos do not travel quite at the speed of light, as believed for decades. An implication is that they have tiny masses, a million times smaller than any other particle masses. Despite being individually almost infinitesimal, neutrinos are so common that collectively they may weigh more than all the luminous stars in the universe. Depending on this aggregate weight, neutrinos may have changed the way galaxies, and eventually stars, have formed since the Big Bang.

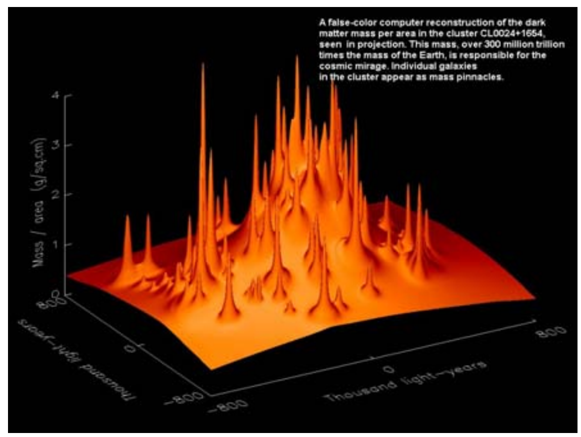


Figure 2.2 *Above left*: The blue light from a faraway galaxy is bent by the presence of mass in the foreground galaxy cluster. We can "see" the presence of dark matter by studying how much the light gets bent. *Above right:* The spikes are galaxies we can see in telescopes, while the big blob is the dark matter [7].

It is very difficult to determine the mass of such elusive and tiny particles. Physicists would like to try two different and complementary methods. One is to look for a phenomenon, called neutrinoless double beta decay, that would be impossible if the neutrinos had no mass, and (since we know now that they *do* have mass) can be measured to determine what their mass is. This decay may happen to any given atom only once in a billion billion billion years. Therefore we need to observe a detection mass consisting of a great many atoms to have a chance of seeing it, and we need a radiologically quiet location so as not to miss it. The other method is to shoot beams of neutrinos from particle accelerators across hundreds of miles into the detector. The way the neutrinos morph from one kind to another would tell us how much their masses differ.

This technique requires a large target device to detect neutrinos from a faraway source and therefore large underground cavities.

2.1.3 What happened to the antimatter?

Just as mysterious as the dark matter that must be there (but can't be seen), and the neutrinos that are everywhere (but are hard to see), is the antimatter that would be easy to see (but isn't there). Why not?

Every particle has an antimatter equivalent (many have been produced or observed in the laboratory), and there is reason to believe that antimatter was abundant in the early universe. In the modern visible universe, there is almost no antimatter at all, and what little there is can be explained by nuclear decays and by high-energy interactions of normal matter. This is fortunate, because when matter and antimatter meet, they annihilate each other in a burst of radiation—hardly a situation conducive to life. But whether antimatter was produced in the Big Bang in amounts equal to normal matter, and if not, what happened to it, are tremendously puzzling questions with important implications for our understanding of the origins and fate of the universe.

This is an exciting frontier of physics at this time. Very recently (late 2006) discoveries related to charge conjugation-parity or "CP" violation (a way of stating why nature seems to prefer normal matter), and "oscillation" between matter and antimatter states, have been announced by accelerator laboratories. DUSEL neutrino detectors with unprecedented active mass (ultimately more than 100,000 tons) could address matter-antimatter asymmetry amongst neutrinos, simultaneously with other important tasks. Long-baseline neutrino studies, using powerful neutrino beams produced by distant accelerator facilities and aimed at DUSEL, would also contribute to solving this mystery.

2.1.4 Are protons unstable?

Protons, the large positively charged particles in the nuclei of all atoms, were long thought to be stable. However, since the early 1970s, attempts to create unified field theories implied that they could (over a very long period) decay.

This might be relevant to the question of where the antimatter went, but experiments to date have shown that the proton lifetime exceeds 10^{33} years, whereas the universe is considered to be only about 10^{10} years old. In any event, proton-stability is an important fundamental property to determine in order to understand particles and fields. One of the most crucial and generic predictions of grand unification is that the proton must ultimately decay; one class of such theories also explains the origin of the excess of matter over antimatter. These theories involve a theoretical upper limit on the proton lifetime that is within a factor of ten of the current lower limit. Thus a next-generation experiment that looks for proton decay has high discovery potential. DUSEL, with its low background and ability to watch for signs of proton decay in a large detector mass, would be an attractive site for such experiments.

2.1.5 How did the universe evolve?

The Sun, as the Earth's closest star, has given us access to a wide range of science. Nowhere on Earth can we as readily study the forces that drive our universe – gravity through heliocentricity, nucleosynthesis through stellar fusion, general relativity through its bending of light, dense plasmas through helioseismology, and neutrinos through their oscillations. In each case new knowledge has been gained, modifying our understanding of the solar system and providing new insights into areas beyond, such as particle physics and cosmology.

At the core of the "Standard Solar Model" (SSM) are four key assumptions. The first is that the luminosity of the Sun, as determined from photon flux, matches consistently with the luminosity as determined by the neutrino flux (presently known experimentally only to within 20-30%). The second is that the Sun is basically in hydrostatic equilibrium. The third is that the heavy-element abundances at the surface of the Sun are present at the center. The fourth is that neutrino "mixing"—the aforementioned morphing of neutrinos from one type to another—correctly explains the observed solar neutrino fluxes on Earth.

All four of these assumptions will be tested with the next generation of detectors, designed to accurately measure the remaining >90% of the solar neutrino flux not yet directly seen. Beyond being a test of today's theories, this round of experiments has exciting discovery potential. The recent four-division American Physical Society neutrino study consequently made the development of a low-energy solar neutrino detector one of its three executive recommendations.

2.2 Dark Life (biology)

One of the most mysterious and intriguing aspects of the deep underground was recently in the news. Far below the world of the surface are microbes that call this inner world home – "dark life." Isolated from the world of sunlight and other forms of energy and material used by surface life, they must be inextricably coupled to physical and chemical processes occurring in this underground environment. Their inputs, stresses, outputs, and effects thereof are necessarily different than what we find at, or at least in communication with, the surface. These microbes represent an extreme of life as we know it, and might even give us a glimpse of life as we don't know it, or life as it once was, as illustrated in Figure 2.3.

Among the questions that dark life might help answer is one of the most profound and basic of questions: when and how did life begin? Some scientists hypothesize that life, in its earliest and most primitive form, might have originated beneath the surface, or at least that the deep environment might have served as its bomb shelter early in Earth's history, during the aptly named Hadean eon, marked by frequent heavy impacts from space.

A deep underground laboratory (ideally one that affords the ability to drill even deeper) would afford a priceless opportunity to study these organisms in an environment uncontaminated by surface life, and in their natural environment, with its heat, pressure, water chemistry, etc. It will also allow "biogeochemistry," the study of how they have altered their environment.

The major areas of research in geobiology are broad and interwoven, but may be thought of in three principal categories: Geomicrobiology, Geochemistry, and Biology. Because understanding life (especially at extremes) requires understanding its physical context, this research is also related to experiments in hydrogeology, rock mechanics, and the coupled interaction of processes related to the ensemble of all of these fields.

2.3 The Restless Earth (geoscience)

Expressions like "rock solid" greatly underestimate the dynamism and the amount of structural detail that geoscientists and engineers see in rock. In fact, many rocks are porous, fractured on small or large scales, or both. Many of the processes that we depend upon, like fluid production and injection, are predicated on the ability of fluids to circulate in "solid" rock. We need a better

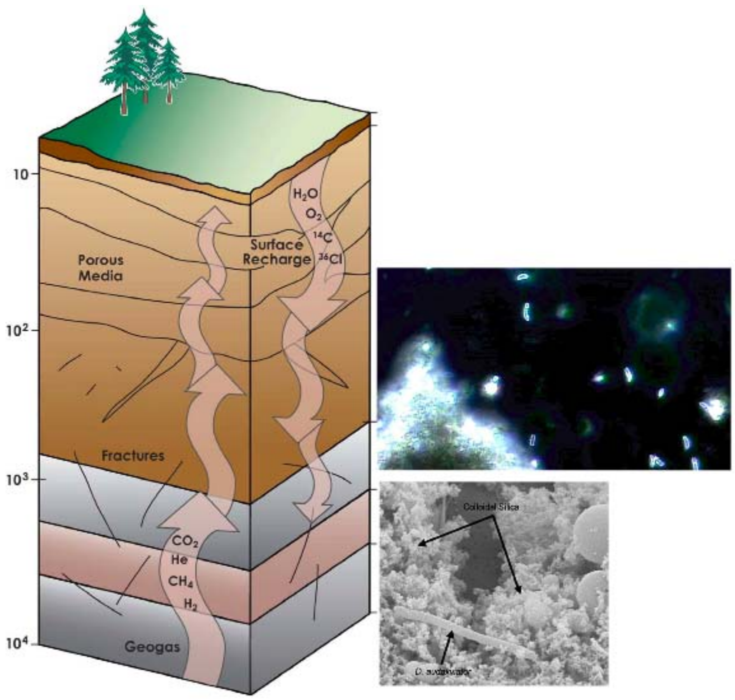


Figure 2.3 Dark Life found at depth without sunlight generated food for nourishment. The rod-shaped bacteria of ~ 4 μm in length were discovered at a South Africa gold mine, in water of several millions of years old, survived on chemical food sources derived from the radioactive decay of minerals in the surrounding rock. Figure adapted from [8] and EarthLab plan [9].

understanding of these matters both to make the best use of finite resources and to protect them against pollution. We also need to understand the mechanics of rock at the temperatures and pressures found deep underground in order to learn how to build on, or in, the earth. Ours is a "living" planet whose rock masses, set in motion ultimately by the geothermal heat, sometimes lurch against each other with devastating effect. A better understanding of rock mechanics deep underground would greatly aid the effort to understand and perhaps someday predict earthquakes. Many of the grand challenges in the study of our restless Earth can be addressed by DUSEL.

2.3.1 What are the interactions among subsurface processes?

Many processes underground "talk to one another." DUSEL will present a rare opportunity to examine these *coupled* thermal, hydrological, chemical, mechanical, and biological processes at length, under real geological conditions, and on a large physical scale. Rates of reaction of minerals under hydrothermal conditions would allow for investigation of strongly coupled processes that are important in many geological environments, but have never been studied under well-controlled conditions over long time periods and large spatial scales.

2.3.2 Are underground resources of drinking water safe and secure?

Hydrology, the study of how water (and, more generally, fluids) moves in the underground, will be a key area of DUSEL investigation, and a large number of questions remain to be answered in this important field.

If Homestake were selected for DUSEL, a wide range of earth-sciences disciplines would be rallied to investigation and collaboration almost immediately—dewatering the lower levels would provide a truly rare opportunity. The understanding of Homestake's low-flow, nearly-neutral-fluid setting with complex but relatively competent rock mass can shed light on deep circulation of groundwater systems, provide hydro-geochemical inputs to the dark-life investigations, and supply hydro-mechanical data to geological engineers.

Fluid flow and transport are active even at considerable depths, and despite the societal importance of these effects, direct subsurface observations and experiments are rare. Samples of deep rock from drill holes are small and have been disturbed by the drilling process, making them unsuitable for testing of factors that control fluid flow. DUSEL would revolutionize the field by providing an opportunity for large-scale, direct observation and measurement, impossible by any other means.

Deep flow and transport research is central to important societal concerns, such as the protection of drinking water and irrigation water supplies, the disposal of hazardous and nuclear wastes, and the remediation of contaminated aquifers. The hydrologic science community would use a deep underground laboratory to study fundamental processes that today, after decades of surface-based research, are still understood in only the simplest of terms. Recharge and infiltration, fracture permeability, physics of multiphase flow, flow in fracture networks and characterization of the networks, verification of well test and tracer test models, characterization of active flow systems and paleoflow systems, coupling of flow, stress, and heat, reservoir potential and permeability of tight rocks all need research. DUSEL would provide deep groundwater regimes that could be isolated and studied within an undisturbed setting.

2.3.3 Can we reliably predict and understand earthquakes?

The S-1 report *Deep Science* points out how information gained from a deep underground laboratory enhances our understanding of earthquake mechanisms and rock behavior under the pressures and temperatures of the deep underground, a vital step toward earthquake prediction. DUSEL will “permit continuous, direct measurements of rock strain as a function of position and sampled volume at depth, both in the immediate vicinity of active faults and in the rock mass. These data would elucidate the influence of geology and human activity on tectonic strain and stress distribution in rock, allow direct observation of energy accumulation near faults and fractures, and provide insights into scaling fault slip processes to larger events.”

2.3.4 Can we make the earth “transparent” and observe underground processes in action?

Geologists and geoengineers who study the deep underground are in almost as extreme a situation as astrophysicists and cosmologists who need to know about dark matter. They have to draw fact-based conclusions about something they can see only in tiny glimpses here and there. The development of imaging technologies is a primary goal of DUSEL. Just as medical imaging techniques have revolutionized nearly every field of medicine, accurate subsurface imaging would benefit every area of research in the geosciences and in rock engineering.

Currently, seismic surveying from the surface or in and across boreholes is the main geophysical tool for imaging the deep earth. The geology through which the waves travel is typically inferred only through general knowledge or through rock samples from sparse boreholes. DUSEL would allow direct verification or “ground-truthing” of geophysical imaging. In DUSEL, surface-based predictions of underground structure could be verified directly within a deep, three-dimensional rock volume that is accessible to back-excavation and known from past mining and core drilling.

The knowledge gained would have significant impact on our lives, such as devising methods of detecting and characterizing underground structures and activity for homeland security applications. Signatures of pumping-induced seismicity can be used to elucidate stress and fluid dynamics. An ideal site for DUSEL would offer the opportunity to run hydraulic fracturing tests with geophysical monitoring, and then excavate the fractured rock to find ground truth. This fundamental evaluation of hydraulic fracturing has immediate application in geothermal energy extraction with enhanced well connectivity. Long-term monitoring of pressure and stress can also decipher the tidal, seasonal, climatic, and tectonic relaxation responses. Electromagnetic techniques are promising for both monitoring fluid and imaging fractures. The streaming potential is sensitive to fluid chemistry and works with both polar and nonpolar fluids, e.g., liquid CO_2. This imaging method has been demonstrated in the identification of hydraulic fracture precursors.

In the following years, seismic instrumentation in many boreholes and along drifts at the site will result in the most densely instrumented geophysical observatory in the world, providing high-resolution data for mapping fracture geometry, rock damage, *in situ* stress through scattering and attenuation of seismic waves by fractures and faults, normalizing non-continuum (and continuum) constitutive models, and more detailed inversion of dynamic source processes. With the rapid development in micro electromechanical systems (MEMS) – a proven technology—scientists anticipate a fundamental paradigm change for data collections in rock physics and geophysics experiments.

With self-assembling and networking capabilities through wireless communications, it is now feasible to deploy thousands of sand-grain-size sensors with microprocessors before excavation near new drifts and large-scale underground caverns or along tunnels for remote, real-time monitoring and testing, and long term monitoring after excavation to measure pressure and stress changes. MEMS, together with nanotechnology, biotechnology, and cyberinfrastructure, are promising technologies called for in a National Research Council report *Geological and Geotechnical Engineering in the New Millennium: Opportunities for Research and Technological Innovation [10].*

2.4 Ground Truth (geoengineering)

As detailed above, the properties of rock—its integrity or lack thereof, ability to withstand a certain size of excavation at a given depth, the safety of working with it, the ability of fluids to flow through it—have a huge if easily overlooked impact on our lives.

2.4.1 What lies between the boreholes?

Rock fractures and faults play a critical role in the geological processes that take place continuously underground – a role impossible to investigate from laboratory research on rock samples alone. DUSEL would permit continuous, direct measurements of rock strain in the field, and would provide an opportunity to evaluate factors that control it and the resulting stress on subsurface rock. Improved understanding of stress and strain distributions within the rock afforded by DUSEL studies would lead to an improved understanding of how energy accumulates near faults and fractures, a vital step toward reliable prediction of earthquake timing or rock failure associated with civil structure. The depth dependence of fracture networks and associated rock mechanics measurements are of fundamental interest to determine if fractures displaying enhanced permeability for flow are also critically stressed.

2.4.2 How can technology lead to a safer underground?

Society depends upon the subsurface not only for fossil fuels, ores, and a great deal of its fresh water, but also for foundations, subways, tunnels, and other large pieces of infrastructure. The subsurface is complicated, varying from one site to another, from one part of a site to another, and even with time. It is hard for engineers to predict what they will find until excavation begins—figuring out "what lies between the boreholes" is a major problem, leading to costly and time-consuming issues such as excessive conservatism or changes of plans during a project.

DUSEL will enable firsthand study of how to remotely sense the characteristics of rock in all its complexity. Predictive models are important as well, and DUSEL will provide excellent opportunities to compare the results to "ground truth." Also to be explored will be the ways that rock responds to human activities such as underground construction. A figuratively and literally deeper understanding of how real rock behaves *in situ*, under full-scale real conditions of temperature and pressure, will be of tremendous benefit. The result will be cheaper, safer, and better-assured use of the underground.

DUSEL will be both a laboratory for and a beneficiary of these advances. Some of its experiments will require excavations that challenge the state of the art; and some of the activities of construction, such as blasting, can be monitored to obtain data.

2.4.3 How does water and heat flow deep underground?

Considering the high societal importance of fluid flow underground, it is not well understood in detail, especially at deep levels. DUSEL will provide an excellent opportunity for observation and experimentation in this area, especially from the standpoint of flow through fractured media. This opportunity will provide essential information on sustainably use and protection of aquifers.

Fluids are not the only things that flow under the earth with important consequences. Understanding heat flow within the earth has been a fundamental question in geosciences ever since Lord Kelvin's calculation in 1862 of a minimum age for the earth of 100 million years based on the temperature gradient in the earth's crust. This simple calculation underestimated the earth's true age by an order of magnitude, largely because it did not consider heat generated from decay of radioactive elements (the discovery of radioactivity was still decades away). A deep DUSEL, including deep boreholes, would offer an ideal setting to understand crustal heat transfer processes within the earth's crust at an unprecedented level. These measurements can be coupled with detailed analyses of the distribution of radionuclides to produce a detailed map of heat flow.

2.5 Synergy

Adaptation of concepts, techniques, and technology from other disciplines has been an important theme for all the disciplines included in DUSEL's Initial Suite of Experiments. DUSEL will provide exciting new venues for cross-disciplinary research that will mutually benefit earth sciences, physics, engineering and the other co-located scientific investigations. In addition to the incremental advances, it is plausible that new fields and research opportunities will emerge. For example, the temperature gradient and fluid movement within the earth's crust has major implications for the extent of life in the subsurface. Understanding the distribution and mobility of radionuclides in the subsurface is crucial for issues as diverse as geothermal energy extraction, underground radioactive waste storage and studies of geoneutrinos produced from the natural decay of uranium and thorium in the rocks. The sensor arrays installed within the underground facility will be used to determine the impacts of the large-scale earth sciences experiments (especially tests involving manipulation of temperature and/or chemical gradients within the rock).

The major areas of research in geobiology are inherently synergistic and cross-disciplinary. Because understanding life (especially at extremes) requires understanding its physical context, this research requires an appreciation of the hydrogeology, rock mechanics, and the processes related to the ensemble of all of these fields. Many experiments may be combined into larger, coherent research themes, benefiting from coordinated and collaborative sampling campaigns and experimental efforts.

Physics experiments require sensitive detectors in large caverns at great depths and earth studies need substantial spatial coverage to quantify scaling and heterogeneity. Improvements in instrumentation can greatly enhance our understanding of processes and will be applicable to very different fields. For example, the photomultiplier technology for physics particle detection within neutrino, nucleon decay, and dark matter detectors could be applicable to fluorescent microbe and tracer detection. Furthermore, it is necessary for both physics and earth studies to conduct long-term experiments in a dedicated underground laboratory, to capture rare events, to improve statistics, and to quantify very slow and subtle geological processes.

The location of an expansive Initial Suite of Experiments in a single facility will “cross fertilize’ these many efforts. There will be sharing of technologies between collaborations as well as disciplines that cannot be realized in a dispersed, non-centralized approach to underground science. Plans already involve the sharing of central facilities, such as low background counting, and ultra-low background material fabrication facilities. The large water-shielded facility, located in the Davis Cavity, is another example of shared infrastructure and synergism within the Homestake Facility. In several cases these fabrication facilities must be located at the site of the ultimate experiment to avoid subsequent cosmic ray activation. As technologies advance supporting ever-lower background environments for many physics research efforts, and as the earth science efforts are coordinated to take advantage of the long-duration opportunities provided by a dedicated facility, these research and technology advances will be freely and widely shared between all the users of the facility.

The education efforts and, importantly, the safety program will benefit from a single coordinated facility – both the exchange of information, but also to draw upon the experiences and advances within these fields to more effectively enrich the education and outreach program, and in the creation a world-leading safety program, one benefiting from underground experiences of the earth scientists and the diverse research experiences of the engineers, physicists and biologists.

3 Education and Outreach Goals

The Homestake Scientific Collaboration and the State of South Dakota envision a world-class education and outreach program that is integral to the entire laboratory enterprise. This program has two overarching goals: 1) to enhance understanding of, and appreciation for, scientific research among the general public; and 2) to leverage the resources of the laboratory to address well documented pipeline issues in science, technology, engineering, and mathematics, especially among under-represented minorities.

The Homestake Scientific Collaboration envisions extensive programming and profound innovations to reach these goals. The magnitude of this vision stems in part from the generous pledge of T. Denny Sanford to develop a science education center. The Sanford Science Education Center will expand the education and outreach that would otherwise accompany the underground laboratory.

American Competitiveness and Global Stewardship: Urgent needs exist nationally to improve science, technology, engineering and mathematics education. Compelling rationale is detailed within such sources as "Rising Above the Gathering Storm" [11], a recent report from the National Academies. Homestake DUSEL takes, as a central part of its charge, becoming a global leader within the education arena.

Serving Diverse Audiences: Important regional audiences that have historically been underrepresented in science, technology, engineering, and mathematics include Native Americans, women and girls (at least in the fields of physics and engineering), and rural Americans. The Homestake Scientific Collaboration is deeply committed to serving these audiences.

Sparking Public Interest and Increasing Public Understanding: Core to the Education and Outreach mission is helping the general public understand science. A citizenry that understands and appreciates science is invaluable to the overall scientific enterprise. Such a citizenry will support financial investment in research and demand high quality instruction for the next generation. Toward this end, an interactive visitor center within the Sanford Science Education Center will stretch minds and captivate imaginations. Visitors of all ages will have opportunities to experience underground science in action and engage with hands-on exhibits. A large tourist audience already exists, and even greater numbers are anticipated as the interactive science center at Homestake DUSEL develops into a national attraction and links with other science learning centers across the country.

Capitalizing on Unique Attributes of Homestake DUSEL: Education and Outreach has a great opportunity to capitalize on the interdisciplinary nature of the science and the unique attributes of the site. Underground science addresses some of the most captivating questions imaginable. The technological and engineering challenges are similarly intriguing. The site is also rich with history, both in terms of mining and science. There also exist magnificent opportunities for surface nature trails that highlight local geology and ecology.

Research Experiences: The Homestake Scientific Collaboration seeks to support students at a wide range of levels, from secondary school through the postdoctoral level, in contributing to the scientific enterprise. Research experiences will provide enrichment opportunities for the region's most motivated and talented middle and high school students. A scarcity of existing opportunities for this audience is a prominent local need. Research experiences at the university level will attract high caliber undergraduate and graduate students to regional institutions.

Supporting Kindergarten through 12th Grade Teachers: Kindergarten through 12^{th} grade teachers represent a critical leverage point for our education and outreach goals. Teachers will have opportunities to engage with research in order to deepen their content knowledge and to become reenergized about their discipline. Homestake DUSEL education and outreach staff will also draw upon scientists and engineers to help facilitate workshops and graduate courses for teachers, to bolster district and statewide systemic reform efforts, and to offer lectures with classroom teachers as a primary audience.

Recruitment and Preparation of Future Teachers: While supporting and helping to retain teachers who are already in the field represents a top priority, there is perhaps none greater than recruiting and preparing the next generation of teachers. Colleges of education have actively participated in planning efforts to date and will serve as core partners into the future.

Partnering with Regional Institutions: Faculty from less research-intensive institutions will benefit significantly from opportunities to connect with world-class science, both for themselves and for their students. Creation of new doctoral programs is considered, both within the pure sciences and also in the fields of math and science education. Area tribal colleges, some with their own teacher preparation programs, have engaged in planning to date and are especially valued partners in reaching and serving Native American communities.

Economic Development: Enhancing the regional climate for science-related entrepreneurship and strengthening the local economy in general are both key goals. Together with the South Dakota Governor's Office of Economic Development, the Collaboration recognizes great potential for spin-off technologies, for new job opportunities, both at the lab and in the vicinity, and for partnerships with technical and vocational schools to prepare a specialized workforce. The Education and Outreach team is planning to infuse entrepreneurship components within programming for kindergarten through 12^{th} grade students and to engage the business community in identifying and addressing needs for a scientifically and mathematically proficient workforce. In addition, undergraduate and graduate-level summer programs will bring science and business majors together for innovation and entrepreneurship training. The first year of a pilot program related to this last concept is, in fact, already underway with other NSF funding.

Distance Learning: Homestake DUSEL resides at considerable distance from many of the partner institutions that will be sending visiting scientists, and is about an hour’s drive from the universities at Rapid City and Spearfish. Furthermore, the science laboratories themselves will be thousands of feet below the surface. Remoteness in all directions renders a powerful cyberinfrastructure and other communication networks especially important. Also, given that kindergarten through 12^{th} grade education throughout the surrounding region is highly rural, motivation is especially strong for developing new approaches to teaching and learning via distance technologies.

Specific goals include a captivating web presence, web-based simulations, virtual underground tours, internet-accessible data sets, data visualization tools, and on-line university coursework. A broadcasting and videoconferencing studio will allow scientists to connect with each other, with kindergarten through 12^{th} grade schools, and with the general public. Finally, two tractor-trailer mobile science labs (Figure 3.1), already in use in South Dakota, are available to take hands-on science modules featuring underground science to the most remote and highest-need school districts.

Figure 3.1 Students in the rural town of Stickney are conducting a chemistry experiment onboard one of South Dakota's Mobile Science Laboratories. Photo by Jerry Opbroek, Black Hills State University, 2003.

Innovation and Research on Teaching and Learning: The Sanford Science Education Center will engage education researchers, K - 12th grade teachers, scientists, engineers, corporate visionaries, and students themselves to study and enhance the teaching and learning of science and mathematics. New doctoral programs in science and mathematics education and a residential pre-college school for testing educational innovations are under consideration. These could serve as powerful engines for transforming education.

Fostering an Intellectually Rich Environment: For the sake of students and faculty in extended residence at the lab, Homestake DUSEL must provide an enjoyable and stimulating environment. Homestake DUSEL has great potential to become an interdisciplinary learning campus for all ages, across multiple disciplines, and across vocations (engineers, scientists, education researchers, kindergarten through 12th grade teachers, and technicians). Accommodations, dining facilities, common areas, and recreational outlets will all contribute. Given the interdisciplinary nature of the research, "in-reach," through which scientists educate and learn from those outside their disciplines, will be especially important. The collaboration is eager and well suited to help facilitate this.

Supportive Climate and Infrastructure: Researchers are busy. It will be essential to establish an education and outreach infrastructure that maximizes scientist impact and gratification within this arena and minimizes burdens. Scientists need myriad ways to contribute, and a culture must be nurtured where contributing is the norm. Toward that end, everyone who participates in education and outreach activities must be learning—scientists and engineers will learn about education; educators and students will learn about science and engineering.

Evaluation: Rigorous program evaluation will be a critical hallmark for all education and outreach components. Programmatic refinements will be driven by evidence. Extensive data across multiple dimensions (e.g., student growth in content knowledge, improved disposition, teacher changes in classroom practice, etc.) will be gathered, and these data will undergo careful analysis to establish connections between interventions and impacts.

Dissemination and Replication: The successes in education and outreach that are accomplished at Homestake DUSEL will be greatly leveraged if programs ultimately become portable and replicable. As noted above, Homestake DUSEL is distant from major cities and it will not be feasible for most United States citizens to visit. To achieve the profound impact on science education that the Homestake Scientific Collaboration envisions, the documentation and dissemination of lessons-learned will be especially crucial. DUSEL staff, visitors and users will author and publish papers in scholarly journals, post reports online, and be ever vigilant to identify pieces that might be transferable and to support field-testing within new contexts.

4 Homestake Project Goals and Requirements

The Homestake project goals are primarily determined by the scientific roadmap for the facility and, in the first phase of DUSEL, by our proposed DUSEL Initial Suite of Experiments selected from the science and research topics delineated by the NSF S-1 Process [12]. The path to establishing the Initial Suite of Experiments to be included in the DUSEL Major Research Equipment and Facilities Construction (MREFC) application will ultimately require input and review by national review committees, as well as negotiations with funding agencies, including the National Science Foundation, the Department of Energy, and other agencies such as Department of Homeland Security and NASA. Though the MREFC proposal will be submitted separately and later, the scientific program must be considered now, because the fundamental properties of the host facility will influence the choice of experiments. The type of rock, size and capacity of the facility, and interferences and limitations imposed by potential shared uses need to be assessed. The experiments, in turn, influence the facility infrastructure, management, and operations requirements. In all the world, the Homestake site has unique advantages in high-quality siting of an impressive suite of scientific experiments and uses; Homestake DUSEL is designed to meet, and in most cases exceed, the S-1 requirements.

Central to our proposal for DUSEL is that the selection and development of the facility will be driven by the science. In our case, this will evolve from ongoing efforts at Homestake, initially funded by the State of South Dakota. The process of determining the scientific and educational uses for this "Homestake Interim Laboratory" has helped tremendously in establishing DUSEL's science requirements. Homestake Interim Laboratory is providing required underground space for scientific uses, and represents the first multi-disciplinary research facility of its kind

Under this state funding, we have established the functions necessary to

- solicit users with calls for Letters of Interest (LOIs),
- from the resulting response to the call, gather specific facility and operations requirements and collect them into a requirements database based on specific experimental proposals,
- evaluate the scientific proposals and match them to the facility, and
- establish preliminary roadmaps with reasonable estimates for timescales, depth and size requirements, and other facility requirements.

This ongoing work provides a head start on providing the required elements for the NSF-supported DUSEL facility.

4.1 The Homestake Interim Laboratory's Early Implementation Program

The closure of the Homestake Mine was announced in 2000. The mine was then prepared for closure and abandonment. This included a thorough cleanup and inspection by the U.S. Environmental Protection Agency through the South Dakota Department of Environment and Natural Resources. This inspection confirmed that the closure conformed to environmental and safety regulations. The facility was capped and sealed in 2003 and efforts were taken by Homestake Mining Company to preserve much of the infrastructure for subsequent use as an underground laboratory.

After capping, pumping of the natural inflow of water ceased and water began to accumulate. Flooding would reach the 4850 Level and its associated infrastructure in ~ 2008 if no action were taken. To preserve the site for DUSEL, the Authority is undertaking actions to reenter the facility, reestablish safe access, and install pumps to preserve the 4850 Level, including rehabilitating the Ross and Yates shafts and conveyances, reestablishment of utilities, and establishing sumps and pumps to expel water.

To achieve these necessary preservation goals, the State was required to obtain title to the facility. An agreement in principle between Homestake Mining Company and the Authority led to the Property Donation Agreement [13] shown in Appendix A6. The State subsequently passed all the necessary legislation and funded a plan to convert the Homestake mine into an interim scientific facility down to the 4850 Level, with funds sufficient to operate the basic facility infrastructure for five years. A summary of the legislation [4] is included in Appendix A3. The resulting Authority-funded Homestake Interim Laboratory, with major developments on the surface and the 4850 Level, serves as the starting point for Homestake DUSEL.

The Authority and the Homestake Scientific Collaboration undertook a study to outline a science program that would be likely to benefit from facilities on the 4850 Level and that would fit within their operating resources. This program in advance of DUSEL is called the Early Implementation Program and will include physics, earth science, engineering and education. Infrastructure for the Early Implementation Program will be funded, initially and primarily, from Authority-controlled resources now totaling $116M.

Having obtained the resources necessary for the conversion and operation of Homestake, the Authority, working with the Homestake Principal Investigators, issued a call for Letters of Interest on 1 November 2005. The solicitation for scientific and educational uses of Homestake, concentrated on, but was not limited to, the Homestake Interim Laboratory at the 4850 Level. Some 85 responses were received. These Letters of Interest span the disciplines of earth science, physics, education and outreach, engineering, biology, and homeland security.

A scientific Program Advisory Committee was established jointly by the Authority and the Homestake Principal Investigators. This standing committee's charge was to evaluate the Letters of Interest and establish recommendations for an Early Implementation Program of the highest scientific quality; to assist in planning for the reentry and rehabilitation of the facility; and to advise on staging the development of the Homestake facility. The Early Implementation Program comprises a phased path into DUSEL's Initial Suite of Experiments. To evaluate the Letters of Interest, the Program Advisory Committee heard presentations at the February 2006 workshop in Lead, South Dakota and held subsequent deliberations on conference calls and in face-to-face meetings. The collection of Letters of Interest, the membership of the Program Advisory Committee, evaluation criteria, committee charge, and final report are available through the Homestake Portal http://www.lbl.gov/nsd/homestake/ [14]. The Program Advisory Committee report [15] is included in Appendix A7.

The recommendations of the Program Advisory Committee and the shape of the Early Implementation Program are based on additional interactions between the Letter of Interest proponents and the Authority to optimize the requirements and match them to Homestake resources and capabilities. Following the first solicitation for Letters of Interest and the Program Advisory Committee report, we negotiated with several proposed experiments that are strong candidates to be included in the DUSEL Initial Suite of Experiments, or which would provide key infrastructure elements to DUSEL. We have developed or are in the process of developing Memoranda of Understanding between these collaborations and Homestake. Several of these users represent R&D work for major experiments. Several Memoranda are with technologically advanced experiments that will be ready for deployment in the coming years. The Early Implementation Program will include world-class physics, earth science and engineering endeavors integrally linked to education and outreach efforts centered at Homestake.

The Early Implementation Program will focus on the Homestake Interim Laboratory, primarily on the 4850 Level, the drifts connecting the Yates and Ross shafts, associated surface facilities included in the transfer and additional levels identified by the earth sciences community as being of particular interest.

The Early Implementation Program provides an opportunity to obtain time-critical data from Homestake while the facility is being reopened, including studies of the impact of flooding on the rock and living organisms—a rare and one-time-only opportunity to obtain knowledge that would otherwise be lost. Additionally, experiments benefiting from early access will develop techniques and prototypes so that they can rapidly produce scientific results as part of the DUSEL Initial Suite of Experiments. In particular, several of the physics experiments fit into this category. Several experiments require low background counting facilities and the development of ultralow background materials. A program to develop these screening facilities is included in the Early Implementation Program. Development will continue with access to the 300 Level in the early stages of DUSEL, where low activity materials can be produced for several collaborations.

In the following sections we present roadmaps for the disciplines and experiments expressing interest in DUSEL for both early and long-term utilization of the facility. The progression for many includes an initial component in the Early Implementation Program, an expansion into the DUSEL Initial Suite of Experiments, and subsequent development in later phases of DUSEL.

Several disciplines or experiments were not well suited to be included in the Early Implementation Program (requiring significant additional research and development); some of these are included in the DUSEL Initial Suite of Experiments, assuming the development can be completed in the pre-DUSEL years.

A few experiments will involve significant investment and development, requiring a commitment on a national scale. For these experiments, initial engineering and design steps are accommodated in the Early Implementation Program or initial phases of DUSEL while the cases for these experiments are developed and the experiments undergo further refinement and review. The Early Implementation Program permits this refinement and review to occur without a significant schedule penalty.

4.1.1 Program Advisory Committee Report

Following accepted practice at both accelerator and non-accelerator laboratories around the world, we formed a Program Advisory Committee composed of outside scientific experts to judge and aid in the formation of an Early Implementation Program of the highest scientific quality. The Homestake Program Advisory Committee was asked to review the Letters of Interest received prior to the announced cut off date. The committee was composed of Professors Frank Sciulli, Columbia, and Derek Elsworth, Pennsylvania State University, co-chairs; Sookie Bang, South Dakota School of Mines and Technology; Derric Iles, South Dakota Geological

Survey;, Ed Kearns, Boston University; Josh Klein, University of Texas; Bill Marciano, Brookhaven National Laboratory; Harry Nelson, UC Santa Barbara; Chris Neuzil, U.S. Geological Survey; Bill Pariseau, University of Utah; Charles Ruch, South Dakota School of Mines and Technology; and Hank Sobel, UC Irvine.

The Program Advisory Committee developed a first draft of the science program for the Homestake Interim Laboratory recommendations to assist with the plans to rehabilitate the mine and to be included in the Conceptual Design Report submission in June 2006. The Committee considered infrastructure limitations and facility limitations in crafting their recommendations for the Homestake Interim Laboratory. While the initial Program Advisory Committee report focused on the Homestake Interim Laboratory, they considered and provided advice on longer-term roadmaps for Homestake.

In addition to the written Letters of Interest, we hosted an open meeting for the Program Advisory Committee where all the proponents were invited to present short papers on their proposals. The slides from these presentations were then posted at the Homestake Portal [14]. The presentations were videotaped and are viewable from the web at http://linnproductions.com/clients/homestake/ [16]. The Program Advisory Committee held several conference calls and a face-to-face meeting prior to drafting their report on 12 May 2006.

We anticipate issuing approximately annual calls for Letters of Interest. The Program Advisory Committee will be requested to provide additional assistance in reviewing requests for occupancy at Homestake and in developing Homestake's scientific programs. We include, below, conclusions and remarks by the Program Advisory Committee in presenting our DUSEL Initial Suite of Experiments. We envision this process will continue, perhaps in an expanded fashion, for Homestake DUSEL.

4.2 DUSEL Initial Suite of Experiments

The proposed Homestake DUSEL Initial Suite of Experiments encompasses many fields, disciplines and essentially all the efforts discussed in the S-1 report. We anticipate that many experiments will benefit from initial research and development phases in advance of the main experimental efforts. The research and development activities and deployment schedules are based upon the Letters of Interest, presentations to the Program Advisory Committee, and recommendations of the Program Advisory Committee. Many of the experiments will require additional input from the funding agencies and community planning processes. However, our inclusion of these experiments in our DUSEL Initial Suite of Experiments reflects the capacity of Homestake and our ability to accept experiments in a staged and evolutionary manner.

We present in Figure 4.1 a summary of the Early Implementation Program and DUSEL Initial Suite of Experiments proposed for Homestake, along with the approximate scheduling of the experiments and their depth requirements. This figure is representative of the expansive and diverse DUSEL Initial Suite of Experiments program, an aggressive timetable, and the approximate infrastructure requirements for Homestake's proposal. The full schedule and infrastructure requirements are discussed in subsequent chapters of this Report.

4.2.1 Particle and Nuclear Physics

In general, particle and nuclear physics experiments require well-shielded underground laboratories with substantial overburden to reduce cosmic rays and cosmic ray spallation products. These experiments frequently require excellent personnel access to the experiments.

In several cases these experiments benefit from the low concentrations of uranium and thorium in the surrounding rock and from radon-reduced air provided to the experiments.

4.2.1.1 Dark Matter

Perhaps the greatest problem in studying the universe is that we can only see about five percent of the material and energy in it [17].

The evidence is compelling that the matter-energy density of the universe is close to unity (in units of the closure density—that is, we need further theory and observation to learn whether it will expand indefinitely or, in the very long term, cease expansion and begin falling back in on itself.) Of that density, only ~5% or less can be attributed to matter composed of ordinary baryons—the kind of matter that we normally see and interact with. The majority of the remainder is made up of “dark matter” (~22%), which neither emits nor absorbs electromagnetic radiation but does have gravitational interactions, and “dark energy” (~65%), of whose properties we presently can only speculate.

The evidence for this belief that something (in fact, a great deal of it) must be there, even though we have not been able to observe it directly thus far, comes from a wide range of astronomy and astrophysics experiments, including studies of galaxy rotation curves, galactic clusters, gravitational lensing, large scale structure, cosmic microwave background radiation, Type Ia supernovae, and Big Bang nucleosynthesis. Taken together, these data provide the basis for a consistent cosmological interpretation. Within that cosmology, other properties can be attributed to the dark matter.

One property is that it is composed of particles that interact through the weak nuclear force. A significant population of these particles, often referred to as WIMPS (weakly interacting massive particles) is expected to be in our own galaxy, and therefore should be amenable to direct detection as the solar system moves amid it. This cosmological evidence is complemented by evidence from experiments and theory (e.g., supersymmetry) in elementary-particle physics that such particles should exist. Searching for and understanding WIMPS has emerged as one of the most important experimental programs in particle physics, astrophysics and cosmology.

These fields, which one thinks of as operating at radically different scales as well as with different research methods, have found tremendous common ground in recent decades; indeed, the search for the direct detection of dark matter is intimately connected and complementary to new particle searches at the soon to be operating Large Hadron Collider.

This is how we arrived at the rather counterintuitive idea that key answers to some astrophysics and cosmology questions may be found in deep underground research facilities rather than on mountaintops or in outer space. The evidence that we seek comes to us in the form of particles rather than light. Underground, we can improve the odds that particles will interact within the view of detectors, and we find quiet backgrounds against which to detect them.

Direct detection experiments for dark matter present extreme technical demands. Very low count rates are expected, and the recoils in the detector will be of very low energy (a few keV), so the experiments require low background environments and sensitive new detector technologies. Present limits have been set by using detectors of modest size (a few kilograms) with novel experimental techniques based on cryogenic crystals or liquids. Expectations of theoretical cross

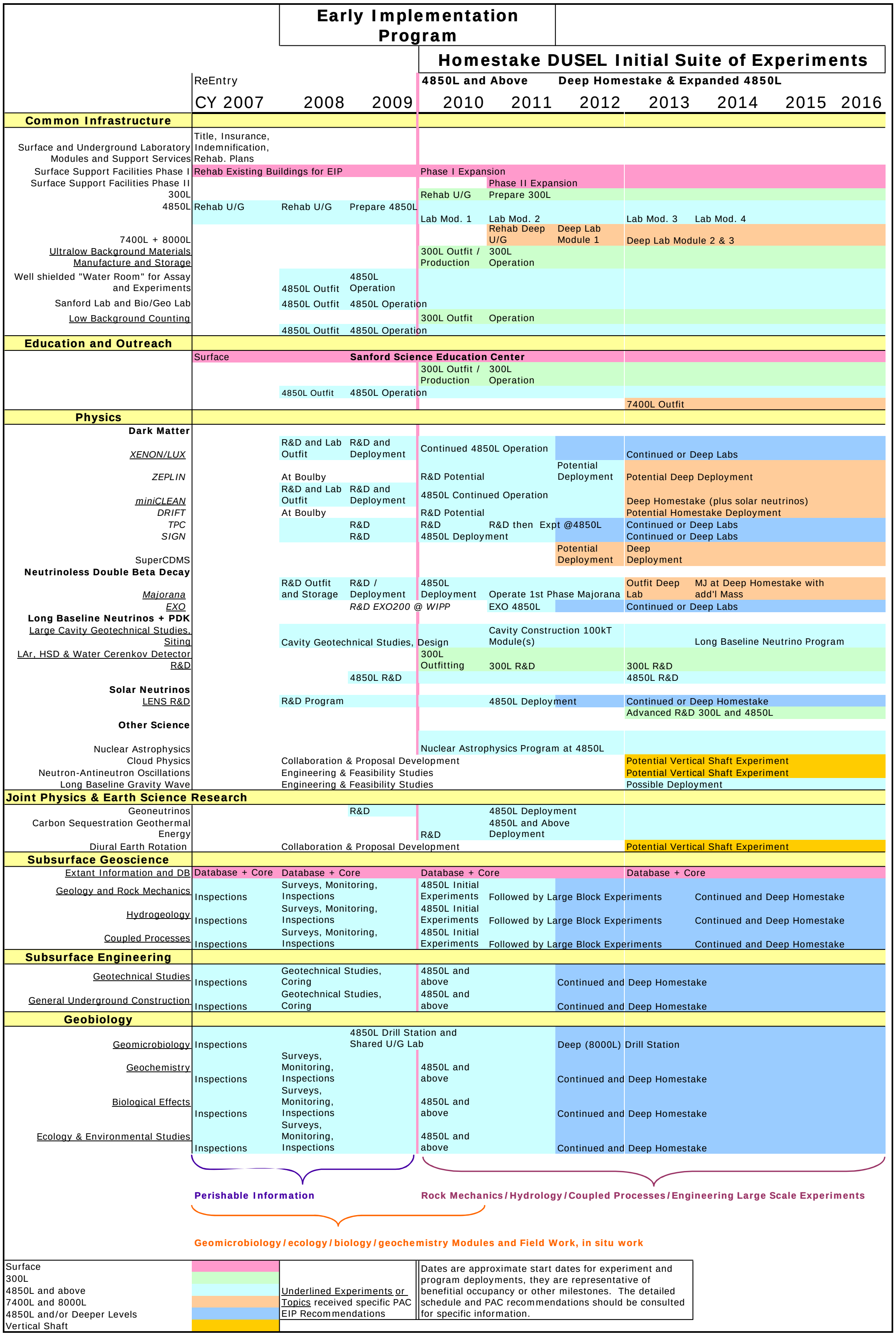


Figure 4.1 The Timeline of Homestake's Early Implementation Program and Proposed DUSEL Initial Suite of Experiments

sections are as low as 10^{-46} cm^2 (that is, the odds that they will interact with something are very small) so we must build detectors that are not only sensitive but also much larger. To achieve this, research and development will be needed in both detector and low background technology. A summary of the recent progress by several experiments is presented in Figure 4.2.

Because of several unique features, Homestake is poised to provide excellent facilities for dark matter programs, providing results on a time scale much faster than previously envisioned by the particle physics community. Among the Letters of Interest for dark matter searches considered by the Homestake Program Advisory Committee are seven (LOIs: 22, 48, 56, 58, 59, 63, 72) that need space and support facilities for either research and development or experimental operation or both. In terms of their readiness for research and development, maturity of technique, or depth requirements, they represent a full range of needs. Therefore an evolving plan for dark matter experimentation would fit well into the sequence of the phased development planned for Homestake. Here we cite some examples for the Early Implementation Program, DUSEL Initial Suite of Experiments, and longer-term future experiments at various depths and scales.

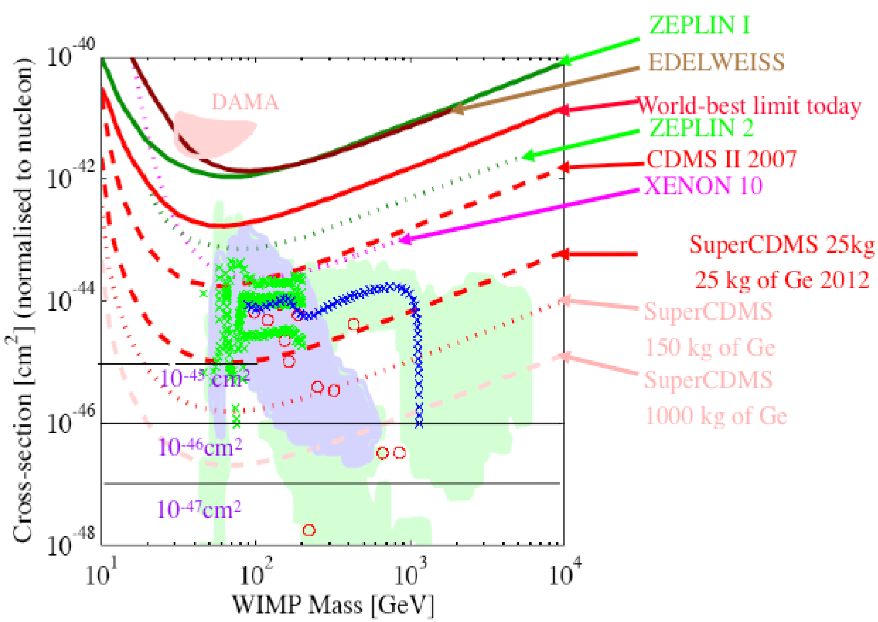


Figure 4.2 Dark Matter Detector Sensitivities for Proposed Experiments. Figure Courtesy of the CDMS collaboration

For the Early Implementation Program at the 4850 Level, the Program Advisory Committee considers two projects particularly suitable in terms of their present stages of development: XENON and miniCLEAN. XENON-10, presently successfully operating as a two-phase liquid xenon detector in Gran Sasso, wishes to expand to the next stage of much larger versions and at a depth greater than is available at Gran Sasso and with the expectation to go deeper at a later stage. Preliminary designs exist for a water shield for either XENON-100 or for a 500kg version (LUX) using the existing neutrino cavern at 4850 Level where Nobel laureate Ray Davis performed pioneering research; use of this cavern saves time as well as expense for excavation and lead-poly shielding. miniCLEAN is at an earlier phase of research and development but, if successful, could rapidly develop into a first operating stage using either liquid argon or neon as the detecting medium. For research and development, miniCLEAN would require less space than XENON-100 or LUX and, as cryogenic liquid techniques, both experiments would share many support facilities. If successful, miniCLEAN and the XENON-10 successor would be candidates for expansion to deeper levels at Homestake.

For the DUSEL Initial Suite of Experiments, in addition to XENON-100/LUX and miniCLEAN, which would be strong candidates, Super-CDMS could also be included. Super-CDMS, a U.S.-Canadian collaboration, was not included in our Early Implementation Program because of the Super-CDMS collaboration's stated preference for carrying out its first phase at SNOLAB. At this stage there could also be several candidates for research and development on emerging techniques, for example, SIGN and TPC, both judged by the Program Advisory Committee to have interesting potential. The former is a high-pressure neon modular detector and the latter a high-pressure gas mixture time projection chamber expected to have track direction sensitivity. The Program Advisory Committee has emphasized that the laboratories being prepared at the 4850 Level be extensive enough so that space should not be an issue if any or all of the above experiments prefer to locate there.

The longer term and/or greater depth candidates would include all of the above experiments, if successful, either to exploit discovery or to improve limits with larger scale, better shielded detectors. At this stage, two additional experiments from the Letters of Interest should be included. These are the ZEPLIN-I, II and DRIFT experiments, currently located at shallow depth (Boulby). ZEPLIN-I, II are successfully operating two-phase xenon detectors, and DRIFT is a low pressure Time Projection Chamber (TPC) aiming for the unique ability to sense WIMP direction. Both have expressed the intention that, should they desire to construct a new device of significantly improved sensitivity for their technique, they would prefer and require one of the deepest levels at Homestake. The indirect detection of WIMPs should also be mentioned as part of a longer-term program. If and when large advanced detectors suitable for proton decay, long-baseline neutrino work, supernovae or solar neutrinos became operational; they too could search for evidence of products from WIMP annihilation in the Sun or the galactic halo. All of the above mentioned experiments are currently under consideration by the Department of Energy/National Science Foundation panel, Dark Matter Scientific Assessment Group (DMSAG), for inclusion in the Roadmap for the future U.S. program in direct detection.

Homestake is especially well suited for dark matter search experiments. Initial assay of the Yates formation (the host rock unit of the proposed 4850 Level and 7400 Level laboratories) indicates that it is an order of magnitude lower in uranium and thorium than typical granite found at other sites including the Canadian Shield, the Rocky Mountains, and the Cascade Range. This is important because the decay of U and Th results in a background of high-energy gamma rays and neutrons from fission and alpha reactions; Homestake would be a particularly quiet place for the detector. Homestake plans to provide a source of radon-reduced air specifically for experiments that are sensitive to airborne concentrations of radon (and radon-decay daughters), thus reducing another troubling source of radioactive backgrounds.

Homestake will develop facilities at several levels. Of particular value is the drive-in access for Homestake DUSEL at the 300 Level. This is probably essential to the dark matter and other experiments requiring the use of low activity materials. Such materials can be processed in well-separated processing facilities using techniques such as electroformed copper refinement. Adequate supplies of materials low in cosmic-ray activation products can be stockpiled at this level. (Refinement of these materials frequently involves sizable chemical processing modules using caustic and acidic solutions. Separating main experimental programs from such chemical processes is a distinct advantage for the facility.) Materials processed at the 300 Level can be transported directly to all levels in the facility without bringing them to the surface, since the 300 Level has a horizontal underground connection to the Ross Shaft and thence other levels.

Detector components could be put together in special assembly areas benefiting from the reduced cosmic ray backgrounds.

Homestake plans on establishing in-house state-of-the-art low background counting facilities on-site to assist with the development of these experiments. Several dark matter experiments would use Homestake's Large Water Room for deployment.

4.2.1.2 Neutrinoless Double Beta Decay

With strong recent evidence that neutrinos have mass and that they transform (oscillate) between flavor states, further questions about fundamental properties of neutrinos have gained prominence. Most notably: What are the actual masses of the three neutrino states? Is the neutrino its own anti-particle (is it "Majorana in nature")? What is the mass ordering (hierarchy) of the neutrinos? What is the exact nature of neutrino mixing? Do neutrino oscillations exhibit CP violation? Of these questions, the first three are addressed by neutrinoless double beta decay ($0\nu\beta\beta$) experiments.

Neutrinoless double beta decay experiments have been reviewed, and their importance affirmed by several prominent studies [18]. Three experiments were selected by the Neutrino Scientific Assessment Group (NuSAG) for funding and given a high priority: CUORE, EXO, and Majorana (see Figure 4.3). All three of these experiments have prepared proposals. The U.S. Department of Energy has given Critical Decision Zero to $0\nu\beta\beta$ experiments in both High Energy and Nuclear Physics. The APS Study and NuSAG report both recommend a phased approach for $0\nu\beta\beta$, with increasing detector mass and specific goals for each phase of the experiment [19]. If necessary, detector masses on the ton-scale may be required.

Of these three experiments, Homestake Interim Laboratory has received Letters of Interest from both EXO (LOI-49) and Majorana (LOI-61). (CUORE is primarily an Italian experiment to be based in Gran Sasso.) The phased approach to the experiments matches the development plans for Homestake. The EXO experiment will be phased into various technology steps. The first stage, EXO200, will consist of 200kg of enriched ^{136}Xe and is currently funded. This phase will focus on measuring the two-neutrino double beta decay mode in a Xe-filled Time Projection Chamber and is scheduled for deployment at the Waste Isolation Pilot Plant (WIPP). In parallel with this deployment, the EXO collaboration plans on developing ion-identification methods to single out the daughter product from $0\nu\beta\beta$ and to subsequently enlarge the detector to ~ 1 ton scale. EXO200 is already on track for deployment in New Mexico and is not being considered for the Early Implementation Program. The second stage of EXO is appropriate for Homestake's DUSEL Initial Suite of Experiments. The 4850 Level provides adequate shielding from cosmic rays for EXO. The experiment, assuming EXO200 is successful and the ion-identification program matures, would be a strong candidate for Homestake's dedicated physics facility with deployment in the time frame of 2010-2012 and within the initial phases of Homestake DUSEL.

The Majorana experiment, an excellent candidate for the Early Implementation Program, proposes to develop an array of isotopically enriched ^{76}Ge semi-conductor detectors. The arrays of 57 detectors would each comprise approximately 60 kg of germanium. The long history of germanium detector and the use of mature segmentation technology promise to provide additional handles to identify and reject backgrounds. This experiment, as well as several dark matter searches, requires the development of ultra-pure materials, especially copper, and extensive low radioactive contamination screening facilities. Work could begin immediately on the copper production facilities, as well as low level screening. The initial deployment of the first Ge module could begin towards the end of the Early Implementation Program. The low background screening, copper manufacturing and initial stages of the Ge experiment would all be strong candidates for research and development funding in the next several years.

The Program Advisory Committee gave a very strong endorsement of the science and the two Letters of Interest for EXO and Majorana, as well as the suitability of Homestake to site them in Early Implementation Program, DUSEL Initial Suite of Experiments and the longer term. The Program Advisory Committee also recommended providing material fabrication and storage space underground. As Majorana develops into subsequent phases and requires additional shielding, it would be moved to lower campuses in Homestake. This move would not be required until after ~2012. The 300 Level or a similar near-surface facility would be well-suited for the copper refinement, purification and storage, low background screening and underground storage. The ease of "drive-in" access for these chemical processes is desirable and would produce rapid progress in the near future. These capabilities would very likely be shared with other experiments. Neutrinoless double beta decay projects could produce some of the first physics results from DUSEL.

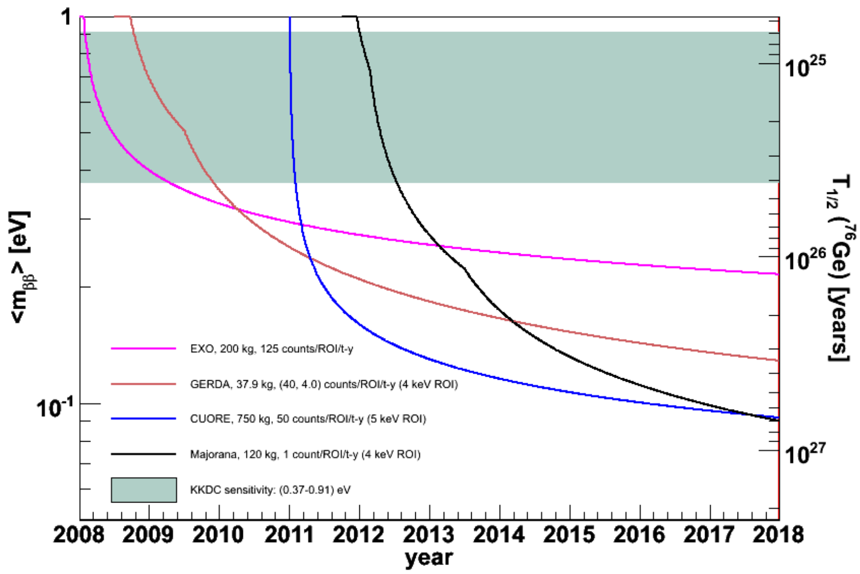


Figure 4.3 Majorana Neutrino Mass Sensitivity for Proposed Neutrinoless Double Beta Decay Experiments. Figure courtesy of the Majorana Collaboration

Neutrinoless double beta decay experiments are also well suited to Homestake. Similarly to the Dark Matter experiments, neutrinoless double beta decay experiments will benefit from the low activity rock and the radon-reduced air supply. Majorana would be a major occupant of the 300L laboratory for the refining of its copper components. The 300 Level assembly area, with its excellent access, and reduced cosmic ray flux would be an ideal site for much of the detector pre-assembly and detector characterization and initial calibration. Materials processed at the 300 Level can be transported to all levels in the facility via an underground connection to the Ross Shaft without bringing them to the surface.

4.2.1.3 Solar Neutrinos

At the core of the "Standard Solar Model" (SSM) are four key assumptions. The first is that the luminosity of the Sun as determined from photon flux matches consistently with the luminosity as determined by the neutrino flux (presently known experimentally only to within 20-30%).

The second is that the Sun is basically in hydrostatic equilibrium. The third, that the heavy elemental abundances at the surface of the Sun are present at the center. The fourth is that neutrino mixing through the Mikheyev-Smirnov-Wolfenstein (MSW) effect correctly explains the observed solar neutrino fluxes on Earth.

All four of these assumptions will be tested with the next generation of detectors, designed to accurately measure the remaining >90% of the solar neutrino flux not yet directly seen. Beyond being a test of today's theories, this round of experiments has exciting discovery potential. The first solar neutrino experiment was designed to measure the fusion model of the Sun, but unexpected deviations eventually led to a fundamentally different understanding of neutrinos. The recent four-division American Physical Society neutrino study consequently made the development of a low-energy solar neutrino detector one of its three executive recommendations.

These detectors will directly observe the low-energy proton-proton reaction neutrino flux, and the ^{7}Be flux is expected to be measured in the near future. At the anticipated event rate, the physics of the MSW mechanism would be confirmed and assumptions of the SSM tested. Deviations could indicate other sources of energy in the Sun, non-equilibrium solar evolution, possible dark-energy influence, resonant spin flavor precession, an unexpected importance of the carbon-nitrogen-oxygen (CNO) cycle, or several other possibilities. By measuring both charged-current and elastic-scattering reactions, the presence of sterile neutrinos could be revealed and better values of the neutrino mixing matrix extracted.

Since these detectors require a low-background environment, DUSEL is a natural home and would greatly facilitate their realization. Current elastic-scattering scintillator experiments in Italy (Borexino) and Japan (KamLAND) are measuring the ^{7}Be flux. Experiments discussed for Homestake DUSEL to measure the pp flux are LENS, CLEAN, HERON, MOON, TPC, SIGN and potentially others.

LENS (LOI-4) is a charged-current experiment, and is illustrative of the high-quality spectral information achievable with this method. Due to its triple-coincidence tag, the dominant background activity of the indium target material can be handled and only a moderate depth of ~2000 mwe is required. While extensive physics can be achieved by taking ratios of several energies, this experiment requires an independent overall calibration to obtain absolute efficiency. A 4% pp measurement should be achievable in five years with a 125-190 ton detector (8% indium by weight).

Several elastic-scattering experiments could provide the required counterpart measurement. These experiments have the advantage of larger rates and a well-known cross section, but suffer from less spectral information, lack of a coincidence signature and the need to be deep underground. CLEAN (LOI-56, including the miniCLEAN concept for dark matter) and HERON (not an Letter of Interest at this time) are cryogenic scintillation detectors, making use of their ability to have low intrinsic background.

The CLEAN concept involves liquid Ne and a wavelength shifter on the surface of the container where phototubes are mounted. Event positions can be reconstructed via the luminance distribution at the surface. HERON makes use of both the scintillation light and electrons liberated in liquid helium by ionizing radiation to reconstruct the energy and position within the fiducial volume, and to reject events that have multiple interaction sites, such as Compton interactions. TPC (LOI-63) proposes to explore development of a large gaseous Time Projection Chamber, which could have directional sensitivity to neutrino elastic scattering at energies above

100 keV in the pp spectrum. SIGN (LOI-72) is developing an array of high-pressure neon drift/scintillation tubes which could be utilized on the high energy solar neutrino flux via coherent neutral current scattering by the neon nuclei. Designed primarily for dark matter, its other goals include also solar and supernovae neutrinos. Finally, LOI-64, a high-current ion accelerator project, proposes to measure small cross sections relevant and important to the fusion reactions that take place in the Sun (see Sec. 4.2.1.5, Nuclear Astrophysics). These experimental techniques are presently in different stages of development, so they are not yet expected to be considered as full-scale candidates for Early Implementation Program. Nevertheless, the Program Advisory Committee has strongly endorsed research and development utilizing Homestake. We have included an active nuclear astrophysics program in our DUSEL Initial Suite of Experiments.

In general, solar neutrino experiments will directly benefit from the Homestake site in ways similar to the neutrinoless double beta decay and dark matter experiments. The lower activity of surrounding rock and low-radon air are particularly favorable aspects of this proposal. As an example, miniCLEAN, following its campaign of dark matter experimentation, is intended to evolve into a solar neutrino detector. It would then require greater depth to avoid spallation in the neon target by muons; The Homestake site is ideally adapted to accommodating the full sequence of required depths from Early Implementation Program to DUSEL within the same facility. The facilities at the 300 Level are of particular interest to solar neutrino experiments for the creation and/or storage of low-activity materials prior to their use in construction of larger versions in order to reduce cosmogenic radioactivity created in them earlier when on the surface; this will be an easily accessible common-use facility for detector preparation and commissioning.

4.2.1.4 Large Multipurpose Detector, Long Baseline Neutrinos, Proton Decay and Astrophysical Neutrinos

A large underground detector with an active mass greater than 100 kt could become a key *shared physics research facility* for the future U.S. particle, nuclear and astrophysics research programs. A sensitive large detector with appropriate technical capabilities will address questions of fundamental importance, such as nucleon decay and matter-antimatter asymmetry amongst neutrinos. The detector will also serve as a facility for continuously observing natural sources of neutrinos and cosmic rays. All these tasks are active *simultaneously*.

Homestake received two Letters of Interest and subsequent inquiries for consideration as potential programs for long baseline neutrino and nucleon decay physics. The Letters of Interest represented the two leading technology types being considered worldwide for constructing appropriate detectors: 100-1000kt water Cherenkov (LOI-8) and 100kt liquid argon tracking (LOI-52). While acknowledging the present uncertainties associated with the setting of policy for the entire U.S. particle physics program, the Program Advisory Committee emphasized and strongly endorsed the long term scientific significance of large detectors for this physics. Further, the Committee affirmed the suitability of Homestake's 4850 Level.

The large detector must have a mass in excess of 100 kt to have significantly greater statistical reach to search for nucleon decay and to collect enough neutrino interaction events from accelerator-based neutrino beams with very long baselines to measure oscillation parameters with greater precision. The detector needs to have a low energy threshold (< 5MeV) and good energy resolution to detect supernovae and solar neutrinos. It should have good pattern recognition, timing and particle identification capability to distinguish electrons from muons and pions. To exploit the full scientific potential of such a detector, it will have to be located deep underground to shield it from cosmic-ray background. Currently, only three technologies–water Cherenkov, liquid argon time-projection, and liquid scintillator–have been proposed to meet these requirements.

4.2.1.4.1 Physics Goal of Large Multipurpose Detector

There is now an abundance of evidence that neutrinos oscillate among the three known flavors ν_e, ν_μ, ν_τ, indicating that they have masses and mix with one another. Indeed, modulo an anomaly in the LSND experiment, all observed neutrino oscillation phenomena are well described by 3 generation mixing, which is described by 2 mass squared differences (Δm^2_{32}, atmospheric and Δm^2_{21}, solar), 3 mixing angles (θ_{12}, θ_{23}, θ_{13}) and a phase (δ). Atmospheric neutrino oscillations are governed by mass squared difference $\Delta m^2_{32}=m^2_3-m^2_2$ = +/- 2.5 10^{-3} eV^2 and mixing angle $\theta_{23}\sim 45^o$; findings that have been confirmed by accelerator generated neutrino beam studies at Super-Kamiokande and MINOS. As yet, the sign of Δm^2_{32} is undetermined. The so-called normal mass hierarchy, $m_3 > m_2$, suggests a positive sign, which is also preferred by theoretical models. However, a negative value (or inverted hierarchy) can certainly be accommodated and if that is the case, the predicted rates for neutrino-less double beta decay will likely be larger and more easily accessible experimentally. Resolving the sign of the mass hierarchy is an extremely important issue. In addition, the fact that θ_{23} is large and near maximal is also significant for model building. Measuring θ_{23} with precision is highly desirable.

In the case of solar and reactor neutrino oscillations, one finds $\Delta m^2_{21}=m^2_2-m^2_1$= 8x$10^{-5}$ eV^2 and $\theta_{12}\sim 32^o$. Again, the mixing angle is relatively large (relative to the analogous Cabbibo angle $\sim 13^o$ of the quark sector). In addition, Δm^2_{21} is large enough, compared, to Δm^2_{32}, to make long baseline neutrino oscillation searches for CP violation feasible and in fact likely to yield positive results, i.e., the stage is set for a future major discovery (CP violation in the lepton sector).

Currently, we know nothing about the value of the CP violating phase $\delta \sim (0 < \delta < 360^o)$ and only have an upper bound on the as yet unknown mixing angle θ_{13} ($< 13^o$) or $\sin^2 2\theta_{13} < 0.2$. Knowledge of θ_{13} and δ would complete our determination of the 3 generation lepton mixing matrix and provide a measure of leptonic CP violation via the Jarlskog invariant.

$$J_{CP}^{Leptonic} = (1/8) \sin^2\theta_{12} \sin^2\theta_{13} \sin^2\theta_{23} \cos\theta_{13} \sin\delta$$

which could easily turn out to be much larger (with above parameters current limit is $J_{CP}^{Leptonic}$ <0.05 $\sin\delta$) than the analogous quark degree of CP violation $J_{CP}^{Quarks}\sim 3\text{x}10^{-5}$. Based on our current knowledge and future goals, the DUSEL based neutrino program should include:

1. Completing the measurement of the leptonic mixing matrix
2. Study of CP violation,
3. Determining the values of all parameters with high precision including $J_{CP}^{Leptonic}$ as well as the sign of Δm^2_{32}
4. Searching for exotic effects perhaps due to sterile neutrino mixing, extra dimensions, dark energy, etc.

Among those future neutrino physics goals, the search for and study of CP violation is of primary importance and should be our main objective for several reasons outlined below. A single large detector at Homestake coupled to a Super Neutrino beam from FNAL or BNL can address all of these fundamental issues in neutrino physics.

CP violation has so far only been observed in the quark sector of the Standard Model. Its discovery in the leptonic sector should shed additional light on the role of CP violation in nature. Is it merely an arbitrary consequence of inevitable phases in mixing matrices, or something deeper? Perhaps, most important, unveiling leptonic CP violation is particularly compelling because of its potential connection with the observed matter-antimatter asymmetry of our universe, a fundamental problem at the heart of our existence. The leading explanation is currently a leptogenesis scenario in which decays of very heavy right-hand neutrinos created in the early universe give rise to a lepton number asymmetry which later becomes a baryon-antibaryon asymmetry via the B-L conserving 't Hooft mechanism of the Standard Model at weak scale temperatures.

Leptogenesis offers an elegant, natural explanation for the matter-antimatter asymmetry; but it requires some experimental confirmation of its various components before it can be accepted. Those include the existence of very heavy right-handed neutrinos as well as lepton number and CP violation in their decays.

Direct detection of those phenomena is highly unlikely; however, indirect connections may be established by studying lepton number violation in neutrinoless double beta decay (see Section 4.2.1.2) and CP violation in ordinary neutrino oscillations. Indeed, such discoveries will go far in establishing leptogenesis as a credible, even likely, scenario. For that reason, neutrinoless double beta decay and leptonic CP violation in neutrino oscillations are given very high priorities by the particle and nuclear physics communities.

Designing for CP violation studies in next generation neutrino programs has other important benefits. First, the degree of difficulty to establish a credible CP violation experiment and determine $J_{CP}^{Leptonic}$ is high but currently tractable. It requires an intense proton beam of about 1—2 MW and a very large detector (250-500kt Water Cherenkov or its equivalent). Such an ambitious infrastructure will allow very precise measurements of all neutrino oscillation parameters as well as the sign of Δm^2_{32} via ν_μ disappearance and ν_μ to ν_e appearance studies. It will also provide a sensitive probe of “New Physics” deviations from 3 generation oscillations, perhaps due to sterile neutrinos, extra dimensions, dark energy or other exotic effects.

In addition to its accelerator based neutrino program, a well-instrumented very large detector offers other physics discovery opportunities. Assuming that it is located underground and shielded from cosmic rays, it can push the limits on proton decay into modes such as $p \rightarrow e^+ p^o$ to 10^{35}yr sensitivity or beyond, a level suggested by gauge boson mediated proton decay in supersymmetric GUTS. Indeed, there is such a natural marriage between the requirements to discover leptonic CP violation and see proton decay (i.e., an approximately 500 kt water Cherenkov detector) that it could be hard to imagine undertaking either effort without being able to do the other. Other significant topics for which such a large detector would also have additional physics capabilities are: a) Atmospheric neutrino oscillations with very high statistics. b) The predicted relic supernova neutrinos left over from earlier epochs in the history of the Universe, a potential source of cosmological information. c) Study of the 100,000 or so neutrino events from a supernova in our galaxy (should there be one during the operating period; they occur about every 30 years). The physics potential of a very large underground detector is extremely rich. The fact that in the same device it can also be used to determine (or bound) leptonic CP violation and measure all facts of neutrino oscillations gives such a facility outstanding discovery potential.

4.2.1.4.2 Feasibility of Large Detectors in Homestake

Of the technologies discussed, water Cherenkov appears to be the one capable of reaching 100 kt of fiducial mass or greater with minimum technical development. The advantage of a water Cherenkov detector is that it is a proven technology that has been perfected over several decades. It is also a technology that allows very large dynamic range in energy for event detection (from 5MeV to 50GeV) and therefore it is a natural choice for taking advantage of a low background deep environment. Water Cherenkov detectors are in operation in Japan (Super-Kamiokande with a total mass of ~50 kt) and in Canada (the Sudbury Neutrino Observatory, or SNO, with 1 kt of D_2O and 7.5 kt of H_2O). A large detector based on cryogenic liquid argon time projection technology has also been proposed for Homestake DUSEL. Such a detector has very high energy resolution and event recognition capability. This capability will allow such a detector to have high sensitivity to modes such as $P \rightarrow K^+$+anti-ν, which has final state particles that are difficult to measure. The key technical problem for a liquid argon detector is an engineering design that will allow scaling up from the current size of about 600 t, achieved in ICARUS in the Gran Sasso laboratory, to 100kt, needed for the next generation experiment. An additional technical challenge is locating this cryogenic noble gas in an underground environment. LOI-52 proposes to resolve these issues.

The Homestake DUSEL laboratory offers a number of advantages for the science and technology discussed above. They are: 1) the ability to make reliable, well-costed designs for large caverns (with total volume of >100,000 m^3) at great depths (4850 Level) in the Yates formation, 2) the likelihood of the timely implementation of large detectors if they are built modularly, and 3) sufficient distance from both Fermilab (1300 km) and Brookhaven National Lab (2540 km) for a long baseline neutrino experiment. These three features of the Homestake DUSEL site make it unique compared to any other potential detector site in the world (For reference, the distance from Homestake to CERN is 7370 km and to JPARC in Japan it is 8240 km). A preliminary plan (LOI-8) with an estimate for cost and schedule for a 300 kt water Cherenkov detector was presented to the Neutrino Scientific Advisory Group (NuSAG) on 20-21 May 2006 [19]; this presentation and a detailed document is available through the Department of Energy NuSAG committee and the U.S. long baseline study [20]. Figure 4.4 presents the 100 kt detector cavity concept. The plan as presented calls for simultaneous construction–over a 5-year period–on 3 detector modules of approximately 100 kt each so that considerable economy can be obtained. The total capital cost will depend on the aggressiveness of the schedule (a more aggressive schedule will mean lower total cost) and the total number of photomultiplier tubes needed for the technical requirements. The detector construction plan benefits greatly from the Homestake Early Implementation Program, during which extensive coring can be done at the 4850 Level site to make detailed engineering layout and estimates for the caverns.

The Program Advisory Committee was very support of the long baseline neutrino program based either on water or liquid argon technology.

Accelerator Neutrino Beam Feasibility: As part of a US long baseline neutrino study effort [20] a new accelerator produced Super Neutrino beam from FNAL, which is considered the primary choice for a source, has been examined. A previous design for a beam from BNL also exists. Here we focus on FNAL as the primary source. A conceptual design has been reviewed recently at FNAL to increase the total power from the 120 GeV Main Injector (MI) complex after the Tevatron program ends [21]. In this scheme, protons from the 8 GeV booster, operating at 15 Hz, will be stored in the recycler (which becomes available after the shutdown of the Tevatron program) while the MI completes its acceleration cycle, which can be shortened from the current 2.2 sec to 1.33 sec. In a further upgrade the techniques of momentum stacking using the antiproton accumulator, and slip-stacking using the recycler will raise the total intensity in the MI to ~1.2 MW at 120 GeV.

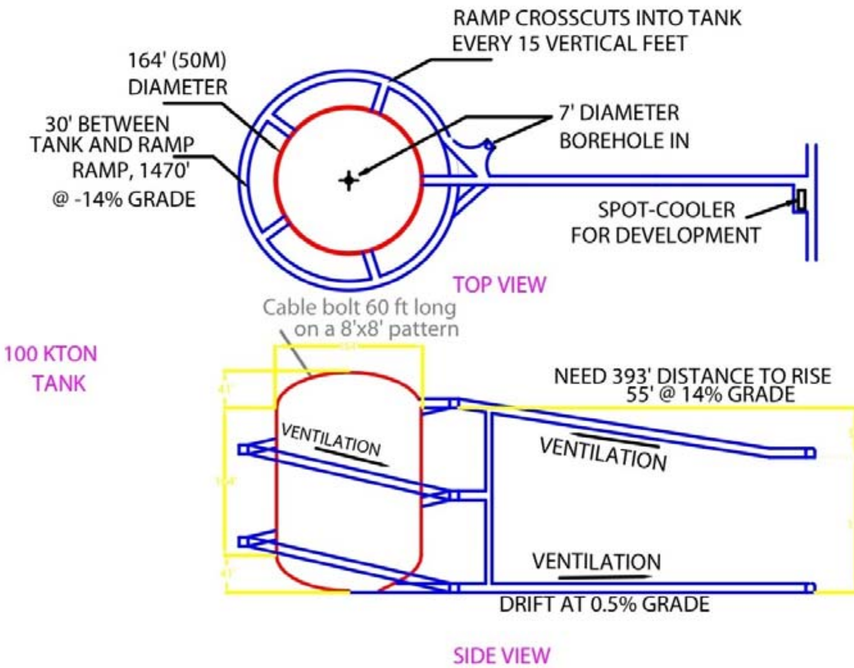


Figure 4.4 Preliminary design for a single cavity with nominal dimensions of 50m diameter and 50m height to house a 100kt mass water Cherenkov detector. The upper ramp for access to the cavity will be at the 4850 Level. A preliminary stability analysis for 50m span/height was conducted by the proponents.

Separately, a new neutrino beamline that exploits the current FNAL infrastructure and takes full advantage of the planned intensity upgrade, from FNAL to Homestake has been examined. The preliminary conclusion is that a new beamline from the Main Injector to Homestake could be accommodated on the FNAL site and the cost and schedule could be estimated with good confidence based on an appropriate extrapolation of the NuMI beamline construction experience. The new beamline would have a downward angle of 5.84^{o} (distance of 1289km to Homestake). The decay pipe of such a beamline can be up to 400m in length and 4m in diameter. Such dimensions, including an on-site near detector to calibrate the beam, can lead to a very intense and flexible facility. The intensity and spectra from such a beam have been reported as part of the US long baseline study. The neutrino baselines are presented in Figure 4.5.

4.2.1.4.3 Neutrino Measurements Using Accelerator Produced Beams

Summary of Simulation Studies and Projected Sensitivity:

With 120 GeV protons, the full power of 1.2 MW from the FNAL Main Injector can be obtained with annual yield of $>10^5$ events for total fiducial mass of 300 kt at Homestake. The choice of proton energy depends on optimization of signal versus background, which is not completed yet. At lower energy of 30-60 GeV with power level of 1 MW the event yield will be ~50,000/year in the absence of oscillations. These numbers will be modified by a factor of ~1/2 by oscillations and produce dramatic oscillated energy spectra that can be used for precise measurements. We

are still investigating the best use of these spectra and the tradeoff between event rate and backgrounds from high energy neutrinos for the best CP violation results. We have used the event yield from ~30 GeV protons and a simulation of energy resolution and backgrounds in a water Cherenkov detector. The sensitivity to various parameters is shown in Figures 4.6, and 4.7.

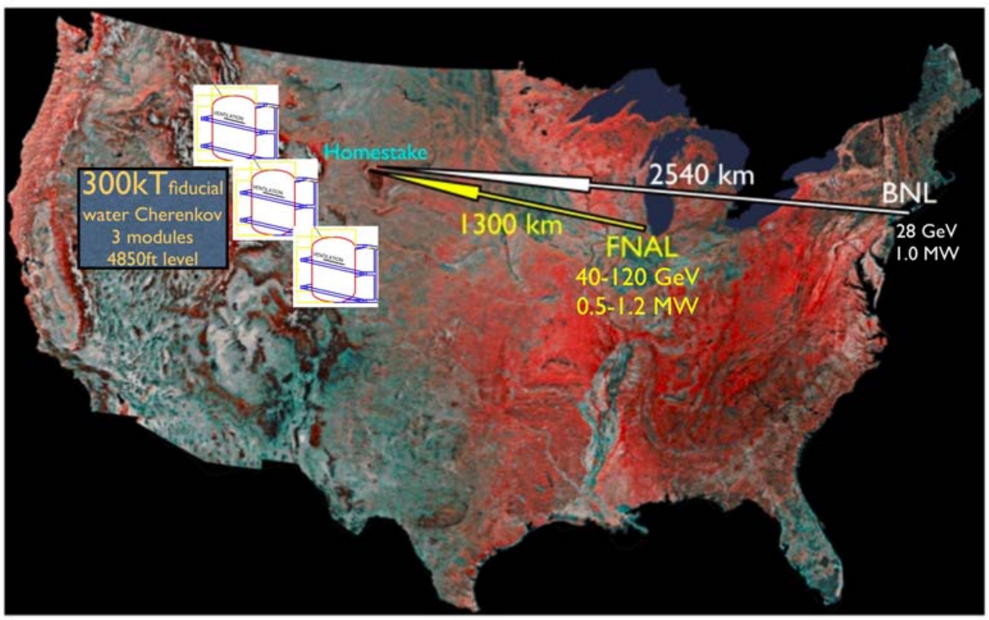


Figure 4.5 Possible long baseline accelerator neutrino experiment using a large detector at Homestake. The important parameters of the experimental setup are shown. A beam from both BNL and FNAL has been examined.

In these figures the currently known oscillation parameters are assumed to be at their central values with their respective errors. The results shown include the effect of varying the known parameters within their errors. The results are robust with respect to these variations and that is one of the strengths of performing this measurement with a longer baseline and a new beam that is designed to have signal events from a wide range of oscillation phases.

Although much optimization still needs to be performed, it is clear that with the planned size of the detector and beam intensity the sensitivity for $\sin^2 2\theta_{13}$ could be <0.005; the mass hierarchy and CP violation could be determined to values of $\sin^2 2\theta_{13}$ of about 0.008 also. Figure 4.6 shows the precision with which a joint determination of δ and $\sin^2 2\theta_{13}$ can be made with no ambiguities at the end of a decade long program of measurements. It should be observed from

Figure 4.6 that the precision on δ does not depend strongly on the value of $\sin^2 2\theta_{13}$, which is the leading variable in the rate of $\nu_\mu \rightarrow \nu_e$. This observation coupled with preliminary conclusions from the U.S. long baseline study shows that even if the current round of smaller scale experiments succeeds in finding a non-zero value of θ_{13}, a program of the scale we are considering here will be needed to determine CP violation in the leptonic sector. Observation of a non-zero θ_{13} will, in fact, add considerable motivation to this program.

It should be remarked that along with the crucial measurement of CP violation, it has been shown that the dramatic spectrum of muon and anti-muon neutrino disappearance will lead to a very precise (<1%) measurement of Δm_{32}^2, $\sin^2 2\theta_{23}$ and strong limits on CPT violation. Such a program of measurements alone is highly valued.

Separately, it has been shown that if one could build a 100 kt liquid argon time projection chamber [22] it would have similar reach to these parameters as in Figures 4.6 and 4.7. Such a detector would have better signal efficiency and background rejection capability to compensate for the factor-of-3 lower detection mass.

4.2.1.4.4 Improved Search for Nucleon Decay

Current status of experimentation

The "classical" proton decay mode, $p \rightarrow e^+\pi^0$, can be efficiently detected with low background. At present, the best limit on this mode ($\tau_{1/2} > 5.4\text{x}10^{33}$ yr, 90% CL) comes from a 92 kt-yr exposure of Super-Kamiokande. The detection efficiency of 44% is dominated by final-state π^0 absorption or charge-exchange in the nucleus, and the expected background is 2.2 events/Mt-yr.

The mode $p \rightarrow$ anti-νK^+, is experimentally more difficult in water Cherenkov detectors due to the unobservable neutrino and the fact that the kaon energy is below the Cherenkov threshold. The present limit from Super-Kamiokande is the result of combining several channels, the most sensitive of which is $K^+ \rightarrow \mu^+\nu$ accompanied by a de-excitation signature from the remnant ^{15}N nucleus. Monte Carlo studies suggest that this mode should remain background free for the foreseeable future. The present limit on this mode is $\tau/Br > 2.2\text{x}10^{33}$ yr (90% CL).

Requirements for the next decade

Since the lifetime of the nucleon could range from just above present limits to many orders of magnitude greater, progress in this search must be measured logarithmically: increases in sensitivity by factors of a few are insufficient to motivate new experiments. Thus, continued progress in the search for nucleon decay inevitably requires much larger detectors. The efficiency for detection of the $e^+\pi^0$ mode is dominated by pion absorption effects in the nucleus, and cannot be improved significantly. An order of magnitude improvement in this mode can only be achieved by running Super-Kamiokande for 30-40 more years, or by constructing an order of magnitude larger experiment.

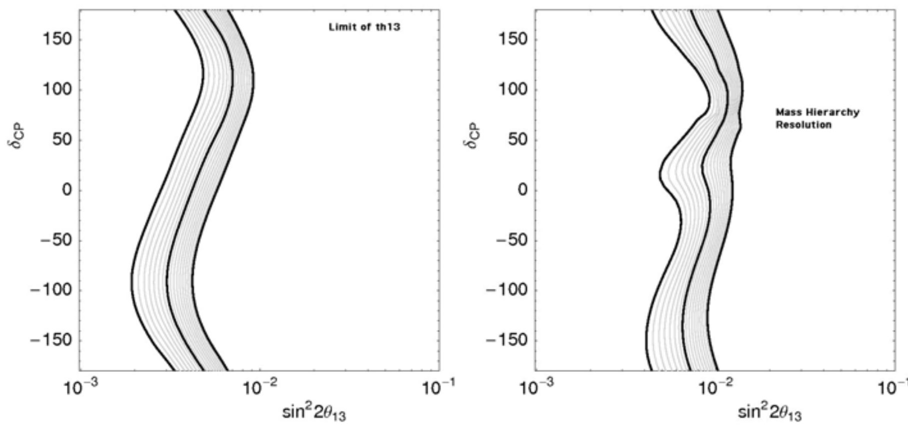


Figure 4.6 Discovery reach for $\sin^2 2\theta_{13}$ with 300 kt of fiducial mass and 5 yrs of neutrino and antineutrino running each (left). The right hand plot demonstrates the potential for resolving the mass hierarchy issue. The sensitivity is shown as a function of the CP phase δ and $\sin^2 2\theta_{13}$. The discovery can be made on the right side of the curves with confidence level of 3, 4, and 5 sigma from left to right (dark curves) [23].

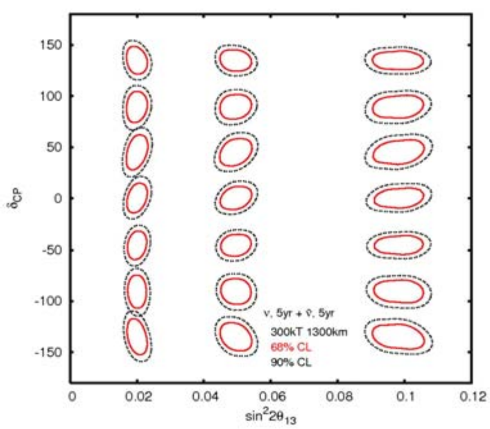


Figure 4.7 Simultaneous determination of δ (degrees) and $\sin^2 2\theta_{13}$ after neutrino and antineutrino running. The precision at 68% and 90% C.L. is shown at 21 different points. At each point we simulated the spectrum and calculated the measurement precision using the statistics of the simulated signal and background and the assumption of 10% systematic errors on the background [24].

The decay modes of the nucleon are also unknown and produce different experimental signatures, so future detectors must be sensitive to most or all of the kinematically allowed channels. Moreover, the enormous mass and exposure required to improve significantly on existing limits (and the unknowable prospects for positive detection) underline the importance of any future experiment's ability to address other important physics questions while waiting for the proton to decay.

New facilities under consideration

A variety of technologies for discovery of nucleon decay have been discussed. Of these, water Cherenkov appears to be the only one capable of reaching lifetimes of 10^{35} years or greater. Cooperative, parallel studies of a future underground water Cherenkov proton decay experiment are underway in the U.S. and Japan. The proposed designs have fiducial volumes which are about 20-25 times the Super-Kamiokande fiducial volume.

Other techniques, for instance liquid argon or scintillation, have been discussed and may have significant efficiency advantages for certain modes that are dominant in a certain broad class of SUSY theories. Liquid argon time projection chambers potentially offer very detailed measurements of particle physics events with superb resolution and particle identification. Liquid Argon feasibility will be demonstrated in the near future with the operation of a 600-t ICARUS detector. If expectations are correct, it should have a sensitivity that is equivalent to a 6000-ton water Cherenkov detector in the $p \rightarrow$ anti-$K^+\nu$ mode. The liquid scintillator approach is being explored with the 1-kt KamLAND experiment. It should also have enhanced sensitivity to this mode by directly observing the K^+ by dE/dx and observing the subsequent $K^+ \rightarrow \mu^+\nu$ decay.

Performance and feasibility

Detailed Monte Carlo studies, including full reconstruction of simulated data, indicate that the water detectors could reach the goal of an order of magnitude improvement on anticipated nucleon decay limits from Super-Kamiokande. With sufficient exposure, clear discovery of nucleon decay into $e^+\pi^0$ would be possible even at lifetimes of (few) x10^{35} years, where present analyses would be background-limited, by tightening the selection criteria. For instance, with a detection efficiency of 18%, the expected background is only 0.15 events/MT-yr, ensuring a signal:noise of 4:1 even for a proton lifetime of 10^{35} years. A water Cherenkov detector would also provide a decisive test of super-symmetric SO(10) grand unified theory by reaching a sensitivity of a (few) x 10^{34} years for the ν K^+ mode. The search for n-nbar oscillation is another test of baryon non-conservation. While this is not one of the favorite predictions of conventional SUSY grand unification, this process, taking place in the nuclear potential, can reach an equivalent sensitivity to baryon non-conservation of 10^{35} years.

As we have discussed, a much smaller liquid argon could do particularly well on the mode anti-νK^+ as the efficiency could be as much as 10 times larger than that in the water Cherenkov detectors due to the extraordinary pattern recognition capabilities. Due to this, a single observed event could be powerful evidence for a discovery. The $e^+\pi^0$ mode however would be limited by the smaller size of these detectors.

R&D towards more efficient and economical photo-detection – both improved conventional photo-multiplier tubes and more novel technologies – while not required to build the next large detector, could reduce its cost and increase its physics reach considerably. This R&D should be strongly supported, since it will also benefit a host of other research efforts.

4.2.1.4.5 Astrophysical Neutrinos

The detector technologies will lead to enhanced detection and study of neutrinos from natural sources such as the Sun, Earth's atmosphere and lithosphere, and past and current supernova explosions. There may also be previously unsuspected, natural neutrino sources that appear when the detector mass reaches the hundreds of kilotons scale. The liquid scintillator technique is of particular note here because it could allow the detection of low energy antineutrinos from Earth's lithosphere.

Solar neutrinos have already been observed in the Super Kamiokande and SNO detectors [25]. If the large detector concepts discussed here result in construction of the underground experiment, it may become possible to increase the observable event rate enough to clearly observe spectral distortion in the 5 to 14 MeV region. One could also measure the as yet undetected hep solar neutrinos (with end point of 18.8 MeV) well beyond the ^8B endpoint (~14 MeV). These measurements would require a comprehensive understanding of the detector systematics and energy resolution, but a better determination of the solar spectrum as well as detection of the day-night effect with high statistics would represent a significant advance in the evolution of solar nuclear physics measurements.

The observation of supernova neutrino events in a large neutrino detector of the type being discussed in this proposal is straightforward and has historical precedent. The SN 1987A supernova was seen by *two* large water Cherenkov detectors (11 events in Kamiokande-II (total mass~3 kt) and 8 events in IMB (total mass~7 kt)) that were active in proton decay searches at that time [26]. The predicted occurrence rate for neutrino-observable supernovae (from our own galaxy and of order 10 kiloparsecs distant) is about 1 per 30 years, so events will be very rare [27]. However, the information from a single event, incorporating measured energies and time sequence for tens of thousands of neutrino interactions, obtained by a very large neutrino detector, could provide significantly more information than has ever been obtained before about the time evolution of a supernova. In addition to obtaining information about supernova processes, the small numbers of SN1987a neutrino events have been extensively used to limit fundamental neutrino properties. Supernova processes continue to have very high interest because of the recent detection of the acceleration of the rate of expansion of the universe using type Ia supernovae. Recent work has shown that diffuse neutrino events from past core collapse supernova (which produce neutrino bursts) could be used in to gain independent knowledge on the cosmological evolution parameters [28]. Therefore we regard detection of supernova neutrinos, either as a burst from a single supernova or as a diffuse source from past ones, as a key mission of the DUSEL multipurpose detector.

With some 20-100 times the sensitive mass and, hopefully, a lower neutrino energy threshold (a few MeV), the energy and arrival-time spectra would have statistical power that the earlier detectors could not provide. The uncertainty of obtaining a supernova event may make this research topic insufficient to motivate construction of its own detector. But when this topic is added to the mission of a multipurpose detector, the increased science potential at virtually no additional cost to the integrated program is very compelling.

Finally, we note that there may be galactic sources of neutrinos that are of lower energy and greater abundance than the ultra high-energy neutrino sources to be explored by detectors such as the ICECUBE Cherenkov detector now being constructed deep under the Antarctic ice sheet by an NSF sponsored collaboration. Galactic neutrinos have a natural source in inelastic nuclear collisions through the leptonic decays of charged secondary pions. This source is expected to be of comparable intensity and energy distribution to the high-energy photons that are born from neutral pion decays in the same collisions [29]. Such neutrino sources, currently not detectable with Super-Kamiokande, could be seen by a megaton-class neutrino detector that runs for several decades.

4.2.1.4.6 Depth Requirements

Accelerator Neutrino Physics: A careful examination of the cosmic ray background shows that despite the strong rejection against cosmic ray induced background using the short (~10 μ s) time window keyed to the accelerator pulse, it is better to deploy a long baseline detector deep underground to minimize risk. Homestake allows such a possibility in a natural way.

We have calculated the approximate muon rate within the accelerator pulse in a 50m diameter/height cavity at various depths from the surface in Table 4.1. For Table 4.1 we have assumed one year of running corresponding to 10^7 accelerator pulses of 10μs length. For this same period of running with the anticipated beam intensities we expect ~10,000 events. To cleanly extract the beam related events without resorting to extensive pattern recognition and an active veto, the minimum depth required is ~1000 mwe. At the proposed depth of 4850 ft (4100 mwe) the Homestake detectors will have very little difficulty extracting beam related events. As we show in the next section this depth is also essential for non-accelerator physics and to maintain future potential of the detector facility.

Table 4.1 Rate of Cosmic Ray Muons within the beam pulse time (10μs) per year (10^7 pulses) for a 50 m diameter/height detector as a Function of Depth

In-time cosmic ray muons/yr	Depth (mwe)
5×10^7	0 (surface)
4230	1050
462	2000
77	3000
15	4400

The design impact of cosmic ray backgrounds on a water Cherenkov detector and a liquid argon TPC has been examined by the U.S. long baseline study group [20]. Their conclusion is that it is not possible to operate a very large (100 kt) water Cherenkov detector at or near the surface. For a fine grained detector, such as a liquid argon TPC, it is possible to collect data on the surface within the beam spill with good efficiency and reject most cosmic rays, but the ultimate rejection needed (10^8 for muon cosmic rays and 10^3 - 10^4 for cosmic ray photons) has yet to be demonstrated. For both technology choices a deep location (perhaps at a more modest depth for a liquid argon TPC) reduces the risk and increases the potential for physics. We should remark that Homestake also allows for the possibility of deploying a detector at shallower depths, including the 300 Level. Combination of the shallow and the truly deep capability will allow flexibility for future planning.

Non-accelerator Physics: It is difficult to consider all possible non-accelerator physics channels and precisely predict the optimal depth for either a water Cherenkov detector or a liquid argon detector. The answer could easily depend on various technical assumptions, but it is certainly clear that depth comparable to or larger than present detectors (Super-Kamiokande is at 1000 m of rock or 2700 mwe depth) is needed for the best physics reach.

Nucleon decay modes can be divided in two classes: ones where all of the nucleon energy is visible and ones where some of the nucleon energy escapes detection. In the first case, the total momentum and energy balance is a powerful tool for background reduction, and it has been often argued that these modes should require only modest shielding from cosmic rays. Indeed, most of the decay modes that were searched for in the first generation detectors required only modest depth. IMB operated successfully at a depth of 2000 feet. However, in a very large water Cherenkov detector, cosmic rays not only produce background, but also reduce the live-time of the experiment by keeping the detector occupied by frequent large energy deposits. If we require live-time to be more than 90%, a shallow depth of few tens of meters appears sufficient. This conclusion does not include consideration of the data rate, which is continuous for non-accelerator physics, and could be unmanageably high near the surface. The requirement of a reasonable data rate (<100Hz of muons) increases the depth required to approximately the Super-Kamiokande depth.

For the second class of nucleon decays in a water Cherenkov detector, a low energy tag from dexcitation photons may need to be used (For example $P \rightarrow$anti-νK^+ with a ~6.3MeV gamma from ^{15}N de-excitation followed by $K^+ \rightarrow \mu^+ \nu$ with lifetime of 12ns). These require low energy thresholds for photons. This is difficult with a background of fast-neutron (spallation products from muons in the detector or in the surrounding rock) induced low energy background events at shallow depths. Nevertheless, since the tagging photon is in-time to the main event (with time window of < 50 ns), one could conclude that these events also may not require much more than Super-Kamiokande depths. A subclass of events is, however, subject to fast neutron backgrounds. As an example of this, the mode ($N \rightarrow$anti-ν anti$-\nu$ ν) can be searched for by observing the de-excitation of the residual nucleus. The proposed Homestake detector depth (~ 4100 mwe) would reduce the muon background by about a factor of 10 with respect to Super-Kamiokande and increase sensitivity to these modes with low visible energy.

For a liquid argon TPC, much higher resolution may permit relaxation of these issues. In particular, the anti-νK^+ mode could be much easier to detect because the kaon could be identified by its energy deposit (dE/dx). Nevertheless, some minimum depth will very likely be necessary to reduce backgrounds from fast neutrons and to reduce the data rate to manageable levels.

For solar neutrinos in a water Cherenkov detector, the important issue is deadtime from spallation induced fast neutron backgrounds. At Super-Kamiokande this deadtime is ~ 20%. To maintain the same deadtime for a much larger detector, depth similar to or greater than Super-Kamiokande (2700 mwe) will be needed. For a liquid argon detector, there could be relaxation of this requirement because the dead volume around a cosmic muon could be better defined by tracking.

For a supernova in our galaxy (10 kpc), the signal level is so large (~10000/sec over a 10 sec burst), that the spallation background at depths as shallow as 500 mwe are manageable. For detection of supernovas in neighboring Andromeda (~750 kpc), however, greater depth (>1300 mwe) is needed. Optimizing depth for diffuse relic supernova neutrino search needs to consider the deadtime loss as well as spallation backgrounds such as ^{9}Li which sequentially beta- and neutron decays. This search may require depths similar to Super-Kamiokande or deeper, even if one could get the enhancement in signal to background from gadolinium loading.

In summary, the driving issues for depth consideration for future large water Cherenkov or liquid argon detectors will be backgrounds to low energy events from spallation products and data rates. If one wants to maintain sensitivity to specific important physics channels such as $P \rightarrow$anti-ν K^+ in a water detector, and solar and supernova neutrinos in either technology, depth in the same range as the current Super-Kamiokande detector is needed. Greater depth will enhance the physics reach of the detector. The depth chosen for the Homestake detector (4850 ft) allows full exploitation of the detector (with only 0.18 Hz cosmic muon rate for each 100kt module) and allows for future possibilities.

4.2.1.5 Nuclear Astrophysics

The Big Bang created the light elements: hydrogen, helium and traces of lithium. All other elements result from nuclear or neutrino interactions in stars. A variety of processes have been identified for different stages of stellar evolution. Initially, lighter elements are processed by nuclear fusion reactions, fusing protons into helium through the pp chain. At later stages, the helium is “burned” into carbon, and subsequently carbon into oxygen, silicon and heavier elements. Nuclear fusion terminates near iron at mass ~60. Heavier elements require sources of additional energy and particles. Supernovae and sequential neutron captures are thought to be responsible for the formation of heavier elements to uranium.

While nuclear fusion takes place at the center of stars at tremendous thermal temperatures, the effective energy of the individual ions is very low, typically below the Coulomb barrier. The reaction rates for these processes are controlled by the rapidly falling Maxwellian spectra of particle energies and the rapidly rising nuclear cross sections dominated by penetration of the Coulomb barrier. The overlap of these processes results in the *Gamow peak* in reaction rates. The center-of-mass energy for the Gamow peak is usually at ~10 keV and the reaction rates are extremely slow. Proper modeling of nucleosynthesis requires good understanding and measurements of these reaction rates. While the general form of nucleosynthesis has been understood for ~50 years, the exact details are only now being approached through measurements performed with underground accelerators and detectors. There remain 10 to 20 reactions that are essential for fully understanding the formation of the light elements.

Measuring these reactions in the laboratory requires extremely stable accelerators, high currents, high detection efficiencies, and the extremely low background rates only available in an underground location with natural shielding amounting to 1000 mwe or more. Recently, a dedicated accelerator facility was commissioned at Gran Sasso. Counting rates in these experiments are typically a few events per month. A measurement of a single cross section can take more than a year of data collection and associated calibration and determination of the systematics. The current facility at Gran Sasso (LUNA) is limited in space and restricted in its ability to mount new experiments. (Many experiments require a unique experimental design.)

In the U.S. there is a growing nuclear astrophysics community interested in pursuing these topics, including JINA at the University of Notre Dame, and efforts at a number of other facilities (Yale, Triangle Universities Nuclear Laboratory, Oak Ridge National Laboratory, and the LBNL 88-Inch Cyclotron). Homestake received a proposal (LOI-64) from a group developing a new high current accelerator to approach the $^{4}He(^{3}He,\gamma)^{7}Li$ reaction. The accelerator will require several years to develop. The initial experimental stages will take place above ground, in Berkeley. This effort does not fit in the time window of the Early Implementation Program, but the current efforts to develop new high current accelerators and significant advances in detector technology, including large arrays of segmented germanium gamma-ray detectors and charged-particle detectors, make this field attractive for the DUSEL Initial Suite of Experiments. We envision an enlarged program beyond this initial experiment. The current Letter of Interest focuses on the $^{4}He(^{3}He,\gamma)^{7}Li$ reaction as their first experiment. Other members of the active U.S. community would be encouraged to join with the authors of this Letter of Interest and develop a more extensive use of Homestake. See, for example, the website at http://www.jinaweb.org/dusel .

The Program Advisory Committee recommended that an underground high current ion accelerator, such as proposed in LOI-64, could form part of a high-profile activity at DUSEL providing first-rate scientific advances and also providing a useful and economical complement to larger projects in nuclear physics elsewhere, such as the Rare Isotope Accelerator. It also encourages the proponents and Homestake to work together to develop a plan for deployment of an accelerator into the laboratory at some time after the Early Implementation Program and matched to progress on the accelerator itself. It was also noted by the Program Advisory Committee that small groups, typically university-based, working in this field would significantly benefit from additional research and development funds to advance the development of these experiments and to prepare them for deployment underground.

In Homestake, the 4850 Level is well-shielded and would be a good location for an extensive nuclear astrophysics program requiring low cosmic ray fluxes. The current program at Gran Sasso, LUNA, is seeking a significant expansion and is experiencing competition for the limited floor space there for new accelerators and experiments. A representative of the LUNA collaboration visited Homestake and participated in the DUSEL planning. The availability of large rooms, well-isolated from other experiments sensitive to potential accelerator-produced radioactive fields makes Homestake an excellent location for an extensive North American nuclear astrophysics program. It would benefit from the good access to the 4850 Level with multiple conveyances, redundant power feeds to the underground, and custom-developed ventilation for the laboratory modules. The envisioned high-current, low-energy accelerators would require special attention by the environmental, health and safety program. Homestake's custom-developed EH&S program provides a good basis to coupling the accelerator safety issues to the special requirements for working underground. For the foreseeable future the 4850 Level would be adequately shielded for the p-p and CNO nuclear astrophysics programs. As additional accelerator/detector rooms are required, Homestake has an available footprint to host them.

4.2.2 Geoneutrinos

Neutrinos and anti-neutrinos are produced in many radioactive (beta) decays. The decays of the long-lived radioactive uranium and thorium chains and potassium produce anti-neutrinos with an energy spectrum extending to several MeV. While radiogenic heat production is thought to drive the Earth's mantle convection and cause plate tectonics and earthquakes, alternate hypotheses, including a naturally occurring critical mass of uranium at the core of the earth (georeactor), have been proposed. The observation of terrestrial neutrinos, effectively integrating over substantial volume of the surrounding crust and mantle (dimension ~100 km), termed geoneutrinos, could verify the origins of majority of the Earth's terrestrial heating as originating from radioactive decay in the mantle and crust. The experiment would also confirm or refute the georeactor hypothesis.

Recently the KamLAND experiment [30] in Japan reported the first observation of these geoneutrinos. This measurement was limited by backgrounds caused by the high flux of neutrinos from the nearby nuclear power plants. Additional geological studies indicate that the radiogenic concentrations significantly vary between continental and oceanic crust. A measurement that is clearly from a single region will be critical to solidify these hypotheses of the distributions of radionuclides in the earth. The Homestake site is well separated from reactors. A preliminary estimate concludes that the reactor background deep underground in Homestake would be ~ 7% of KamLAND's. A measurement at Homestake will provide valuable information for future reactor neutrino experiments and may improve the KamLAND results by constraining the geoneutrino backgrounds to their reactor neutrino spectrum.

LOI-71 expresses interest in just such an experimental program. The development of a geoneutrino experiment will require several steps before a proposal can be written and a collaboration developed for an experiment of this scale (~1 kt of detector mass). The collaboration has recently received LDRD funding to pursue Monte Carlo simulation of detector designs, and has requested FY07 funding to perform basic scintillator property measurements. This preliminary work and collaboration building place geoneutrinos out of the scope of the

Homestake's Early Implementation Program; however, these studies would be well suited for research and development during the Early Implementation Program period. A geoneutrino experiment, if adequately developed in the coming years, could be included in the DUSEL Initial Suite of Experiments. If a segmented geometry proves feasible, this is a particularly attractive option for rapid deployment in Homestake.

Measurements of geoneutrinos represent one of the synergistic purely-research-driven opportunities at DUSEL, with significant impact on both the earth science and physics disciplines. While concurring that this is not an Early Implementation Program experiment, the Program Advisory Committee recognized the importance of the science and encouraged the proponents to pursue this goal for inclusion at Homestake in the longer term.

In addition to detecting geoneutrinos, such an experiment would also be able to serve as a sensitive monitor for galactic-supernova neutrinos. It should be noted that the sensitivity to supernova neutrinos would be limited by the mass and be primarily restricted to electron anti-neutrinos, but could be sensitive to other neutrino flavors through elastic scattering if the internal radioactivity were low enough. This latter signal would be a model-insensitive measure of the luminosity and energy of non-electron type neutrinos from a supernova. If the internal radioactivity is adequately controlled and a deep site is selected, this experiment would also be able to monitor p-e-p solar neutrinos. Due to the shallow depth, the p-e-p neutrino signal is swamped by cosmogenic background at KamLAND. Borexino, with its smaller fiducial volume and shallower depth, is primarily aimed at the detection of ^{7}Be neutrinos.

Homestake is a particularly suitable site to host geoneutrino experiments. A modular detector design could be very rapidly deployed in many of the existing rooms in the facility with a minimum of preparation. A larger monolithic detector design would require a large room to be created, but there is ample evidence that the site can support cavities large enough for a 1kt geoneutrino detector. Homestake's ventilation plans and extensive laboratory design enables the necessary air supply and physical isolation of the geoneutrino as may be required for fire safety. Homestake's general position in the middle of the continental crust, far removed from power reactors, presents Homestake with a very low level of background neutrinos.

4.2.3 Biology, Geoscience, and Geoengineering

An aura of mystery surrounds the underground environment because of its paradoxical combination of immediacy and inaccessibility. Society depends on it tremendously for minerals, energy, water, and disposal of wastes. Even researchers on global warming associated with excess atmospheric CO_2 seek solutions to sequester the carbon within the earth. And, of course, much of society's infrastructure is underground, interacting with such disciplines as rock engineering and hydrology. Understanding this environment would inform humankind in using the subsurface more safely and efficiently and protecting it from contamination.

The subsurface is a complex environment, containing a multitude of different scales of heterogeneities and discontinuities as the result of the restless earth responding mechanically and chemically to various forces. Heat from radioactive decay of primordial, long-lived elements is dissipated. Fractures are often the conduits of fluid flow and rock-fluid chemical reactions, but not all fractures flow equally. Why do some flow but not others? Can we improve geophysical imaging technology to "see" underground processes? These are questions that have fundamental economic as well as scientific importance. And perhaps most intriguing of all, and recently in the news, is that deep within the subsurface environment are microbes that call this inner world home – "dark life." Inextricably coupled to physical and chemical processes occurring in this underground environment, dark life can tell us a great deal.

Multidisciplinary research teams are poised to investigate the central scientific questions about geologic processes and life and how they interact in the deep subsurface environment. These studies include those inspired by the economic implications of a site with a long history of mineral extraction, the prospect of finding extreme and exotic life forms, and studies of the fully-coupled earth system - mechanical, hydrological, chemical, biological and thermal – which are relevant to the nation's energy and environment problems. The ability to go *into* the earth provides ground truth for testing hypotheses and developing new methods of geophysical imaging to make the earth transparent.

4.2.3.1 Unique Attributes of Homestake for Earth Sciences and Engineering

The premise of the Homestake Scientific Collaboration is that the former mine offers golden opportunities for meeting the science objectives described by the S-1 document *Deep Science*. There many earth sciences and engineering disciplines can attack the wide range of questions open to study. The overall plan for the geosciences and geoengineering capitalizes on the unmatchable opportunities for access to the volume (more than 30 cubic kilometers!) and types of rock present at the Homestake site. *It may be the only facility in the United States that can accommodate such a wide range of experiments envisioned for an underground laboratory.*

Long-term geoscience and geoengineering experiments, such as those associated with creep monitoring or heating projects, are only possible in a dedicated facility. The absence of production activities at a site whose sole purpose is scientific and engineering research ensures that experiments are installed and maintained without concern for future interference or lack of access. The infrastructure associated with the Homestake Laboratory is unparalleled in terms of both vertical and horizontal dimensions. Having unfettered access ensures that suitable sites are available to a particular project–a tremendous asset. Finally, in many instances, the geosciences require a highly specialized situation where a particular type of environment is found; Homestake DUSEL offers a variety of rock types, degrees of isolation, and depths.

The dedicated Homestake DUSEL is well suited for isolating long-term experiments from interference from mission-oriented or active-mining-related requirements and considerations. The multiple existing levels, separated by ~150 ft, are connected by shafts, winzes, and extensive ramps, so access is excellent. The lateral extent of many levels is over 5 km. Homestake is located in a seismically quiet zone ideally suited for a deep observatory. Earth science studies can start in the upper levels and ramps accessible during the reentry and Early Implementation Program, then proceed to deeper levels during and after the rehabilitation and construction phases for DUSEL. The phased approach is perfectly suited for the depth-dependent interests and anticipated early results in earth studies.

Homestake penetrates a geology that has been folded and locally altered by intrusion of much younger igneous rocks, making it an ideal site for frontier research into the basic factors controlling all subsurface processes in heterogeneous media over a wide range of scales.

Although the Homestake DUSEL site is dominated by metasedimentary rocks, a variety of rock mechanical properties can be found within the sequence. This variety allows experimental programs that require either more ductile rock properties, e.g., the Homestake Formation, or stiffer units, such as the Yates Member of the Poorman Formation. In addition, some portions of the facility were intruded by rhyolite dikes during the Tertiary period, approximately 55 million years ago. These rocks extend through the 8000 Level to the surface and offer additional options for studies in geochemistry, mineralization, and rock mechanics. The extensive infrastructure in the subsurface ensures that experiments requiring three-dimensional access are not restricted to a simple tunnel configuration. From a standpoint of access to the rock volume, the Homestake Laboratory may be the only economically and physically viable option for some of the more ambitious and compelling rock mechanics and heating experiments.

The comprehensive investigations will not be confined to the active laboratories at the 4850 and 7400 Levels, but will make full use of the various rock environments in rock past the 8000 Level. For example, the geomicrobiology and water geochemistry investigations can characterize both shallow and deep micro-ecology within geo-volumes never before available. Working rooms exist at a depth of 8000 ft, and there is proven ability to drill down to 11,000 ft from the 8000 Level. This offers the possibility of geomicrobiology sampling deep enough at great depths to test the limits of life in both time and space. In addition, because Homestake provides vertical access as well as horizontal, it also provides access to older and more isolated strata than most or all other sites likely to be proposed for DUSEL. Indeed, much of the water in the deeper part of the mine has been isolated from the surface for millions of years. This provides a much more interesting habitat for exploring origins of life and biosustainability.

At present there are re-enterable test bores from the surface extending to a depth of 1.5 km. The network of multiple-branched, directionally-drilled surface-based boreholes further expand the spatial extent accessible from underground workings. This degree of access extends to the extensive system of boreholes throughout and adjacent to Homestake that can host monitoring instrumentation as anticipated by the "Transparent Earth" initiative. An important adjunct to the *in situ* access is the full access to more than 20,000 boxes of cores at the Homestake core library covering the immediate laboratory volumes and the surrounding area. This core library was donated to the Authority and will have a significant impact on studies involving mineralogy, petrology, and economic geology. The large library of existing literature and studies of the Homestake rock volume ensures that a very large amount of information and insight is already available about the site, allowing research to begin immediately.

The Homestake hydrological system is not particularly well understood, but offers the opportunity to study fracture flow ranging from the deepest parts of the underground to the surface. The hydrological system has made its importance known by the small, but significant, inflow of water into the 8000 Level through boreholes that were drilled downwards from that level. Although the inflows of water into the underground total only 700 gallons/minute, and much of that is from surface sources, the connection to deep water reservoirs and proximity to larger fracture systems at the intermediate levels opens interesting possibilities for the study of fracture flow, paleohydrology, water geochemistry, and fluid flow in general in the upper crystalline crust of the Earth.

The already close cooperation between the operational arms of the laboratory and the science and engineering research will provide advantages throughout the development of the laboratory. For instance, during the early construction activities, it is anticipated that studies in water geochemistry, microbiological ecology, microseismic investigations, and rock mechanics studies will start as soon as safe working conditions are reestablished. This ensures that both scientific and operational baseline studies are undertaken, providing all-important measurements to compare with conditions that develop during the course of the life of the laboratory. Studies of this sort will provide the operations management for the laboratory with important data as well. For instance, a very ambitious program of large-span excavations to support the physics experiments is slated for the 7400 Level. Detailed measurements of rock mass behavior during and after excavations will allow fundamental improvements in design and construction of long-span caverns, potentially resulting in substantial cost savings, reduced risk, and improved safety.

4.2.3.2 DUSEL Initial Suite of Experiments for Earth Studies

The ongoing process of developing the initial suite of Homestake DUSEL geo-experiments is based on an open solicitation of Letters of Interest submitted by single- and multi-member research teams. More than 60 earth study Letters of Interest were analyzed by the Program Advisory Committee in light of the activities necessary to carry out the Early Implementation Program, and the S-1 inputs for the DUSEL Initial Suite of Experiments. The breadth of interests represented by the more than 60 Letters of Interest emphasize the importance of both the large volumes and great depth of the DUSEL to push the boundaries of earth science and engineering.

The Homestake Scientific Collaboration is an open organization that welcomes innovative research, and the presently established collaborations will continue to grow and mature. Although many of the experimental programs that have been put forward are the product of individuals or small groups, the consolidation of these ideas into cohesive programs has progressed well during the past months. Development of a coordinated experimental program for the experiments was enthusiastically endorsed and promoted by the Program Advisory Committee.

The Program Advisory Committee grouped the earth sciences Letters of Interest around two unifying themes: the study of deep life, and the characterization of complex behavior of the crust. The first addresses fundamental questions regarding origins and evolution of life in an extreme environment, where life-sustaining resources are meager. The second examines the role of the complex interactions of stress, temperature, fluids, chemistry, and biology on the response of the Earth's crust and its fluids at large spatial and temporal extent. This knowledge is necessary for the safe engineering of the very large-span caverns proposed for the parallel physics program. Both deep life and coupled processes have been enduring central themes within the deliberations of the S-1 community.

For the Early Implementation Program and leading to the longer-term suite of experiments, the Letters of Interest were categorized as **Perishable Data**, **Geobiology**, **Hydrology**, and **Rock Mechanics**. The Homestake DUSEL Initial Suite of Experiments for earth studies encompass all *themes* identified by S-1 [31, 32], Appendix A8, and contributing to the establishment of laboratories identified in the EarthLab report [9]. This includes the Surface Laboratories for core, water, gas, and microbial analyses, experiments, and archives; ***Transparent Earth*** with the deep seismic observatory; ***Groundwater*** with the deep flow and paleoclimate laboratory and observatory; ***Rock Deformation*** with the induced fracture and deformation processes laboratory; ***Mineral and Energy Prospecting**, **Coupled Processes*** with the deep coupled processes laboratory; and ***Deep Life*** with the ultra-deep life and biochemistry observatory. Figure 4.8 illustrates the feasibility of the Homestake site to incorporate all these experiments. The S-1 report described a significant set of goals for the geosciences and engineering in an underground laboratory setting, and posed a series of questions that could be addressed in that environment. The Homestake DUSEL earth studies are formulated to directly address some of the "Grand Research Questions" in the solid-earth sciences being developed by NRC for DOE, NSF, NASA, and USGS on origins of earth and life, how the earth works, and the interaction between life and the rock record [33].

Tables 4.2 through 4.4 correlate these goals and questions raised by the S-1 report to the interests shown in the initial Letters of Interest submitted to the Homestake DUSEL. Most of the earth science Letters of Interest propose to start with the Early Implementation Program and evolve naturally into the DUSEL Initial Suite of Experiments, with site selections for localities of longer-term experiments, mainly for coupled process testing in blocks. We discuss Letters of Interest related to Perishable Data and Mineral Geology; the Program Advisory Committee strongly supports these data gathering, assimilation and packaging activities and encourages the Authority to initiate them as soon as is feasible. Care must be taken to ensure that important suites of data are not lost, that the inventorying of core recovers all measurements of likely relevance to the broad suite of users, and that the ultimate mine/laboratory model be easily accessible to the community via electronic open-source access.

In the following three tables, the Letters of Interest are grouped by the S-1 grand challenges of Dark Life, Restless Earth, and Ground Truth, and for collaborations and specific approaches to address the questions and to implement the required tasks [34]. This represents a first step to further organize and encourage formation of multi-disciplinary, multi-institution, cross-cutting, and issue-driven collaborations.

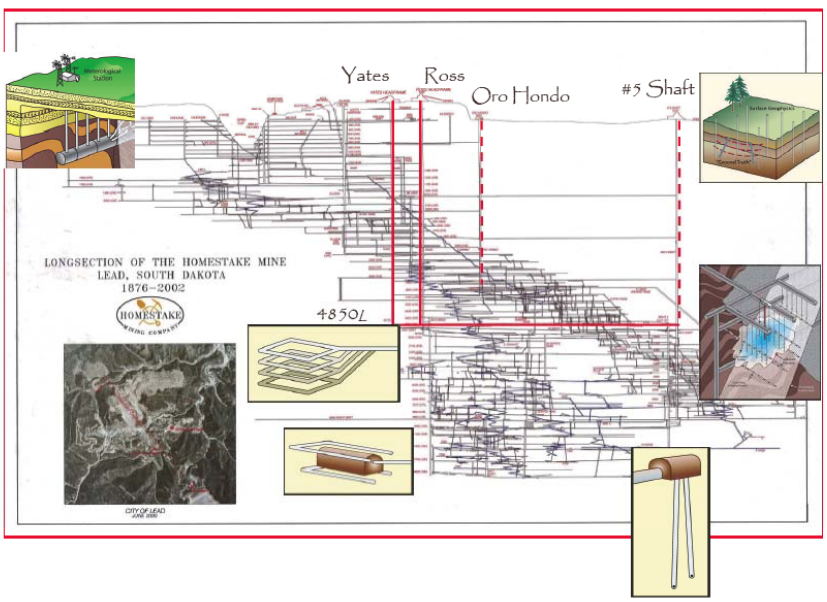


Figure 4.8 Earth Science experiments for Homestake Early Implementation Program leading to DUSEL Initial Suite of Experiments.

Inserts clockwise from upper left represent groundwater recharge studies and surface laboratory processing perishable data, seismic observatory for transparent earth, rock deformation measurements associated with induced fracture, deep boreholes for dark life search, site investigation and geotechnical engineering for large cavern excavation, and coupled block testing ([9] and [31]).

Table 4.2. Dark Life Questions and Geobiology Letters of Interest. See Table 4.3 for additional hydro-geochemical proposals related to geobiology.

Goals/Questions	Collaborations for experiments that will address this issue (LOIs)	Specific approaches to implement required tasks (LOIs)
How do biology and geology interact to shape the world underground?	Ecology/geomicrobiology – LBNL (38); Geomicrobiology on geochemistry, transport, corrosion – Princeton (75, 76, 77); Coupled Process, near surface to deep – Oak Ridge Nat. Lab. (78, 79)	Low radiation on human – Brookhaven Nat. Lab (14); Microbial evolution –U Tennessee (15); Soil, health physics, microbial population – SDSU (29, 30, 32); Microbiological analysis – U. Wisconsin (70)
How does subsurface microbial life evolve in isolation?	(38); Limits of life – New Mexico Tech. (80)	Microbial diversity – SDSMT (53)
Did life on earth originate beneath the surface?	(38); (80)	Autotrophy – SDSU (81)
Is there life underground as we don't know it?	(38); (80)	Bioprospecting – SDSU (28)

Table 4.3. Restless Earth Questions and Geoscience Letters of Interest. See Tables 4.2 and 4.4 for geomicrobiology and geoengineering proposals related to geoscience.

Goals/Questions	Collaborations for experiments that will address this issue (LOIs)	Specific approaches to implement required tasks (LOIs)
What are the interactions between the various processes controlling the subsurface environment?	Coupled process – LBNL (41); Block test of rock failure – Penn. State (55); Hydro/Mechanical - U. Wisconsin (65); (78)	Partitioning between hinges - Montana Tech. (10); Gold mineralization, role of iron, thermal history, breccia evolution, volatile in dikes – SDSMT (18, 20, 21, 44, 68); Faulting and fracture – U. Hawaii (43); Stress-Fluid Monitoring - Freie U. Berlin (60)
Are underground resources of drinking water safe and secure?	Hydrogeology, geochemistry – LBNL (36, 37)	
Can we reliably predict and control earthquakes?	Sensors – UCB (13); Geophysics – LBNL (39); (55)	
Can we make the Earth "transparent" and observe underground processes in action?	(39)	Cosmic Ray – LBNL (42)

Table 4.4. Ground Truth Questions and Geoengineering Letters of Interest. See Table 4.3 for geoscience proposals.

Goals/Questions	Collaborations for experiments that will address this issue (LOIs)	Specific approaches to implement required tasks (LOIs)
What are the mechanical properties of rock?	Mining Engineering - SDSMT (4)	Deformation, scaling, and stress in Yates - U Utah (1, 2, 3); Fracture network - Virginia Tech. (34)
What lies between the boreholes?	(13); (39)	Mapping/surveying-Montana Tech (9); Geological model, mapping - U. Minnesota (45, 46); Mapping – Virginia Tech. (47) Database, acoustic mapping – SDSMT (11, 62)
How does rock respond to human activity?	Rock mechanics geotechnical – LBNL (40)	(1)
How does water flow deep underground?	(36)	Dewatering, hydrological instrumentation, footprint – SDSMT (6, 12, 24)
How can technology lead to a safer underground?	Risk assessment – Virginia Tech. (35); (40)	(1); Robotics – SDSMT (25); Rock Bolting and Backfills - Montana Tech. (67)

4.2.3.3 Geomicrobiology–Dark Life

The Grand Challenge dark life questions and geobiology Letters of Interest are listed in Table 4.2. The integrated geomicrobiology approach can evolve from ecology and environmental studies to the search for life, with potential societal benefits including bioprospecting for useful microbial chemicals, more complete understanding of controls on microbial activity and growth in subsurface environments. In this latter case, the enhanced ability to predict the activity and distribution of microbes in subsurface strata will assist our ability to use these cells in subsurface processes. Such processes include alteration of fluid movement in the subsurface which could be used to manage carbon sequestration, biomining efforts, bioremediation, and repository security. The geochemistry Letters of Interest analyzed in this section are also an integral part of geoscience investigations of Section 4.2.3.4.

4.2.3.3.1 Search for Life

Microbial inhabitants of the deep terrestrial subsurface depend on energy and nutrients from ancient organic matter, inorganic sources associated with the host rocks and associated fluids, and a range of other abiotic sources, such as H_2 from radiolysis and hydrocarbon gases. Microbial populations are typically sparse, isolated in pores, slow growing/respiring, and sometimes starved or resource-limited relative to their surface-dwelling counterparts. The geological isolation of deep subsurface microbial communities elicits questions related to origin and requirements for life, evolution, diversity, coupled biogeochemical processes such as mineral formation and dissolution, as well as constraining limits for life on Earth or beneath the surface of Mars and other planetary bodies. Advances in our understanding of the origins, diversity, distribution, and function of microorganisms in deep, often extreme, subsurface environments will rapidly expand our knowledge of geomicrobiological and biogeochemical processes on Earth and beyond. DUSEL provides a unique opportunity to enhance the concurrent development of increasingly sophisticated tools for reconstructing the relationships among all parts of the Tree of Life.

4.2.3.3.2 Bioprospecting

Bioprospecting and the discovery of novel microorganisms from deep subsurface habitats provide opportunities for developing new pharmaceuticals, processes for biochemical and chiral-specific synthesis, biotechnological applications, environmental remediation and energy production. Deep under the Earth's crust, the diversity of microbes relies upon the variety of nonphotosynthetic biogeochemical processes that allow them to survive and force them to adapt to extreme conditions. Discovering how life persists under the extreme conditions of heat, pressure, lack of water and O_2, salinity, and extreme pH at depth on our own planet can open new avenues for basic and applied research. In general, non-photosynthetic chemoautotrophs are expected to be prevalent in Homestake geologic formations.

4.2.3.3.3 Ecology and Environmental Studies

Human and animal activities, e.g., mule-drawn ore cars, during 126 years at the Homestake Mine have certainly impacted local ecology by introducing a wide range of chemoheterotrophic surface microorganisms and offering unique opportunities to investigate evolution/adaptation. Early research would focus on the transport and adaptation of surface microbial communities to deeper environments. Processes to be investigated include mineral precipitation and dissolution reactions, geochemical evolution of groundwater (both long- and short-term), and bioprospecting for novel traits of indigenous microbial communities, as well as the transport and migration of the cyanide-degrading microbe isolated by the Homestake Mining Company which is used in surface remedial actions. In humid areas of the mine biofilms are apparent, not only on the rocks but also on structural materials containing corroded metals and decaying wood.

4.2.3.3.4 Integrated Geomicrobiology Approach

As DUSEL becomes accessible to researchers, the first attempt in geomicrobiology will be sampling at representative sites of soil, rocks, and groundwater. Multidisciplinary collaboration is essential for drilling and coring rock samples, which will provide critical information on geomicrobiology, geochemistry, geophysics, and rock mechanics. In particular, geomicrobiologists will examine the cores for signature microbes and their metabolic activities utilizing tracers. Access to the 4850 Level will enable detailed analysis of transport and migration of subsurface microbes, microbial adaptation and evolution in ancient sequestered groundwater, ecological genomics and gene transfer, responses to contamination (and to the presence of DUSEL), biofilm formation, function, and relation to fracture transmissivity, groundwater-rock reactions driving ecosystem energy flux (e.g., geogas), and other dynamic factors such as temperature, pressure, seismicity, and time of hydrological isolation.

As DUSEL proceeds to the 8000 Level, where the temperature may reach close to 60° C, it is of great importance to explore deep extreme microbial ecology in localized fractures, boreholes, and coreholes. As flooding at Homestake DUSEL has continued to expand its boundaries below the 5000 Level, it is pertinent to investigate the influence of flooding in the deep environments. There is an indication that "upwelling" below the 8000 Level may exist to limit the zone of influence, as a relative large inflow at the 8000 Level [35]–see Appendix A9–may be associated with the deep borehole to 11,000 ft drilled from the 8000 Level. The prospect of finding ancient bacteria at Homestake depths is very good, as deduced from the recent discovery of an exotic strain of microbes at a South Africa gold mine in a fracture zone at depth of 2.825 km (9268 ft) intercepted by an exploratory borehole into an unmined zone ~100 m above an ore contact [8]. The fracture water is millions of years old, and the microbes survive on nonphotosynthetically derived sulfide and hydrogen, suggesting that the deep crustal biosphere may be energy-rich in a way that can sustain microbial communities indefinitely.

Deep groundwater moves extraordinarily slowly, and microbes on fracture surfaces depend on flow-limited nutrient flux. In the absence of appreciable flow, microbes may also create micro-zones depleted in substrates that can be replenished only by diffusion. Because biomineralization and biogas formation hinder the nutrient flux by closing pore throats, these microniches may go through cycles of growth, steady state, and decay. The appearance of so many of the bacteria and 16S rDNA clone libraries in samples obtained from the deep subsurface hints at a strategy by which organisms in diffusion-limited habitats first grow, deplete their local nutrient supply, and then sporulate or become exquisitely efficient in order to survive. When local nutrient concentrations again become permissive, the spore then germinates and the cycle begins anew. In this situation, it is unknown how or whether spores can germinate or vegetative cells can divide when the environment imposes extreme spatial constraints, such as pore spaces that are only barely larger than the microbial cells themselves.

Deeper levels of DUSEL might have partitioned some areas into discrete zones, where hot, saline and old waters were segregated. Under the influence of fractures with various depths, widths, and frequencies, ancient microorganisms sequestered in these zones might have established distinct evolutionary lineage. Geological samples from greater depths of multiple holes in these segregated areas are therefore expected to provide fundamental information on the presence of life in deep extreme environments and further implication on the origin of life on Earth and limits of life in the biosphere. As an exceptional geomicrobial observatory, Homestake DUSEL will continue to provide unlimited, crucial information on Earth's history and its future path.

One of the abiding mysteries of our existence is the origin of life. Since we have no deep understanding of this problem, we have no way to constrain the time span or circumstances necessary for life to emerge from prebiotic chemistry. However, if we consider the possibility that the emergence of life is a relatively rare event, then either it was repeatedly extinguished during the period of Earth's heavy bombardment or it had a refuge from the surface chaos. This is one of the more compelling reasons to consider the subsurface as the preferred, and possibly essential, habitat for early life on Earth. If subsurface environments of today resemble those of early Earth, it is also reasonable to entertain the possibility that the deep subsurface still harbors the most ancient of life forms.

The dark life questions (see also S-1 report [5], Chapter 2, and Table 4.2) are addressed with specific approaches by the geomicrobiology collaboration. Example science questions and directions include:

(1) Have the cyanide-degrading bacteria that were backfilled with treated waste into the stopes survived, and are they active?

(2) Are there microbes of anthropogenic origin present in drifts of different ages? Do they represent a distinct microbial community structure signature that can be linked to mine activities and/or time of abandonment?

(3) Since the mine is so old and some drifts were abandoned more than 60 years ago, prior to the use of antibiotics, do anthropogenic bacteria that have survived represent an archive for unique studies, and are these pathogens and other bacteria that were just "discovered" also present?

(4) How long have microbes been separated from surface ecosystems? And can evolutionary rates be quantified?

(5) Is the mutational profile, inferred from sequence analyses, distinctive, reflecting expected differences in mutagenic processes?

(6) Do the remaining genes evolve faster or more slowly than surface counterparts?

(7) Do they exhibit genomic signatures characteristic of small population size?

(8) Do subsurface microbes show much greater spatial structuring of populations and smaller genetic population sizes? If so, is it linked to processes of genomic evolution?

(9) Are genomes reduced in size and streamlined relative to their surface counterparts?

(10) What roles do phage, lateral gene transfer and other mechanisms play in evolution?

(11) How is genome content evolved in the absence of host and higher cell densities?

(12) How have they adopted to different stress regimes since some are nonexistent (ultraviolet and oxidative stresses) while energy, nutrient, radiation, dehydration are continuous?

(13) How could macromolecules (e.g. nucleic acid, lipids, and proteins) remain stable for millennia? (Evolutionary gradients, eco-genomics, and primitive life; Fluid, energy, and organizational transport; Impacts of human intervention on subsurface ecology.)

The major research emphases of the geobiology Letters of Interest are broad and interwoven, but fall into three principal themes: Geomicrobiology, Geochemistry, and Biology. The endeavors proposed in these fields are also related to experiments envisioned for hydrogeology, rock mechanics, and in the coupled interaction of processes related to the ensemble of all of these fields. Correspondingly, as with other earth sciences efforts, many of the proposed Letters of Interest may be combined into larger and more coherent research themes, benefiting from coordinated and collaborative sampling campaigns and experimental efforts.

4.2.3.3.5 Geomicrobiology Letters of Interest

[LOIs 15, 28, 29, 32, 38, 53, 70, 75, 76, 77, 78, 79, 80, and 81]: Microbial studies proposed for the Homestake DUSEL cover the essential areas of the subsurface microbial ecosystem. Common research thrusts are gathered under the rubric of "Ecology/geomicrobiology collaboration for microbe evolution" envisioned by LOI-38. This vision encompasses almost all proposals related to geomicro-related research. LOI-70 also proposes a comprehensive research scheme, integrating geomicrobiology with geochemistry and geophysics. The geomicrobiology proposals can be further grouped into three major areas based on the scope of the proposed studies: (i) evolutionary/phylogenetic diversity [LOIs: 15, 29, 38, 53, 81]; (ii) metabolic diversity [LOIs: 28, 32, 38, 79], and; (iii) ecological diversity – interactions between microbes and deep underground environments [LOIs: 38, 70, 75, 76, 77, 78, 79, 80]. In particular, LOIs 78 and 80 address the importance of interactive studies in geosciences and propose multidisciplinary, long-term plans to characterize coupled processes of biology, geology, hydrology, chemistry, and engineering, and further understand the limits of life on Earth.

The majority of the Letters of Interest propose step-wise, phased approaches to research. As the 4850 Level becomes available, research foci are on the migration of surface microbes into the DUSEL environments, emphasizing evolutionary trends, adaptation in deep environments, and identification of novel microorganisms. At the 8000 Level, the research foci are further expanded and shifted to examine microbial activities in deep and extreme environments: metabolic uniqueness and divergence, novel metabolic pathways and biochemical components (membrane lipids), and the impact of underground geochemical properties on microbial communities. However, all Letters of Interest except 78 and 80 are ready to implement their experiments immediately after mine reentry is allowed.

The mainstream approaches are identified as: molecular studies for genomics and metagenomics of unculturables using PCR-based DNA cloning and sequencing; denaturing gradient gel electrophoresis (DGGE), DNA microarrays, etc.; visualization of biofilms with fluorescent in-situ hybridization (FISH); characterization of hydrocarbon-containing fluids with stable isotopes; selection of autotrophs and organotrophs; and identification of novel microbial metabolites.

4.2.3.3.6 Geochemistry Letters of Interest

[LOIs: 20, 21, 37, 44, and 68]: The chemical attributes of the rock and fluids adjacent to the proposed DUSEL dictate the characteristics of the deep environment. Abundant information is available on geological properties of the Homestake mine; however, it is important to examine in detail the evolution of gases, the composition of rocks, and the inclusion fluid that will affect the biological systems directly or indirectly. LOI-37 proposes a comprehensive step-wise collaborative research effort on the chemical evolution of fluids in the Homestake hydrological system. In particular, outcomes of the studies on thermal history, fluid flow and inclusion, and fracture-matrix interaction in rocks may provide important clues on life history and microbial evolution in Homestake. Various experimental approaches are proposed to determine and refine: the partitioning effects of gaseous and liquid CO_2 and other elementals; elements of litho-stratigraphy and thermal history; the role of iron formation; lithostatic pressure/fluid inclusion; crustal assimilation using isotopes; volatile evolution; and fluid flow and fracture-matrix interaction in the fractured rock system using conservative and reactive tracers.

4.2.3.3.7 Biological Effects Letters of Interest

[LOIs: 14 and 30]: The DUSEL environment is substantially shielded from cosmic rays that can cause negative impacts on human health at the genetic and behavioral levels. Two Letters of Interest hypothesize that ultra-low-level radiation can improve biological properties of the human cells, although potential adverse impacts may still exist. Proposed studies are intended to measure (1) the effects of low-level radiation on human cells, invertebrates, and small mammals and (2) the mutation rates and survival/repair of radiation (^{60}Co)-induced damage.

4.2.3.4 Subsurface Geoscience – Restless Earth

The grand challenge Restless Earth questions and geoscience Letters of Interest are in Table 4.3. An initial focus on the dewatering operations can rally the wide range of earth science disciplines to strengthen collaborations needed to solve many important, but sometimes taken for granted, issues. The understanding of low-flow, nearly-neutral-fluid setting with complex but relatively competent rock mass at Homestake can shed light on deep circulation of groundwater systems, provide hydro-geochemical inputs to the dark life in the last section and hydro-mechanical inputs to the ground truth geoengineering in the next section. Subsurface geophysical imaging is an integral part of geoscience with equal significance in geoengineering, to be analyzed in the beginning of the next section. It is prudent to point out that the geoscience Letters of Interest, analyzed by the Homestake Collaboration and evaluated by the Program Advisory Committee, will start with realistic tasks and tackle the grander questions in the long run.

4.2.3.4.1 Hydrology

Fluid flow and transport are active at considerable depths. Direct subsurface observations and experiments are rare. Samples of deep rock from drill holes are small and have been disturbed by the drilling process, making them unsuitable for testing of factors that control fluid flow. DUSEL would revolutionize the field by providing an opportunity for large-scale, direct observation and measurement, impossible by any other means. Deep flow and transport research is central to important societal concerns, such as the protection of drinking water and irrigation water supplies, the disposal of hazardous and nuclear wastes, and the remediation of contaminated aquifers. The hydrology community would use a deep laboratory to study fundamental processes that today, after decades of surface-based research are still understood in only the simplest of terms. Recharge and infiltration, fracture permeability, multiphase flow, flow in fracture networks and characterization of the networks, verification of well test and tracer test models, characterization of active flow systems and paleoflow systems, coupling of flow, stress, and heat, reservoir potential and permeability of tight rocks all need research. DUSEL would provide deep groundwater regimes that could be isolated and studied within an undisturbed setting.

4.2.3.4.2 Monitoring of Dewatering Operation

Upon initial reentry, sensors can be installed in winzes and along vertical boreholes to measure the elevation of the water table and electrical conductivity of water at various depths, and to monitor the rising and then falling water table and associated change in stress. During 126 years of mine operations, the flow field surrounding Homestake has been dominated by dewatering; that is, mine workings will continue to act as fluid sinks, and flow has been toward them even over the past several years of flooding. The monitoring of humidity and microclimate conditions along the drifts using microsensors, and the identification of water inflow zones at all levels are also planned before, during and after the dewatering operation. Dewatering has introduced air into the system, probably allowing fractures to desaturate near the drifts. Once desaturated, the permeability of a fracture can decrease dramatically and flow may even be diverted from drifts by capillarity. The rock mass will go through the transition from saturated to unsaturated states. Homestake with multi-drift access is ideal for studying the critical zone (the dynamic interface between solid earth and its fluid envelopes). The critical zone with the transition from saturated to unsaturated states is one of the specific areas that are ripe for major scientific breakthroughs as discussed in the NRC Report *Basic Research Opportunities in Earth Science* [36].

The hydrogeology collaboration envisions working with the Authority team during the rehabilitation period to identify zones of observable flows, collect rock and fluid samples and select sites with active flow characteristics suitable for additional experiments. A significant footprint from the existing mine will be maintained with the establishment of a scientific protocol to define unique and major features underground. In test sites identified, flow path modification experiments can be conducted with tracers, chemical solutions, microbes, and thermal and mechanical stresses to reduce or enhance the formation permeability and storage capacity. In active manipulation experiments, flow direction and magnitude can be changed by altering prevailing inflows or using boreholes from drifts to capture additional inflow or to inject water. In addition to dewatering of the deep levels, test sites around and below the open pit with levels connected by ramps are of interest for recharge studies for the determination of the cone of influence of dewatering and to define the interaction between recharge and regional flow field. Similar zones of ramps and levels accessible at the 4850 Level and the deep region above the 8000 Level are also candidate sites for fluid migration and coupled process testing in DUSEL.

4.2.3.4.3 Hydrogeology and Hydromechanical Letters of Interest

The types of access afforded at Homestake can be used to address a number of topics of fundamental interest, including fracture permeability and connectivity [LOI-36], solute transport and dispersion in fracture networks [LOI-36], and the effect of stress state on hydraulic and transport properties [LOI-65]. Examples of specific questions that might be addressed include: LOI-36: Is flow distributed across fractures, largely channelized within fractures, or largely along fracture intersections? LOIs 1, 3, 65: How does the stress state affect permeability and permeability anisotropy, and can these properties be predicted from the stress state? LOI-65: How do permeability and permeability anisotropy change with depth? LOIs: 2, 36, 65: How does permeability change with the scale of measurement? What roles do intergranular porosity, dead-end pores, and velocity variation in fractures play in dispersion and tailing, and does their significance change with scale? LOI-37: What is the source of water now entering the mine? What is the geochemistry of subsurface waters, and how has it been altered by mine activities?

Most if not all of the hydrogeology and hydromechanics research will rely upon background data from mine records and cores and from monitoring (which should begin as soon as possible). Synthesis of this background information will provide the framework necessary for planning experiments by (for example) delineating lithologic boundaries and geologic structures [LOI-45], identifying major fracture zones and extensive (continuous drift-to-drift) fractures [LOIs: 45, 46], identifying water inflow locations, and providing estimates of gross rock-mass permeability. Monitoring priorities include rate of water-level rise and concurrent deformations and/or displacements [LOI-12, 6].

Access to rock volumes at various orientations via shafts, drifts, and boreholes (either existing or future, drilled from drifts or from the surface) will permit geophysical characterization for integration with other data as a basis for later studies [LOIs: 39, 47, 60, 62]. Geophysical tomography is possible using energy sources and detectors along boreholes, shafts and drifts.

4.2.3.4.4 Rock Deformation

Rock fractures and faults play a critical role in the geological processes that take place underground – a role that is impossible to investigate from laboratory research on rock samples alone. DUSEL would permit continuous, direct measurements of rock strain in the field, and provide an opportunity to evaluate factors that control it and the resulting stress on subsurface rock. Improved understanding of stress and strain distributions within the rock would lead to an improved understanding of how energy accumulates near faults and fractures, a vital step toward reliable prediction of earthquake timing. The depth dependence of fracture networks and associated rock mechanics measurements are of fundamental interest to determine whether fractures displaying enhanced permeability for flow are critically stressed [37].

4.2.3.4.5 Rock Mechanics Letters of Interest

Letters of Interest relating to rock mechanics and to geohydrology [LOIs: 1, 2, 3, 4, 34, 35, 36, 40, 41, 43, 62, 67, and 11, 45] focus on an improved understanding of how rock masses respond to load. "Load" is understood in a broad sense and includes changes in the ambient stress field induced by excavation and loads imposed by gravity and by forces of tectonic origin in geologic time. These latter loads are responsible for the current configuration of the Homestake rock mass that is replete with fascinating folds on folds, distributed slip on foliation planes, kink bands in graphitic schists, late igneous intrusives that cross-cut relict bedding, occasional shear zones, and deep fractures bearing hot water under high pressure, and so on, including massive units that seem indurated to high strength but lack foliation. The great geologic variety and the presence of more than 600 km (370 miles) of development openings make the Homestake site a most attractive candidate for the study of rock mechanics over scales ranging from micrometers to kilometers. Most importantly, these scales can be related in a sound scientific manner at Homestake. The Program Advisory Committee comments that the rock mechanics studies have an important contribution to make to the safe operation of the laboratory, and to the provision of early experimental data in support of the design and construction of large caverns. In addition, there are more homogeneous rock volumes potentially well-suited to large cavity construction.

Over a shorter time scale of a decade, there are data that can be updated and used to good advantage in engineering research concerning time-dependent deformation mechanisms of Homestake Precambrian meta-sedimentary rock units (the Poorman, Homestake, and Ellison Formations are exposed in the Homestake underground). The lessons learned from these features could well have applicability to other rock masses as the underlying mechanisms are identified and quantified at various scales, including laboratory scale (several centimeters), intermediate scale (large block, pilot galleries of several meters), excavation scale (tens of meters for pilot scale cavern to full scale detector caverns), and the far-field scale (hundreds of meters).

A unique opportunity exists to investigate the mechanics of rock mass deformation in the Yates Member of the Poorman Formation exposed on the 4850 Level between the Ross and Yates shaft. The Yates Member is massive and strong and is a leader among several candidate sites for the 100kt neutrino detector caverns whose science is strongly supported by the physics community. Adequate space is easily available to increase the number of caverns to 10 or more as required by the requirements of the science. The Program Advisory Committee observed that having a dedicated facility where science and engineering have the first and only priority would aid considerably in advancing knowledge on a broad front of many disciplines and in achieving specific study objectives by teams of investigators who have expressed great interest in the Homestake site. There would be no surprises and delays such as could be encountered were the mine still operating as a mine with business as the first priority.

4.2.3.4.6 Crustal Heat Flow

Understanding heat flow within the earth has been a fundamental question in geosciences ever since Lord Kelvin's calculation in 1862 of a minimum age for the earth of 100 million years based on the temperature gradient in the earth's crust. This simple calculation underestimated the earth's true age by an order of magnitude, largely because it did not consider heat generated from decay of radioactive elements. DUSEL offers an ideal setting to understand crustal heat transfer processes within the earth's crust at an unprecedented level. The depth of the mine, coupled with deep boreholes will enable precise measures of temperature variations within the upper 4 km of the earth's crust. These measurements can be coupled with detailed analyses of the distribution of radionuclides in the Homestake system to produce a detailed map of heat flow. The diverse geological rock units within the Homestake will have different concentrations and distributions of radionuclides, affecting heat generation within those units. In addition, it will be possible to examine the impact of the degree of water saturation within the rocks on heat transfer processes and the re-distribution of heat-producing elements by examining variations in heat flow as the accumulated water in the deeper part of the mine is removed. The sensor arrays installed within the mine will also be used to determine the impacts of the large-scale Earth Sciences experiments (especially tests involving manipulation of temperature and/or chemical gradients within the rock). The anticipated results of these investigations will yield a unique understanding of heat flow in the continental crust.

These studies of heat generation and transfer within the Homestake system will also provide essential information for many of the other studies planned for the DUSEL. Heat transfer within the crust is clearly a fundamental issue for earth scientists and engineers studying the viability of sustained extraction and development of geothermal resources. The temperature gradient within the earth's crust also has major implications for the extent of life in the subsurface. Understanding the distribution and mobility of radionuclides in the subsurface is crucial for issues as diverse as underground radioactive waste storage and studies of geoneutrinos produced from the natural decay of uranium and thorium in the rocks.

4.2.3.4.7 Coupled Thermal-Hydrological-Chemical-Mechanical-Biological Processes

The depth and extent of Homestake shafts and drifts offer opportunities to conduct *in situ* experiments on different scales and at different depths. More importantly, they will allow access, at multiple orientations, *across* rock volumes of various sizes, permitting greater control of experimental boundary conditions than is usual. The Program Advisory Committee supports the varied range of activities proposed in the Letters of Interest, and the scientific questions which they propose to address. In particular, they enthusiastically endorse those which address issues of scaling in space and time, afforded by the large size and extended occupancy of the proposed laboratory, examine perplexing issues in the hydrogeology of fractured rock, and address the roles of coupling among geobiological, geochemical and geophysical processes.

The Homestake presents a unique opportunity to investigate coupled thermal, hydrological, chemical, mechanical, and biological processes in a very different geologic, mineralogic, and hydrologic environment than has been attempted previously. The largest underground thermal test in the world was performed at Yucca Mountain, Nevada, which is in Miocene-age high silica rhyolitic tuffs (granitic chemical composition) that had previously undergone little alteration or deformation. This test yielded invaluable geochemical and isotopic data on the evolved gases and aqueous fluids in fractured rock for over eight years in a system ranging in temperature from about 25 to over 200ºC. The test was a key breakthrough for the development and validation of computer models for reactive geochemical transport in fractured unsaturated rocks, which have since been successful in capturing the evolution of the water and gas chemistry over several orders of magnitude difference in the permeability of the fracture system compared to the welded tuff rock matrix. Yet the volcanic tuffs at Yucca Mountain are low in iron and are in the unsaturated zone, resulting in a relatively oxidized geochemical environment, and low in nutrients for microbiological activity. Being in the unsaturated zone at near atmospheric pressure results in a system that is dominated by steam generation and vapor transport, rather than fluid pressure-driven hydrothermal convection.

In contrast, the host rocks of the gold-bearing horizons at Homestake are Fe-rich, highly reduced metamorphic rocks (graphite is a common constituent), are strongly deformed, and are deep in the saturated zone. The abundance of reduced ore minerals make the geochemistry quite unique in terms of the coupled system of water-rock interaction and metal transport under hydrothermal conditions. The metamorphic mineral assemblage at Homestake is very different from that of the rhyolitic tuffs at Yucca Mountain. Reaction rates are highly dependent on reactive surface areas, which in turn are a function of the hierarchy of scale of fluid flow, geologic structure, and mineral fabric. Thus the well-developed metamorphic fabric of the Homestake iron formation and the adjacent lithologies would provide a unique system in which to monitor fluid flow and reaction-transport processes under a well-controlled thermal environment. The analysis of thermal waters using stable and radiogenic isotopes as well as major ion geochemistry would yield a wealth of information that could be used to validate coupled process models that include thermal, hydrological, chemical, and mechanical processes. For example, because the rocks are approximately 2.2 billion years old, the $^{87}Sr/^{86}Sr$ ratios of the individual minerals will be very different, owing to the different initial Rb/Sr ratios in the minerals. Therefore, shifts in the isotopic ratios of strontium in waters reacting with the minerals could be used to constrain their rates of reaction under hydrothermal conditions.

In terms of understanding thermally-induced fluid pressurization, hydrothermal convection, mechanical deformation, and mineral alteration, heating of these rocks under saturated conditions would allow for investigation of strongly coupled processes that are an important phenomenon in many geological environments, but which have never been studied under well-controlled conditions over long time periods and large spatial scales. Experiments at the scale of 100-meter or larger rock blocks could be sited between existing adits and monitored from adjacent adits. Because of the low thermal conductivity of rocks, the effects of heating would be localized to a relatively small region around the heated block. Many coupled processes and their effects could be examined, such as fracture generation and propagation, microseismicity, microbial and colloid transport and plugging. The experiment would also be a unique system to test novel geophysical techniques as well as *in-situ* thermal, chemical and biological sensors in extreme environments over long time periods.

4.2.3.4.8 Mineral Exploration Research Letters of Interest

There are several Letters of Interest related to the petrogenesis of ore bodies and economic geology [LOIs: 10, 18 ,20 ,21 ,44]. These proposed activities do not require early access to the mine, but are very well suited for the opportunities presented by the Homestake and associated mine records. The Homestake mine was operated continuously for 126 years until 2002. Although the occurrence of gold at the Homestake mine was studied extensively as part of the exploration and mining process, significant information about the gold and its host rocks remains to be discovered. Industrial and other uses of gold throughout the world are not diminishing and gold will continue to be in demand in the foreseeable future. By any standard, the gold at Homestake is a world class deposit, and an improved understanding of the genesis of gold deposits at Homestake has direct and immediate relevance to mineral development in the U.S. and the world. *Note that these are research interests whose results will be applied elsewhere. Mining and other commercial extractive operations will not be conducted at Homestake.*

4.2.3.4.9 Perishable-Data Letters of Interest

This activity preserves existing information related to the geology, hydrology, rock core archive, 3-dimensional layout of the facility, and other related data; takes advantage of a one-time opportunity to gather geologic, hydrologic, engineering, and biological information that will occur as the facility is reopened, and, gathers new information which can be used for planning and design of later experiments and underground laboratory space. The Homestake mine records include rock core, paper files, and information within a Vulcan mining software database. The rock cores have been transferred to the Authority and are available for scientific study. The approximately 20,000 boxes of core are being inventoried by the South Dakota Geological Survey. Important paper files selected by Homestake Mining Company from their archives have been donated to the Adams Museum in Deadwood, South Dakota. The rest of the information must also be compiled and put into database-ready format for linking with related information and dissemination via the Internet (LOI-11 addresses this activity). Chapter 8 describes in more detail the vast amount of reference materials currently available.

Collection of certain information related to the mine geology, mine hydrology, engineering properties of the rock, and biological properties of media such as mine water must be initiated immediately upon reopening of the mine or the opportunity to gather such information will be lost [LOIs: 1, 6, 12, 24, 36, 37]. Other proposals to gather similar information require early and ongoing, but not immediate access to the mine. Among the types of information to be gathered are stress-strain and geophysical characterization of the rock, measurement of water levels in the mine, water inflow rates to the mine, occurrence and orientation of fractures, biological signature of the stagnant and incoming mine water, 3-dimensional mapping of fractures, and 3-D mine or surface geology if further needs are identified [LOIs: 3, 40, 43, 65; possibly 39 and 45, 46, 55]. Several of the Letters of Interest regarding these subjects have common or related themes and could mutually benefit from combining research efforts resulting in the most comprehensive and best information. Additionally, the use of micro technology [LOI-13] should be considered wherever possible for purposes of subsurface monitoring or data gathering. Subsurface data collection might also benefit from the development of robotic technology for remote collection of data [LOI-25]. Such technology could prove valuable by reducing the requirements for ventilation in remote areas of the mine and minimizing risks to personnel.

4.2.3.5 Subsurface Engineering – Ground Truth

The grand-challenge Ground Truth questions and geoengineering Letters of Interest are in Table 4.4 of Section 4.2.3.2. Stability of underground excavations is a primary motivation for rock engineering. Collaborations among industry, academe, and national research institutions are paramount for the success. Many of the LOIs analyzed in the geobiology and subsurface geoscience sections are closely related to the geoengineering tasks.

4.2.3.5.1 Transparent Earth - Sensors and Geophysics

The development of imaging technologies is a primary goal of DUSEL. Just as medical imaging techniques have revolutionized nearly every field of medicine, accurate subsurface imaging would benefit every area of research in the geosciences and in rock engineering. Currently, seismic surveying from the surface or in and across boreholes is the main geophysical tool for imaging the deep earth. The geology through which the waves travel is typically inferred only through general knowledge or through rock samples from sparse boreholes. DUSEL would allow direct verification or "ground-truthing" of geophysical imaging. Surface-based predictions of underground structure could be verified directly within a deep, three-dimensional volume of rock accessible to back-excavation and known from past mining and core drilling.

DUSEL Transparent Earth is a plan to install and operate a permanent seismic observatory illuminating the volume of the Homestake DUSEL facility from all six possible directions. The Homestake DUSEL site offers a unique opportunity - the large volume of mine working of the deepest mine in North America is surrounded and underlain by literally hundreds of open boreholes, which can affordably be instrumented with accelerometers [38]. With access to depths away from near-surface noise, Homestake is ideal for observation of broadband signals from activities within the facility and from seismic events at local, regional, and teleseismic distances. This specialized seismic array can allow the community to image rapid dynamic changes in the rock mass. For instance, investigators can immediately begin to estimate seismic parameters of events associated with de-watering, excavation, and various rock mechanics experiments, and estimate source kinematics caused by activity within or near the underground facility. Given the damage location of the event determined by the array, the affected rock mass can be excavated to find the source damage in the rocks. When found, a direct connection can be made between the damage process and seismic waves generated. This fundamental knowledge would be applicable to any bedrock sites, and help answer important questions concerning the energy budget of fracture growth and dynamics, local frictional behavior within a rock mass, seismic scaling laws, and interpretation of seismic moment tensors.

Homestake DUSEL offers the opportunity to develop new geophysical imaging techniques. Knowledge gained would have significant impact on our life, such as devising reciprocity methods of detecting and characterizing underground structures and activity for homeland security applications. Signatures of pumping-induced seismicity can be used to elucidate stress and fluid dynamics. Homestake offers the opportunity to run hydraulic fracturing tests with geophysical monitoring, and then excavate the fractured rock to find ground truth. This fundamental evaluation of hydraulic fracturing has immediate application in geothermal energy extraction with enhanced well connectivity. Long-term monitoring of pressure and stress can also decipher the tidal, seasonal, climatic, and tectonic relaxation responses. Electromagnetic techniques are promising for both monitoring fluid and imaging fractures. The streaming potential is sensitive to fluid chemistry and works with both polar and nonpolar fluids, e.g., liquid CO_2. This imaging method has been demonstrated in the identification of hydraulic fracture precursors.

In the following years, seismic instrumentation in many boreholes and along drifts at the site will result in the most densely instrumented geophysical observatory in the world, providing high-resolution data for mapping fracture geometry, rock damage, *in situ* stress through scattering and attenuation of seismic waves by fractures and faults, normalizing non-continuum (and continuum) constitutive models, and more detailed inversion of dynamic source processes. With the rapid development in micro electromechanical systems (MEMS)–a proven technology–we anticipate a fundamental paradigm change for data collections in rock physics and geophysics experiments. The integrated circuit processing and micromachining greatly lower the cost and reduce the size of sensors, motors, structures, and electronic systems to the micron-centimeter scale. With self-assembling and networking capabilities through wireless communications, it is now feasible to deploy thousands of sand-grain-size sensors with microprocessors before excavation near new drifts and large-scale underground caverns or along tunnels for remote, real-time monitoring and testing, and long term monitoring after excavation to measure pressure and stress changes. MEMS, together with nanotechnology, biotechnology, and cyber infrastructure, are promising technologies called for in a National Research Council Geoengineering Committee report *Geological and Geotechnical Engineering in the New Millennium: Opportunities for Research and Technological Innovation* [10].

Even with all the advances in microelectronics the fact still remains that radio transmission through geomaterials is not possible in the practical sense. Given the high dielectric of water and rock, Maxwell's equations show that only a very few wavelengths can pass through the materials. If a high data rate is required, a high radio frequency is needed and the propagation distance is in the tens of centimeters. On the other hand, Sakata Denki (a measurement technology company) has developed an ultra low frequency device for the Japanese nuclear storage facility that can send a signal through 100m of granite. However, the ultra-low frequency severely limits the data transmission rates.

4.2.3.5.2 Large Cavities Geotechnical Engineering to Construct Detector Halls

During the life of the mine a number of permanent caverns were mined. In particular, permanent excavations of up to 10 m span are present on both the 4850 and the 7400 Levels. These openings notably include the cavern that housed Nobel Laureate Ray Davis's seminal underground experiment on solar neutrinos. The long-term stability of these excavations, sited at DUSEL depths, strongly suggests that the space needs of DUSEL Initial Suite of Experiments can be met using standard design and construction processes. Given this statement, it is believed that the core engineering tasks required to build the underground facilities can be performed by industry, using conventional contractor selection criteria and contract formats. Research conducted during this period will focus on complementing, supplementing and extending the collection of core engineering data and analytical processes required to support the facility design. Core tasks will be performed in close consultation between designer, constructor and partner researchers. Given the research objectives of the facility, this consultation will not only allow for the definition of site and experimental requirements and optimization of the excavations relative to *in situ* conditions, but will also ensure that the field research needs for work performed from investigation through operation are fully-integrated into the overall project plan [39]. General engineering research elements are further described in the next section. The balance of this section will focus on engineering issues pertaining directly to the design and construction of the physics facilities in general and the larger permanent caverns, in particular.

Within the context of a discussion relative to the construction of the underground facilities, it should be acknowledged that site-specific investigation work will be needed to confirm the suitability of the layouts and cavern sites that are adopted in this Report. However, we believe that the general geometry and geoengineering characteristics of the host rock units are already well defined within and adjacent to the mineralized areas. In developing the layouts we were able to reference a large core library, a mine-wide 3-D data base (Vulcan software), and a number of detailed engineering reports documenting the results of rock mass studies undertaken during the later working years of the Homestake Mine [40 - 45]. The rock engineering knowledge gained by reference to this extensive suite of documents has been supplemented by discussions with senior mine personnel, intimately familiar with conditions throughout the mine.

We believe that these data sets, used in combination, provide a very sound basis from which to develop an initial layout of the campuses and site the major permanent openings. This is not to say that the layout and site plans should be considered final. On the contrary, the plans shown in the Conceptual Design Report were primarily developed for scoping purposes, and the design remains flexible, pending acquisition of more site-specific information. Site-specific investigation is required in all rock mass volumes intended for DUSEL development to support the layout and siting optimization processes. Campus layouts and sites for all the major excavation may be subjected to modification, as necessary, to reduce, or ideally avoid, the possibilities of encountering adverse ground conditions during construction.

The site investigation work required to support the design of the underground facilities is scoped-out in detail elsewhere in this Conceptual Design Report. However, for the purposes of outlining potential areas of engineering research, associated with the construction of physics caverns, we envisage that the investigative work will be phased to allow the designers to first identify "stay-away zones," as might be associated with shear zones, contacts, or highly-fractured or burst-prone rock mass volumes; and second, select the best of the remaining rock mass volumes for the siting of major excavations. Thirdly, to facilitate the final design of these major excavations, a more detailed investigation of local strength and stress properties may be warranted. At these sites, exploratory galleries may also be required to permit large-scale, in-situ observation and testing, and allow for the pre-excavation installation of reinforcement and monitoring systems.

As noted above, several physics collaborations are calling for the excavation of major caverns. These permanent caverns, categorized for the purposes of this discussion as being 20m or greater in span, have been requested at all laboratory campus levels. In addition, on the 4850 Level, plans are developing [20] for the construction of one or more caverns to house a Long Baseline detector. As currently scoped, this experiment would require the construction of one or more very large caverns, ranging in span from 50 to 70 m with a combined excavated volume in excess of 500,000 cubic meters. From a rock engineering perspective, such large-deep structures would push the "precedent envelope" for large-span permanent underground facilities, mined at depth in hard-blocky rock formations. From a management perspective, such caverns will represent a major commitment of resources and potentially include a significant element of construction risk. The safe and cost-effective design and construction of such large-deep rock caverns will necessarily require the application of industry best practices. Given the largely unprecedented dimensions of the Long Baseline cavern(s) and likely price tag, cavern research may be worthy of consideration within the context of DUSEL's engineering research program. Successful completion of research tasks that can result in a beneficial impact on construction duration, cost and/or risk could warrant funding with a goal of improving the overall viability of the experiment and potentially improving industry practices.

As clearly demonstrated by the Letters of Interest submitted to date, exciting opportunities exist to incorporate compelling engineering research in to the DUSEL program. Research tasks in the areas of site investigation and characterization, rock-support modeling and construction monitoring can all contribute to a better cavern construction process and, on a more fundamental level, advance the state-of-the-art in hard-blocky rock engineering. Adroit collaboration between scientists and facilities engineers will be mutually beneficial to ensure that all research opportunities of value are recognized, seized and fully exploited. Early research conducted in the areas of geosciences and rock mechanics can provide complementary data sets that can enhance the definition of the rock mass materials and fluids and consequently support the design of improved structures. Engineering data sets gathered during investigation and construction can provide the geo-scientists and rock engineers with new insights in to the *in situ* behavior of the rock mass materials and fluids under the influence of a changing stress environment and provide the ground-truth data needed for remote-sensing validation. Synergies generated between scientists and engineers working in this shared geologic space can result in research advances that are far greater than either would have achieved if each were working individually.

The products of such research will not only benefit the cavern excavation process at DUSEL and contribute to our basic understanding of the DUSEL rock mass, but would also be applicable within a much broader scientific and engineering context. Homestake's hard-blocky rocks condition are, to first order, similar to many other metamorphic and igneous rock masses. Results from a Homestake cavern engineering research program could find immediate and broad application on many construction and mining sites, both in the U.S. and internationally.

4.2.3.5.3 Underground Excavations

With hundreds of miles of shaft and tunnel existing from depths of 300 to 8000 feet below the surface, the Homestake DUSEL site offers many diverse opportunities for research to be conducted across a broad spectrum of engineering topics, including site investigation and characterization, design and construction, rock engineering and mining technology.

During investigation and characterization activities, the parallel research effort will not only provide for a more thorough pre-excavation "baselining" of rock mass conditions within the site boundaries, but also allow for the performance of key peer-reviewed tasks. A preliminary list of peer-reviewed projects has been developed for the Early Implementation Program. These projects are aimed at improving the observer's ability to remotely probe and model the solid-earth for engineering purposes. Subsequent excavation within the modeled volumes will allow for "ground-truthing," recalibration and refinement of the design models. The incorporation of research at this stage will be critical if the full value of this scientific endeavor is to be garnered.

During DUSEL construction, it is also envisioned that research tasks will be performed. Engineering research during this period will focus on the development of instrumentation that allows for accurate comparison of as-modeled and as-observed ground responses and provide real-time design guidance to the construction process. The development of better predictive models and rapid feedback to the constructor can support a "design as you go" construction strategies that can contribute greatly to the development of a safer, more reliable and cost-effective rock excavation process.

During DUSEL operation, there will also be multiple opportunities to perform research at isolated sites within the extensive network of existing and newly-mined excavations. Sites can be designed for short or long-term study of large and small excavations and in-place rock mass volumes, under researcher-controlled conditions to investigate key areas for research of rock under stress and water flow in fractures. Sites will also be designated for testing excavation and support equipment, material innovation and personnel training. Once access and utilities are restored, this dedicated facility will open-up many opportunities for cross-discipline synergies.

4.2.3.6 Energy and Societal Benefits – Energy Prospecting

Each year, energy consumption increases and more greenhouse gases are emitted into the atmosphere. By 2020, one-third of the world's population may lack access to clean water, air, and affordable energy. That same year, it's estimated, U.S. energy demands will have risen 40 percent from today's levels, an increase that far outpaces the nation's energy production capabilities. If steps are not taken soon, later generations will inherit a world that looks vastly different than today's. DUSEL can play a leading role to address the nation's and world's urgent needs to sustain energy supplies and improve the environment, with focused research on processes and technologies critical for developing renewable energy and carbon neutral energy.

Specifically, we discuss the research potentials for geothermal energy and for carbon storage evaluations at Homestake DUSEL. **Energy Prospecting** is an S-1 theme for DUSEL.

4.2.3.6.1 Geothermal Energy Extraction

The natural heat of the Earth is virtually inexhaustible. The USGS has estimated that electrical energy producible from geothermal reservoirs to a depth of 3 km exceeds 100,000 megawatts electrical (MWe) for thirty years. The currently installed geothermal electric power production is less than 3,000 MWe. From a societal perspective, the grand challenge is to greatly increase the contribution of geothermal energy to the U.S. energy supply mix over the next 10 to 50 years. In addition, beneficial heat recovered from geothermal systems may be used for a variety of applications (e.g., heat pumps to heat and cool buildings, agricultural green houses, recovery of oil from tar sands, etc.). For geothermal energy extraction, enabling technology is needed to find or create, maintain, and control permeable fracture systems to sustain high flow rates. Upon reentry at Homestake, we can delineate flow paths and select sites for flow path modification experiments. DUSEL offers an ideal setting to understand heat flow at a previously unrealized level, with interests both from physicists on geoneutrinos associated with natural decays of U and Th in the rocks, and from earth scientists and engineers on sustained geothermal extraction and development of geothermal resources. The enhanced geothermal systems can use CO_2 as a heat transfer fluid, tackling geothermal extraction and carbon sequestration simultaneously.

4.2.3.6.2 Carbon Sequestration

Effective carbon storage in underground formations is impeded by leakages. For carbon studies, DUSEL experiments dedicated to understanding the sealing properties of faults and the interaction with CO_2 would provide valuable new information, with potential leakage paths accessible at multiple depths. There are existing winzes, dead-end drifts, and boreholes at Homestake for siting sand- or rock-filled experiments. There are also historic information and data available at Homestake for sand backfills [46] in stopes that have undergone long-term interactions in the presence of microbial communities. Since microbe-assisted conversion of carbon dioxide into methane is an attractive carbon neutral approach, we can assess if research of this or a similar innovative approach is feasible at Homestake.

4.2.3.6.3 DUSEL and SECUREarth

These research potentials are examples of the cross-cutting approaches needed to find solutions for energy and societal challenges. We strongly advocate coupling the DUSEL facility with the other national initiative: SECUREarth [47] (Scientific Energy/Environmental Crosscutting Underground Research for Urgent Solutions to Secure the Earth's Future), which is under development through the National Research Council for DOE, NSF, NASA, and USGS [32]. Like DUSEL, SECUREarth emphasizes a multi-disciplinary approach for research and development in underground science and engineering. Teams from academic institutions, industry, and national laboratories can tackle crosscutting energy and environmental problems, such as flow delineation, geochemical alteration, and biological conversion of energy sources to sustain the needs for clean energy and improvements in the environment. Both DUSEL and SECUREarth initiatives can be an integral part of the American Competitiveness Initiative [11].

4.2.4 Other Science

A number of Letters of Interest to Homestake do not readily fit into the main themes of Physics and of Earth Science and Engineering. The Program Advisory Committee found several to be of significant scientific interest and worthy of inclusion in the broader scientific goals of DUSEL. The Program Advisory Committee also noted that there are some features already available uniquely at Homestake which would allow the experiments to achieve their goals; further, it suggests two types of shared infrastructure for them.

One set of three experiments is related to measurements on the diurnal rotation of the Earth [LOI-23], controlled studies of the physical processes in clouds [LOI-33] and a search for neutron to anti-neutron conversion [LOI-7]. Need for an unimpeded vertical shaft on the order of a kilometer in length is common to these three experiments. Suitable space is available at Homestake in one or another of the access shafts. A brief discussion of the scientific significance of these three diverse projects is in order.

- A highly resolved knowledge of the diurnal rotation of the Earth is important in a variety of cosmological observations. The ability to improve measurements of the length of the day or the Earth's rotation rate beyond current knowledge using other means such as GPS, VLBI, LLR and SLR is feasible using an evacuated drop-tube facility.
- Water vapor within the atmosphere exerts an important control on the energy of the planet along with associated controls on an understanding of the weather, its modification and on the evolution of climate. Necessary scales of observation range from the sub-micron to the kilometer and present a challenge in observational science requiring observations at fine resolution but accommodating nucleation trajectories that sample the full scale and heterogeneity of the cloud structure.
- Neutron to anti-neutron conversion is a key test of an un-explained but fundamental symmetry, baryon number conservation. However, Grand Unified Theories of fundamental particles and their interactions have a common feature requiring violation of this symmetry. It is usually argued that the best tests of baryon number symmetry come from proton decay with a violation by one unit; however, n-n-bar oscillation (violation by 2 units) is highly complementary. The two techniques test at very different mass scales and now that lepton number violation has been discovered in neutrinos further impetus has been added to n to n-bar searches. This experiment proposes placing a research reactor on the surface of one of the vertical shafts and measuring neutrons and potentially oscillated neutrons at the bottom of the shaft. This source of neutrinos would potentially interfere with geoneutrino experiments and some solar neutrino experiments, but it is anticipated that the experiments would be significantly out-of-phase with each other and the reactor would be constructed after the completion of the other experiments.

While the Program Advisory Committee agrees that none of these three would be fully realizable as part of the Early Implementation Program and DUSEL Initial Suite of Experiments activities, there are essential preliminary studies which could be initiated and could be facilitated during Early Implementation Program or DUSEL Initial Suite of Experiments. For example, for n to n-bar experimentation, studies are needed to develop a full proposal and technical design, identifying a suitable shaft, engineering magnetic shielding, vacuum quality and safety in a long tube and compatibility with the diurnal rotation experiment sharing the same evacuated tube. Additional issues related to the location of a portable, low power reactor underground need to be worked out. Similarly, for the cloud physics project, design leading to construction of the unique large scale cloud chamber will require first hand knowledge of available space, evaluation of safety issues and compatibility with other experiments.

In addition to the three topics just discussed, there are Letters of Interest (17, 26, 42, 51, 57, 73) that concern the effects of energetic particles on electronic devices, biological systems and development of structure imaging from cosmic rays. In common, these proposals uniformly require access to an underground environment with low-background shielding. The idea is that variable-term-of-occupancy laboratory space be available underground as an incubator for experiments that may not conveniently fit within the more focused physics and Earth Science/Engineering focus of DUSEL. This incubator space would be available, via a review process, to experiments requiring such low-background protection. The potential availability of such space would be an enabling factor in allowing such projects to seek funding and appropriate clearances from their potential sponsors and regulators.

One of Homestake's unique features is access to several vertical shafts. Having a dedicated shaft with several kilometers of unobstructed access is feature unique in the world to this proposal.

4.2.5 Shared Infrastructure

Beyond the essential facilities expected and shared in the normal operation of the laboratory (e.g., safety, beneficial occupancy of underground lab space, experimenters' office space, surface handling for receiving and shipping, high speed internet access, etc.) there are some needs specific to particular experiments for which there is sufficient overlap that there are economies in avoiding duplication by creating some shared infrastructures. As the laboratory moves through Early Implementation Program and into DUSEL phases, these shared infrastructures are expected to increase or be added to as new elements of the science program are introduced. Co-location of some experiments is also considered as part of achieving economies and improved performance for some experiments. The program developing for the Early Implementation Program (and suggested by some Letters of Interest for later experiments) provides some examples being prepared for:

4.2.5.1 Low Background Counting

These capabilities, which will have widespread application to experiments and initial facilities on the surface and underground, will be required as part of the Early Implementation Program.

4.2.5.2 Large Water Room

The Davis cavity is slated for development into a large water shield room. The water shield would house multiple experiments that require significantly enhanced neutron shielding. The addition of gadolinium to the water would further enhance neutron capture and provide a test bed for additional research and development for possible supernovae and neutrino detectors. Preliminary design work indicates that several meters of water shielding could be provided for several collocated experiments.

4.2.5.3 Underground Copper Electroforming and Detector Assembly

The preparation of ultra-pure material frequently involves intensive refining processes utilizing large quantities of chemicals and rigorous quality control practices. These processes capabilities are desired by a small subset of experiments, and could be combined at a relatively low cost. They are greatly facilitated by the drive-in 300 Level; as would be the storage of materials to be brought later to deeper locations but which require shielding to prevent formation of cosmogenic activity in them. Furthermore, detector assembly that requires modest overburden but excellent access for personnel and materials would find the 300 Level a valuable facility. Certain detector

R&D activities would similarly benefit from near surface facilities particularly for early work with potentially hazardous materials such as cryogenic fluids.

4.2.5.4 Co-location of Shaft Experiments

Access to a vertical shaft is required by at least three of the Letters of Interest [LOIs: 7, 23, 33]. Collaborative use of a single shaft would significantly reduce infrastructure costs and increase viability of the individual experiments as part of an ensemble package.

4.2.5.5 Co-location of Underground Laboratories for Earth Science and Engineering

A large proportion of the experiments related to geobiology, hydrogeology, and rock mechanics, which will examine the interaction of coupling between chemical and physical processes (coupled processes) may benefit from co-location. This would include the provision of a laboratory, central to the experimental facility, and the sequencing of multiple but coordinated experiments on a well-characterized block (the coupled processes facility). A basic wet-chemistry laboratory and BioSafety Level 1 microbiology laboratory could also be considered for this grouping. This provision would, at the same time, allow the consolidation of infrastructure needs, and encourage collaborations not yet envisaged by the multiple proponents for the Earth science, geobiology, and engineering experiments.

4.3 Education and Outreach

The multidisciplinary nature of the research to be pursued at Homestake, with its broad base of science and engineering, affords unique opportunities for education and outreach—to spark interest among a local and tourist public (more than two million visitors per year to the Black Hills), to provide students and teachers with access to the frontiers of research, to deepen understanding of research content, to support kindergarten through 12th grade (K-12) teaching improvements, to enhance the already strong earth science research connections within South Dakota and its neighboring states, and to develop new university research opportunities in engineering and physics as well as within math and science education.

Education and Outreach will be among the first organized activities at Homestake and will speak to well-documented "pipeline" problems in math and science. Compelling descriptions of the need to improve math and science education appear in such places as the recent report entitled "Rising Above the Gathering Storm" from the National Academies [11]. Homestake programming will respond to this national need by encouraging pursuit of higher education and subsequent entry into the future workforce in Science, Technology, Engineering and Mathematics (STEM), especially among underrepresented minorities, women, and those from rural America. Programming will also address the need for enhancing understanding of, and appreciation for, scientific research among the general public.

Education and Outreach represents a major motivator for the State to invest in creating a lab at Homestake and plays a central role in the Early Implementation Plan. Serious education challenges exist throughout the region, especially in supporting Native American students. Across South Dakota, and also nationally, K-12 data reveal devastating achievement disparities between Native American and white students. Achievement and enrollment patterns among white students leave plenty of room for improvement, and the Homestake Collaboration is eager to lend support, but even higher in priority is helping to eliminate achievement and participation gaps associated with race and poverty. Within 200 miles of Homestake are Rosebud and Pine Ridge Indian Reservations, two of the poorest communities in the country, both facing significant challenges in meeting academic expectations. K-12 leaders from these communities, as well as higher education partners from Sinte Gleska University on the Rosebud Reservation and Oglala Lakota College on Pine Ridge, have been active in developing the Education and Outreach plans for Homestake.

South Dakota is home to numerous other populations, in addition to Native Americans, that currently are underrepresented in STEM fields. Women remain scarce in physics and engineering—two of the most prominent disciplines to be pursued at the lab. People from rural areas also tend to lack opportunities related to science. Connecting these populations with leading scientists and frontier research has excellent potential to encourage their entry into STEM fields in higher education and later professional life.

Adding to the keen interest and commitment of the State of South Dakota and its citizens, philanthropist T. Denny Sanford has pledged an amazingly generous $20 million gift to seed the establishment of a science education center at Homestake, the Sanford Center for Science Education. Through the creation of this center, Mr. Sanford, the SD Science and Technology Authority, and all of the project collaborators focusing on Education and Outreach show eagerness to contribute to the national effort to enhance the teaching and learning of mathematics and science.

Fiscal responsibility for education and outreach would not fall solely to the National Science Foundation once the Sanford gift has been exhausted, but rather, the Homestake Collaboration would seek synergistic resources from, and partnerships with, the world's most creative talents in the private sector as well. The partnerships would include strong intellectual and creative components above and beyond financial support. An instructive model for involving the private sector currently exists in the Business-Higher Education Forum with their focus on “Securing America's Leadership in Science, Technology, Mathematics, and Engineering” [48].

4.3.1 Planning History

Education and Outreach plans for a putative Homestake Lab were first developed in 2001. Four white papers form the base for currently planned program elements—a Visitor/Outreach Center; K-12 Education; Undergraduate Education; and Research Opportunities for Young Scientists.

In February 2006, an Education and Outreach-specific workshop was attended by ~75 international scientists, K-12 teachers and administrators, academic leaders from South Dakota's regental institutions, local tribal college and technical school faculty, teacher professional development experts, science museum personnel, education program managers for national labs, and state and local elected officials. Guidance was obtained from education staff at LIGO (Laser Interferometer Gravitational Wave Observatory), the Exploratorium Science Museum in San Francisco, Fermilab, Lawrence Berkeley, Oak Ridge National Lab, and Battelle [49]. Project leaders also received summary advice on best practices based on reviews of education and outreach programs at Department of Energy-funded labs and National Science Foundation Centers of Science and Technology. Eight relevant LOIs were submitted to Homestake’s Program Advisory Committee for consideration in the Early Implementation Program.

In Fall 2006, another workshop was hosted at Homestake focusing on regional university involvement. A dozen administrative leaders from regional universities and from the South

Dakota regental system at large considered ways to expand their involvement with the lab. The focus of this workshop was broader than just Education and Outreach, but Education and Outreach was prominent. Ideas such as a mine safety-training program emerged, as did new contacts with tribal colleges and connections among regional science education centers.

4.3.1.1 Collaborating with Native American Communities

Since the earliest discussions of Homestake as a potential site for a DUSEL, proponents have been building relationships and seeking involvement of Native American institutions and individuals. A tribal elder offered traditional Lakota prayers to open one of the very first DUSEL-related workshops in Lead, and numerous members of area tribes and reservation communities have been engaged throughout subsequent planning efforts. This has been especially true within the area of Education and Outreach, which represents one of the most fertile areas for collaboration.

Ownership of the Black Hills is a sensitive topic. Some within the region feel that the states of South Dakota and Wyoming are illegally occupying the Black Hills, having violated treaties the United States made with the Great Sioux Nation in 1851 and 1868. The U.S. Supreme Court has ruled in favor of monetary compensation for the land, but to date that compensation has been refused. The Homestake Collaboration acknowledges this history as important context to the overall initiative and seeks to engage Native American leaders in finding a shared vision for moving forward. Already, representatives from tribal colleges and from K-12 school districts that serve large populations of Native American students have contributed important ideas about how a national science and engineering facility could support their students. Homestake Collaboration members are building on strong relationships that already exist, learning about the educational challenges at hand, and partnering to meet the needs of Native American students. The Homestake Collaboration is deeply committed to including Native American voices and serving Native American audiences.

4.3.2 Major Components of Homestake's Education and Outreach Program

What follows are key categories of programming envisioned over the next five to ten years. This listing is not meant to be exhaustive, but rather, to set a foundation upon which additional innovations, currently unforeseen, can be built. The Sanford Center for Science Education at Homestake, complete with funding beyond what National Science Foundation is able to provide, is expected to help extend the frontier of math and science education.

4.3.2.1 Visitor and Public Outreach Center

The Authority plans to restore and renovate an existing historic building originally used as a fabrication area on the Homestake site to provide exhibition and auditorium space. Hands-on exhibits will illustrate the underground science and engineering; the Ray Davis Nobel Prize-winning neutrino experiment at Homestake will be prominent. The center will feature the history of Homestake (connections to Homestake-Adams Research Center are discussed in Chapter 8), Native American history, culture, and science (drawing upon existing initiatives such as the NSF-funded Native Waters project), and environmental engineering and reclamation.

Exhibits will be developed in collaboration with staff of the Exploratorium, a well-known museum in San Francisco, not far from UC Berkeley and LBNL. These exhibits will be designed to engage the general public, to provide for more extended study by school groups and teachers, and to support university coursework. Plans will draw upon recent experiences at the LIGO project exhibit hall in Livingston, LA. Portable exhibits for use at distant science museum facilities will be created to emphasize the research at Homestake, broadening dissemination and drawing visitors. A proposed new science education center in Butte, MT, representing a regional collaboration with Montana Tech, would be among primary target sites. Permanent IRIS displays of geological forces in Washington D.C., New York, Pittsburgh, and Albuquerque museums are other examples.

Visitors at Homestake would gain important insights by entering the underground, even if only at shallow depths. The 300 Level, with horizontal egress, provides a plausible option for safe underground experiences that would feature scientists at work on accessible research projects.

The surrounding Black Hills area is well suited to directed nature trails that highlight geology and ecology. Among the focal points would be views into the mine's open cut, zones of forest fire recovery, and environmental engineering applications such as ponds of cyanide-consuming bacteria. The trails would provide students and teachers organized access to surface sample-collection sites as well. An outdoor classroom and an astronomical observatory are planned for later development.

4.3.2.2 Research Experiences

Providing research opportunities for pre-college students, undergraduates, K-12 teachers, and even for faculty from less research-intensive institutions is central to the Homestake plan. A program of summer internships that embed students and teachers within scientific research teams is a widely recognized, successful approach. Resident Education and Outreach staff will aid scientist mentors, coordinate logistics, introduce participants to the research facility, arrange safety training, and expedite transfer of research experiences to classroom practice.

Homestake will be an attractive locale to host National Science Foundation REU sites (LOI-16a). Geology field camps (LOI-5) and an underground mapping laboratory for undergraduates (LOI-9) have been proposed. High School Science Academies, to be developed in partnership with South Dakota school districts, would function as focused learning communities within existing schools and serve their most highly talented and motivated students. In times of limited fiscal resources, the most motivated and talented students all too often find scarce enrichment opportunities, yet they represent the nation’s future in science and mathematics. Academy students would be introduced to scientific research at Homestake and work within a research team to gain a deeper appreciation of the content, process, culture, and excitement of science.

4.3.2.3 Professional Development for Teachers

Teachers represent a critical leverage point. Elementary teachers typically have limited content knowledge and sometimes are fearful of teaching science. Secondary teachers have difficulty staying current in their scientific field and often struggle to convey the excitement and inquiry-based nature of the scientific enterprise. Among the scientists within the Homestake collaboration are a number who have supported large-scale, systemic teacher professional development initiatives. Scientists will be enlisted to share their enthusiasm, to help teachers expand and deepen content knowledge, and to advocate for more authentic, inquiry-oriented instruction. Research scientists will connect Homestake science and engineering with basic concepts in courses to be offered as summer institutes at the visitor/outreach center, supplementing the research experience. Education and Outreach staff, research scientists, expert K-12 educators, and participants will jointly prepare instructional materials and make extensive use of exhibits. Education and Outreach staff will attend to logistics and training.

Other efforts will focus on the preparation of future teachers through pre-service training. Black Hills State University, South Dakota's largest producer of teachers, and other nearby institutions, including Oglala Lakota College and Sinte Gleska University, that have significant teacher preparation programs will be enlisted as partners. Student teachers will benefit from research experiences at Homestake and from classes and lectures by visiting and resident scientists. Using LIGO’s successful program as a model, the visitor center will serve as a focal point for teacher preparation coursework. Teachers-in-training will participate in exhibit design, development of children’s programming, and educational research.

4.3.2.4 Engineering

Deep underground excavation procedures will be illustrated at the center. Examples of intriguing mechanical devices such as hoists, pumps, and fans will be displayed. Robotics will be a focus, as robots are likely to be used to explore drifts, collect samples, and attend to issues of lab safety. Plans include providing instructions to visitors to build and test their own robotic devices in simulated conditions on the surface and at the 300 Level. Homestake will serve as a focus to connect engineering research with faculty and students at local and regional university engineering departments and at K-12 schools.

4.3.2.5 Distance Education

Homestake Education and Outreach will make extensive use of Internet-based distance technologies. An online course, “Trace Element Geochemistry,” has been proposed (LOI-85) in connection with a Low Radioactivity Measurement Lab. Every South Dakota school district is wired with its own videoconference studio, which will facilitate dissemination of public lectures and help to maintain contact between scientists, K-12 students, and teachers throughout the academic year. Distance technologies will also be helpful in connecting visiting scientists whose time at the lab may be limited, but are interested in participating in outreach efforts.

4.3.2.6 Lecture Series, Conferences, Workshops & Short Courses

Education and Outreach staff will arrange informal learning lectures for audiences ranging from the general public, to students and teachers, to other professionals, as well as assist in organizing the logistics for scientific workshops and conferences. Hospitality, comfortable residential quarters, and enriching content are all critical to the creation of a vibrant and synergistic intellectual environment.

Homestake will offer a venue for conferences and short courses on specific scientific topics as well as science education. A safety training facility being considered in collaboration with the Mine Safety and Health Administration and regional universities would use the extensive surface and underground infrastructure to develop mining techniques, mine rescue and underground safety practices. Homestake is pursuing near-term opportunities for collaborative training facilities in partnership with industry.

4.3.2.7 Physics Education Programs I – Cooperation with South Dakota Board of Regents

A collaboration of the South Dakota Board of Regents and UC Berkeley Physics Department and Lawrence Berkeley National Laboratory has been established to enhance the physics education programs in South Dakota and the surrounding regions. White papers have been developed and short term goals for enhancing physics education are defined. Proposals are being drafted for curriculum, course, and laboratory module development.

4.3.2.8 Revolutionizing Education

Central to the Education and Outreach enterprise, especially through the science education center, is the notion of revolutionizing the teaching and learning of science, technology, engineering, and mathematics. To this end, two new doctoral programs are under consideration, one in science education and the other in mathematics education. No South Dakota institution of higher education currently offers either. These academic programs, through their faculty (some local, but also nationally recruited), scientist collaborators, students, and other creative partners, will serve as an engine for innovation. Dissertations and journal publications will serve as mechanisms for dissemination.

4.3.3 Education and Outreach Infrastructure

4.3.3.1 Physical Infrastructure

The Authority plans to provide and operate a visitor/outreach center that will be the initial Education and Outreach hub facility. Dedicated space will be available for teachers, students, and scientists with furnished and equipped labs, classrooms, and meeting rooms. These will be enhanced and expanded with DUSEL.

4.3.3.2 Programmatic Infrastructure

Education and Outreach staff, already provided for within the Authority's budget, will be drawn initially from local experts involved in existing programs and will ultimately draw national luminaries as well. The staff will recruit, select, and prepare teachers and students to participate in programs. The Education and Outreach program will provide scientists with opportunities for involvement that range in time commitment, nature of work, and target audience. Scientists will be encouraged to explore core problems of science education and be strategic in leveraging their impact. Resident Education and Outreach staff will advise on requests to build individual education programs specific to scientists' own research interests.

4.3.3.3 Education and Outreach Advisory and Management Structure

Management will include an Education and Outreach director who is supported by associate directors with specific responsibility for the visitor/outreach center's maintenance and operation, for K-12 education, and for teachers' programs. Homestake Lab management will recruit and appoint an advisory committee composed of lab members and local, regional, and national leaders in science, education, and industry.

4.3.3.4 Education and Outreach Early Implementation Program

The DUSEL Education and Outreach plan is to build on existing educational programs, existing infrastructure, and local capacity. Education and Outreach programs are already underway and ready, consistent with conditions of the supporting grants, for adaptation, expansion and consolidation with likely new programs at Homestake DUSEL.

A primary example is South Dakota's Center for the Advancement of Mathematics and Science Education (CAMSE). This Center, with a staff of ten, funded through the State Board of Regents, now resides at the Black Hills State University. Its program includes professional development for K-12 teachers; enhanced preparation of future teachers; enrichment for K-12 students; research on teaching and learning; and evaluation and dissemination of classroom resources. The NSF, the U.S. Department of Education, and South Dakota fund its current 30 projects with an annual budget of $1.8 million. CAMSE brings Ph.D.-level expertise in science and science education, experience with federal grants and projects, and strong relationships across the state and surrounding region. These relationships span South Dakota's regional system and extend into the tribal colleges, the S.D. Department of Education, hundreds of school districts, and thousands of teachers and students.

Through a recent MOU between the Authority and Black Hills State University, CAMSE is currently reorganizing itself into two divisions—one at Black Hills State University and a second at Homestake—and transitioning staff and materials to the Homestake site. One example of a CAMSE project to be adopted is “Science-on-the-Move,” in which two tractor-trailer trucks provide rural schools with access to state-of-the-art equipment and instruction. These trucks represent a ready means for extended outreach of DUSEL-related content.

A second candidate is a NSF-funded local systemic-change grant, the Black Hills Science Teaching Project. Relying heavily on practicing scientists to help elementary and middle school teachers deepen their content knowledge, it works in close collaboration with South Dakota School of Mines and 10 regional school districts that span 10,000 square miles.

A third is South Dakota's NSF-funded Experimental Program To Stimulate Competitive Research (EPSCoR) Research Infrastructure Improvement (RII) Initiative (2006-09). This initiative includes a focus on STEM education within Native American communities and another on informing K-12 audiences and the general public of forefront science. A nationally renowned educational research firm is currently under contract through the EPSCoR RII to explore and document strengths and challenges within South Dakota's educational infrastructure.

4.3.4 Evaluation Plan/Benchmarks

An external evaluation team will be retained to work in partnership with Education and Outreach staff. Rigorous, ongoing evaluation components will make use of participation data, needs-assessments, participant surveys, focus groups and interviews, and expert review panels to assess impact on content knowledge, conceptual understanding, and attitudes. Evaluation will provide formative feedback for program refinement and to inform related efforts at other national facilities. Reports will be posted and papers published in peer-reviewed journals.

4.3.5 Education and Outreach Opportunities

A dedicated science and engineering facility at Homestake presents outstanding opportunities to serve the public through Education and Outreach. Committed support is strong and broad, from philanthropist T. Denny Sanford, to the governor, to the secretary of education, across the university and K-12 systems, and throughout the local population. The region has high needs, and it welcomes the support that a national STEM facility could provide. Small universities and tribal colleges, including significant teacher preparation programs, are close at hand and will benefit from contact with the lab. Effective immediately, existing local Education and Outreach entities, including South Dakota's Center for the Advancement of Mathematics and Science Education (CAMSE), are transitioning programs, educational materials, and staff to allow for rapid and strategic scale-up. Given the proximity of two national parks, as well as Devil's Tower National Monument and Mt. Rushmore, a significant tourist audience already exists. With the addition of a national lab and world-class visitor center, the region could evolve into a major science-oriented tourist destination. The multidisciplinary nature of the science, coupled with such themes as the history of science, the history of mining, the science of mining, environmental engineering and restoration, and Native American culture ensure broad impact of a Homestake DUSEL.

4.3.6 Broader Impacts

The broader impacts are limitless. Regional education from kindergarten through college and beyond will be strengthened. Public understanding of scientific content and appreciation for scientific research will be enhanced. Research findings generated within the educational sciences will inform national efforts to improve science, technology, engineering, and mathematics education. Special attention will be paid to attracting and serving members of Native American communities, residents of rural America, and other audiences currently underrepresented in the disciplines to be pursued at the lab. K-12 teachers as well as teachers-in-training are also key audiences for programming. Investing in teachers, current and future, is especially strategic and will heavily leverage the impact of the scientists, engineers, and education experts at the lab.

4.4 Near-Term Goals, Early Implementation Program and Initial Research Efforts

4.4.1 Common Infrastructure

4.4.1.1 Low Background Counting Facility

A collaboration comprised of UC Berkeley, Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, University of South Dakota, South Dakota State University and Augustana College has proposed to develop a state-of-the-art low background counting facility. Following initial assembly on the surface and then depending on the availability of space this will initially be deployed at the 4850 Level. At least two large volume, low activity germanium gamma-ray counters and associated shielding would be deployed as early as 2008. This facility, operated by the South Dakota collaborators, would provide low level assay and direct γ-ray counting services to all users and specifically to the Homestake Early Implementation Program.

4.4.1.2 Large Water Room

A proposal to develop a large, water-shielded, shared-used facility have previously been submitted to the National Science Foundation (Major Research Instrumentation proposal from Brown and Case Western Reserve). More recently, an enlarged collaboration with participation from Brown, Case Western Reserve, UC Davis, UC Los Angeles, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, UCI, Texas A&M, Boston University, and University of Rochester has proposed research and development of an enhanced water room. This room would pursue multiple research and development tasks, including gadolinium doping of the water to enhance neutron capture and detection. Homestake would host this shared-use application in the Davis Cavity. It would be large enough to host several large experiments including some of those listed below. Homestake proposes to commission the Large Water Room in 2009.

4.4.1.3 Dark Matter Searches

Large volume noble-gas dark matter detectors recently demonstrated [17] dramatic sensitivity gains and potentially excellent scalability. Not surprisingly, investigators have approached Homestake with three proposals, including two based on xenon and one based on argon/neon.

4.4.1.3.1 Large Underground Xenon - LUX

The LUX collaboration (Brown, Case Western, Texas A&M, UC Los Angeles, UC Davis, Lawrence Livermore National Laboratory, and Lawrence Berkeley National Laboratory) proposes to develop a ~ 500 kg xenon detector based on the Xenon10 currently operating in Gran Sasso. LUX would be deployed in the Large Water Room.

4.4.1.3.2 Xenon100

The Xenon100 collaboration (Columbia) proposes a phased deployment of cryogenic xenon dark matter detectors. The Xenon100 collaboration would deploy in a room at the 4850 Level and would not use the Large Water Room at the 4850 Level.

4.4.1.3.3 MiniCLEAN

The miniCLEAN collaboration (Yale, Los Alamos National Laboratory, Boston University, NIST, and Queen's University) proposes to develop a cryogenic dark matter and solar neutrino detector based on argon and neon. The first phases would be hosted at the 4850 Level.

4.4.1.4 Neutrinoless Double Beta Decay – Majorana Project

The Majorana Collaboration (http://majorana.pnl.gov/) proposes to construct a scalable Germanium-diode array. Majorana would make use of the 300 Level to host chemical engineering efforts (copper refining), detector component assembly and storage of materials to reduce cosmic ray activation. The main detector deployment would be at 4850 Level for the first phases (up to 120 kg). Subsequent phases may require redeployment of the array to the 7400 Level laboratory; phasing and deployment options will be refined when better timescales are determined. Majorana would be a major user of the low background counting facility along with the dark matter experiments.

4.4.1.5 Perishable Data

As highlighted in the Program Advisory Committee report, establishing the initial conditions of the laboratory before re-entry and rehabilitation is a high priority.

4.4.1.6 Seismic Array

A collaboration (UC Berkeley, LBNL, and South Dakota School of Mines and Technology) proposes to install an array of surface seismometers using the large number of boreholes. The array would be deployed in 2007.

4.4.1.7 Water Sampling

A collaboration (LBNL, South Dakota School of Mines and Technology, Black Hills State University) proposes to collect water samples at the base of the Yates shaft and analyze the water for biological and chemical components as well as evidence for contamination that would require mitigation. In addition, the collaboration proposes to establish surface monitors and sampling of different surface water sources to establish a database for potential analysis of subsurface water.

4.5 Homestake DUSEL Long Term Goals

As discussed above, our design approach for Homestake DUSEL is to enable phased development and future expansion of the facility without impacting ongoing research. We propose initial implementation of major research campuses at the 300, 4850, and 7400 Levels. In addition to these campuses, much of the workings of the former mine will be available for inspection, monitoring, and assay research that may require periodic or temporary access to the existing 600 km of drifts. The long drift at the 2000 Level and the drifts and ramps beneath the Open Cut have received some attention by earth scientists. Plans for rehabilitating deep levels include maintaining access to nearly all of the 8000 Level, including the existing drill room, which has approximately 24 ft vertical clearance. This room is appropriate for drilling activities and other geoscience support facilities for investigations at the deepest level of the mine.

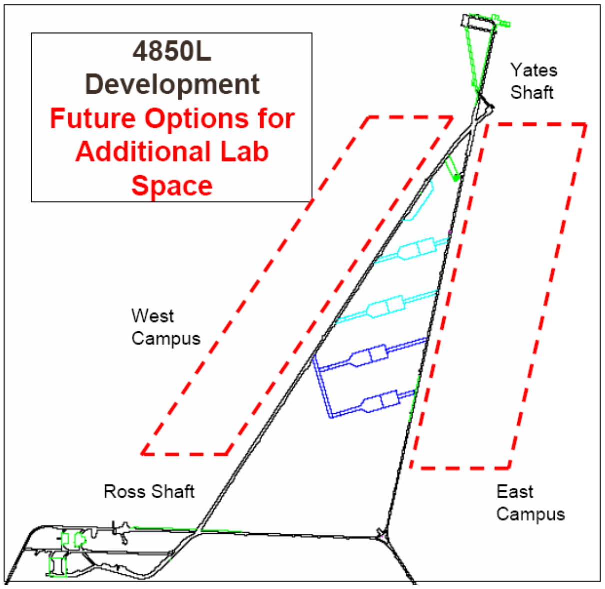


Figure 4.9 Optional areas for future development at 4850 Level to construct additional lab modules or purpose-built chambers for large-detector experiments and other research instrumentation.

Our initial assessment for very large cavities for Nucleon Decay and Long Baseline Neutrino Experiments places these at the 4850 Level (Figure 4.9). Detailed site investigation, rock mechanic studies and geotechnical data for engineering analyses will be accumulated during the Early Implementation Program to identify specific sites for the ~50 m diameter cavities for these experiments. Initial site investigations at the 4850 Level will evaluate rock properties in the region North and West of the main Yates-Ross drift. Locating large chambers in this region places the cavities in the highly competent rock of the Yates Member and facilitates construction access and waste rock removal via the Ross Shaft. The Ross shaft terminates at the 5000 Level, including an existing skip pocket for ore handling. With cavities that may exceed 50 m in height, the top of the cavities may be located at the 4850 Level for personnel access, which situates the bottom of the cavity at a convenient level for rock removal.

4.6 Summary Requirements

Presented in Table 4.5 is our initial development plan for space in at the Homestake Interim Laboratory and DUSEL. Both surface and underground development, the area and volume laboratory space and access drifts are presented. The initial construction schedule presents estimates of the availability of this space.

Homestake Interim Lab and DUSEL Summary of Development of Space and Availability (Underground space fully outfitted and ready for detector installation)	Labs, Shops, Offices Usable Floor Area		Excavation Volume (including access drifts)		Preliminary Construction Schedule (*to be revised)*	
	sq. ft.	sq. m.	cu. yd.	cu. m.	Start	Finish
4850 Level Subtotal	**107,351**	**9,973**	**111,115**	**84,903**		
Ross Shops for Construction Staging	12,469	1,158	5,738	4,385	Apr-08	13/31/8
Davis Lab, Sanford Lab, and Bio-Geo Lab	15,738	1,462	13,543	10,348	Sep-08	Jul-08
Lab Module #1 and Common Facilities	26,464	2,459	25,155	19,221	Oct-10	Sep-12
Lab Module #2	17,560	1,631	21,433	16,377	May-11	Apr-13
Lab Module #3	17,560	1,631	23,121	17,667	Sep-13	Jul-15
Lab Module #4 (excavation only, without lab outfitting)	17,560	1,631	22,125	16,906	Aug-14	Jul-15
7400 Level Subtotal	**63,588**	**5,907**	**98,477**	**75,246**		
Lab Module #1 and Common Facilities	28,468	2,645	29,594	22,613	Jan-12	Mar-14
Lab Modules #2 and #3 (excavation only, without lab outfitting)	35,120	3,263	68,883	52,633	Dec-12	Jan-14
300 Level Subtotal	**8,668**	**805**	**14,007**	**10,703**		
Lab #1, Shops, and E&O Rooms	8,668	805	14,007	10,703	Nov-10	Nov-11
Surface Subtotal	**98,000**	**9,104**				
DUSEL Offices and User Support Areas,Phase 1	10,000	929			Dec-10	Jun-12
Sanford Clean Room and Assembly Shop	6,000	557			Dec-10	Jun-12
DUSEL Offices and User Support Areas,Phase 2	32,000	2,973			Jul-11	Jun-13
Sanford Center for Science Education	50,000	4,645			Sep-09	Sep-11
Total	**277,607**	**25,790**	**223,599**	**170,852**		

Table 4.5 Development schedule for underground and surface facilities at Homestake's Interim Laboratory and DUSEL.

4.7 International Participation

The Homestake Interim Laboratory and then DUSEL at Homestake will be international facilities, with participation by researchers and educators from around the world. The deepest scientific facility in the world, it will attract participants and researchers from physics, earth science, engineering, biology and Education and Outreach. The initial call for Letters of Interest included foreign participation from ten nations including Japan, Canada, Great Britain, Germany, Italy, Spain, Russia, Switzerland, Portugal, and Scotland. These Letters of Interest included some scientific investigations solely sponsored by foreign collaborations.

It is anticipated that scientific participation in experiments and uses of Homestake will be the primary avenue for international participation in DUSEL. In particular, the larger experiments, such as neutrinoless double beta decay, proton decay, geophysics and geomechanics, and collaborations, will naturally include significant international participation.

As the Homestake Interim Laboratory issues subsequent calls for Letters of Interest in the coming years, we anticipate increased international participation in the Program Advisory Committee and perhaps the Board of Overseers. For Homestake DUSEL, we would also anticipate international participation in the Program Advisory Committee, in the consortium of Homestake Users, and in the DUSEL Board of Directors. Communication between the Laboratory Directors will be stimulated with an International Advisory Committee, Program Advisory Committees, and Board of Directors of the major international underground facilities, including Gran Sasso, Kamioka, and SNOLAB, is expected to stimulate coordination between the facilities and maximize the scientific reach of all underground facilities.

Foreign national participation in the DUSEL scientific program impacts the use of DUSEL for National Security and Homeland Security interests. The facility is large enough to provide adequate separation and isolation for these uses so that international participation in the main program will not be impacted. Homestake DUSEL will be, fundamentally, an open laboratory where qualified and adequately supported researchers from all fields and affiliations will have access based on the scientific merits of their proposed work, and will have freedom to publish in the open literature.

4.8 Connections to Other Underground Research Laboratories and Synergy with Other Agency Missions

Homestake Interim Laboratory will be an independent state-operated facility hosting U.S. and international experiments. Funding for the experiments is anticipated to be from traditional funding agencies for such work: the NSF and the Department of Energy. The Homestake Principal Investigators have initiated discussions with management of several other North American research labs, including SNOLAB, WIPP, and Yucca Mountain, to define roles and create an active dialog among the facilities' managements; and with researchers of EarthScope program [50] to strengthen common interests in deep earth science. As the Homestake Interim Laboratory develops, we plan on expanding these discussions to include Gran Sasso, Kamioka, Grimsel, and additional international research laboratories. The Homestake Interim Laboratory is advised by a senior advisory panel. We plan on expanding the 2006 membership to include additional senior researchers from the U.S. and from international laboratories to advise Homestake on the operation of the Early Implementation Program.

Advice to laboratory directorate on the scientific program, operations, and facility development will be obtained from several committees, including an International Advisory Committee; a Program Advisory Committee with representation from international users as well as industrial, educational, and homeland security communities, and an Users Group Executive Committee.

To facilitate both intra-agency discussion on underground science and to maximize DUSEL's impact internationally, the S-1 report, *Deep Science*, proposes a cross-agency Deep Science Initiative. This initiative would stimulate collaboration between the U.S. agencies and integrate the U.S. program and other national initiatives into DUSEL and to fully integrate DUSEL in the international arena. We imagine that the Deep Science Initiative would be hosted at DUSEL and that the Homestake Interim Laboratory would be included in the initial discussions.

5 The Compelling Arguments for Siting DUSEL at Homestake

Many reasons for siting DUSEL at Homestake are presented in great detail throughout this Conceptual Design Report. In this chapter we highlight extraordinary opportunities to positively impact several significant underrepresented communities. This chapter provides an overview and summary of the arguments grouped into the following five categories 1) Physical Characteristics and DUSEL Key Parameters, 2) Local, Statewide and Regional Support, 3) Access to the Underground, 4) Management and Operations, and 5) Forefront Science, Education and Outreach Opportunities.

5.1 Physical Characteristics and DUSEL Key Parameters

Led by Bernard Sadoulet, the S-1 Principal Investigators, having canvassed potential DUSEL users in all disciplines, determined the key parameters, facility requirements and additional advantageous characteristics [51]. The Homestake site characteristics exceed the essential required physical characteristics, including access to depth, available space, support and infrastructure for the research, low radioactivity rock, and a low risk environment, and meets all the additional advantageous parameters.

5.1.1 Depth Requirement

Homestake DUSEL will develop three major *campuses* for stationary experiments at levels 7400, 4850, and 300 feet below ground, corresponding to shielding exceeding, respectively, 7000, 4200, and ~ 150 mwe. At these levels, current planning envisions laboratory footprints of, respectively, 5,000, 11,200, and 900m^2. Homestake DUSEL will also provide access to specialized research environments at levels of 8000, 3900 and 2000 feet below the surface, taking advantage of the long transverse drifts at these levels. A more thorough listing of levels of interest for research in the Homestake facility is presented in Chapter 6, Section 6.5.

5.1.2 Rock Type

Large stable excavated spaces, among them the cavity provided to Ray Davis (dimensions of 20 x 10 x 10 m) exist in Homestake mine at the 4850 Level, 7400 Level (50 x 10 x 3 m), and other levels. Many of these excavations have demonstrated stability for over 40 years. Several geotechnical studies, based on homogeneous rock properties, indicate cavities with 50m spans would be stable at 4850 Level. [40 - 45] The rock in the Yates formation has been documented to contain uranium and thorium concentrations 10 to 20 times lower than in granitic formations. The low radioactivity and the planned provision of radon-reduced air from the surface will provide appropriate environments for many physics experiments requiring radon mitigation.

The Homestake site is located in a geologically interesting and varied environment. The use of the Homestake facility with its existing shafts and drifts will provide a 2700-m *head start* on geomicrobiology studies that will probe the limits, and variety, of life in the underground.

5.1.3 Pristine Regimes

Over 30 km^3 of rock at the Homestake site can be accessed using existing drifts, ramps and shafts. Much of this rock was not the site of mining activities and exists in a nearly pristine state. However, as in nearly all mines, water was pumped from the mining areas. During its 126 years mining gold, the mine was continuously pumped of inflowing water. About two-thirds of this water (documented to be ~ 700 gallons/min) is surface water, while perhaps one third comes from deep sources. Probing underground environments for investigations that are sensitive to dewatering will require drilling out of the impacted zone. The depth will have to be experimentally determined (estimated to be approximately 300 to 500 m). Experiments will require special procedures to ensure the validity of the studies. The vast majority of the Homestake mine's excavations were related to ore extraction and, to a much smaller degree, exploration. There exist large intact blocks in a variety of geological formations that are pristine, impacted neither by excavation nor mining.

5.1.4 Distance from Existing Accelerators

The Homestake site is 1,300 km from Fermilab, 2,500 km from Brookhaven National Lab, 7,400 km from CERN, and 9,000 km from JPARC in Japan. The "Brookhaven – Fermilab Future Long Baseline Study Group" is developing preliminary design features for a very long baseline neutrino experimental program between these sources and Homestake DUSEL [20]. These baselines would cleanly resolve matter effects from CP effects and foster a rich neutrino properties research program, including determining the MNSP matrix elements, especially θ_{13}; determining matter hierarchy; and observing CP violating phase over a large range of variables. The larger detectors required for these measurements, if positioned deep enough, can simultaneously support research in nucleon decay, solar neutrinos, supernovae neutrinos and additional related studies.

5.1.5 General Accessibility

Homestake DUSEL will be a dedicated facility, continuously accessible at all times during the year. It will be uncompromised by competing activities such as mining or transportation that impede access in other facilities. Redundant conveyances will ensure safe and continuous access to the underground, even during preventative maintenance and service periods. Current plans include installing a new automated personnel lift providing access from the surface to the 4850 Level and refurbishing the main conveyances in the Ross and Yates shafts to support materiel and equipment transport. We are examining plans to convert the lifts into a "super" lift to provide a substantially larger lifting footprint. Redundant power feeds from the surface will ensure continuous, uncompromised power and communications. Title to the entire 186 acre surface facility and the entire underground site is held by the South Dakota Science and Technology Authority. Ownership of the site by the Authority provides assurance of at least 30 years of access to the site for DUSEL. Access to the underground will not be influenced by future mining activity or changes of ownership. The Homestake site is accessible via the Rapid City airport (which is served by multiple air carriers from Denver, Chicago, Minneapolis and Salt Lake City) and by interstate highways and major rail lines. The site is a ~ 40 mile drive from Rapid City. Within 50 miles of the mine there are three communities, including Lead, providing all essential services: housing, medical, education, recreation, food, etc. There are collaborating universities in Rapid City and Spearfish.

As the premier underground research facility, access will be assured to all researchers, regardless of nationality, with appropriate training and conformance to facility procedures (such as workers compensation insurance coverage, etc.). Homestake DUSEL will fully conform to NSF policies concerning classified and proprietary research. The vast Homestake site can provide segregated sites and isolated facilities for Homeland Security applications that require isolation without impacting other research efforts.

5.1.6 Safety and Site-specific Requirements

Safety will be a primary focus for the Homestake Interim Lab and DUSEL management. Research in a facility shared with mining operations would have to follow Mine Safety and Health Administration-prescribed safety procedures, which, while instilling a culture of risk awareness, are not always appropriate for science and engineering efforts. Free of this constraint, Homestake DUSEL will develop a customized, state-of-the-art safety program that will embrace many of the essential mining safety components, but will also include the required experimental research safety components. The new Homestake ES&H programs will build on the Homestake mine’s century-long safety history and instill a culture of safety at all levels and phases of the scientific programs.

5.1.7 Management

Homestake DUSEL will be a dedicated scientific facility. Indeed, the property donation agreement with Barrick Corp. forbids such uses as extraction of ore or the establishment of solely economic endeavors in the facility.

Management for both the Homestake Interim Facility and DUSEL will assure its users and sponsors that the scientific programs will be directed and managed by scientists and educators. As a dedicated scientific facility, Homestake DUSEL will guarantee unbiased freedom of inquiry to all scientific disciplines, including physics, earth science, geology, engineering and biology.

Education is a principal motivation for the impressive state support for Homestake DUSEL – education and public outreach will be a major focus.

5.1.8 Risk

The Homestake site was operated as a gold mine for over 126 years. The mining, operational, maintenance and geologic records have been transferred to the South Dakota Science and Technology Authority (the Authority). This comprehensive documentation of the physical characteristics and excavation experiences not only serves as a valuable scientific resource, but also gives confidence that Homestake DUSEL can be developed with low risk. The existing and rehabilitated infrastructure will allow a productive science and engineering research program to be established with little delay. The extraordinary support at the state level provides substantial capital to cover startup costs.

5.1.9 Key Parameters

To be responsive to the scientific users in developing the Homestake Interim Laboratory and DUSEL, we will create additional laboratory space as required with a minimal impact on existing research activities.

Before closing the Homestake mine, Barrick Corp authorities established a mine-closure plan that included a full environmental assessment and documentation of conformance to the Environmental Protection Agency's requirements. These documents, which have been included in our Design Reports, are made available to the public by the EPA.

The Authority will obtain all licenses and permits for construction and operation as a part of the rehabilitation for the Interim Facility. Title, insurance and indemnification issues have already been resolved by the Authority.

5.2 Local, Statewide and Regional Support, including Available Funding and Property Agreement

The State of South Dakota has been an exceptionally strong and steadfast supporter of DUSEL for the past six years. The State has worked actively with the scientific advocates for Homestake DUSEL to obtain the transfer of the property from the Homestake Mining Company, its former owner, and then from Barrick Corp. following its merger with the Homestake Mining Company. In January 2004, the two parties signed an Agreement in Principle to transfer title of the facility to a South Dakota public entity. In February 2004, the South Dakota legislature created the South Dakota Science and Technology Authority, endowed it with bonding authority, enacted the required state indemnity and immunity statutes, and funded it with $14.3M to be added to an existing $10M Department of Housing and Urban Development grant.

The State contracted with Dynatec Mining Ltd. to establish the preliminary engineering plan for the reentry and rehabilitation of the facility and to provide a realistic cost and schedule estimate for DUSEL. A summary of the Dynatec Plan [47] is provided in Appendix A10. A major focus of this plan deals with the Homestake mine's accumulated water.

The current governor of South Dakota, Michael Rounds, has made Homestake DUSEL a cornerstone of his administration's goals of promoting research, education and economic diversification in South Dakota. In October 2005, the State legislature approved (with a remarkable 96 to 4 favorable vote) an additional $19.9M for the Authority to fully fund the Homestake site rehabilitation, to provide funds for indemnification and an adequate contingency for initial basic operations of the underground laboratory, and to provide initial insurance. A summary of the state legislation is provided in Appendix A6. The State funding represents a commitment of ~$50 for every person in South Dakota to support the Homestake Interim Laboratory and DUSEL. In April 2006 the property donation was completed; title was transferred in May 2006 [see Appendix A6]. The Authority moved to the Homestake site and has added staff to maintain the facility and prepare for its reentry and rehabilitation. The Authority continues to discuss rock disposal and shared water treatment facilities with Barrick. The "open cut" at the Homestake site could provide a nearly limitless rock-disposal site adjacent to the Homestake site. The Authority continues to pursue these synergistic, shared activities that can yield tremendous advantages to DUSEL in the longer term.

Locally there exists effectively unanimous support for Homestake DUSEL. The educational and outreach potential for underrepresented minorities, in particular Native Americans, have united the local, state and regional support for DUSEL at Homestake. At DUSEL workshops we have had good representation by the Oglala Lakota College and the Sinte Gleska University. A good example of this support was at the recent Program Advisory Committee meeting and Letter of Interest Workshop in February 2006, all the meals for the ~120 participants were provided by the Lead, Deadwood, Rapid City, and Spearfish local governments and community booster groups.

In South Dakota a single Board of Regents that governs six universities has been, and continues to be, a strong DUSEL supporter. Working with the University of California, the Board is developing plans to advance physics education in the state, leading ultimately to establishment of a doctoratoral program in physics. Following the recent call for DUSEL-related R&D proposals by the NSF and DOE, UC Berkeley partnered with three South Dakota campuses to propose the development of a low background counting facility. An established education and outreach program in the region, the *Center for the Advancement of Math and Science Education* (CAMSE) [53], funded by a NSF grant, will relocate approximately half of its existing program to the Homestake site from Black Hills State University. The Homestake Scientific Collaboration and the Authority are hosting regional workshops to engage the South Dakota and nearby regional academic institutions in the Homestake DUSEL scientific and education programs. Included are institutions in Wyoming, Montana, Nebraska and North Dakota.

We are working with the State to provide advanced Internet connectivity to Homestake DUSEL as well as to the research universities in South Dakota (South Dakota School of Mines and Technology, University of South Dakota, and South Dakota State University). Phase 1 of this state program would connect Homestake DUSEL, Earth Resources and Observation Center (EROS) [52] and the research universities to the national grid through the major hub at Kansas City and provide ~10 GB/s connectivity. New fiber would be installed from the surface to the research levels in the facility to ensure seamless connectivity from the experiment to the surface facilities and hence to the external research participants.

The regional support for Homestake DUSEL was dramatically reinforced in June 2006 with the dramatic announcement by T. Denny Sanford of a $70M donation to establish an interim facility, including a science education facility, and to assist in the creation of a deep laboratory at the Homestake site. Combining the State's contribution of $46M with the Sanford Gift of $70M provides Homestake DUSEL with approximately half the estimated capital required to establish DUSEL and begin research early.

In all, Homestake DUSEL has received unequaled support at all levels – local, state and regional—making it the premier site for DUSEL.

5.3 Access to the Underground Facilities

The depths available at the Homestake site are appropriate for the world-class research program envisioned by the US and international users of DUSEL. To establish and support this research program, both space underground and convenient access to that space must be provided by the host facility. Homestake's Interim Laboratory staff will complete most of the prerequisite steps needed to establish access to DUSEL.

The Homestake Interim Laboratory plans provide for reentry to the facility and the rehabilitation of the Yates and Ross lifts. A variety of improvements to underground access will be completed, including a high-speed, automated personnel lift, dedicated to the 4850 Level, that will give superior access compared to multi-mode or shared-access lifts. In our current schedule the 4850 Level laboratory could be prepared for beneficial occupancy as early as 2008. This early availability will substantially alleviate the underground space shortage documented in the S-1 Report "Deep Science"[5] and Appendix A4. This access to underground research space at the Homestake site will significantly stimulate the US research and development program for many of the essential research fields highlighted in the S-1 report. An active research and development program, coupled to early scientific results obtained from the Homestake Interim Laboratory, will significantly enhance the potency of the arguments for DUSEL.

Homestake's Early Implementation Program substantially reduces the risks inherent in creating a deep facility over other proposed sites. It provides accelerated access for key scientific programs and allows a smooth transition to the full DUSEL program. See chapter 4 for discussion of the transition from the Homestake Interim Laboratory into DUSEL.

Homestake DUSEL will be dedicated to scientific purposes; it will not be compromised or fettered by competing mining or economic interests. This will permit excavation underground to proceed according to scientific priorities rather than those imposed by a host mining entity. The dewatering program will similarly be established without competition from other interests. Access to the existing space will be guaranteed for at least 30 years, and additional regions of the facility will be made available as research programs require additional space.

5.4 Management and Operations

Management and operation of the Homestake Interim Laboratory will begin as a authority-run laboratory. The Authority has title to the facility, has started to refurbish the surface buildings, is adding staff to maintain the property and to prepare for rehabilitation, and has dealt with the legal, indemnification, immunity, and insurance issues for the site. The Authority will be the facility management entity for the Homestake Interim Laboratory.

The management plans include a strong partnership with the scientific collaboration and the creation of several critical scientific management positions. Independent expert oversight and review committees will be established.

The initial tasks for the Homestake Management team will be 1) the reentry and rehabilitation; 2) establishment of the 4850 laboratory; 3) establishment of the science education center, and 4) preparation for DUSEL.

The management team for DUSEL will evolve out of the structures established for the interim laboratory. This approach has many advantages for DUSEL. Many of the key safety and operations management positions will have been staffed, with key personnel trained and functioning in their roles. The process of establishing the scientific program is in place and is operating. The initial Letters of Interest have been solicited and, with the Program Advisory Committee's advice, the initial scientific program is being developed from these responses. The engineering and safety reviews are being established, as are operational procedures and rules of conduct. This presents the NSF with a functioning laboratory to be expanded and adapted into a full-fledged DUSEL. The framework for the Interim Laboratory management and operation has been designed to permit this smooth transition into DUSEL.

The scientific collaboration working with the Authority has vast experience with underground experiments and underground research laboratories. Its members bring direct international experimental experiences from Sudbury, Gran Sasso, Kamioka, Strippa, Oroville, Soudan, WIPP, Yucca Mountain, and other national and international underground research laboratories. There is a strong national laboratory participation in the Homestake DUSEL proposal, making resources and expertise at the Lawrence Berkeley, Brookhaven, Fermi, Oak Ridge, and Los Alamos National Laboratories available to assist with the planning of the facility. This national laboratory experience incorporates planning for large-scale experiments and also establishing and operating user facilities, including establishing management and safety procedures.

5.5 World-class Science, Education and Outreach Opportunities

The breadth of Homestake DUSEL's scientific programs and the time scale for establishing them contribute to the compelling arguments for siting DUSEL at Homestake. Homestake is a massive site, capable of supporting and fostering essentially all of the disciplines and experiments presented in the many national and international studies of DUSEL science. In the long term these efforts will strengthen DUSEL by increasing the users of the facility and stimulating a larger user pool. These research efforts would continue to operate as DUSEL is constructed.

The experiments in Homestake's Early Implementation Program address some of the most important and exciting programs facing physicists, biologists and earth scientists today. Homestake management is working actively with dark matter collaborations, nuclear-astrophysics accelerator groups, and several collaborations pursuing neutrinoless double beta decay experiments. As research and development phases for these experiments mature, we anticipate that several of these initial efforts will advance to be included in the Initial Suite of Experiments. We note in passing that the 300 Level space has attracted more attention from several fields, including physics experiments that require modest shielding for R&D efforts and education and outreach endeavors than has been previously discussed at S-1 meetings.

The Program Advisory Committee report highlighted the importance of developing shared infrastructure facilities and establishing the site baseline characteristics before rehabilitation commences. An experienced group of underground physicists has joined South Dakota university faculty in proposing a state-of-the-art low background counting facility. Efforts that have been initiated include water sampling, establishing a seismic array, and developing a database of geological, hydrological, and geochemical site features.

By providing this early access to underground facilities, we are assisting in creating a more advanced and technologically sound suite of experiments to be considered for DUSEL. Homestake DUSEL is preparing to host a larger suite of experiments and enabling more research opportunities for DUSEL by substantially expanding the time window for these experiments and by having already prepared much of the necessary suite of support services and facilities. Homestake management is establishing the world's first deep multidisciplinary facility for science, one that will advance several fields that are in dire need of underground facilities now.

Education and public outreach have been made a major focus of the Homestake DUSEL proposal, responding to the regional needs. The state has pledged substantial capital and personnel to the creation of a state-of-the-art science and education center. Coupling new initiatives to the existing South Dakota *Center for the Advancement of Math and Science*

Education program will enable a similarly accelerated start for the education and outreach efforts at Homestake DUSEL.

5.6 Summary

The Homestake site offers the lowest risk site for DUSEL. It offers the best “time to science” and also to education, public outreach, and collateral gains for the region. The proximity to several underrepresented communities will enable Homestake DUSEL to have significant impact. Education and public outreach will be an integral part of our efforts from the start. Homestake DUSEL enjoys outstanding local, statewide, and regional support, unlikely to be equaled by other proposed DUSEL sites; it is without vocal or public opposition.

Research of the highest importance for our physics, earth science, and engineering communities will be addressed in the near future. The efforts will be completely science and education driven, with no conflict with, or disturbance from, mining, transportation, or other priorities.

Homestake’s site characteristics will foster the full spectrum of research promoted by the S-1 report and other national and international studies. Its plans for making underground space available at deep, intermediate, and shallow sites will accommodate a broad spectrum of experiments envisioned by the S-1 study. This spectrum will expand as the programs mature. Several Homestake formations are low in intrinsic radioactivity, a factor of 10 to 20 lower than typical granitic formations. Homestake DUSEL will provide clean rooms, new laboratory space with radon-reduced air and the ability to host the most sensitive experiments, helping make it the premier underground research laboratory in the world.

Homestake DUSEL is easily expandable in all dimensions – additional underground laboratories will be developed in a phased approach over the coming decades to accommodate our continually evolving research efforts. The rock at Homestake is known to be capable of hosting large stable excavations for decades.

Homestake DUSEL has an experienced and capable management team in place to establish the Interim Laboratory, to plan for and to provide a smooth transition to DUSEL. The scientific collaboration has vast experience in all the disciplines proposed for DUSEL, as well as experience in establishing and operating user facilities.

We propose a phased plan for creating DUSEL. The first steps, managed and operated by the Authority, will establish much of the essential infrastructure and initiate scientific and engineering investigations. This interim facility will significantly alleviate the world-wide shortage of underground laboratory space. Homestake DUSEL will then evolve to provide the space and infrastructure required for an ambitious Initial Suite of Experiments and subsequent expansions as required by the science.

6 Design Concepts and Infrastructure Development for Homestake Interim Lab and DUSEL

In this chapter we present a description of the Homestake site, plans to re-enter the facility to preserve the site for subsequent development into DUSEL. We go on to describe our conceptual plans for providing underground research space and surface support facilities for DUSEL's Initial Suite of Experiments and the Early Implementation Program.

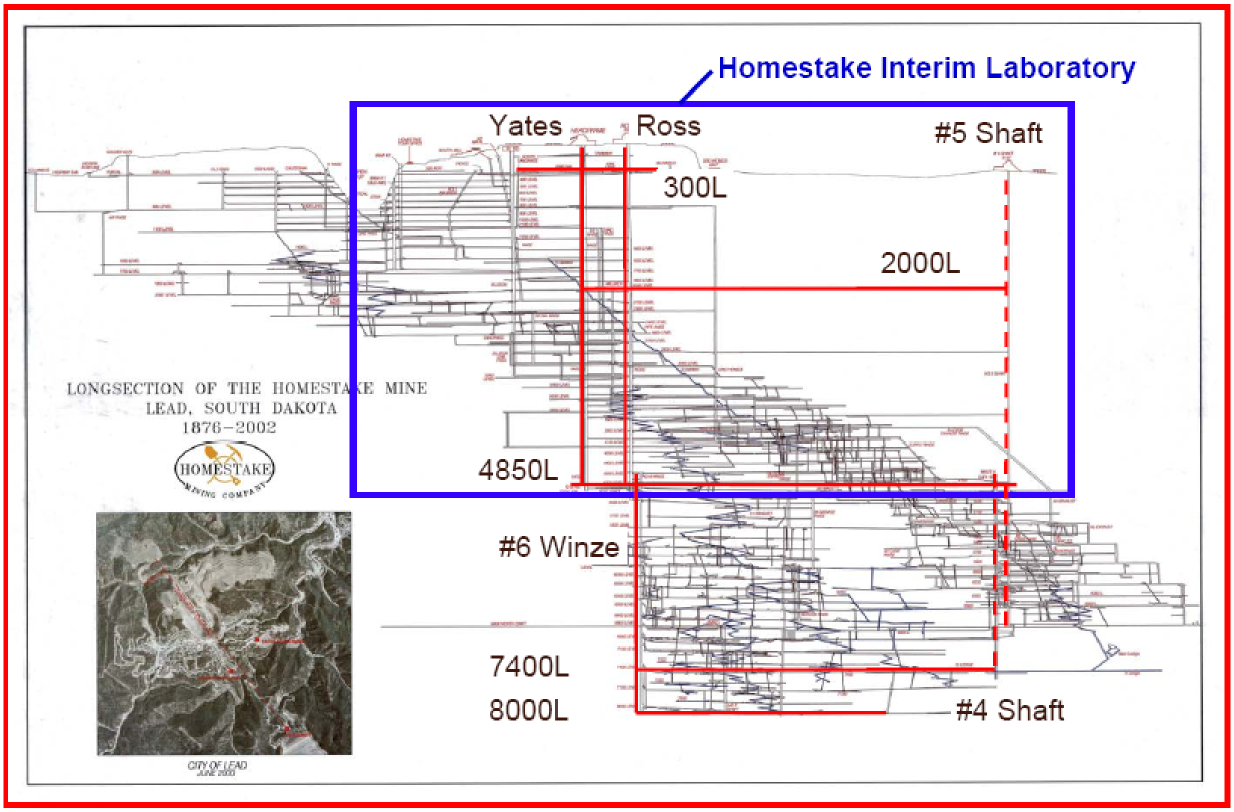


Figure 6.1 Homestake Mine Long-section: Homestake Interim Lab development and access to 4850 Level and DUSEL development and deeper levels access to 8000 Level. A high resolution version of the figure is located at http://neutrino.lbl.gov/homestake/S2_Supporting_Documents/ .

6.1 Overview of Existing Site Conditions and Infrastructure at Property Transfer

The Property Donation Agreement [Appendix A6] transfers 75.3 hectares (186 acres) of surface property with more than 20 existing buildings and structures to the South Dakota Science and Technology Authority (the Authority). The underground workings comprise approximately 324 hectares (800 acres) with more than 600 km (370 miles) of shafts and tunnels at approximately 60 levels extending to 2484 meters (8150 ft.) below the surface, and including more than 30 cubic kilometers (7.2 cubic miles) of rock mass. Figure 6.1 is a Long-section view that represents the underground workings of the mine projected onto a single plane of the drawing, and Figure 6.2 shows a schematic representation of the primary shafts and drifts that were in use for mining operations prior to closure. Figure 6.3 highlights the surface buildings near the Ross and Yates shafts that are planned for initial use and development for DUSEL. The property transfer also includes the core-sample archives and extensive operations, maintenance, and mine closure records from the former Homestake Mining Company (see Chapter 7 for a detailed description).

Following the property transfer, the Authority has begun hiring staff, purchasing equipment, restoring infrastructure, and coordinating subcontracts to manage the mining-to-labs conversion effort for development of the Homestake Interim Laboratory and preparation for DUSEL. The primary roles and responsibilities of the Authority staff for the conversion project are as follows:

- Oversee and insure safe operation of the Authority's Homestake Interim Laboratory property and infrastructure.
- Develop plans for facility and infrastructure rehabilitation and upgrades to implement the Program Advisory Committee recommendations for science and engineering research.
- Manage design and engineering for re-entry to mid-levels, rehabilitation of surface and underground infrastructure, and excavation for new underground laboratory development.
- Manage and supervise construction for re-entry, infrastructure rehabilitation, new excavation and development of surface and underground facilities to support Early Implementation Program experiments.
- Prepare for management transition to Homestake DUSEL facility and science operations.

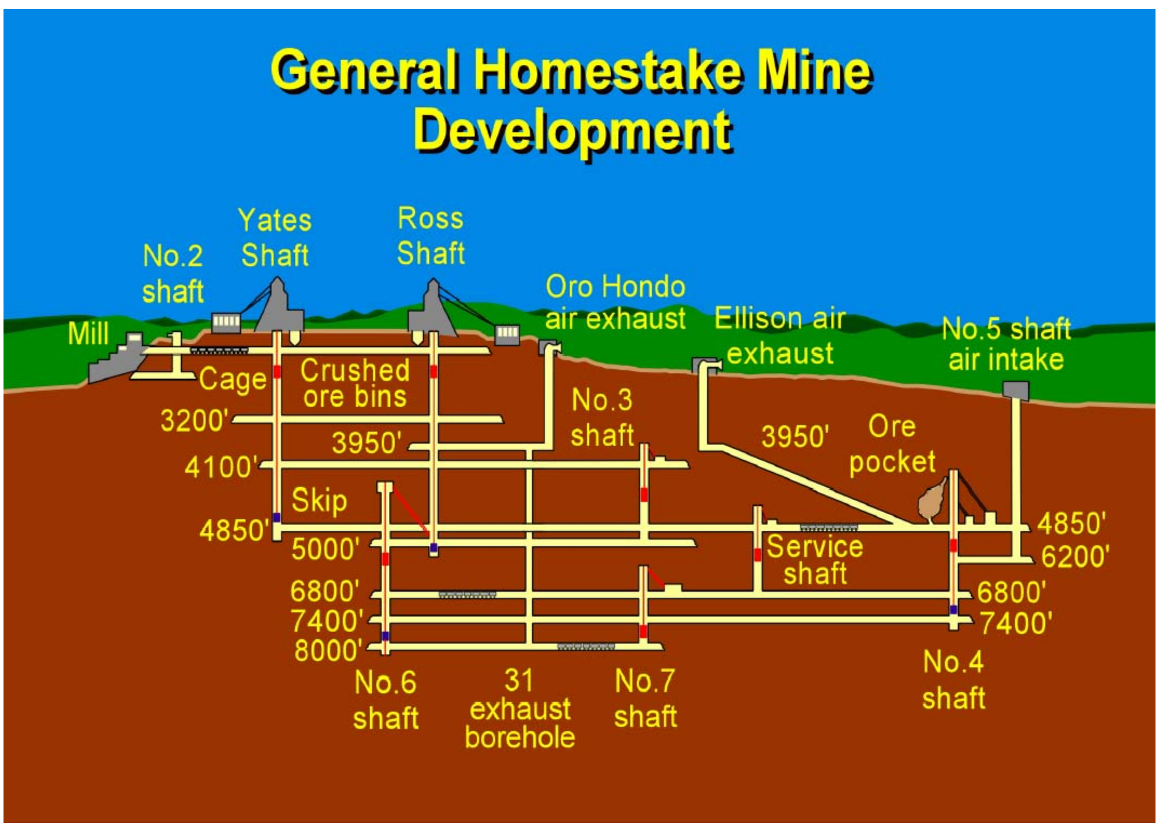


Figure 6.2 General Homestake Mine Development: A schematic representation of the primary shafts and drifts that were in use for mining operations prior to closure in 2003.

All access shafts and portals to the mine have been closed since July 2003 and sealed to restrict airflow in the mine. A preliminary Yates inspection was carried out on 10 June 2006 and recorded the good condition of the entire shaft and infrastructure. On 7 December 2006 the Ross shaft was inspected and similarly found to be in good condition. Sealing the mine to restrict airflow has reduced corrosion and other deterioration of mine infrastructure by controlling the cycling of humidity and temperature underground. However, closure halted removal of accumulated water. Water has been accumulating in the deep levels at an estimated rate of approximately 700 gallons per minute. The most recent monitoring point indicated that the water had risen to 5600 Level in November 2006, with a slightly slower rate of rise than predicted.

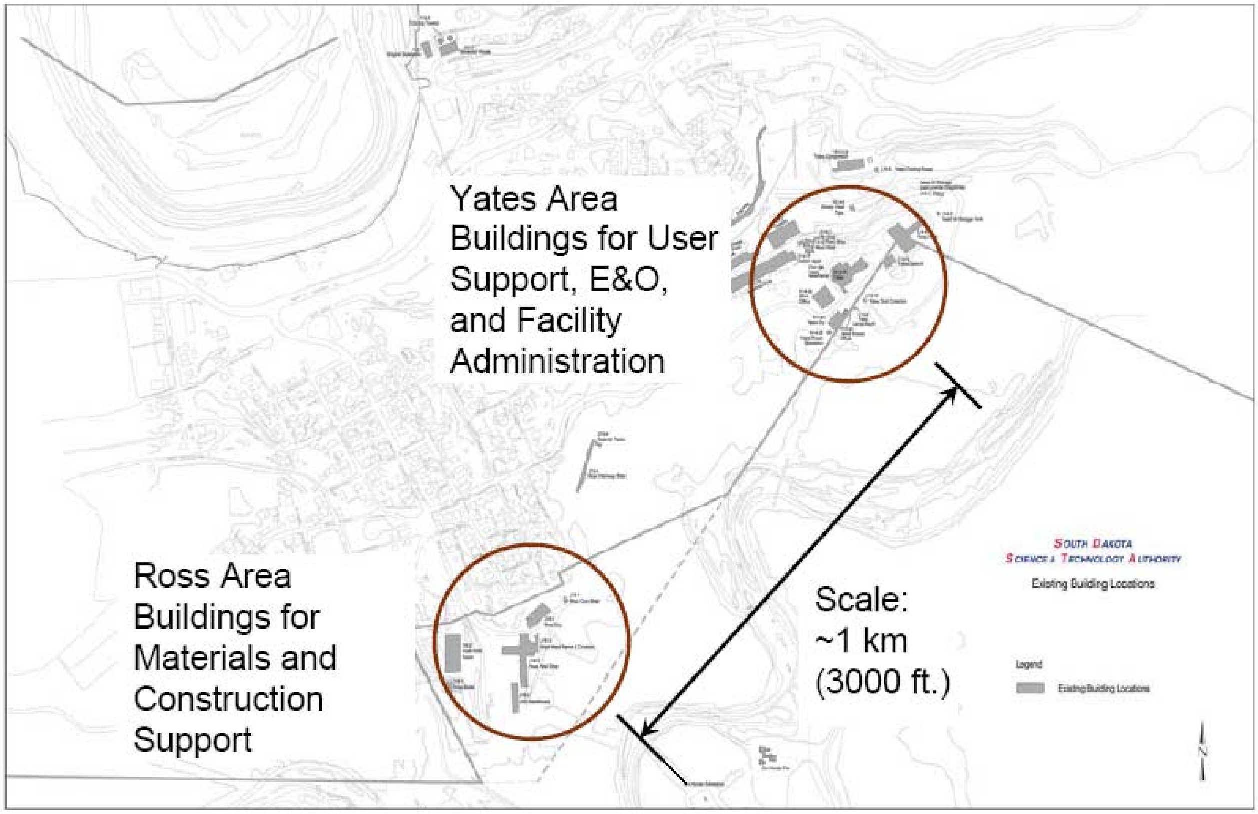


Figure 6.3 Homestake site surface plan and existing structures for laboratory programs.

6.2 South Dakota Science and Technology Authority's Mine Re-entry and Rehabilitation Plan

One can view the mine infrastructure as a two-level facility: the upper levels from surface to 4850 Level being served by one set of utilities, pumping systems, electrical power distribution, ventilation, conveyances, shafts and ramps, and the deeper levels from 4850 Level to 8000 Level by a second set. The sequence for re-entry and rehabilitation of the mine exploits the separation of infrastructure by providing initial access to 4850 Level and above, with rehabilitation and development which enables early occupancy for research activities in the Early Implementation Program. Access and occupancy at the 4850 Level will also serve as a base for dewatering and re-entry to the deeper levels.

Restoration of the #6 Winze and rehabilitation of ramps from 4850 Level to 8000 Level can be accomplished concurrently with initial science operations at the upper levels. The 7400 Level is selected as a preferred candidate for the primary deep campus for DUSEL because it meets many of the scientific requirements for depth, suitable rock properties for excavation of chambers for large detectors at reasonable cost, and the existing lower infrastructure provides a good platform for development at this level. The #6 Winze provides primary access to the deep campus, and a ramp system from 4850 Level provides both secondary egress and movement of material and equipment. Access to the deepest level of the mine at 8000 Level will also be maintained and may be further developed for experiments which require this depth. There is an existing Drill Room at 8000 Level, which will be available and suitable for bio- and geo-sciences research immediately upon re-entry to this level.

A detailed report, "Feasibility Evaluation of the Conversion of the Homestake Underground Mine to the Homestake Underground Laboratory," [52 and Appendix A10] was prepared by Dynatec Corp., an independent mining company, and presented and reviewed in December 2004. This report demonstrates feasibility of the mining-to-labs conversion program and identifies specific activities that are needed for re-entry and rehabilitation of mine infrastructure in order to support underground research. It provides a preliminary basis for planning, cost estimates, and schedules, which have been further developed for this Conceptual Design Report and for the Authority's program for both re-entry activities and on-going operations.

Pumping of water, from both naturally occurring inflow and processes for mining operations, is common in all underground mines and was practiced in Homestake. Water inflow at the Homestake site has been characterized; it is estimated that 2/3 of the total 700gpm inflow originates from upper levels (primarily from surface inflow) and the remaining third from deeper sources. The current water level is monitored with sensors stationed every 600 feet in the Ross and #6 shafts. Flooding and water accumulation in the deeper portions of the mine raises three main issues that are addressed in the re-entry plans:

- The first issue is the level of deterioration of mine infrastructure, i.e., conveyances, power, air conduits, and ground support. The near neutral pH of water in this mine retards corrosion of ground support compared to that seen in mines with strongly acidic water. Following dewatering, plans for re-entry include replacing all mechanical, electrical and conveyance infrastructure below the 4850 Level, and thorough inspection of ground support to determine what maintenance is required, and installation of bulkheads to isolate portions of the mine that will not be used for research activities.
- The second issue is delayed access to deep underground locations. With the current schedule for re-entry, accumulated water will restrict access to deeper levels during the Early Implementation Program. Access from the surface to the 4850 Level will continue to be open and the lower sections of the Ross and Yates shaft conveyances above the 4850 Level will remain dry. The Authority's plan is to intercept and remove inflowing water above the 5000 Level and establish and maintain the water level at or below the 5300 Level. The Homestake mine model predicts accumulated water will not reach the 5000 Level until September 2007 [55]. Maintenance pumping will prevent water accumulation from rising above this level. The upper infrastructure, which has not been flooded, is expected to be in good condition, with some anticipated maintenance requirements. The hoists, motor generator sets, cables, pumps, ventilation and electrical equipment have been properly mothballed and are available for re-installation and commissioning.

- The third issue is that accumulation of water may jeopardize studies of biology and geo-microbiology. Water flow has been inward for the life of the mine. The enormous hydrostatic pressure of water in the deep rock and its low permeability prevents water from flowing from mine openings back into the rock. Studies that require unperturbed conditions must drill beyond a limited cone of disturbance created by the inflows. Similar drilling would have been required even if the pumping had continued unabated. The Homestake site can host such drilling efforts laterally and vertically from many levels and ramps, and we expect only small and manageable impact for these studies.

For re-entry to 4850 Level and above, the Authority will perform the following primary tasks, with personnel safety being an essential priority at every step:

- Perform detailed video camera inspections of the Yates, Ross and #5 shafts.
- Re-establish power to site services under the Authority utility contracts.
- Inspect and re-commission the Ross and Yates hoist systems to restore the conveyances.
- Re-commission mine ventilation systems with modifications, which will support the Homestake Interim Laboratory and DUSEL requirements to provide intake air through the Ross and Yates shafts, and exhaust through the #5 shaft and/or Oro Hondo shaft, for support of new excavation and construction.
- Inspect, repair or replace timbers in the Yates Shaft, which were identified for maintenance at mine closure.
- Inspect, repair or replace steel supports in the Ross Shaft, which were identified for maintenance at mine closure.
- Inspect all accessible drifts, ramps, and shafts at 4850 Level and above; evaluate conditions at the time of re-entry, and initiate maintenance as required for safe access and egress.
- Construct ventilation-isolation bulkheads at Ross and Yates shafts for drifts that are not intended for the Homestake Interim Laboratory and DUSEL access. Install or modify ventilation control doors to establish intake and exhaust air flow as required.
- Inspect and repair underground electrical power distribution systems, including re-installation of transformers and switchgear at several levels for the Homestake Interim Laboratory and DUSEL campuses, and enable temporary power supplies for entry to other levels for identification of monitoring station locations.
- Inspect and re-activate piping and pumping systems above 5300 Level. Accumulated water will be maintained at or below the 5300 Level while awaiting authorization to initiate dewatering for DUSEL. For dewatering below 5300 Level, the existing winch operation at the #6 Winze will be temporarily converted to a hoist. A series of portable pumping stations will be lowered into the #6 Winze and a floating barge used to maintain the lowest pump on the retreating water surface.
- Re-commission existing or install new water treatment facilities (on the surface) as required to achieve acceptable water quality for DENR Water Discharge Permits. Water from upper levels may not require treatment; however, accumulated water from the deep levels is likely to require cooling and additional treatment to mitigate total dissolved solids.

6.2.1 Re-entry Plan to Install Ross Shaft Pumping System

In February 2007, SDSTA approved the re-entry plan for installation and commissioning of the pumping system at the Ross Shaft, which is presented in Appendix A11 “Homestake Re-entry and Dewatering Program Plan.” This plan comprises a phased sequence for safe re-entry to initiate dewatering which will hold the accumulated water below the 5000 level. It will enable construction access and development of the mid-level campus at 4850 level and above and access for future installation of pumping systems at the #6 Winze to dewater the entire facility to the 8000 level. The project phases for this effort include the following primary tasks:

(1) Rehabilitation and re-commissioning essential surface infrastructure for hoist operations at the Ross Shaft, installation of two new exhaust fans at the #5 Shaft for ventilation, re-commissioning electrical power distribution systems, and securing all necessary environmental permits for pumping and water discharge;

(2) Re-entry for inspection and rehabilitation shaft infrastructure and intersecting drifts, installation of ventilation bulkheads to isolate the fresh-air circuit at the Ross Shaft and selected drifts for future access and development, installation of new power supply cabling and refurbished transformers and switchgear, installation of refurbished pumps and piping at the four primary pumping stations along the Ross Shaft at 1250, 2450, 3650, and 4850 levels, installation of new fiber optic cable for communication and controls; and

(3) Operation and maintenance of the pumping system, ventilation, hoists, and Ross Shaft infrastructure to provide continuous dewatering to support development and operation of the interim laboratory, aiming to begin steady-state operation by the end of calendar year 2007.

6.3 Surface Buildings and Structures

The existing surface infrastructure at the Homestake Interim Laboratory was built primarily to support previous mining operations. Many of these buildings are significant assets for mining-to-labs conversion. Some facilities and their functions will continue to be needed to support underground access and activities for underground construction and lab operations. However, in the absence of ore processing and high-volume, production-scale mining, other buildings are available and suitable for conversion or remodeling to suit the needs of the lab, to be developed concurrently as research operations and user support become the primary activities at the site. Of the buildings and structures included in the property transfer, there are several prime candidates for continued use or development for the Homestake Interim Laboratory and DUSEL, including:

- Yates Shaft complex to be developed for facility administration, site services and user support:

  Mine Office and Administration Building
  Yates Safety and Dry Building
  Yates Headframe and Crusher Building
  Yates Hoist Room
  Machine Shop Building
  Main Warehouse
  Foundry Building
  Yates East Substation

- Ross Shaft complex with minimal remodeling for construction staging and maintenance:

  Ross Headframe and Crusher Building.
  Ross Hoist Room
  Ross Dry Building

Ross LHD Warehouse
Ross Pipe Shop
Ross Substation

- Other Buildings and Facilities with functional infrastructure:

Water Treatment Facilities
Oro Hondo Substation
Oro Hondo Fan
Kirk Fans
#5 Ventilation Shaft

Initial planning has focused on maintenance and preparation of surface facilities needed to support re-entry, rehabilitation, and new construction of underground lab modules. During the next project stage for Preliminary Design, design concepts will be developed to remodel space for site services and user support (e.g., administrative offices, classrooms, surface laboratories, and shops) and Education and Outreach (e.g., classrooms and conference rooms, visitor center, displays and demonstrations). Buildings in the Yates Complex which are being studied for these functions include the Mine Office and Administration Building, Yates Safety and Dry, Machine Shop, Warehouse, and Foundry. These five buildings alone offer nearly 9300 m^2 (100,000 ft^2) of floor space available for facility and lab operations in the Yates Complex.

The Authority is currently converting 5400 square feet on top floor of Yates Dry for safety, offices, meeting rooms, as illustrated in Figure 6.4.

Figure 6.4 Conversion of the Yates Dry for safety offices, meeting rooms and office space.

6.4 DUSEL Campus Development at Near-Surface, Mid-Levels and Deep Levels

Initial development to support early access to mid-levels for Early Implementation Program experiments and R&D will focus on the 4850 Level underground campuses for the Homestake Interim Laboratory: with primary access via the Yates and Ross shafts, as shown in Figures 6.2 and 6.3. Planning for infrastructure rehabilitation and alterations at re-entry includes considerations to enable phased development of lab modules and common facilities for eventual DUSEL programs at near-surface, mid-levels and deep-level campuses at the 7400 and 8000 Levels. According to preliminary plans, ventilation fans for the #5 Shaft will be converted to exhaust air, and the Yates and Ross shafts used for intake air, which facilitates access to other drifts and ramps throughout the mine (such as the long drift at the 2000 Level) for off-campus underground research including biosciences, geosciences, and geomechanics, which may require access to a variety of rock types and conditions, and physics experiments that may require a greater degree of isolation.

6.4.1 Near-Surface Campus at the 300 Level

Preliminary engineering for underground construction to initiate Early Implementation Program research activities will begin as soon as funding is available. Figure 6.5 shows a development concept at the 300 Level adjacent to the Ross Shaft where the existing Power Tunnel portal provides horizontal entry from Kirk Road. A new drift and portal (5m x 5m) will allow drive-in access to the 300 Level campus which will initially have a total of approximately 925 m^2 (10, 000ft^2) of floor space in these new rooms and access drifts. This concept also includes options for future development of additional near-surface space for DUSEL experiments and activities that are suitable at the 300 Level.

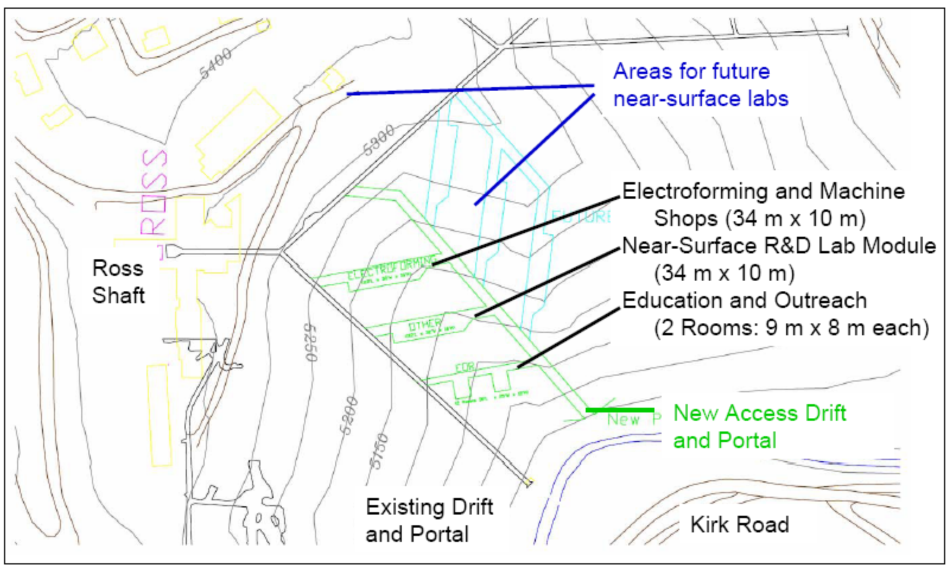


Figure 6.5 Development Plan for Near-Surface Facilities at 300 Level. Total excavated space for initial excavation at 300 Level provides more than 925m^2 (10,000 ft^2) for labs, shops, access drifts, and E&O.

Pending funding availability with an aggressive schedule for excavation and outfitting, beneficial occupancy of underground labs at the 300 Level may occur as early as 2010 to support Early Implementation Program and R&D experiments such as a near-surface Low-Background Counting Facility, Low-Background Materials Manufacturing and storage (i.e., Copper electroforming and machine shops), R&D facilities for several experiments which will be implemented later at deeper levels, and classroom/display space for E&O. Access and construction at 300 Level may be done concurrently with the mid-levels re-entry and infrastructure rehabilitation program.

6.4.2 Mid-Level Campus at 4850 Level

Development of the 4850 Level as a primary campus for DUSEL has several attractive features which are well matched to scientific goals. At this level, the overburden provides approximately 4100 mwe, which meets or exceeds the overburden depth needed for a wide range of experiments, as discussed in Chapter 4. Initial assessments of rock mass undertaken by Pariseau, Golder, NIOSH, and RESPEC [40-45] indicate that, for geotechnical and engineering purposes, both the Yates and Poorman rock are conducive to the construction of large excavations using appropriate state-of-the-industry ground support techniques in moderate stress regimes. The base of the Yates shaft terminates within the Yates Member at 4850 Level for convenient, direct access from the surface for lab personnel and materials.

By exploiting the combined operation of conveyances at both Yates and Ross Shafts, phased excavation activities at 4850 Level may be done with access by construction crews via the Ross Shaft concurrently with access for on-going lab operations staff via the Yates Shaft. Existing mine infrastructure provides supply air through both shafts, which permits temporary construction barriers to isolate construction from clean areas for research activities. The conversion plan includes Yates Shaft upgrades to enhance accessibility with an automated personnel lift for 24 hour/7 day access, a large cage (approximately 4m x 4m) for lab materials and equipment, and defined space for services and utilities, including ducting for low-radon air from the surface, as shown in Figure 6.6. Waste rock removal and mobilization of construction materials and equipment will utilize the existing conveyances in the Ross Shaft, which terminates at 5000 Level. As discussed above, early access to 4850 Level by the Authority will enable pumping to keep accumulated water from rising above 5300 Level, which will reduce the time and cost for re-entry and infrastructure rehabilitation at 4850 Level. Site investigation and geotechnical studies for development of lab modules at 4850 Level may begin as early as 2008.

6.4.3 Existing Cage Dimensions and Capacities

Yates Cage Hoist (shown in Figure 6.7)

- Maximum Cage dimensions: 1.4 x 3.7 x 2.2m high (side-by-side)
  (4’ 8” x 12’ 1.5” x 7’ 2” high)
- Maximum cage payload: 5,450 kg (12,000 lb), nominal
  5,900 kg (13,000 lb), allowable at half-speed.

Ross Cage Hoist

- Maximum Cage dimensions: 1.3 x 3.8 x 2.2m high (double deck)
  (4’ 4-5/8” x 12’ 5” x 7’ 2” high)
- Maximum cage payload: 5,450 kg (12,000 lb, nominal
  6,100 kg (13,400 lb), allowable at half-speed.

#6 Winze Cage Hoist

- Maximum Cage dimensions: 1.3 x 3.7 x 2.2m high (double deck)
  (4’ 4” x 12’ 1-1/2” x 2.2m high)

- Maximum cage payload: 5,450 kg (12,000 lb), nominal
  6,400 kg (14,000 lb), allowable at half-speed.

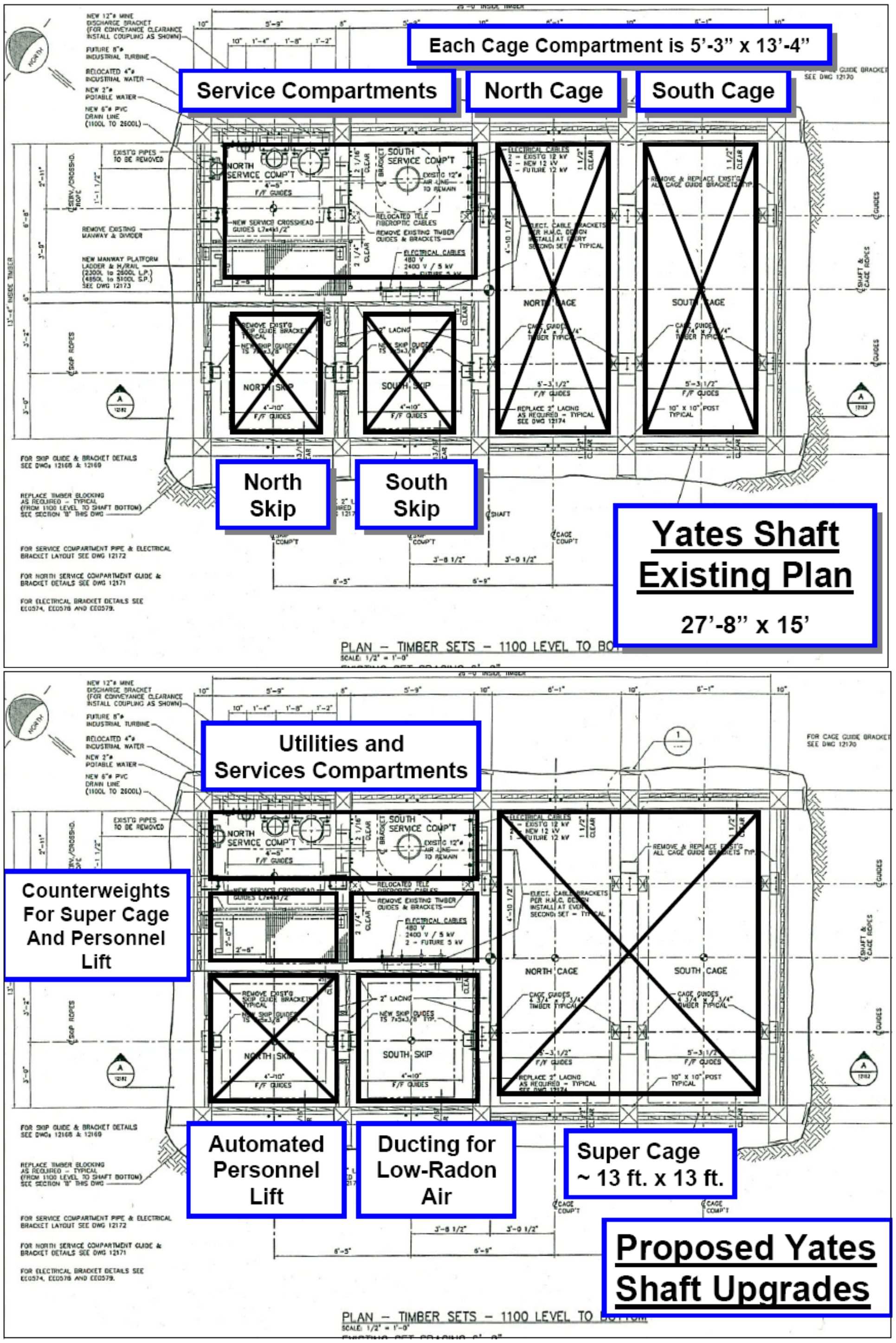


Figure 6.6 Existing (top) and proposed (bottom) layouts for the Yates Shaft and conveyances. Smaller cages and skips will be replace by a large Super Cage for material and equipment, and ore skips will be replaced by an automated lift for personnel.

Ramp System to Deep Levels:

A series of ramps connecting levels between the 4850 and 8000 Levels provide secondary egress and also a back-up transport path for mobile equipment and construction materials which may not fit in the #6 Winze cage hoist. Primary staging for materials and equipment will be done at the 4850 Level Ross Shops for construction and installation activities at the 7400 Level campus, and space will also be made available for staging at the 7400 Level during excavation and laboratory construction.

Waste Rock Hoist Capacities and nominal daily capacity with 3-shift (22 hours) operation:

Yates Ore Hoist:	182 metric tons/hour (200 tons/hour)	4,000 metric tons/day (4,400 tons/day)
Ross Ore Hoist:	137 metric tons/hour (150 tons/hour)	3,000 metric tons/day (3,300 tons/day)
#6 Winze Ore Hoist:	173 metric tons/hour (190 tons/hour)	3,800 metric tons/day (4,180 tons/day)

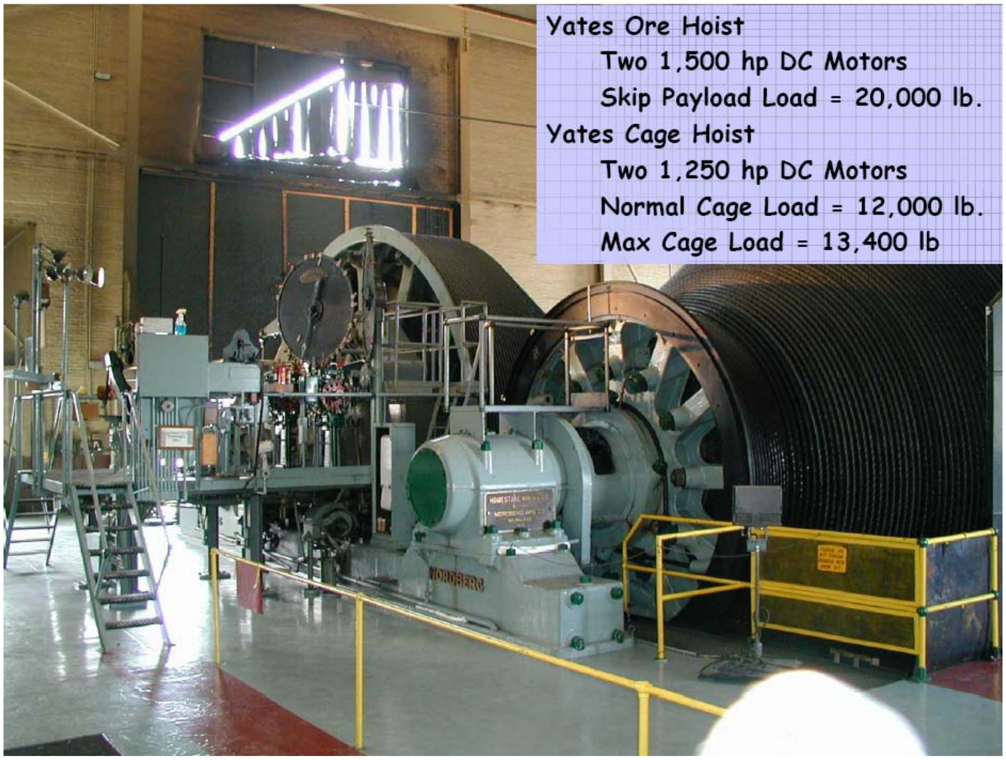


Figure 6.7 Photograph of the Yates Cage Hoist and controls, located in the Yates Headframe.

6.2.1.1 Hoist Upgrade Options to Increase Size and Weight Capacities

Feasibility studies and cost estimates were done by the Homestake Mining Company in 1997 and 2001 to evaluate upgrades to the hoists and conveyance systems at the Yates shaft and #6 Winze. The study in 1997 considered relatively modest alterations to the Yates production hoists to increase the capacities to handle loads between 15 to 18 tons, and to increase the capacities of the service hoists to 10 tons. In addition to some structural enhancements, alterations included several new components such as hoist ropes, brake systems, clutches and clutch linings, and improved hydraulics for the existing two ore skips and two cages.

The study in 2001 considered major alterations to the Yates shaft to install a "super-cage" which could handle shipping containers up to 9' x 9' x 20' size and 25 ton load capacity, and also to install a smaller hoist and personnel lift. The nominal super-cage size was 13' x 22'. This configuration would also require major changes to the Yates shaft and headframe, hoists, and the drifts at the 4850 level.

For this conceptual design, we have proposed relatively modest and cost-effective upgrades to the Yates shaft and hoist systems. As described above in Sections 6.4.2 and 6.4.3, we plan to install a single super-cage (~13' x 13') to replace the two existing cages, and a smaller automated

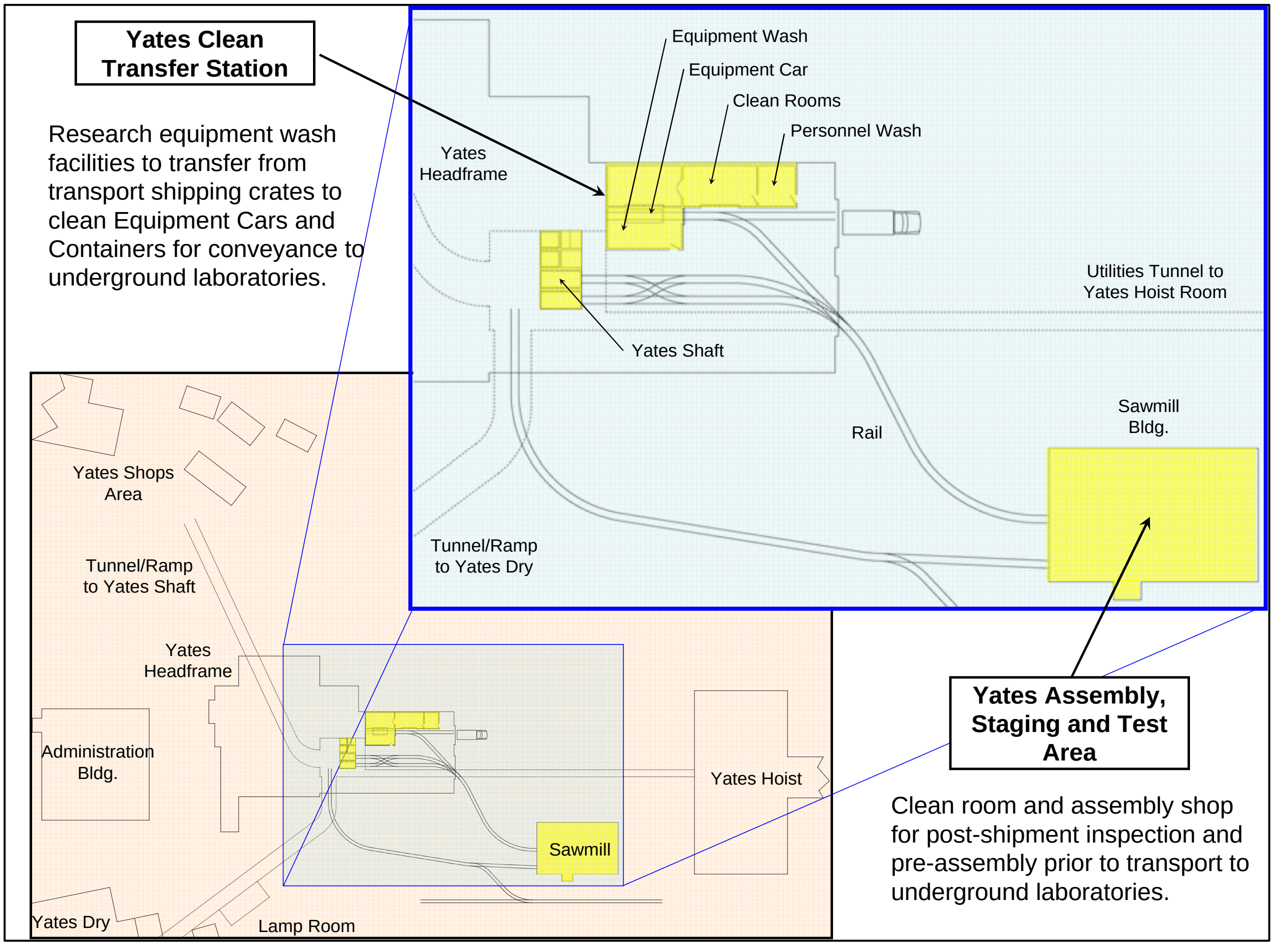


Figure 6.8 Proposed surface facilities to prepare materials and equipment for conveyance to underground laboratories, including the Yates Clean Transfer Station within the existing Yates Headframe building, and alterations at the Sawmill Building for the Yates Assembly, Staging, and Test Area.

lift for personnel. Shipping containers and other large equipment which exceeds the super-cage size capacity may be slung under the cage, hanging vertically. This configuration was done routinely for mine operations to transport bundles of rail and pipe up to 30 feet in length. This will require minimal alterations to the Yates shaft infrastructure and will significantly enhance capabilities for larger-size loads of material and equipment and dedicated access for personnel. Options to increase the load capacity are also being considered, and upgrades will be matched with identified requirements and budgetary constraints.

Other temporary configurations are possible which could accommodate additional weight capacities and/or sizes, depending on the combined requirements. For example, we currently have the option to replace the cage with a crosshead and guide assembly in order to handle oversize loads which exceed the cage nominal size constraints. In addition, without the weight of the cage itself, the weight capacity for the hoist system using a crosshead assembly is increased by approximately 4 tons. Similarly, other scenarios are feasible to develop economical, cost-effective design configurations which may handle special or specific requirements.

A key component of our design concept for the Yates super-cage is the planned development of surface infrastructure at the Yates Headframe building and at the nearby Sawmill building for inspection, cleaning, pre-assembly, testing, and re-packaging components as they are received from shipment. Development of the Sawmill building into a staging area with a clean assembly shop and construction of a Clean Transfer Station in the Yates Headframe building are also included in the construction plans, and shown in Figure 6.8. We anticipate that a standard practice for movement of materials and equipment from the surface to underground will necessarily include a careful inspection of all parts to insure that any damage which might have occurred during shipment can be identified and repaired prior to taking those parts underground.

Whenever possible, components and subsystems will be cleaned, pre-assembled and tested on the surface to minimize the work required to assemble and commission the systems underground. This is similar to procedures that are typically done at other underground research facilities such as SNOLab. We plan to develop and make available to users standard transport containers which match the size capacities and constraints for conveyance of parts from the surface to underground laboratories. The customized containers will have appropriate provisions to handle the atmospheric pressure differential between the surface and underground and also to maintain cleanliness, for example, using a "double-bagged" design, as needed. Standard practice for effective underground construction and commissioning will likely require surface inspection and preparation following receipt of shipments and before parts and sub-assemblies are taken underground – for engineering, safety and security considerations.

A further consideration regarding project scope in the context of overall systems design for accessibility and material transport is scheduling and availability of the hoist and conveyance systems. With Homestake being a dedicated facility for science, all decisions regarding priorities for access and services will be under the control of DUSEL management. At other underground research facilities, such as SNOLab, scheduling for both personnel and material transport must be coordinated with concurrent mining operations, generally with secondary priority to production requirements.

6.4.4 Phased Development for 4850 Level Campus

Figure 6.9 shows the existing workings and major geological features at 4850 Level. The encircled area near the Ross and Yates Shafts will be developed for the mid-level campus, and illustrates the approximate contact region between the rock of the Yates Member (Yf) and the Poorman Formation (Pf). Initial plans for excavation of new lab modules will be done within the triangle. Excavation for future modules and purpose-built chambers for large detectors is feasible outside the triangle to the east and west, with good proximity to existing drifts and shafts for access, waste rock removal, services and utilities, and ventilation. Figure 6.10 shows with more detail several of the existing rooms that are available for development and outfitting at re-entry to 4850 Level. Direct access to this area also provides immediate opportunity to begin coring and site investigations. This will provide data for studies to evaluate rock properties at specific locations prior to detailed design and excavation for lab modules.

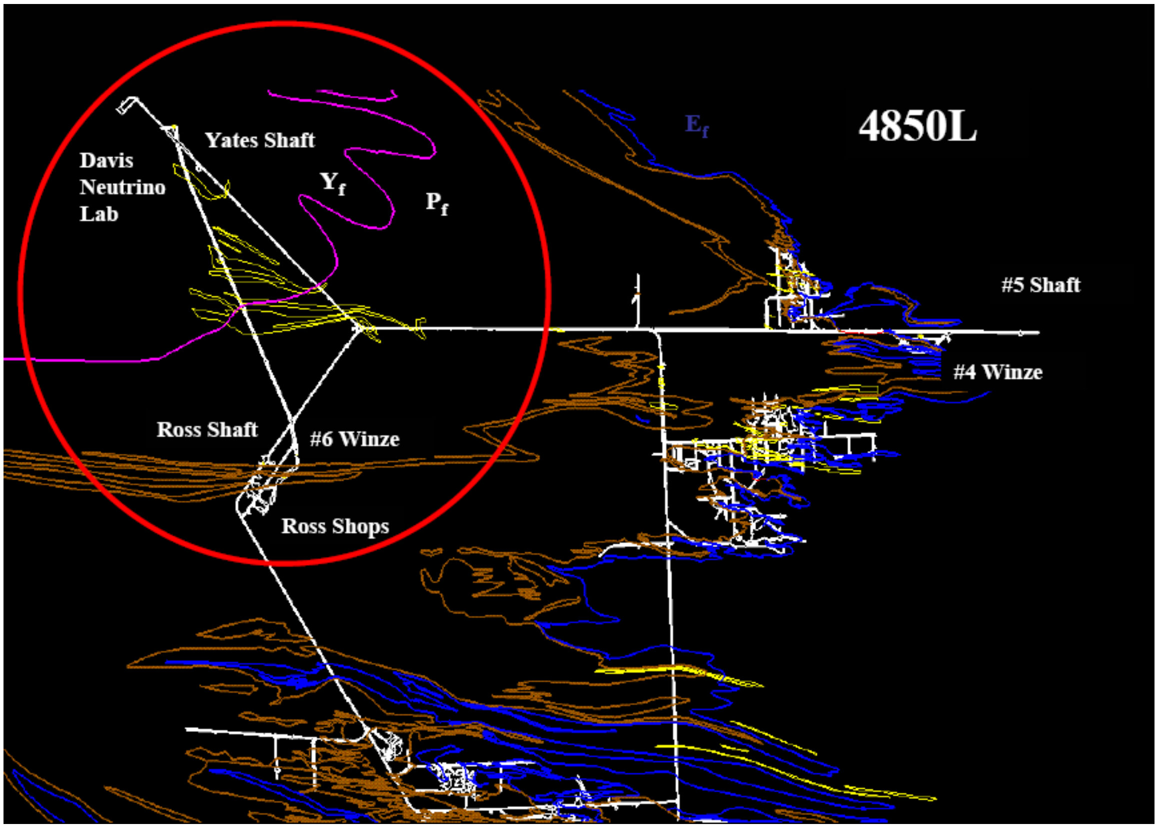


Figure 6.9 Homestake Mine 4850 Level workings and geological features. Encircled area near Yates and Ross Shafts will be developed for the DUSEL Mid-Level Campus. Preferentially, large excavations will be done within the competent rock of the Yates Member (Yf).

The proposed development plan for the mid-level campus is shown in Figure 6.11, which demonstrates a phased sequence of excavation for new lab modules, common facilities and services, and construction maintenance shops. This plan provides more than 6,000 m^2 (65,000 ft^2) footprint at 4850 Level.

The first stage of excavation, which may start as early as 2008, will enlarge the existing Ross Shops to be used for construction materials and equipment maintenance. Because this space is adjacent to the #6 Winze and accessible to the ramp systems to deeper levels, it will also be used to support construction of labs at 7400 Level for the deep campus. Excavation in Stage #1 includes expansion of the existing Davis Neutrino Chamber to increase the height of the room. It will be developed for a Water Shield Facility, initially planned for the LUX and CLEAN experiments as described in Chapter 4 for the Early Implementation Program. In the area immediately adjacent to the Davis Neutrino Chamber, two new rooms will be excavated: a laboratory which may be outfitted for R&D and early implementation of the Majorana Experiment (20m x 6m x 5m high) and a smaller Control Room (9m x 6m x 5m high) which may be shared by both the LUX, CLEAN and Majorana experiments. Excavation in Stage #1 also develops a large laboratory (32m x 9m x 5m high) to be used as a base of operations for Geosciences and Biosciences research in both Early Implementation Program and DUSEL. For this first construction stage at 4850 Level, outfitting may be completed by mid-2009 to begin installation of research instrumentation.

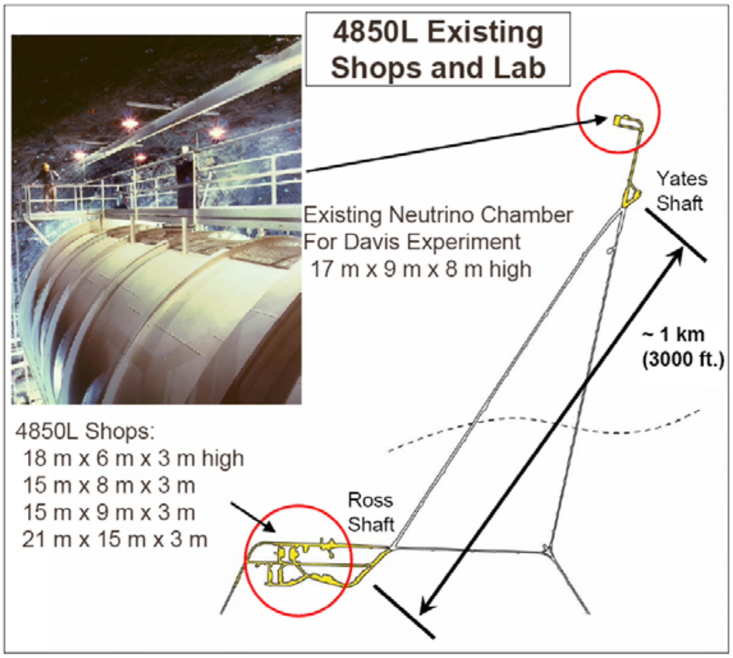


Figure 6.10 Existing chambers near Yates and Ross Shafts, available for development and outfitting at re-entry to 4850 Level. Existing drifts provide direct access for coring and site investigation to initiate detailed design for excavation of additional lab modules.

The second excavation stage at 4850 Level is scheduled to begin directly on completion of stage #1, ideally to maintain continuity for construction crews and equipment. Continuity of the construction and excavation work will avoid incurring significant, additional costs for mobilization and de-mobilization if there is a gap in the construction schedule. In developing the excavation sequence and schedules, we have aimed to match the construction scale and sequence with several drivers:

(1) anticipated maturity of scientific programs to specific requirements and their likely schedule for readiness of research instrumentation;

(2) project management objectives to maintain uniform staffing levels for both sub-project design teams and construction crews;

(3) develop reasonable cost profiles to be negotiated with the funding agencies for the duration of the project;

(4) scaled to optimize workloads for construction crews and equipment to enable concurrent operations in alternate areas for the sequence of activities to drill and blast, remove waste rock, and install ground support; and

(5) balanced design scale to minimize costs and risks for excavation and outfitting with shared infrastructure among multiple experiments rather than isolated chambers for each experiment.

Item (5) is a significant cost driver identified by our preliminary estimates, which indicate that laboratory infrastructure and outfitting are likely to be a major cost element for underground experiments. By developing reasonable sized lab modules that may host more than one experiment, laboratory infrastructure costs may be shared among multiple experiments.

Excavation stage #2 will develop new space along the Yates-Ross drift to be used for common facilities and services, and two general-purpose lab modules within the Yates-Ross triangle. The large Common Room (~50m x 15m x 5m high) is located along the main access drift and will be outfitted for utilities and services to support the mid-level campus (electrical power transformers and switchgear, air handling equipment for ventilation and filters, communications and monitoring systems, compressed air, purified water, and emergency response equipment and refuge station).

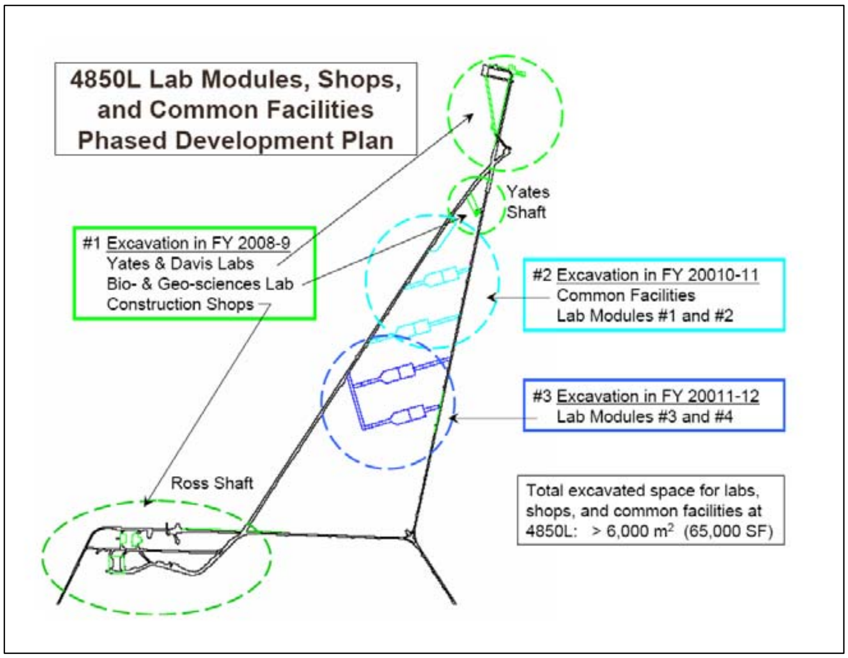


Figure 6.11 Development Sequence at 4850 Level provides construction access via Ross Shaft isolated from on-going lab operations with staff access via Yates Shaft. Each of four large lab modules (~50 x 20 x 15m high) provides shared outfitting and common services for multiple experiments.

The Common Room will support user services and wash facilities for an initial transition from the mine environment to a clean, laboratory environment. Each of the Lab Modules (~50m x 20m x 15m high) within the Yates-Ross triangle will have a secondary transition to purpose-built clean rooms that meet the requirements of specific experiments. Each lab module will be outfitted for specific experimental configurations, and a nominal module design is presented below to serve as a basis for preliminary project planning and estimates. Stage #2 construction may start in FY11, pending availability of construction funds. Duration for excavation will be approximately one year, plus up to one year for outfitting to prepare for beneficial occupancy to begin installation of research instrumentation.

The third excavation stage at 4850 Level may begin in FY11 or FY12, pending experimental needs and funding. The current plan for development of the 4850 Level campus includes a budget for excavation of the two additional lab modules in this stage, but excludes costs for outfitting and research instrumentation in these modules. This approach is most cost effective to exploit continuity for construction by eliminating an additional mobilization and de-mobilization cycle, and also enables flexibility to tailor the outfitting to match experimental requirements which may be identified as DUSEL research programs mature during the next few years.

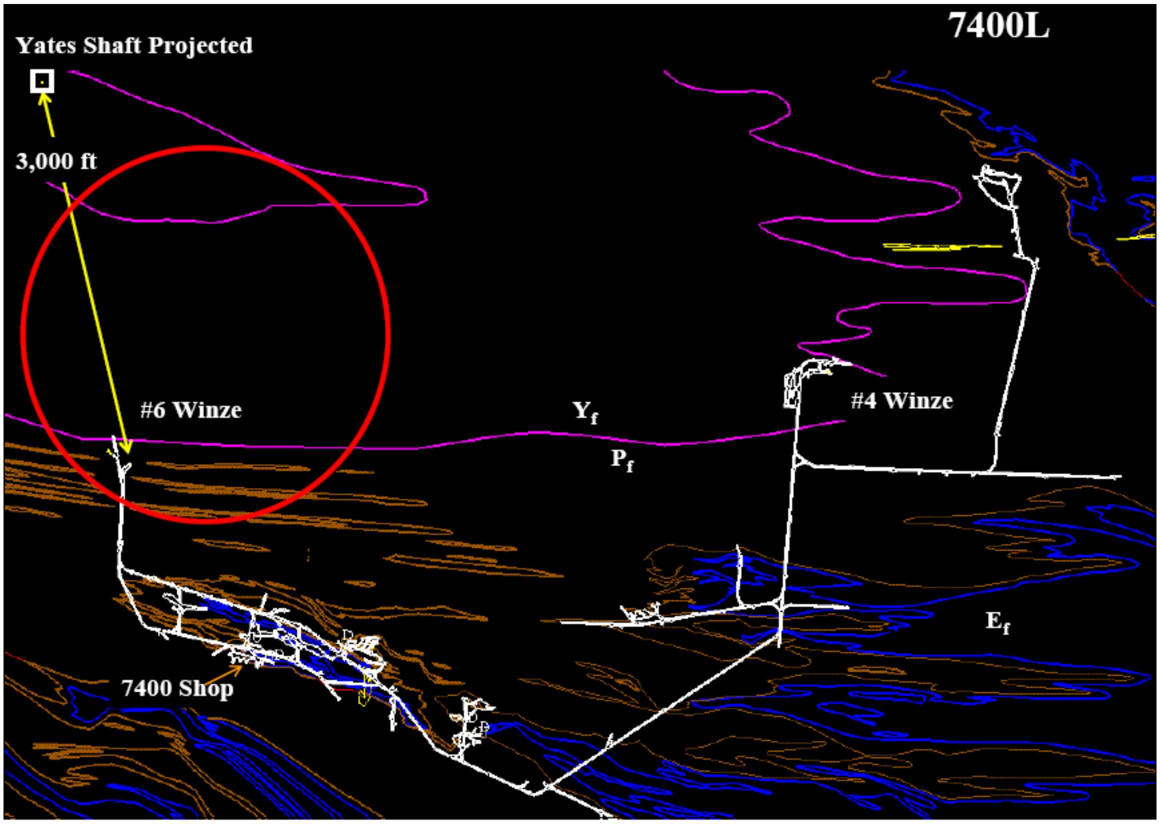


Figure 6.12 Homestake Mine 7400 Level workings and geological features. Encircled area near #6 Winze will be developed for the DUSEL Deep-Level Campus. Preferentially, large excavations will be done in the more competent rock of the Yates Member (Y_f).

6.4.5 Deep-Level Campus at 7400 Level

The #6 Winze provides primary access to the levels below 4850 Level. A ramp system between 4850 Level and 8000 Level provides secondary egress from the deeper levels, and also provides access for materials and mobile equipment from the construction staging areas at 4850 Level. Figure 6.12 shows the existing workings at 7400 Level and the encircled area near the #6 Winze in the Yates Member (Y_f) is the preferred site for excavation of lab modules and large detector chambers. The existing 7400 Shop (~42 x 9 x 5m high) may be used for construction materials, staging, and equipment storage. Intake air is directed through the #6 Winze, and air controls doors will direct the exhaust air to the #4 shaft.

Plans for development of the deep-level campus, shown in Figure 6.13, follow a similar, standardized approach with the ladder-type layout for lab modules as used at 4850 Level. This configuration enables phased construction concurrently with adjacent lab operations, primary and secondary egress paths, excellent options for routing ventilation and utilities, and allows cost-effective, optimal scheduling for construction activities. The plan includes initial excavation of a Common Room for facilities and user services near the user entrance from #6 Winze, and a construction materials and equipment room on the opposite leg.

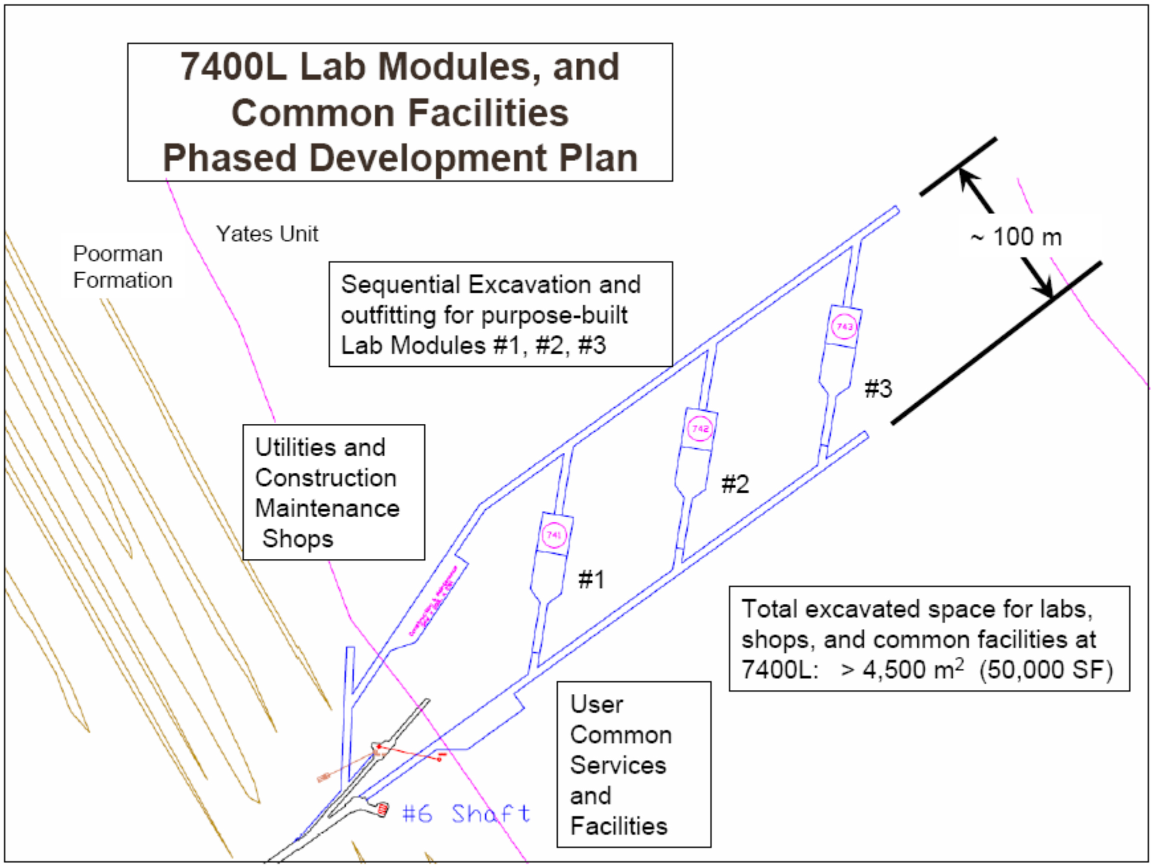


Figure 6.13 Homestake Mine 7400 Level Concept for DUSEL Deep-Level Campus, planned for sequential development of Common Space and Construction Areas, and three purpose-built lab modules each with shared outfitting and services for multiple experiments.

Excavation of the three proposed lab modules will be done in sequence for early experiments to begin in Lab Modules #1 while construction is continued for Lab Modules #2 and #3. With this configuration, the total excavated footprint at the 7400 Level campus is more than 4,500 m^2 (50,000 ft^2). The planned budget for construction at 7400 Level includes excavation of all three Lab Modules, outfitting for the Common Room and Lab Module #1 at the 7400 Level, but excludes outfitting of Modules #2 and #3. As at the 4850 Level, this approach is most cost effective to exploit continuity for construction by eliminating an additional mobilization and de-mobilization cycle, and enables flexibility to tailor outfitting to match experimental requirements which may be identified as DUSEL research programs mature during the next few years.

6.5 Primary Levels in Homestake of Interest to Research

Although the most intensive activity will be associated with the upper and lower campuses and will focus on the 7400, 4850, and 300 Levels, other levels will require some amount of continued access. Some of the levels will be maintained for operational purposes and some will be maintained to provide access to important areas of the underground for experimental

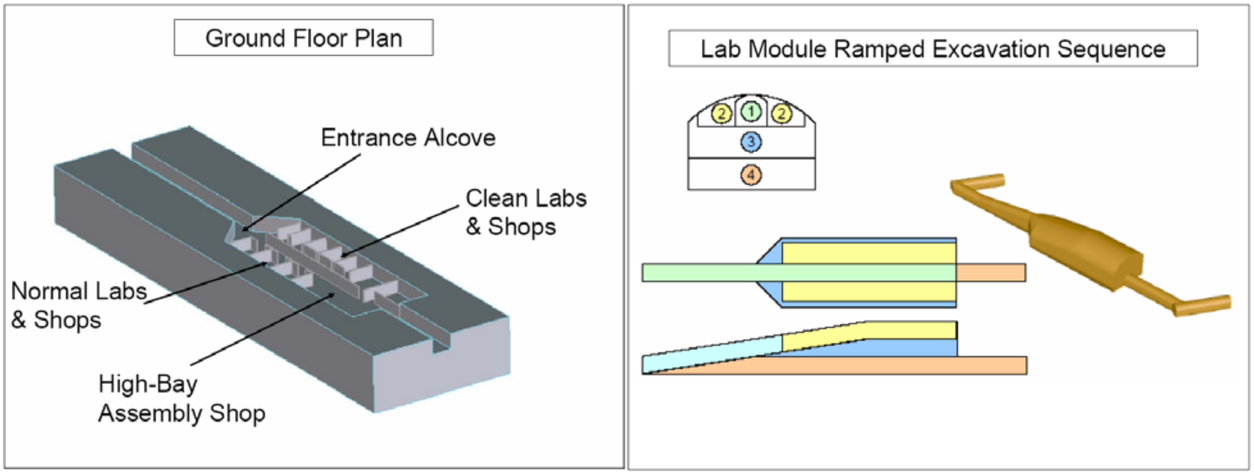


Figure 6.14 Nominal layout and Ground Floor Plan (left) for typical Lab Module. Ramped excavation sequence (right): (1) access drift and heading top cut, (2) slash top bench, (3) middle bench, (4) bottom bench and exit drift. Floor plan outfitting will be purpose-built for specific experimental requirements.

purposes. Table 6.1 lists those levels deemed to be most important, but the selection of these levels for continued maintenance does not necessarily preclude access to other levels and areas in the underground. In addition the ramp system provides for exceptional access to many of the geologically varied environments in the Homestake facility.

6.6 Lab Module Concepts, Common Facilities and Services

A concept for a standardized lab module configuration is presented in Figures 6.14 and 6.15. This nominal configuration is used as a basis for planning, analysis, and estimating to develop the conceptual design for Homestake DUSEL. As specific information for individual experimental requirements becomes available, this concept for excavation and outfitting will evolve with additional detailed engineering and design. The nominal design has a footprint of approximately 50 x 20 m and the maximum ceiling height is 15 m over half the length of the room. With construction of a partial mezzanine floor, a portion of the module may utilize the full

Table 6.1 Levels in the Homestake Facility of Interest for Research

Level	Priority (1 is highest)	Justification/Comments
300L	1	Experiments are currently planned for this level; potential walk-in access for experiments and education and outreach
800L	2	Offers access to the north; will be useful for underground mapping educational purposes; older part of underground and may be important for geomicrobiology
1100L	3	May offer access to sump for water collection; only a limited amount of the level would have to be maintained
2000L	2	Provides very wide access; will be useful for underground mapping educational purposes; will be important for geosciences; and may be important for geomicrobiology

2600L	2	Connects the two main areas of mineralization at depth; important for geoscience—study of mineralization; good connector throughout this depth of the underground
3800L	3	May be redundant to 2600L but offers access to the #5 shaft and may be useful for both geoscience and maintenance of the shaft; may be important to provide depth access (provides access between the 2600L and 4100L)
4100L	2	Connects the two main areas of mineralization at depth; important for geoscience—study of mineralization; good connector throughout this depth of the underground
4850L	1	Primary level for laboratory module development
5900L	2	Offers access to the #4 winze and to wide areas of the underground; midway between 4850L and 6800L
6800L	1	Connection to the #5 shaft; important to maintain monitoring of underground facilities
7400L	1	Primary level for laboratory module development
7700L	4	May be a useful level to drift under the 7400L experimental area for a cryogen dump and other utilities; use is speculative at this time
8000L	1	Required for access for deep drilling for geomicrobiology; is the location of the skip pocket for rock from the 7400L; required for pumping of water from the deepest levels

15 m ceiling height for a high bay assembly shop with overhead crane capability for material handling. Including the build-out with a mezzanine and entrance alcove, total usable floor space is approximately 1,600 m^2 (17,600 ft^2). For several proposed experiments with similar infrastructure requirements, it will be cost-effective to develop lab modules to have shared services to the extent feasible, and purpose-built rooms for detectors and other functions that may be unique to an experiment.

The shared services within modules may include functions such as clean rooms and wash facilities, electronics and mechanical shops, communications and control room, meeting room and offices, storage, emergency response equipment and refuge, electrical and mechanical utilities (including purified water systems and reduced-radon air), emergency exhaust or containment/drainage systems for hazardous materials. Many of these functions add significant cost to lab and experiment outfitting and may be used only intermittently during installation and normal operations. Early planning to co-locate experiments with similar requirements to enable shared services will be beneficial for both cost and schedule management.

Accessibility is another important design issue associated with planning and development of lab modules. Upgrades to the conveyances at the Yates Shaft will increase clearance capacity to handle equipment containers, construction materials, and lifting fixtures up to ~4m x 4m in cross-section. The cage may be rigged to handle vertically longer lengths of containers, such as lengths of piping structural components, with the primary limitation being maneuvering the vertical lengths from the shaft into horizontal drifts. The nominal cross-section in the main Yates-Ross drift is approximately 4 x 4m (13 x 13ft.), with some tight regions to be expected. Rehabilitation of existing access drifts and excavation for any new drifts will maintain a minimum stay-clear area of 3 x 4m (10 x 13ft.), with expanded widths at passing zones and at sharp turns and junctions for adequate swing length around corners.

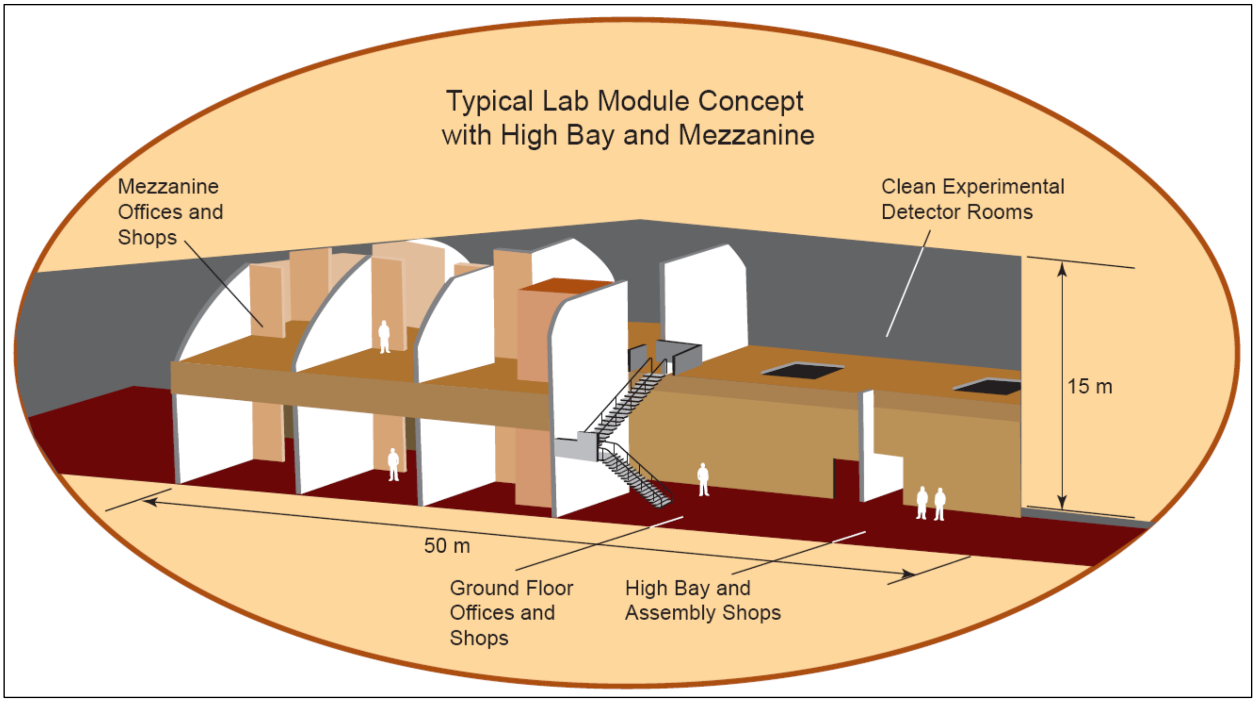


Figure 6.15 Cut-away view of chamber opening for Lab Module concept with high bay and mezzanine for multiple experiments.

The nominal design for new, primary access drifts for lab modules is 5m x 5m in cross-section in order to provide space along the walls and ceiling for mechanical and electrical utility distribution and drainage. Figure 6.16 shows a concept to define clearances and utilities in new drifts, including space reserved for ventilation ducting for specific experiments that may require reduced-radon air supply, isolated exhaust for fume hoods or boiloff gas from normal operations, and emergency exhaust to contain and isolate potentially toxic gases for personnel safety.

For most standard construction materials for laboratory outfitting, normal material-handling equipment may be used to transport supplies from shafts to each lab module, comparable to construction material handling in a typical surface building. For specific research instrumentation and materials which may require special handling to maintain cleanliness or to prevent damage to sensitive components, we will develop standard transport containers which can be loaded and sealed at the surface under clean-room conditions, and moved underground using engineered lifting fixtures and handling features. It is important that all containers and equipment moved from surface to underground must insure that atmospheric pressure changes with elevation do not cause any damage, leakage, or hazardous material spills. We expect that standard shipping containers for the trucking industry, for example, would not be acceptable for material handling and transport into the mine. Shipments will normally require inspection for damage upon receipt at the site. Often, pre-assembly and testing of some components will be done at the surface to facilitate trouble-shooting and maintenance prior to underground installation.

6.7 Geotechnical Studies: Stability Analyses to Support Site Selection

Large openings have been excavated at many locations within the mine and have demonstrated excellent stability for several decades, including rooms at the 4850, 6800, 7400, and 8000 Levels in a variety of rock types. In addition, recent geotechnical analyses and feasibility studies have been done to evaluate potential sites and prepare preliminary plans for large excavations for installation of experiments. Modeling behavior of the host rock for laboratories has shown that large rooms can be constructed and remain stable at 4850 Level, 7400 Level, and 8000 Level when proper detectors in various ground support is installed.

Tesarik *et al*. (2002) [42] modeled a cylindrical room. Their calculations showed that room shape can be adjusted to improve room stability. Rooms with an arched crown and height to width ratio of 1.5:1 will be stable at 4850 Level with cross sections of 50m x 50m, and at 8000 Level with cross sections of 18m x 18m. Golder Associates (2004) [45] showed that a 50 m domed cavern with height to width ratio of 2:1 is controllable at 7400 Level using currently available ground support technology.

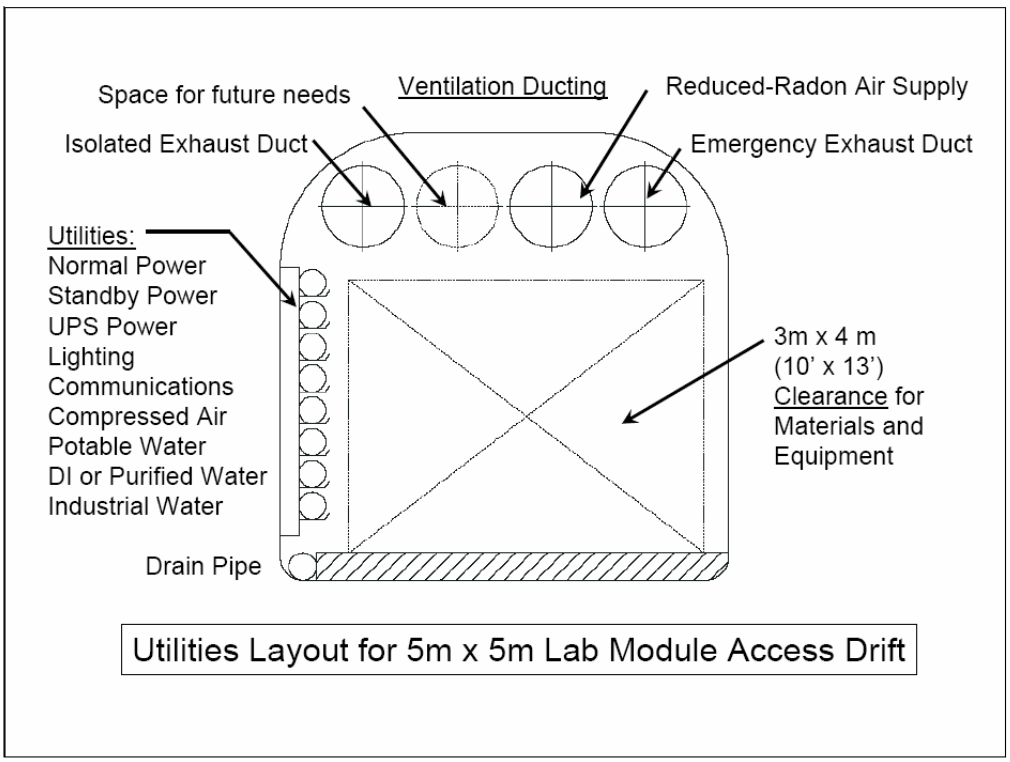


Figure 6.16 Nominal Lab Module access drift layout, with defined clearance for materials and equipment and reserved space for utilities and ventilation ducting.

Table 6.2 Preliminary recommendations for rock support for lab module excavations (~50 x 20 x 15m high) at mid-level and deep-level campuses. (Golder, 2006) [44]

FORMATION	LEVEL	LOCATION	BOLTING	SHOTCRETE
Poorman Formation	4850L	Roof	5 m long bolts @ 2 m c/c	90 mm fibre reinforced shotcrete
		Side Walls	8 m long bolts @ 1.75 m c/c	100 mm unreinforced shotcrete
	7400L/8000L	Roof	5 m long bolts @ 1.75 m c/c	100 mm fibre reinforced shotcrete
		Side Walls	8 m long bolts @ 1.5 m c/c	90 mm fibre reinforced shotcrete
Yates Unit	4850L	Roof	5 m long spot bolts	none
		Side Walls	4 m long bolts @ 2.5 m c/c	none
	7400L/8000L	Roof	5 m long bolts @ 2.5 m c/c	none
		Side Walls	4 m long bolts @ 2.25 m c/c	50 mm unreinforced shotcrete

Based upon rock mass conditions reported by Tesarik *et al.* (2002) [42], Golder Associates (2006) [44 and Appendix A12] performed the most comprehensive study to date. They examined stability of the proposed Lab Module layout geometries for Homestake DUSEL, which consist of (1) a parallel pattern for the rooms with 60 m center to center spacing, and (2) rooms of similar size and spacing but arranged in echelon. They considered depths at 4850 Level, 7400 Level, and 8000 Level as well as varying orientation of the rooms with respect to the major horizontal stress. A realistic sequence for room construction was considered wherein a 5 x 5m top heading is excavated followed by side slashing, excavation of a middle bench, and finally excavation of the bottom bench.

Subject to further confirmation of site-specific rock properties, this model demonstrates viability for rooms with 20 m span and 15 m height. Due to assumptions made in the failure criteria, relative paucity of data on the rock mechanics, and relatively small difference in compressive stress between values perpendicular and parallel to the schistosity, isotropic behavior was assumed for the purposes of the model. They conclude that Lab Module construction in the Yates Member will not have problems at 4850 Level with plasticity or micro-cracking, and have only limited, manageable zones at 7400 Level and 8000 Level on sidewalls, with these types of disturbances being limited to 2.5m or less. Excavation in the less competent rock in the Poorman Formation is expected to experience a plastic zone considerably larger at 7400 and 8000 Levels with the sidewall plastic zone extending up to 6 or 7 m into the rock. They determined that the 60 m center to center spacing for the lab modules is acceptable and is independent of layout pattern. Table 6.2 shows their preliminary recommendations for rock support systems for the nominal lab module configuration planned for the mid-level and deep level campuses.

6.8 DUSEL Excavation and Ground Control Guidelines and Standards

For production mining at Homestake, a mature set of guidelines was established for drilling and blasting operations and for ground control in new excavations and reconditioning with considerations for various rock conditions including stress conditions and geometry of openings, duration of required accessibility, proximity of other openings, personnel exposure, and potential for violent ground failure. These guidelines and associated mining technologies which were derived from analytic studies and also confirmed by many decades of experience will provide an excellent basis to develop requirements and standards for excavation and ground control of new openings for DUSEL underground laboratories.

However, we recognize that excavation and underground construction standards for laboratory applications will be significantly more stringent than those that may be acceptable for mining operations. Site investigation and geotechnical analyses prior to detailed design and excavation are critical to insure that both personnel safety and equipment protection is maintained with long term stability of all underground facilities. Traditional excavation and ground control methods for production mining operations will require greater care and coordination for quality assurance and construction management. Detailed engineering, excavation process specifications and controls will address issues and concerns that are not typically present for production mining. For example, in addition to standard rock support, long-term stability of large openings may require specific rockburst control measures such as ground preconditioning using destress blasting. The Golder report includes a program for site investigation and geotechnical analyses to determine specific rock properties and site conditions to be used for detailed design and engineering for excavation of the lab modules, with the following recommended tasks:

1. Conduct an underground face/mapping program at proposed locations of large excavations to measure all parameters required for Bieniawski's Rock Mass Rating, NGI Tunneling Quality Index, definition of joint fabric and joint orientations.
2. Establish a drilling program for rock mass characterization, hydrogeological characterization, selection of samples for a laboratory testing program, and in-situ stress measurements.

Proximity of new excavations to concurrent lab operations will generate additional requirements and controls to prevent damage to research instrumentation and loss of research data quality. Recent experience at SNOLAB with new excavation being done close to the on-going SNO experiment confirm that monitoring and control techniques can be effective to minimize detrimental effects. SNOLAB excavated drifts as close as 110m from the center of the SNO experiment and major cavity excavations as close as 155m. During this excavation the SNO experiment continued operation and data collection. The experiment consists of evacuated glass PMTs (9438 PMTs) and high pressure, helium-filled proportional tubes suspended in water. Data collection and operation of SNO continued throughout the entire excavation of the SNOLAB extension. During major blast operations, the detector recorded momentary increase in noise and electrical pickup, but no loss of detectors was observed. The SNO experiment monitors the surround water volume with a hydrophone sensor. This sensor recorded the coincidence of the increase of PMT and electronics noise signals and NCD signals (resistive coupling dropout and MUX noise) with the blasts. The duration of the increase of signals was a few seconds. In the case of the "break out" blast where the new SNOLAB drift connected to the existing SNO access drift, operators were on-hand to power-down the detector if necessary, but even this blast at ~ 110m from the center of the SNO experiment did not warrant such protective actions.

During the next project phase, DUSEL design standards for excavation and ground control will be prepared for the Preliminary Design, to be incorporated with construction subcontracts, construction management and oversight to insure compliance. Site investigations to further evaluate proposed locations for lab modules and other large openings will be initiated immediately after direct access to the potential sites becomes possible during the re-entry. A preliminary analysis of fall of ground during Homestake operations is included in Appendix A13.

6.9 Facility Electrical Systems: Power, Controls, and Communications

Primary power distribution on site is fed at 69 kV from the Kirk Switch Station. This station is supplied from the general power grid owned by Black Hills Power and Light. The Kirk Station feeds power through two independent 69 kV overhead lines to the East Substation and Ross Substation, shown schematically in Figure 6.17. The Ross substation provides underground power via the Ross Shaft, and the East Substation supplies power via the Yates Shaft, both tied to a substation at the #6 Winze on the 7700 Level. One of the first tasks for the mining-to-labs conversion will be to re-establish power for the surface site and underground services, which were shut off at mine closure. The existing surface electrical substations and distribution network have been maintained and are fully operable, and portions of the surface distribution system have stayed in service for the ongoing Homestake Mining Company work for environmental remediation. We expect that full power can be restored to the site within a few days.

The power capacity requirements of the converted facility will be significantly less than what was used for previous mining operations. The existing infrastructure provides an excellent base and equipment inventory with multiple options for implementation with future laboratory facilities, including power lines, transformers and switchgear. Existing emergency generator sets are also available to provide backup power for both life-safety and support systems in the event of a grid power failure. Capacity of the distribution system is more than sufficient for future operation of the fully developed facility and all anticipated loads during construction.

6.9.1 Utilization of Existing Mine Power Distribution

For initial re-entry, dewatering and later construction, the required electrical power will be drawn from the existing power distribution at the two main substations (East and Ross substations) and distributed to various level substations located underground. The underground electrical equipment removed prior to mine closure will need to be re-installed and the distribution systems reconditioned or replaced to be operational. All of the cable and electrical equipment at deeper levels that has been submerged will need to be replaced. Whenever possible, equipment may be reconditioned for temporary use, then kept in service until the permanent system is completed. On the surface, the Yates hoists, Ross hoists, ventilation fans, and selected air compressors will be reconnected and operate as previously. The #6 Winze Hoists will operate off the existing power system only until the new power distribution system is completed. The new, primary underground power supply system will be taken off the 12.4 kV bus at the East Substation.

The facility has a large inventory of miscellaneous electrical cables, switchgear and other electrical equipment that will be assessed and used wherever possible.

6.9.2 Redundant Power Supply Systems and Underground Distribution

New power to underground laboratory facilities will be supplied via two fully redundant distribution systems. Two 3c# 500 MCM cables will provide power to 4850 Level through the Yates Shaft from existing 12kV feeder circuit breakers at the East Substation. Power distribution to deeper levels will connect at 4850 Level to the #6 winze and continue to the 7400 Level and 8000 Level. These power feeders will loop in and out to the level substations at 2600 Level, 4850 Level, 6800 Level, 7400 Level and will loop in only and terminate at the substation on 8000 Level. The primary voltage of 12.4 kV will be stepped down to 4.16/2, 4 kV, 480/277 V and 120V levels to satisfy all requirements for pumps, fans, and other equipment at various voltage levels. Also, a redundant 12 kV overhead line, which is under-slung via the East Substation overhead line, will be installed for backup power to either substation.

As a redundant supply and backup to the main feeders at the Yates Shaft, two cables of equal size and capacity will also be installed through the Ross Shaft and to the #6 Winze, and will connect to all the same level substations as the primary feeder. At either shaft, the power feeder cables will have sufficient capacity to supply the entire underground facility power demand. For normal operation and construction activities, we expect that the underground loads will not exceed the allowable capacity of one shaft feeder system, which provides a redundant supply to accommodate maintenance activities or temporary outages at either location.

Existing substations will be configured as follows in order to utilize existing equipment and maximize efficiency, with full redundancy as needed:

- A 20 MVA transformer, existing in the East Substation will be installed into the Ross 69kV Substation to provide redundancy of the underground 12kV distribution system, and feed the underground dewatering pumps main transformer.
- A 5 MVA 12/4.16kV transformer existing in the Yates Compressor Substation will be installed in the existing Ross 69 kV Substation, to feed the Upper Ross Underground Pumps at 4160 volts.
- A redundant overhead 12kV line will be installed under slung the existing East Substation Overhead 69kV line, providing redundancy of primary power and providing means to supply power in times of maintenance of equipment, and/or events.

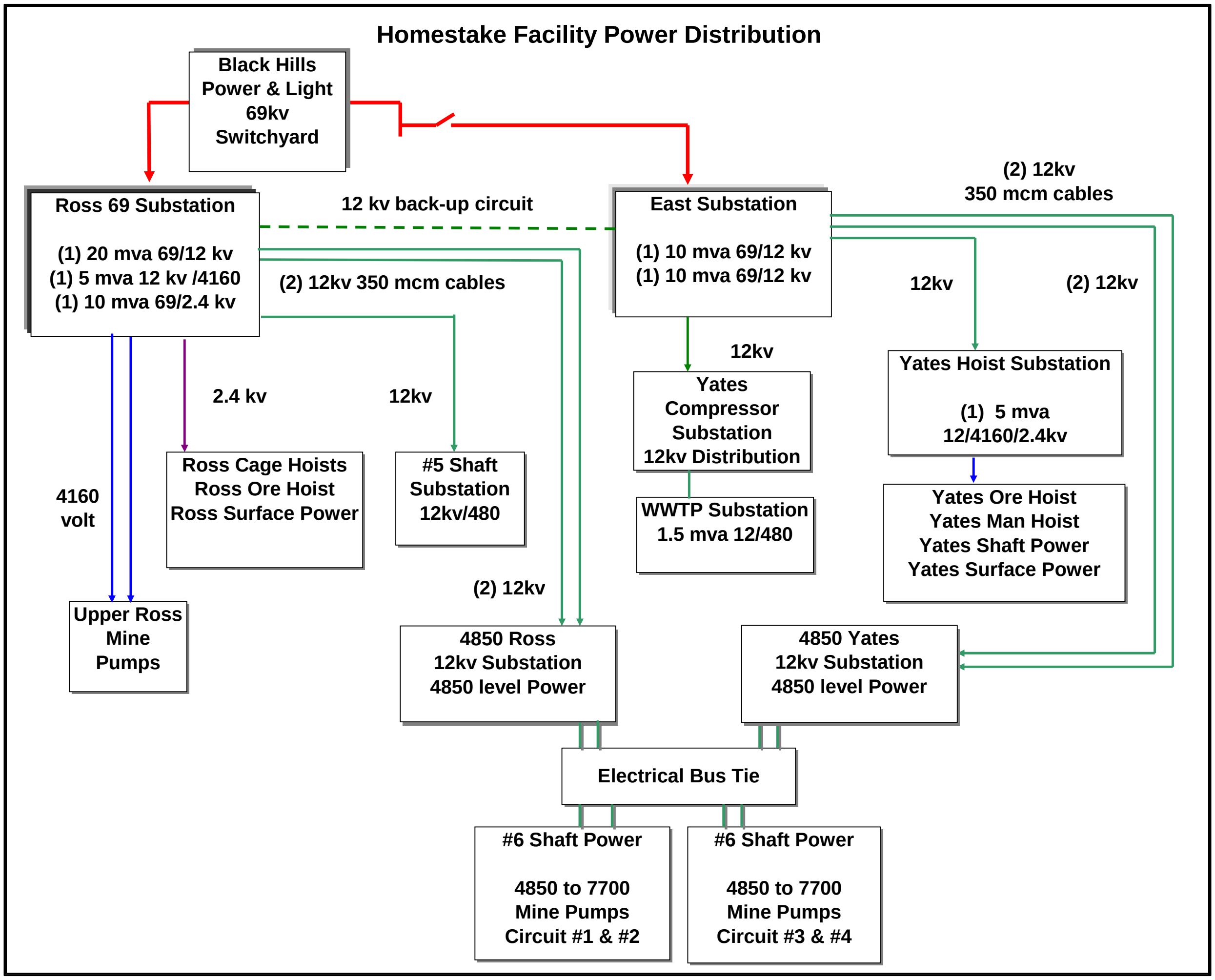


Figure 6.17 Schematic of the two facility substations and primary electrical power distribution network for Homestake DUSEL.

The East Substation status will be reconfigured as follows:

- Two Existing 69/12.4kV 10MVA transformer will remain and feed 12kV power to Yates Hoists, Surface areas, and two underground feeder 12 kV cables.

The Ross Substation status after changes:

- One 20 MVA 69/12kV transformer feeding power to Underground 12kV feeders.
- One 10 MVA 69/2.4kV transformer feeding power to Ross Hoists.
- One 5 MVA 12/4.16kV transformer feeding power to Upper Ross Underground pumps.

6.9.3 Typical Standards for Electrical Installation

- Power cable used at all voltage levels will be armored type MC. In underground shafts, special shaft cable type SWA or Vertiteck and Verlock will be installed.
- All permanent substations will be enclosed, ventilated and pressurized with filtered air.

- Cabling will be installed in cable trays and wiring and protection will be in accordance with NEC to meet the requirements of authorities having jurisdiction over electrical installations in underground facilities.
- All electrical switchgear will meet ANSI standards and be installed on a concrete pad. Transformers used will be of a dry type, 80C degrees rise, insulation class H and be of completely enclosed and ventilated construction.
- Substation floors will be sloped for drainage.
- The new distribution system will be installed with ground fault monitoring and ground fault trip where required. The existing system will be inspected and upgraded where required.
- The system power factor will be maintained at a value above 0.9 at all times with use of capacitor banks.

6.9.4 Power Allowances for Major Loads

Existing infrastructure will support a total connected load, not including the stand-by units, of more than 20,000 kW, of which up to 10,000 kW is the nominal allowance for the load connected underground. A rough estimate of the distribution and maximum allowance for major loads is shown in Table 6.3. The allowance should significantly exceed the actual loads (to be determined as requirements and designs mature for the facility and experimental systems).

Table 6.3. Allowed and expected nominal values of major loads.

Item	**Allowance kW**	**Nominal Load kW**
Ventilation and Chiller systems	7,000	3,500
Pumping and Water Management systems	3,000	1,500
Hoists	3,000	1,500
Lighting and misc. underground utility power	1,000	500
Surface Buildings	1,000	500
Underground laboratories and experimental systems	1,000	500
Auxiliary power during new construction and excavation	4,000	2,000

In a total loss of normal and redundant power supplies, all loads considered vital for life safety and emergency systems would be supplied from diesel generator sets. Two existing generators will be used: a 500kW generator will supply the # 5 shaft ventilation fan on the surface, and a 1500kW generator will feed the Yates Auxiliary Cage Hoist and underground loads such as the Auxiliary Cage Hoist at the #6 Winze and selected essential loads at the 4850 and 7400 Levels. Emergency power underground will be supplied at 12.4 kV with a 3c# 2AWG cable installed in the Yates shaft to the 4850 Level, continuing via the #6 Winze to the 7400 Level.

Automatic transfer switches (ATS) will be installed at each location with essential loads. Each ATS will be connected to the extended central control system (Intellulation IFIX) for automatic start-stop of the diesel generators and for control of automatic power switching between normal and stand-by power supply configurations. Uninterruptible back-up power may be installed by users for specific experimental requirements.

6.9.5 Communications and Controls

All the existing systems including Intellulation IFIX, leaky feeder radio, hardwired PA, telephones, and fiber optics cabling will be extended to the project areas and laboratories to enable safe automatic/remote controls, communication, monitoring and safe manual overrides. One element of the proposed R&D Plan is to evaluate existing technologies and commercially available systems, and to develop criteria and specifications for installation and potential integration or commonality of new equipment for underground communications, health and safety monitoring, control systems for experiments and remote operations, and data acquisition. We expect that facility management systems for monitoring and controls will be maintained separate and distinct from both health and safety and other experiment control systems.

6.9.6 Lighting

The lighting system will utilize fluorescent fixtures, high or low bay high-intensity discharge lighting, and also battery-powered fixtures. The lighting fixtures will be enclosed to match the area classification and all will be powered from normal power distribution. In the event of normal power interruptions, the battery-powered units at area exits and other key locations will engage and only a selection of the remaining area lighting fixtures will transfer to the stand-by diesel power and be thus turned on with a short time delay of approximately 15 seconds. During emergencies, the normal standard area lighting illumination will be somewhat evenly reduced to a level for people to either safely move through the area or just move out of the affected area.

6.10 Pumping Systems and DUSEL Water Management Plan

The DUSEL water management plan includes rehabilitating and re-commissioning the pumping systems used for mining operations prior to closure, as shown schematically in Figure 6.18. A sequence of settling sumps and pumping stations along the Ross Shaft will be put back into service following re-entry to 4850 Level, to capture the inflow, holding the accumulated water level below 5300 Level until funding and authorization is available to proceed with dewatering.

Other water management plans to reduce surface water inflow into the mine include potential opportunities to divert surface water and storm runoff away from the Open Cut. Currently, water collected in the Open Cut reports to the 1100 Level within the mine, and drains toward the Ross Shaft for pumping. Similarly, it may be feasible to reduce surface inflow at the #5 Shaft to reduce pumping requirements within the facility. During the next project phase for preparation of a Preliminary Design, a comprehensive DUSEL Water Management Plan will be developed. The initial effort for the Homestake Interim Laboratory will prepare detailed plans for dewatering and mining-to-labs conversion, to be coordinated with planning for all other DUSEL project activities and facility operation.

6.11 Facility Ventilation System Plans and Air Volume

The mine in its current closed state has had the main entries sealed. In order to re-establish ventilation, the seals on the Yates, Ross, Oro Hondo, and #5 Shafts will be removed to allow the ventilation system to be re-activated. Figure 6.19 shows a schematic of the ventilation system and air-flow circuits for mining operations prior to closure. Initially, one of the exhaust fans at the Oro Hondo Shaft will be energized to draw fresh intake air through the Yates and Ross shafts and allow personnel to safely re-enter the mine. When safe access to the mine is established, ventilation bulkheads will be installed at selected drift levels along each shaft to isolate unused portions of the existing mine workings from the fresh air circuit. The bulkheads will provide a ventilation barrier, but will include appropriate drainage paths and personnel access doors. We anticipate that up to 50 bulkheads are needed along the Yates Shaft and 40 along the Ross Shaft. Ventilation control for access to deeper levels below 4850 Level will also include installation of bulkheads at selected levels along the #6 Winze and the ramp system to 8000 Level.

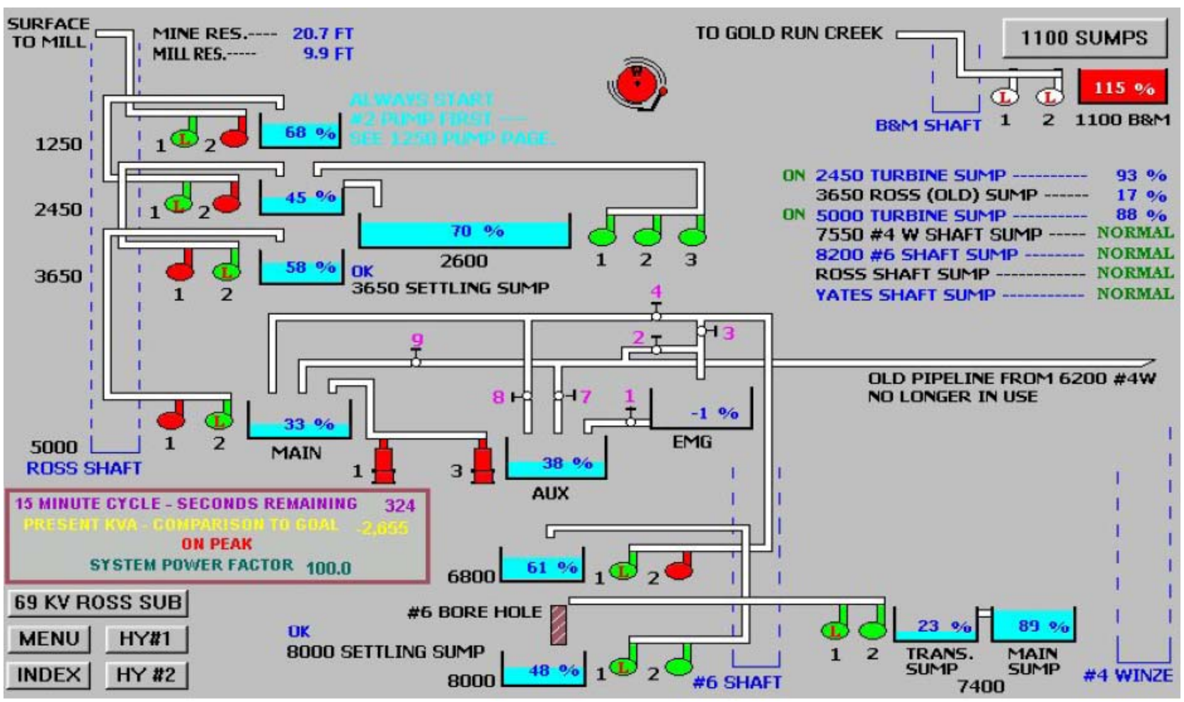


Figure 6.18 Homestake pumping systems schematic for mining operations prior to closure in 2001, showing primary pumping column with sumps along the Ross Shaft and deep level pumping along #6 Winze.

Several different scenarios for alterations and upgrades have been considered to determine appropriate, cost-effective ventilation in a variety of operating conditions. A final configuration will be developed during the next project phase as experiment and laboratory requirements become well-defined, and phased development of underground space and infrastructure is established. Currently, the design basis for our preliminary project planning is to maintain the Yates and Ross shafts for intake air during all phases of development. The path for exhaust air will be shifted from the Oro Hondo shaft to the #5 Shaft during the course of infrastructure development at 4850 Level, dewatering, and development at 7400 Level and deeper. We anticipate that the existing variable-speed exhaust fan currently located at the Oro Hondo Shaft will be moved to the #5 Shaft to be used for primary ventilation of both mid-levels and deep-levels. The existing back-up exhaust fan at Oro Hondo may remain in service for intermittent operation as needed during maintenance or other outages of the primary fan. The primary variable-speed fan has a 3,000 HP synchronous motor and approximately 520,000 cfm air volume capacity. It may be operated at reduced speed for energy cost savings to be matched to actual air volume requirements of the facility, which are expected to be less than 2/3 of the fan capacity at final operating conditions of the underground laboratories.

6.11.1 Preliminary Ventilation System Feasibility Study

The Dynatec Feasibility Study for mining-to-labs conversion, see [52] and Appendix A10, includes a preliminary study and analysis of ventilation requirements for one of the initial concepts to support lab development at the 7400 Level. It evaluated three operating scenarios: (1) Initial re-entry, dewatering, and operations to support initial excavation and construction of a laboratory at the 7400 Level, (2) Normal laboratory operations, and (3) Additional excavation and construction activities at 7400 Level concurrent with lab operations.

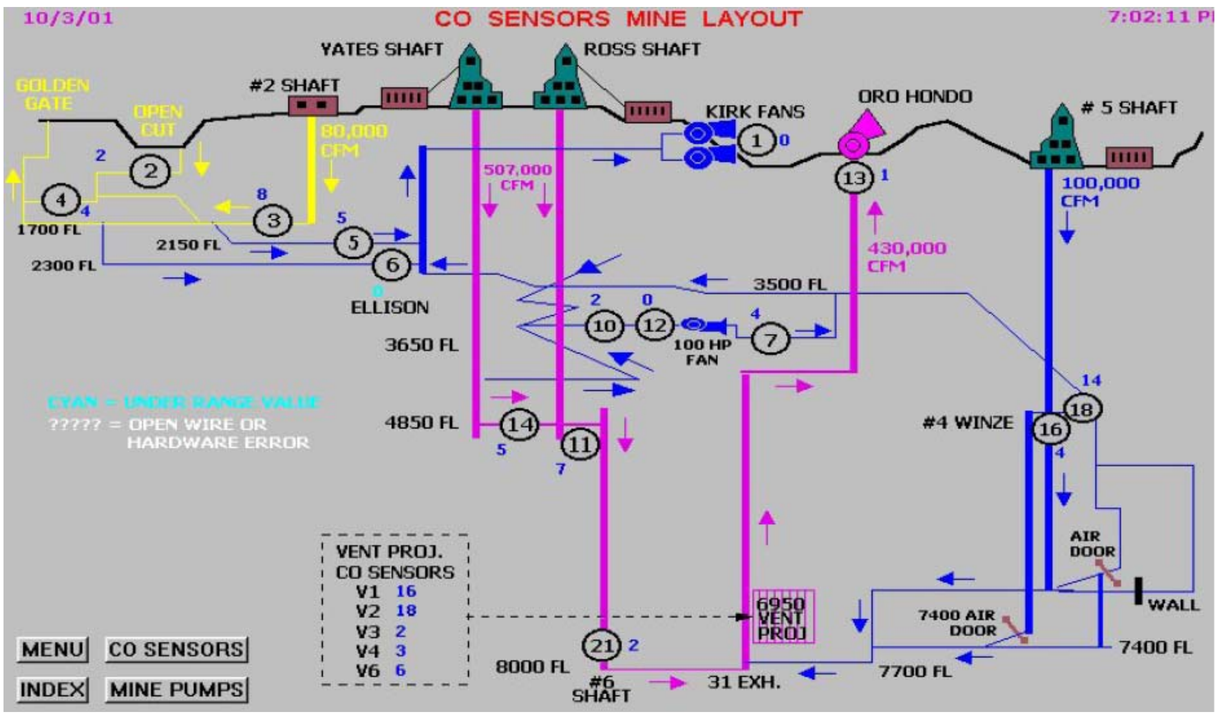


Figure 6.19 Homestake primary ventilation system schematic showing air-flow circuits for mining operations prior to closure in 2001. A proposed configuration for DUSEL will move the primary exhaust fan from Oro Hondo to #5 Shaft and retain the existing back-up fan at Oro Hondo shaft.

Details from the Dynatec ventilation system [56] feasibility study are summarized in Appendix A17, including concepts that address the following primary engineering issues and requirements:

- Avoid cross-contamination by separating the exhaust streams from operational science and engineering laboratories, and from that of any expansion (i.e. rock excavation) for new facilities.

- Limit exposure of laboratory staff to potentially toxic atmospheres resulting from a system failure during DUSEL operations (experimental tank rupture, etc.) by providing defined escape routes to the surface in fresh air.
- Limit DUSEL excavation contractors' exposure to potentially toxic atmospheres resulting from blasting, excavation, and emergency events (e.g., underground fires) by providing defined escape routes to the surface in fresh air.

Although specific air volume requirements are not yet available for each DUSEL experimental system and other construction and operational activities, the study describes nominal ventilation system configurations derived from established mining engineering knowledge and experience. We recognize that further analysis is required as design requirements mature and the sequence is defined for development of underground space at the 4850 and 7400 Levels, and potentially other levels. The analyses presented in Appendix A14 confirm that sufficient ventilation capacity is feasible using existing mine infrastructure, and some additional new equipment may be installed for cost-effective operation of underground research facilities.

6.11.2 DUSEL Air Management Plan

In the next project phase, follow-on studies will evaluate specific issues associated with underground laboratories and experiments to prepare a comprehensive DUSEL Air Management Plan. Further analyses must establish the volume and purity of air for the proposed Initial Suite of Experiments and cleanroom environments, and will be integrated with requirements for concurrent excavation in other parts of the facility. Planning will consider removal of heat from all sources for air temperature control, control of particulates and humidity, and delivery of radon-reduced air to radiation-sensitive experiments and labs. Exhaust air control will incorporate options to split and isolate flow paths for potential discharges of hazardous or toxic gases, cryogen boil-off gases, fumes and smoke, and other contaminants. Intake and exhaust systems will include air control for both normal operations and credible accident conditions for spills, fire, or other scenarios, and will define personnel evacuation paths with sufficient air quality for health and safety. Early definition of the DUSEL Air Management Plan will provide a basis for development and selection of both experimental systems and facility infrastructure.

An initial ventilation plan is being prepared for the re-entry program described in Section 6.2, which specifies initial installation of two exhaust fans at the #5 shaft. This will provide approximately 120,000 cfm air flow capacity not only for the initial re-entry and pumping installation, but also for excavation, construction, and operation of initial laboratory modules at the 4850 level for the Early Implementation Program. This configuration will provide for fresh air through both the Ross and Yates Shafts, with up to 80% of the air directed through the Yates Shaft to support various scenarios for concurrent excavation and laboratory operations. The ventilation plan includes discussion of controls which will minimize the risk of fire due to spontaneous combustion at levels where fire risks have been identified, and also to control the air flow of fire by-products for safe egress if a fire does occur. The initial ventilation plan is also consistent with current concepts for continued development at 4850 level for DUSEL, re-entry to deep levels, dewatering, development and operation of laboratory modules at the 7400 level. A draft-version of the ventilation plan is included in Appendix A15.

7 Homestake Reference Information – Status and General Description

The miners' gold may be gone, but a vast deposit of researchers' and engineers' gold remains in the form of varied and voluminous data about the Homestake site. The data include information about the history, mining practices, microbial research in mineral processing and waste treatment, and engineering activities. The existing data include a tremendous literature on the geologic properties, distribution of geologic units, and economic potential. Production of over 42 million ounces of gold during the 126-year lifetime of the mine guaranteed that generations of talented geologists and engineers studied myriad parameters and concepts. Topics of studies in the geosciences ranged from investigations of the environments of deposition of the host rocks for the mineralization, the mineralization itself, regional metamorphism experienced by the host Precambrian rock, and the subsequent intrusion of a host of younger rocks during the Tertiary period ~ 55 million years ago. From an operational standpoint, the mine was a leader in geotechnical studies associated with deformational effects of construction in the underground environment. Engineering was a prime consideration in the safe and productive operation of the facility, and the documentation of the work was as complete as the engineering was competent.

As the mine is converted into a scientific facility, the types of data that will be of particular use can be categorized based on their immediacy of use for construction, value as scientific baselines, the historical significance. The categories include materials that are:

- Useful for providing the basis for advanced scientific and engineering studies,
- Of importance from a historical and educational standpoint,
- Useful for engineering studies for advanced construction of large or unusual cavities in the underground environment, and
- Useful for the routine operations of the future laboratory.

Furthermore, the data can be identified as to their nature. The types of materials include paper reports, maintenance manuals for apparently nearly every piece of equipment in the facility (including the vast array of equipment that has been donated), computer files, and materials from drill cores from both the Homestake underground and surrounding areas of the Black Hills. In addition to the materials themselves, the experience of the people who operated the mine is an invaluable asset. This might be termed "soft" information as opposed to the "hard data" preserved in files, and consists of the presence of former employees of the mine in both the local area and the region.

7.1 Paper and File Resources

The Homestake Mining Company has donated over 10,000 cubic feet of operational and maintenance records related to the Homestake Mine to the Adams Museum and House facility in nearby Deadwood, SD [57 and Appendix A16]. The Homestake collection includes thousands of historic photographs and glass negatives, architectural drawings, maps of the mine and area, blueprints and patents, geological records of the Black Hills, original correspondence, daily journals, Homestake operation and production records, original artwork, the extensive geological specimen collection, equipment manuals, and scientific records. This collection will provide the focus for the planned Homestake-Adams Research Center. The goals of this center are threefold:

- First, the collection will be re-housed in a climate-controlled facility and acid-free environment.
- Second, the archival management team will identify and scan the photographs, glass negatives, maps, blueprints and drawings deemed of major research value, making them digitally available both on-site and via the Internet. The Homestake-Adams Research Center will be located in Deadwood, South Dakota. The City of Deadwood has committed to investing over $1.5M to purchase and retrofit a building to serve as a climate-controlled and secure research center that will be operated by the non-profit Adams Museum and House and open to the general public. In early 2006, Deadwood completed the purchase of a building to house the research center.
- Third, In addition to serving as an archive, the Homestake-Adams Research Center will be the site for hosting scientific and historical lectures, and will include exhibits about the history of mining and Homestake.

The preservation of the Homestake records is of special significance in assisting the Authority as it works to create a deep underground science lab. Access to the Homestake records will save the Authority both time and money as well as providing critical information that will protect the health and safety of the miners and scientists who work underground.

Resources for preservation of the information have already been identified and an ambitious search for additional funds has begun. For over sixteen years and as mandated by State law, Deadwood has used revenue generated from gaming taxes to restore, preserve, interpret and protect this National Historic Landmark District. While the number of dollars dedicated to historic preservation is finite and spread over many projects, the non-profit Adams Museum and House receives half of its operating budget from gaming tax dollars. As the Black Hills' oldest history museum (built in 1930), the Adams Museum has emerged as a nationally recognized and award-winning museum.

With a commitment from the City of Deadwood to use bonded funds to purchase and retrofit a building to serve as a research facility, Homestake Mining Company donated the Homestake collection to the Adams Museum and House in May 2005. Since that time, the Adams Museum and House has received a five-year, $100,000 per year commitment from the Adams-Mastrovich Family Foundation to help support inventorying, cataloguing, relocating, creating digital access, and establishing the Homestake-Adams Research Center. A strategic plan has been developed, an archivist (hired April 2006) and two assistant archivists (starting in May 2006) have been hired, and a request for proposals to transform the former F.L. Thorpe building into a climate-controlled and secure facility has been prepared.

The commitment of identified funding guarantees a long-term, stable base for preservation efforts in the area. As a result, great confidence can be held that the paper documents detailing operations and important studies by the operation company will be properly archived. Cooperation between the Authority and the Adams Museum has been assured, although it must be noted that the voluminous nature of the records has precluded full assessment of their extent to date. Examples of specific data can be offered, however. In one instance, examination of one set of records showed that it contained a study of the water inflow into the underground as a function of level [Appendix A9]. This type of information has already proven to be invaluable in estimating the effect and extent of the water inflow in designing systems to intercept water and return it to the surface during the Homestake Early Implementation Program phase of the project.

Geologic maps for each level, incorporating both drifting and core information, are also preserved in this archive. Although some of this data may be redundant to the VULCAN database, which was also transferred to the Authority, the paper copies of the maps represent a compilation of untold numbers of geologists and engineers during the history of the facility.

7.2 Technical and Scientific Human Resources

Descriptions of the existing information would not be complete without a discussion of the data associated with an experienced workforce. Following the closure of Homestake, many of the operating personnel found employment in other underground mines. Others remained in the area in either alternative occupations or as part of the Homestake closure operation. Many of the more experienced and capable former employees have expressed a desire to return to the operation. As a result, the Authority is enjoying great success in contacting the key personnel who will be needed to operate the underground in an efficient and safe manner. The experience of the former Homestake technical staff is complemented by the documentation of the long Homestake experience in the routine operation of the facility. For instance, Homestake even had its own handbook for rock bolting. This wide range of experience extends to specific techniques in ground support, general maintenance, and construction.

Other resources that are available in terms of people and expertise are also notable. For instance, the South Dakota Geological Survey is actively participating in archiving the drill cores from Homestake. Although the headquarters for the South Dakota Geological Survey is located in the eastern part of the State, a well-staffed field office is located in the western part of the State. Similarly, Wyoming also has an active geological survey in keeping with the tradition of the importance of geology to the development of the western states.

From the standpoint of academic institutions, geosciences and geoengineering are represented well in the surrounding institutions. Within South Dakota, the South Dakota School of Mines and Technology offers degrees in geology and geological engineering at the undergraduate, Master's, and Ph.D. levels. Programs in mining engineering (Mining Engineering and Management) and civil engineering are also important at South Dakota School of Mines and Technology and provide the opportunity for both collaboration and experience to the DUSEL project. Elsewhere in South Dakota, the University of South Dakota has an undergraduate program in Earth Sciences, and South Dakota State University has several engineering programs including civil engineering.

Outside of South Dakota, but still within the general region, academic institutions with strong geoscience and engineering programs include the University of Wyoming (located within 540 km, or ~6.5 hours driving time, from Homestake), Montana Tech, University of Montana, Montana State University, University of Nebraska, North Dakota State University, and the University of North Dakota. Opportunities to form regional organizations promoting cooperation are abundant and will be discussed further in a later chapter in this report. In addition to the United States Geological Survey water resources regional office in Rapid City, the USGS EROS Data Center is located in Sioux Falls, SD. This large facility is a major data management and research center for remotely-sensed data. Memoranda of Understanding are in place between the EROS Data Center and both the South Dakota State University and the South Dakota School of Mines and Technology and have included exchange of personnel between the Center and the academic institutions. The interest of personnel from EROS in scientific problems in the Black Hills is long-standing and has resulted in numerous imagery products and projects.

7.3 Digital Resources

The VULCAN software system describes itself as the world's leading 3D geological modeling, surveying and mine planning software. The VULCAN web site indicates that the program performs as a platform for spatial information, modeling, visualization and analysis in fields, and it is used in applications ranging from mine planning and design to rehabilitation and environmental management. During the 1990s, a concerted effort was initiated by Homestake to transfer mine maps, geochemical information, and locations of cores taken in the underground into the VULCAN database and program system. This leads to increases in efficiencies in the engineering and engineering design as well as providing a vehicle for better geological interpretations.

In addition to being a convenient format to store geological and engineering information, this database environment can provide a graphical environment to both display and manipulate the three-dimensional information that is an integral part of working in the underground. In the case of the Homestake database, the geology is mapped on each level, and the locations of the exploration drill holes are included as separate files. The database, therefore, can be used to evaluate what was done and also to evaluate the possible consequences of future actions.

It should be noted, however, that, although the database is a tremendous asset, it is only as good as the information that is contained within it. The data were generated throughout the history of the mine by numerous individuals with different approaches to mapping and, in some cases, different criteria for mapping and logging of the geology. This has resulted in some excellent work in selected areas, but vertical cross sections that integrate the geology from level to level upwards are not as complete at the present time. Considerable work will be necessary to fully integrate the geologic mapping that is currently available into a facility-wide system.

It is anticipated, however, that the VULCAN database will continue to be used and updated as the refurbishment and new construction proceeds because it is a widely used and extremely useful tool for mine planning and design. It should also be noted that excellent tools are available for exporting the data to other programs used for geological studies.

7.4 Closure Reports

During closure activities and investigations were undertaken by both government agencies and the operating company to document the conditions in the mine. The studies were performed from the viewpoints of the entities commissioning the work. For instance, the South Dakota Department of Environment and Natural Resources was particularly concerned with documenting what environmental hazards might be remaining in the underground, along with the present state of chemical parameters such as the composition of water within the mine. The department’s perspective, although somewhat similar to that of the operating company, was to identify any problems that might remain from the operations in the mine and provide information about potential problems that might develop in the future, particularly from the standpoint of water geochemistry. Therefore, the department’s documentation tended to be a snapshot of what the mine looked like at the time of closure (e.g., Nelson 2003a; Keenihan and Nelson 2003; Townsend *et al.* 2003; Nelson, 2003b). [58-61 and Appendices A17-A20] Records and studies from the operating company consist of extensive documentation regarding actions taken to remediate potential environmental problems encountered during the closure, removal of equipment from the underground, and mothballing and preservation of facilities destined to remain underground. These records have been carefully maintained and are available to the South Dakota Science and Technology Authority (the Authority) and other State agencies.

Those records show the great efforts that were made to ensure that the underground did not develop environmental problems and assured the regulatory agencies that the steps were taken. Additional studies that will be extremely helpful during the refurbishment and future development stages were also undertaken. For instance, predictions regarding the rate of inflow and the rate at which the water level would rise were made by Zahn (2002) [55] based upon the methodology of Rahn and Roggenthen (2002) [62] and the available information from the VULCAN database. Other studies, such as that by Geochemica (2003), [63 and Appendix A21] were commissioned to predict how the geochemistry of the waters flowing into the mine would change as a result of chemical interaction between the water, wall rock, and back fill as a function of time. These studies and the supporting geochemical and geohydrological data will function as the baseline and characterization from which the next phase of geochemical and geohydrological studies will benefit greatly.

7.5 Literature Resources

The literature relating to the Homestake Mine and the surrounding area is voluminous and covers the span of history from the first expeditions by the U.S. government in the 1800's to the present day. DeWitt (2003) [64] assembled an extensive bibliography of the articles written on the geology of the Black Hills area up to the year 2003. Although the geologic bibliography is an important resource, it does not include many of the engineering studies. In all, over 3,600 references on the geoscience of the Black Hills region are listed in this compilation. Of these references, over 145 are identified as being specifically of interest to the Homestake area (Campbell, 2005) [65]. Other published resources consist of many geologic mapping projects that cover the entire Black Hills area at scales from 1:250000 and 1:125000 (e.g., Dewitt and others, 1989; Darton, 1921) [66, 67].

Many 7 1/2 degree quadrangles have been mapped at the 1:24000 scale in the Black Hills but, more importantly, the entire northern tier of the Black Hills uplift is now mapped at this scale and those maps are available for use in geological studies. Aeromagnetic maps are available for the entire Black Hills area (e.g., United States Geological Survey, 1962) [68] as well as company reports commissioned by Homestake during its exploration activities in the northern Black Hills. Similarly, measurements of gravity field of the Earth in the region are closely spaced and well documented (e.g., Kleinkopf and Redden, 1975 [69] and Homestake company reports). Within the mine itself, Nutsch (1989) [70] made approximately 1200 measurements of the gravity field on many of the levels, yielding an overall average of 2.82 g/cm^3 for the underground.

Although it is not possible to describe the great number of previous investigations that are available, below we call particular attention should be called to examples of data that will be especially useful to the construction, design, and maintenance of the facility. Because Homestake has been a site for physics experiments for over 40 years and has been considered for an underground laboratory for more than six years, a substantial amount of information is available that is pertinent specifically for the physics community.

For instance, the radon content has been measured at the 4850 Level and was found to be ~ 1 – 5 pCi/l. The U, Th, and K content of rocks from the Homestake underground was measured recently from cores from the Homestake Core Archive. Table 7.1 shows the values for these elements in cores from Yates Member, the Poorman Formation, and rhyolite dikes from nine different boreholes drilled from near the 4850 and the 7400 Levels. The low values of all three of these radiogenic elements in the Yates are consistent with a basalt as the parent rock type. The values from the volumetrically smaller Tertiary rhyolitic intrusive rocks were averaged because the differences between samples were small.

Table 7.1. Uranium, Thorium, and Potassium values from the Homestake Core Archive [71]

Core/Core Location	**U (ppm)** **± 5 - 10%**	**Th (ppm)** **± 5 – 10%**	**K (%)** **± 1-2%**
Core #11537 Yates Member - vertical hole starting at 4850L (1/2way between Ross and Yates Shafts)	0.160 0.55	0.20 0.30	1.54 2.12
Core #11553 Yates Member drilled from 4850L – multiple samples measured	0.21 0.19	0.30 0.19	1.12 0.92
Core #15537 Poorman Fm. Horizontal hole at 7200L	0.080	0.25	0.010
Core #15532 Yates/Poorman from 7300L to 7450L multiple core samples measured	0.080 0.085	0.25 0.25	0.104 0.125
Core #18627 Yates Member drilled from 7400L – multiple samples measured	0.18 0.49	0.24 0.20	1.01 0.57
Cores #15680-820, 17581-822, 11553-059, 11537-180, rhyolite dikes -- averaged from four samples	8.6	10.8	2.9

Geotechnical information and analyses are available for the Homestake underground due to the requirements imposed upon mining over the course of the history of the mine and requirements specific to the construction of rooms to support physics experiments at the 4850 and 7400 Levels. Table 7.2 shows the *in-situ* stress stated in psi determined for the Homestake underground as a function of depth below the surface in feet (h).

Table 7.2. In-Situ Stresses in Homestake Underground Formations

	Pariseau *et al.* (1987) [35] 6950 to 7100 level	Tesarik *et al.* (2002) [37] 3050 to 7400 L
Vertical Stress	$S_v = 1.25h$	$S_v = 1.25h$
Horizontal Stress perpendicular to strike	$S_{h1} = 2078 + 0.57h$	$S_{h1} = 2078 + 0.53h$
Horizontal Stress parallel to strike	$S_{h2} = 121 + 0.53h$	$S_{h2} = 121 + 0.55h$

Numerous reports and papers dealing with the stability of rooms for the physics experiments have been prepared. An initial modeling study by Tesarik *et al*. (2002) [42] showed that large rooms with 50m roof spans in the Poorman Formations are stable at 2141 m below the surface when the rock is reinforced with cable bolts. Later modeling studies included those performed by RESPEC, Inc. (2001) [43], which showed that the rock was strong enough to provide stable excavations of 18 x 18m cross section at a depth of 2256 m (7400 Level) and 2438 m (8000 Level) and 50 x 50m cross section at a depth of 1478 m (4850 Level). More recent work by Golder Associates Ltd. (2006) [44] evaluated a more detailed geometric model that was 50 m long x 20 m wide x 15 m high at the 4850, 7400, and 8000 Levels. Based upon this work, the recommended spacing between the rooms at the 7400 and 8000 Levels should be 60 m from the center of one room to the next. However, these modeling analyses are based upon relatively few measurements of the properties of the Yates Member and Poorman Formations. Additional measurements will be required as the design of the excavations proceeds.

7.6 Homestake Geothermal Gradient

The temperature profile as a function of depth is important for a number of the proposed research areas at the Homestake DUSEL, including investigations of the limits of life in extreme thermal environments and hydrological flow systems. Immediately upon exposing the rock to the cooling effects of ventilation, the rock temperature begins to fall and care must be taken to determine the original temperature of the rock in order to calculate an accurate geothermal gradient that will allow prediction of temperatures at greater depths with some confidence.

Estimates of the geothermal gradient based upon measured temperatures exhibit significant variation, although temperature measurements in the underground are relatively sparse. Roy *et al.* [72] provided two estimates of the geothermal gradient based upon measurements from the Homestake underground. Measurements in the vicinity of the Lead #4 Winze for a depth range of 1455-2048 m yielded a value of 23.4 (+/- 0.8)^o C/km and a value of 19.0 +/- 1.2^o C/km in the Yates Shaft for a depth range of 584-1508 m. Ashworth [73] documented the instrumentation of a borehole that extended over 14 m into the rock on the 7000 Level. Temperatures were acquired from the borehole over an extended period of time and showed that the effects of ventilation could be felt over the entire length of the borehole. Extrapolation of the well-behaved temperature variations in the borehole, however, allowed Ashworth to predict that the virgin rock temperature at that level to be 55^o C. Assuming an average surface temperature of 7.5^o C, this corresponds to a geothermal gradient of 22.3^o C/km.

The 120^o C isotherm represents one of the current estimates as to the thermal limit of life in the subsurface. The variations in thermal gradient yield estimates of the depths to reach the 120^o C isotherm of 15,800 ft (4.8 km), 16,550 ft (5.0 km), and 19,400 ft (5.9 km), respectively. Although the range in estimates of the geothermal gradient may be due inadequate equilibration of the temperature measurements in some cases and cannot be ruled out, variations in thermal conductivity of the rock and rock/water systems that might also be operating are another possibility. Clearly, additional measurements of the thermal system in the Homestake underground are required.

7.7 Porosity and Permeability in the Homestake Underground

The rocks that were originally deposited in the area of the Homestake Laboratory probably had abundant porosity and permeability. This sequence of sedimentary rocks ranged from the anoxic fine-grained sediments of the Poorman Formation to greywackes that would become the Ellison formation. The Poorman Formation also contains the Yates Member at its bottom, which has been interpreted as part of a volcanic pile upon which the younger units were deposited [74], The sequence, which may include up to 7500 m in the vicinity, was metamorphosed between 1.72 and 1.84 Ga [75]. Therefore, any porosity and permeability associated with the original sedimentary rocks probably was eliminated at that time. Later intrusion of rhyolite dikes during the Tertiary also did not have any significant associated porosity.

Because the original porosity was destroyed by metamorphism, the presently available porosity and permeability in these crystalline rocks must be associated with fractures and fracture networks developed in the vicinity of Homestake. Little information is available regarding the present distribution of fracturing and fracture flow in the Homestake underground although indirect evidence for its existence is abundant. In general, two types of porosity and associated permeability can be identified. The first type is that which was developed as a result of creation of the underground workings themselves. Zahn [55] attempted to quantify the volume of voids created as part of the mining and dewatering program in the Homestake underground in order to prepare predictions of the rate of filling of the underground due to cessation of pumping. Zahn assigned a value of 0.01% to the rocks near the workings primarily based upon estimates of similar crystalline rocks from other areas. The hydraulic conductivity of these igneous and metamorphic rocks is low, approximately 10^{-7} cm/s, based upon pumping and recovery testing of the Precambrian rocks [55] (equivalent to a permeability value of 10^{-16} m^2). This value lies in the range for non-fractured metamorphic and plutonic rock, 10^{-17}–10^{-20} m^2, and fractured metamorphic and plutonic rocks, 10^{-12} – 10^{-15} m^2 [76].

The second type of porosity/permeability in the Homestake underground is associated with the fracture network that exists throughout the underground, albeit in highly variable fracture densities. Although definitive studies of fracture densities and locations are not available, a 1990 study of the sources of inflow of water into the underground can provide some information. This study showed that much of the inflow water originates directly from the surface. However, at least half of the 700 gal/minute being delivered to the underground workings must come via fracture systems. This water must be flowing from fractures that connect the workings to a much larger hydrologic system. The same 1990 study showed that the inflow at the 8000 Level amounted to approximately 110 gal/minute, and some of this water apparently was coming from boreholes drilled downwards as part of the deep drilling exploration activities. This suggests that the deeper boreholes tapped into a larger, deep hydrologic system that, while not capable of delivering large amounts of water, were nonetheless sufficiently significant in extent to deliver water on a continuous basis. The removal of water during the long history of mining apparently did not induce significant stream flow losses in the Homestake area, further indicating that the surrounding formation had a relatively low effective permeability and that the dewatering operation induced only localized unsaturated zones (to allow human entry into the underground workings, which are likely to be surrounded by a steep cone of lowered water table.)

7.8 Core Archives

In 2005, Homestake Mining Company transferred ownership of the archive of drill cores taken by the company over many years of operation; the core archive now contains about 91km of core. Curation of the core has been undertaken with the help of the Authority, private contractors, and the South Dakota Geological Survey. The South Dakota Geological Survey is archiving the core, establishing protocols for its use, and making the Homestake core accessible through its web-based database. The locations where the cores were acquired in the underground are included as part of the VULCAN database. The net effect of this is to increase the volume of the Earth's crust available for investigation from the approximately $30km^3$ exposed in the drifts of the mine to a total of $250km^3$. In addition, the cores provide information on the volume of rock between the exposed areas of the drifts. Thus, the drilling will assist the proper choice for sites for these experiments in terms of the rock properties, geohydrological characteristics, and physical logistics.

The uses for the core range from scientific to engineering studies that are uniquely suited to the use of rock from the cores. Material for detailed investigations of radiometric dating and isotopic studies has already been furnished to both international and U.S. researchers. A study of the rock mechanics properties of the Yates Member of the Poorman Formation is being conducted in support of the DUSEL project using materials from core extracted from both the 4850 and the 7400 Levels. Some of the core is pertinent especially in relation to anticipated additional coring taken as part of the initial experiments to be conducted at DUSEL.

As Homestake Mining Company explored for additional reserves and attempted to understand the regional and local geology to the best extent possible, they drilled a series of holes to investigate the volume beneath the mine. It appears that they were able to recover core material in excess of 915 m. below the 8000 Level of the mine, and it is anticipated that core from this operation will be locatable within the database. This material would then be useful in designing and understanding cores derived from proposed drilling for geomicrobiological sampling. One of the more ambitious projects of this type would entail positioning a drill rig on the 8000 Level and drilling an additional 8000 ft. down to a total depth of 16,000 ft. which would ensure that the 120^{o} C. isotherm would be reached. This would, therefore, test the limits of life in this extreme geothermal environment. The existence of cores recovered from at least the upper portion of such geology would be helpful in both designing the sampling program and interpreting the results from the drilling.

7.9 Project Websites

The project uses web-driven technology to collect and disseminate information among members and the general public. The primary portal for the Homestake collaboration is http://www.lbl.gov/nsd/homestake. This site contains much information and many links for communication with the members of the Homestake Scientific Collaboration as well as providing a location for storage of previous presentations, meetings, and news. Videos of presentations of Letters of Interest (LOIs) from the February 2006 meeting in Lead, S.D. are especially interesting because they preserve a snapshot of the concepts being considered at that time, many of which have now been incorporated into the DUSEL Initial Suite of Experiments discussed in this report. Links to the Authority are provided. Information of the PAC members, its charge, and its report is distributed to the public through this portal.

The vast array of data currently available through the literature and through private company documents contributed to the Authority and the DUSEL project is recognized as constituting a mass of information that is difficult to navigate. Therefore, web sites that begin the process of identifying where site characterization data and background literature can be found have been established. Although they are in the preliminary stages, they have already reached the point of being useful for geoscience and, to a limited extent, geoengineering investigations. These data and collection of existing information and added references are available to the public and the collaboration through the index *references* and through subsidiary compilations such as the Homestake Reference Information Book. At later phases of this initiative, it is anticipated that links from these resources will allow access to interactive applications that will allow manipulation of at least portions of the VULCAN database. It is also anticipated that pertinent information from some of the more important paper copies of Homestake-provided data would also be referenced and linked as resources become available.

7.10 Homestake Letters of Interest – Early Implementation Program and DUSEL

In November 2005, the Authority and the Homestake Scientific Collaboration issued a call for Letters of Interest from potential users of Homestake. The primary purpose of the solicitation of users was to assist in planning for Homestake's Early Implementation Program and to identify candidates for early access to the facility. These users would be composed of both research and development stages for experiments as well as including experiments that were ready for deployment in the near term and those following a phased approach where the first phase would be included in the Early Implementation Phase. The complete list of LOIs, the presentations made to the Program Advisory Committee, and the Program Advisory Committee report are presented at http://www.lbl.gov/nsd/homestake/LOI.html . We present in Appendix A5 the listing of the 85 Letters of Interest originally submitted with the first report. The Authority continues to receive additional Letters of Interest and inquiries about possible uses of Homestake. We anticipate subsequent calls for Letters of Interest in the coming years.

7.11 Memoranda of Understanding

Subsequent to the Program Advisory Committee meetings and receiving their recommendations the Authority and the Homestake Scientific Collaboration have focused on defining the near-term scientific users for Homestake's Early Implementation Program. The first step in this process is to work with the users to establish their facility requirements in greater details and to establish Memoranda of Understanding between the users and the Authority. The current status of Memoranda of Understanding is presented along with the Letters of Intent in Appendix A5.

7.12 Initial Research Efforts

The initial research efforts at Homestake's Early Implementation Program will necessarily focus on a few selected disciplines, but will include experiments of international importance. In physics, the initial efforts include dark matter searches, neutrinoless double beta decay experiments, and a low energy solar neutrino experiment, addressing some of the most compelling problems of the day. For the earth sciences we will focus on establishing the facility baseline prior to opening and dewatering the facility. This includes establishing a sensitive seismic array, as well as obtaining and analyzing water samples from the surface and the underground to begin establishing the geochemistry and geomicrobiology content of the water.

Several efforts to establish essential infrastructure, including low background counting, are being proposed to the NSF and the Department of Energy. Another collaboration is proposing to begin the geotechnical work and initial coring required to plan for large cavities. This effort will investigate rock properties, excavation and stabilizing techniques for large cavities, and geological features influencing the placement of ~ 100kT cavities. The conversion of the Ray Davis cavity to a large water shielded room is also under active discussion with a collaboration that wishes to pursue both the general purpose shielding infrastructure and R&D towards gadolinium doping of the water for neutrino detection.

Education and public outreach is actively working on establishing a presence at Homestake in the coming year to serve as the initial focus for an extensive education and outreach program.

8 Homestake User Support and Environment

To an extent that will pleasantly surprise many, Lead, South Dakota is an accessible and appealing location for a national laboratory.

It is located in the beautiful Black Hills, an ancient mountain range that is host to Mount Rushmore, Crazy Horse National Memorial, the Black Hills National Forest, popular resorts, pristine mountain lakes and thriving communities which provide amenities that continue to attract upscale in-migration from overcrowded coastal areas and cities.

Artists, celebrities, entrepreneurs, young retirees and wealthy people are included in that in-migration, drawn by scenic, educational, cultural, and recreational assets. Within minutes of the Homestake site, lab personnel and visitors will find what they need to make their stay productive and enjoyable. The Black Hills offer the ideal location for workshops, lecture series, field camps, and collaboration meetings due to the availability of inexpensive lodging and meeting spaces.

The environment is conducive to energized, productive work because of the facilities and amenities available, a modern cyberinfrastructure, and a community known for its friendliness and demonstrated commitment to the success of the laboratory and its users.

In this section we will highlight the major needs of a user at this facility, including transportation, housing, dining, health care, schools, recreation, the arts, science-related community organizations, religious organizations, institutions of higher learning, cyberinfrastructure, computer support (including service, sales, programming and maintenance), libraries, and a labor pool skilled in electronics, computer, and machining/fabrication industries.

8.1 Homestake User Liaison Office and Users' Support

The laboratory staffing plans describe three groups of particular importance to users of the Homestake facility. Within the Science and Engineering Research Program is a *User Liaison* whose primary purpose is to interface with users and to guide them through all aspects of performing research at the Homestake site. This position will grow to two FTE by FY16. Within the *Education and Outreach Group* are the training, public outreach and relations and visitor center functions, in addition to traditional education and regional university partnership functions. The Education and Outreach office will be staffed with 11 FTE, including administrative support, by the end of the construction phase and throughout the operations phase.

The *Facility Operations and Site Services Office* will handle most of the liaison functions required by facility users. This office will provide training support, EH&S training and assistance, housing and transportation support, shipping, receiving, shops and trades assistance, computing assistance, preparation for and transportation to underground facilities, user housing, human resources, and business operations. This office also includes the critical Environmental, Health and Safety functions. It will be staffed by 62 FTE by the start of DUSEL operations.

8.2 Visitor Center, Dining Facility, Housing

The \$70M donation by Mr. T. Denny Sanford to the South Dakota Science and Technology Authority (The Authority) includes \$20M for the creation of a visitor center and a revolutionary new education and outreach facility, to be known as the Sanford Center for Science Education. The Authority anticipates spending approximately \$1.5M of its own resources to support those components. The visitor center is to include hands-on interactive science exhibits, a restaurant, and a gift shop. The Sanford Center for Science Education will be housed in an existing 25,000 square foot building on the Authority's property. A second level in this building will be added. This facility will contain on-campus housing for students, video/animation production facilities for educational programming, multi-media transmission capabilities for distance learning, and conference facilities including meeting rooms, a small theater, classrooms and laboratories. Dining facilities (cafeteria, snack bar and private dining rooms) for students, staff and visitors will be included and will serve as the cafeteria for the DUSEL. It is anticipated that ~$3M of the gift will be used to help support operations of the education center through 2012. This funding may also be used to support utility and other occupancy and infrastructure expenses of the center. Plans call for this project to commence in 2008 and to be completed in 2009.

For those interested in housing off the laboratory campus, a review of the rental property market in the Lead/Deadwood and Spearfish areas indicates one, two and three bedroom apartments and homes are available in Lead/Deadwood. Two and three bedroom apartments, duplexes and townhouses, including furnished units, are available in Spearfish. The pace of residential development in the Black Hills area strongly indicates the presence of well-capitalized, experienced, and competitive developers who are readily able to meet growing demands for housing required by the lab and associated organizations. Public opinion surveys of the area consistently find overwhelming support for continued growth.

8.3 Cyberinfrastructure at Homestake

State-of-the-art broadband Internet connectivity to research institutions throughout the United States and the world is essential for DUSEL. This cyberinfrastructure will encourage and support communications and the free dissemination and distribution of data obtained from the Homestake experiments, endorsing the Homestake DUSEL as a world-class research facility and link South Dakota with the national high speed Internet backbone. The Governor's office is committed to establishing high speed broadband connectivity in the state.

The South Dakota Board of Regents, which oversees South Dakota's six Regental universities, has proposed to the Governor's office a plan developed with a national consultant to connect the major research institutions in the state with the backbone necessary to support gigabyte transmissions (see Appendix A22). This plan has been developed with other states as part of the Northern Tier Network Consortium. The plan outlines establishing high speed broadband connectivity from the North Dakota border near Fargo south to the major hub in Kansas City. Within South Dakota (Figure 8.1), the GB fiber, with 100 GB future capabilities, would connect Kansas City to Sioux Falls, west through Pierre and Rapid City, thence to Lead (Homestake site).

The network provides critical cyberinfrastructure connecting the universities (University of South Dakota, South Dakota State University, Northern State University, Dakota State University, South Dakota Schools of Mines and Technology, and Black Hills State University) and major research institutions in the state (United States Geological Survey EROS data center, South Dakota Public Universities Research Center, Graduate Research and Education Center and Homestake DUSEL).

The plan extends the GB fiber to DUSEL as part of the over 1100 miles of network backbone

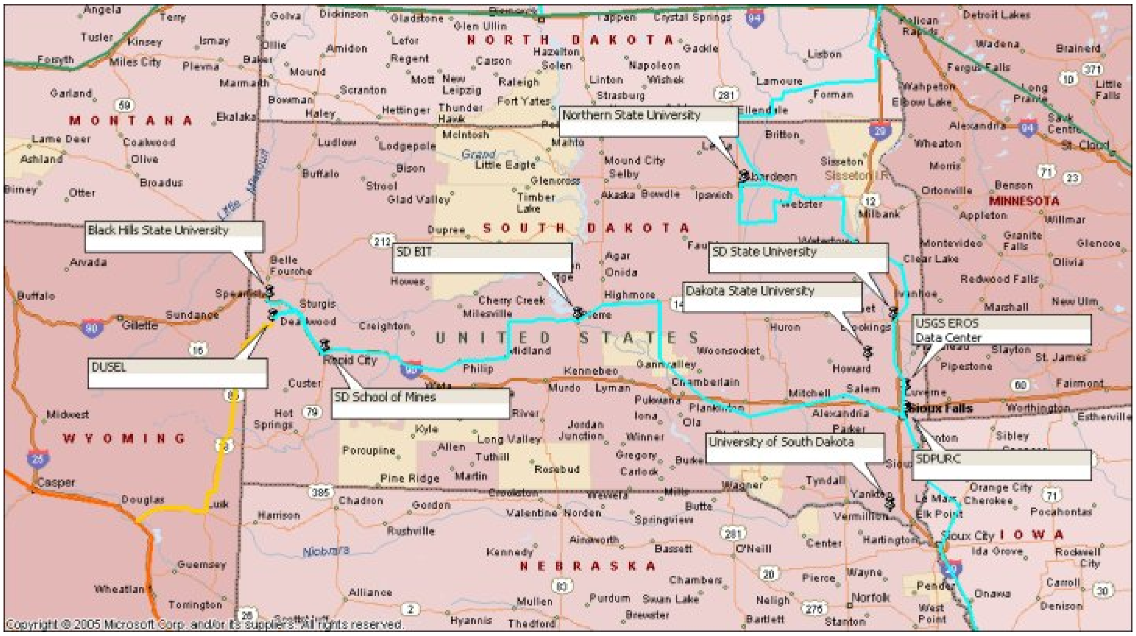


Figure 8.1 Proposed GB backbone connecting Homestake to the Kansas City Hub and the Northern Tier Network Consortium.

fiber already in place in the state with, a 20-year right-to-use of the network. At the Homestake facility, fiber would be installed from the surface down to all research levels providing seamless connectivity to researchers across the United States and throughout the world. The initial engineering proposals for providing underground connectivity are presented in the Dynatec Rehabilitation Study of 2005. To prepare for the growing needs for connectivity, the staffing plan includes 3 to 4 information technology staff.

As an example of the use of cyberinfrastructure for work similar in nature, several large, complex physics detectors have demonstrated that, with adequate connectivity, the experiments can successfully be monitored and operated remotely. These experiments include the KamLAND experiment in Japan with experimental shifts being taken in the United States, the Sudbury Neutrino Observatory with remote shifts taken from Laurentian University, and the MINOS experiment at Soudan, with shifts being taken at Fermilab. Naturally, there exists a need for local operators to respond to some critical situations, but much of the routine operation for many of Homestake's experiments would be handled remotely. These experiments also provide a good model for understanding the volume of data, the speed of transmission necessary and remote handling of data that will be required by the experiments at Homestake DUSEL.

At Homestake DUSEL we envision developing a local computer "farm" to store and distribute data. With time and growing uses, we envision the development of substantial support for users beyond these basic operations. The Homestake site has opened discussions with the National Center for Atmospheric Research to investigate potential collaboration and participation by DUSEL in the NCAR data storage, data distribution and geocollaboration efforts.

A cyberinfrastructure proposal will be submitted to NSF through the EPSCoR office requesting support in obtaining fiber connectivity from Rapid City South Dakota to DUSEL, and the first year of operating costs. The NSF cyberinfrastructure proposal requests $670k for a one-time cost for fiber connectivity from Rapid City to Lead (55 miles) and $127k for the first year of operating costs. The state of South Dakota will be expected to provide connectivity from Rapid City to the national grid.

In addition to cyberinfrastructure at Homestake DUSEL, the local universities in Rapid City and Spearfish have IT and computer support departments and research libraries.

8.4 Regional University Participation in Homestake DUSEL

The Authority is working to ensure that South Dakota's universities, neighboring EPSCoR programs and other regional universities recognize the opportunities for research, education and outreach associated with a successful DUSEL at Homestake. The Authority has appointed Dr. Daniel O. Farrington, formerly the System Vice President of Research for the South Dakota Board of Regents, as Regional University Liaison Officer to assist with this effort.

Regional universities submitted a number of "Letters of Interest" for research, education, and outreach projects at Homestake DUSEL. The Authority is working with the DUSEL Homestake Principal Investigators to ensure that as many collaborators from regional universities as possible can be legitimately and professionally integrated into the proposed initial suite of experiments and education and outreach activities.

In order to capitalize on these regional expressions of interest in deep underground research, a workshop for neighboring EPSCoR state research executives was held on October 20, 2006 at the Homestake site. The workshop was very successful in helping to develop a strategy and roadmap for regional participation in the DUSEL activities. This was particularly important in the EPSCoR states banding together to advance the goals of each institution and the DUSEL. There was a consensus that future workshops on long span excavation, safety, physics, K-12 outreach, and undergraduate and graduate education and outreach would be especially valuable in building the necessary collaborations.

In order to advance the research goals of the state and the DUSEL, the South Dakota Board of Regents is encouraging the research universities (South Dakota School of Mines and Technology, South Dakota State University, University of South Dakota) to actively work together in new and innovative ways to develop a physics doctoral program within the state.

Given the wealth of scientific, engineering, and education possibilities, formalization of a well-defined organizational structure designed to promote the cooperation on a regional basis is highly desirable. The Great Plains Collaboration (GPC), which currently consists of contacts from four of the surrounding NSF EPSCoR states, is a direct result of this organizational activity. The collaboration focuses on a group of "centers of excellence," defined as major research activities encompassing a range of related scientific directions.

These "centers" are seen as being dynamic constructs that are sufficiently agile to be formed and modified as the scientific directions warrant. As a result of meetings and contacts at all levels in the regional university structure, four potential "centers of excellence" were identified at this stage of the Homestake DUSEL. Recognizing that technology transfer and building of research capacity has been termed a "contact sport," the Collaboration promotes a philosophy of facilitating interaction among the research interests within South Dakota, the region, and the nation. Ideally, cooperative projects will be "regionally grounded"; that is research capabilities from the region can be used to augment, facilitate and conceive projects in concert with external researchers. As a result, improvements in the critical mass of faculty and students from South

Dakota and regional universities can be accomplished, which will result in increased support for programs supported by federal agencies and private industry.

The centers identified thus far would be Mining Resources, Earth Sciences and Engineering, Microbial Ecology and Bio-prospecting, Cloud and Weather Science and Modeling and an ultra-low background counting facility. These centers provide examples of the breadth of possibilities, as the first two represent areas of research that can potentially support ongoing operational activities at the laboratory, whereas the second two represent research opportunities that exploit the unique features of the underground laboratory. For partners external to the region, th establishment of the centers will provide a specific contact that can facilitate projects and potentially provide a venue for interaction with the resources of the region. Within the centers, subgroups interested in specific projects will find fertile ground for nourishing the cooperative efforts that can promote interactions that will help both the quality of the scientific enterprise and improve the regional capabilities in science and engineering.

8.5 General Accessibility

Homestake DUSEL will be a dedicated facility continuously accessible at all times during the year. It will be uncompromised by competing activities such as mining or transportation that impede access in other facilities. Redundant conveyances will ensure safe and continuous access to the underground even during preventative maintenance and service periods.

Current plans include installing a new automated personnel lift providing access from the surface to the 4850 Level and refurbishing the main conveyances in the Ross and Yates shafts to support material and equipment transport. We are examining plans to convert the lifts into a “super” lifts to provide a substantially larger lifting footprint. Redundant power feeds from the surface will ensure continuous, uncompromised power and communications. Title to the entire 186 acre surface facility and the entire underground site is held by the Authority, which will provide assurance of at least 30 years of access to the site. Access to the underground will not be influenced by future mining activity or changes of ownership. The Homestake site is accessible via the Rapid City airport (which is served by multiple air carriers from Denver, Chicago, and Salt Lake City) and by interstate highways and major rail lines. The site is a ~ 40 mile drive from Rapid City. Within 50 miles of the mine there are three communities, including Lead, providing all essential services: housing, medical, education, recreation, food, etc. There are collaborating universities in Rapid City and Spearfish.

As the premier underground research facility access will be assured to all researchers, regardless of nationality, with appropriate training and conformance to facility procedures (such as workers compensation insurance coverage, etc.). Homestake DUSEL will fully conform to NSF policies concerning classified and proprietary research. The vast Homestake site can provide segregated sites and isolated facilities for Homeland Security applications that require isolation without impacting other research efforts.

8.6 Transportation and Access

Lead (population ~3,027) is conveniently situated in the northern Black Hills with easy access on a well maintained highway system to surrounding communities and to the regional airport in Rapid City. Lead is approximately an hour’s drive from Rapid City (population ~ 88,500 in metropolitan area) and its airport, less than half an hour from Spearfish (population ~8,600), home of Black Hills University, one half hour from Sturgis (population ~6,476), site of the internationally famous motorcycle rally that draws more than half a million visitors for a week every August, and a little over one hour from Hill City (population ~861), a small sawmill and tourist town that has been transformed into a thriving arts community. Lead is adjacent to the historic city of Deadwood (population ~1,300). Rapid City and the surrounding communities are known as the Banana Belt of South Dakota for the characteristically mild winters that are much gentler than those in the "blizzard alley," hundreds of miles to the east on the open prairie, whose meteorological reputation is unfairly and unfortunately often confused with that of the Black Hills. Even though Rapid City and the surrounding communities located at higher elevations, such as Deadwood and Lead, receive considerable amounts of snowfall, temperatures rebound after a snowfall and sunny skies generally prevail.

January and February daytime temperatures can average in the 30s; however, temperatures will quickly approach the 50s and 60s due to the Chinook winds. Temperature inversions can result in warmer weather in the higher elevations of the Black Hills than in Rapid City. Arctic air intrusions come and go quickly. January and February monthly snowfall averages five inches in Rapid City and fifteen inches in other areas of the Black Hills. The snow often melts quickly in the foothills and plains, while the deeper snow remains at the higher elevations, a boon for outdoor recreational activities. July and August are sunny and dry. Temperatures generally climb into the 80s and 90s yet the humidity is low and the winds are breezy. Low temperatures at the higher elevations can be in the 40s and even the 30s during a typical summer evening.

8.6.1 Travel Time to the Homestake Site

Travel from most major U.S. airports across the country to the Homestake site in Lead can be completed in six and one half hours or less. Interstate highways and well maintained state highways allow for comfortable and efficient motor vehicle travel from all directions into Lead.

8.6.1.1 Air Service

Rapid City Regional Airport experiences an average of only one day of closure per year due to inclement weather.

Travel time from Rapid City Regional Airport to Lead is about one hour on the interstate highway for all but the final seventeen miles, which are a new four lane state highway.

Rapid City Regional Airport is served by four airlines with hub connections to Minneapolis (NWA), Salt Lake City (DELTA), Las Vegas (Allegiant), Denver and Chicago (United). Flight times from major cities to Rapid City, including layovers are listed in Table 8.1.

The Rapid City Air Task Force and the Rapid City Regional Airport administrators are continually working to increase the number of carriers and flights in and out of Rapid City. Members of the Air Task Force are keenly aware of the Homestake project and the need for convenient and affordable air service for all the parties involved with the project now and in the future. Their efforts have paid off in recent months, as evidenced by the following data.

Number of Flights Per Day to Rapid City

- United Express/Denver: 7 flights per day
- United Express/Chicago: 1 per day during peak season (The Black Hills Air Service Task Force is currently negotiating adding two Chicago/Rapid City direct flights per day on a year around basis.)

- Northwest/Minneapolis: 3 per day, with additional flights added during peak season in the summer
- Sky West Delta connection /Salt Lake City: 3 per day Delta (Delta Airlines and airport officials are discussing adding direct flights between Rapid City and Cincinnati or Atlanta.)
- Allegiant Air/ Las Vegas: 2 times per week nonstop - Wednesdays and Saturdays (Will change to Fridays and Mondays beginning February 9, 2007.)

Number of Flights Per Day from Rapid City

- United Express/Denver: 7 flights per day
- United Express/Chicago: 1 flight per day during peak season
- Northwest/Minneapolis: 3 flights per day
- Sky West Delta connection/Salt Lake City: 3 flights per day
- Allegiant Air/Las Vegas: 2 times per week nonstop - Wednesdays and Saturdays (Will change to Fridays and Mondays beginning February 9, 2007.)

Table 8.1 Travel times to Homestake site from Selected Cities

Travel from City	Air and Drive Times	Total Travel Time (1 way)
Albuquerque	3.5 hours (includes 1 hour layover in Denver) plus 1 hour drive to Lead	4.5 hours
Atlanta	5.5 hours (includes 1 hour layover Minneapolis) plus 1 hour drive to Lead	6.5 hours
Boston	5.5 hours (includes1 hour layover Minneapolis) plus 1 hour drive to Lead	6.5 hours
Dallas	4.5 hours (includes hour layover Denver) plus 1 hour drive to Lead	5.5 hours
Chicago Option #1	4.5 hours (includes1 hour layover Minneapolis) via Northwest plus 1 hour drive to Lead	5.5 hours
Chicago Option #2	2.5 hours direct via United plus 1 hour drive to Lead	3.5 hours
Knoxville Option #1	8 hours (includes 3 hour layover Denver) via United plus 1 hour drive to Lead	9 hours
Knoxville Option #2	8.5 hours (includes 2 hour layover Memphis, 1 hour Minneapolis) via Northwest plus 1 hour drive to Lead	9.5 hours

Travel from City	Air and Drive Times	Total Travel Time (1 way)
Los Angeles - LAX	5.5 hours (includes .75 hour layover Denver) plus 1 hour drive to Lead	6.5 total
New York, LaGuardia Airport	5.5 hours (includes 1 hour layover Minneapolis) plus 1 hour drive to Lead	6.5 hours
Philadelphia	5.5 hour (includes 1 hour layover Minneapolis) plus 1 hour drive to Lead	6.5 hours
San Francisco	3.5 hours (includes 30 minute layover Salt Lake City) plus 1 hour drive to Lead	4.5 hours
Washington DC, Reagan Nat'l Airport	5 hours (includes 1 hour layover Minneapolis) plus 1 hour drive to Lead	6 hours

These travel times compare very favorably to travel times associated with current and proposed underground sites as seen in the following chart.

Table 8.2 Travel times from San Francisco to current and proposed underground sites.

Laboratory Site	Air and Drive Times	Total Travel Time (1 way)
Toyama, Japan	10 hour flight, 2 hour bus, 2 hour layover, l hour flight, 1 hour drive	16 hours
Sudbury, Canada	5 hour flight, 1 hour layover, 1 hour flight, 45 minute drive	7.75 hours
Gran Sasso, Italy	11 hour flight to Heathrow, 3 hour layover, 3 hour flight to Rome, 2 hour drive	19 hours
Empire, Colorado	2 hour flight, 1 hour drive	3 hours

8.6.1.2 Rental Cars

Four rental car agencies serve Rapid City Regional Airport. Long term car rental arrangements can be made to provide guaranteed availability, and in some instances, parking spots in the rental lot just a few feet from the door of the terminal building can be assured and the car heated in anticipation of renter's arrival based upon outdoor temperature.

8.6.1.3 Highway System

There is an excellent road system to and from the airport to Lead, as well as throughout the Black Hills, including high quality city, county, state and interstate highways. Travel time between Denver and Lead (389 miles) is 8 hours. Travel time between Minneapolis and Lead (649 miles) is 10.75 hours. A four lane connector highway is under construction to link Rapid City, South Dakota and Denver, Colorado.

8.6.1.4 Charter and Tour Buses

The charter and tour bus industry places organized visitation within accessible reach for student groups in a 1,000 mile radius from Lead. For example, transport by motor coach and seven nights lodging (double occupancy) for 45 passengers from Chicago to Lead during the "shoulder months" of March through May and September through November is approximately $480 per person.

8.7 Hospitals and Health Care

The Black Hills communities (Rapid City, in particular, which has more than 200 physicians and surgeons) have exemplary medical personnel, facilities and services, including specialty clinics such as cardiology, endocrinology and dermatology. Community health facilities serve a wide area, including South Dakota and parts of North Dakota, Montana, Wyoming and Nebraska.

8.7.1 Black Hills Community Health Services

8.7.1.1 Lead-Deadwood

The Lead-Deadwood Hospital offers a comprehensive range of medical, diagnostic and surgical services including intensive care, emergency room services, rehabilitation and therapeutic programs.

8.7.1.2 Rapid City

Rapid City Regional Hospital has 310 beds and 2,291 employees and emergency helicopter service. There are three surgery centers in Rapid City. The John T. Vucurevich Cancer Care Institute provides inpatient and outpatient medical and radiation oncology services and clinical trial research service.

Rapid City Regional Hospital is staffed with emergency medicine physicians and nurses who are certified in Advanced Cardiac Life Support. The staff is trained to provide a full range of medical care for all ages from minor illnesses to life-threatening emergencies. In addition, physician specialists provide on-call coverage 24-hours a day to respond to medical emergencies.

The Rapid City Regional Hospital ER team provides services to persons within a 250-mile radius of Rapid City.

Rapid City Regional Hospital provides access to the best specialists from a wide range of specialties, including:

- Trauma and emergency surgery
- Emergency medicine
- Orthopedic surgery
- Neurosurgery
- Spine Surgery
- Vascular Surgery
- Interventional Radiology
- Comprehensive rehabilitation

8.7.1.3 Spearfish

The Spearfish Regional Hospital and the Family Medical Center Clinic are centralized in one location. Twenty four hour emergency care is available. Services include onsite laboratory and pharmacy, the Woman's Health Care Center, Home Care and Hospice program.

8.7.1.4 Sturgis

Under the umbrella of the Rapid City Regional Hospital system, the Sturgis Regional Hospital contains a 25-bed Critical Access Hospital, an 84-bed Medicare-certified nursing home, a Medicare-certified home health agency, and a specialty clinic for visiting physicians. The hospital offers a comprehensive range of medical, diagnostic, and surgical services including intensive care, obstetrics, rehabilitation, and therapeutic programs, as well as 24 hour a day emergency care. The Specialty Clinic draws 9 Specialists to the facility. The nursing home includes skilled, intermediate, and special care beds.

8.7.1.5 Trauma Centers and Emergency Care Response

8.7.1.5.1 Trauma Levels

Level I: Provides the highest level of care for patients with complex injuries, having emergency physicians, nurses and surgeons immediately available.

- To be a verified trauma center often means the hospital is a teaching hospital with specialized residencies.

Level II: Provides treatment for complex and severe trauma patients with emergency physicians and nurses in-house and surgeons available upon patient arrival. These centers offer a broad range of specialists, diagnostic capabilities and support equipment.

Level III: Provides stabilization to the trauma patient, with emergency physicians and nurses immediately available and surgeons without specialization located within in 20 minutes.

8.7.1.5.2 SDSTA on Site

- There is a person trained in first aid on site during every shift.
- Annual training is provided for First Aid, CPR, and AED.
- Key personnel will be trained as First Responders.

8.7.1.5.3 Lead-Deadwood Regional Hospital and Rapid City Regional Hospital

The Lead-Deadwood Regional Hospital is a Level III trauma center located three miles from the Homestake site providing 24-hour emergency and ambulance services with an 18 bed facility for inpatient care. This hospital also offers a comprehensive range of medical, diagnostic and surgical services including:

- Intensive/Coronary Care Unit
- Inpatient/Outpatient Surgery
- Radiology
- Laboratory
- Respiratory Care

- Physical Therapy
- Cardiac and Pulmonary Rehabilitation
- Durable Medical Equipment Services

Rapid City Regional Hospital functions as a Level II trauma center, located 45 miles east of the Homestake site. Specialized physicians are on call 24 hours and are located within 20 minutes of the hospital. Once a major trauma is known, the required specialized physicians are often alerted to the situation and are in-house when the patient arrives.

8.7.1.5.4 Black Hills Life Flight

- Black Hills Life Flight is a fully integrated medical transport team offering rapid access to emergency rotor wing (helicopter), fixed wing (airplane), and critical care ground transportation.
- The Black Hills Life Flight team has the highest level of training and certifications and has the most up-to-date equipment available to respond to most emergency situations. Black Hills Life Flight works closely with Rapid City Regional Hospital Emergency Department and physicians to ensure the highest quality of patient care.
- The Life Flight response time to the Homestake site is 20 minutes.
- The Black Hills Life Flight provides transportation from the Rapid City Regional Hospital to other specialized patient care areas in the surrounding states. (Wyoming, Minneapolis, Nebraska, Iowa, and Colorado are a few of the states that a patient may be transferred to depending on the patient's need).

8.7.2 Veterans Services

The Black Hills is a premiere location for military retirees from around the country, especially those who have served at Ellsworth Air Force Base near Rapid City. These individuals have, in many cases, served at bases around the world and have chosen the Black Hills as their retirement home. Currently 4,505 United States Air Force retirees live in the Black Hills. Comprehensive services and medical care are offered to veterans. The Veterans Administration Black Hills Health Care System is located at Fort Meade, near Sturgis and approximately a thirty minute drive time from Lead. This facility provides primary and secondary medical and surgical care, along with residential rehabilitation treatment program services, extended nursing home care and tertiary psychiatric inpatient care services. There are sharing arrangements with Ellsworth Air Force Base, South Dakota Army National Guard, and other community partners.

8.7.3 Children's Care and Rehabilitation/ Rehabilitation Supply

The Children's Care Rehabilitation and Development Center in Rapid City helps children with special challenges from mild to severe. Staff members are trained in special education, psychology, and challenging behaviors. There are family-centered programs on an outpatient and outreach basis. Children's Care offers developmental screenings, consultation, and programs to enhance the normal development of children from birth through school age. Outreach is supported by a subsidy from the Children's Care Foundation, financial support from the South Dakota Elks Association and the Scottish Rite Foundation.

The Center houses Rehabilitation Medical Supply a full-service medical equipment supplier. Its staff members have the expertise to provide independence for people with limited mobility.

8.8 Educational Institutions

8.8.1 Schools, Elementary and Secondary

See Appendix A23 for a discussion on the local elementary and secondary schools in the area.

8.8.2 Higher Education

Associate, baccalaureate, masters and doctoral degrees are available through the West River Higher Education Center in Rapid City. Doctoral degrees are offered in Atmospheric, Environmental and Water Resources; Geology and Geological Engineering; and Materials Engineering and Science.

8.8.2.1 South Dakota School of Mines and Technology

The South Dakota School of Mines and Technology (SDSM&T) is a state university founded in 1885 providing undergraduate and graduate degrees in science, engineering and interdisciplinary sciences. SDSM&T has approximately 2,100 traditional and non-traditional students from 39 states and 31 countries. Of special note is a mining collection with many items related to the Black Hills mining industry and the Homestake site. SDSM&T is the host institution for the Black Hills Natural Science Field Station, a cooperative program formed by a consortium of colleges offering field courses in geology and geological engineering programs. SDSM&T partners with tribal colleges and universities in the region in order to increase degree offerings and transfer opportunities for students enrolled at these institutions, which include Oglala Lakota College and Sinte Gleska University.

The school's Advanced Materials Processing and Joining Laboratory provides research and development opportunities. It has three-dimensional friction stir processing equipment that provides the capability to join large, curvilinear structures in ferrous and non-ferrous alloys directly from CAD/CAM files. On-going projects involve the engineering programs at SDSM&T and other academic institutions, government laboratories and industrial partners.

8.8.2.2 Black Hills State University

Black Hills State University (BHSU) in nearby Spearfish has 3,896 enrolled students and is the home to one of eight Centers of Excellence at universities throughout the South Dakota Board of Regents system. BHSU's Center of Excellence is the Center for the Advancement of Mathematics and Science Education (CAMSE). CAMSE's mission is to support the teaching and learning of math and science from kindergarten through college and beyond. CAMSE's mission is consistent with the vision for education and outreach to be associated with Homestake DUSEL. BHSU will assume a leadership role in the Homestake Interim Laboratory and DUSEL activities.

8.8.2.3 National American University

National American University (NAU) is a private, regionally-accredited, multi-campus institution of higher learning with the central campus located in Rapid City. The university provides career and professional undergraduate and graduate programs on campus and through distance delivery. It is accredited by the Higher Learning Commission and is a member of the

North Central Association. It offers a Master of Business Administration, Bachelor of Science and Associate of Applied Science degrees. It is affiliated with Human International Universities and Colleges Consortium, Japan; Augustana College, Kenya; Universidad del Mar, Chile; Skyline College, United Arab Emirates and Skyline Business School.

8.8.2.4 Oglala Lakota College

Oglala Lakota College is located approximately two hours from Lead and is one of the first tribal colleges in the United States. The college was chartered by the Oglala Sioux tribe to provide educational opportunities that enhance Lakota life. The college awards associate, bachelors, and graduate degrees. Areas of study include Agriculture and Natural Resource Development, Education, Math and Science, and Lakota Studies. The institution has college centers in various communities on the Pine Ridge Reservation. Enrollment is 1,400, with a full-time equivalency of 900 students. It is a North Central accredited institution.

8.8.2.5 Sinte Gleska University

Founded in 1971, Sinte Gleska University is named in honor of a Lakota warrior chief. The university is located nearly three hours from Lead on the Rosebud Indian Reservation. In addition to certificates and associate's degrees, bachelor's degrees are offered in arts and science, education, business administration and Lakota Studies. The overall academic goal of the Lakota Studies Department is to integrate traditional Lakota values and history in a bi-cultural setting that meets the challenges and complexities of Lakota society. A master's degree is available in Human Services.

8.8.2.6 Western Dakota Tech

Western Dakota Tech (WDT) provides technical education. One of four state-supported postsecondary technical institutes in South Dakota, WDT offers twenty five career programs ranging in length from 9 to 18 months. Western Dakota Tech grants Associate of Applied Science degrees and diplomas upon completion of individual program requirements. Through WDT's Corporate Education Center, a wide variety of non-credit classes, workshops, and short-term training programs are available. WDT serves more than 4,000 students each year through full and part-time enrollment and non-credit courses. Currently 850 students are enrolled full-time students. Courses are available days, evenings, weekends and on-line.

Of particular interest to the Homestake project is the welding program, which has 80 machines, 62 students currently enrolled, and six instructors. The program has room for 40 new students a year. According to a November 12, 2006 article in the *Rapid City Journal,* the school is considering incorporating more mining technology into its programs. WDT has already combined machining and drafting into the welding program to give students a solid background in industrial welding.

8.9 Recreation

The distance to Lead may cause some scientists, faculty and students to plan fewer but longer trips, which gives rise to questions about the social environment they might encounter on a longer stay. Such concerns are easily allayed. Lead is in the beautiful Black Hills of South Dakota, a major national and international tourist destination. Main attractions include **six** national parks, monuments and memorials: Mount Rushmore National Memorial, Devil's Tower National Monument, Badlands National Park, Jewel Cave National Monument, Wind Cave

National Park and Crazy Horse Memorial. Except the Badlands, all are located within the 1.2 million acre Black Hills National Forest.

Because of these national assets, a major share of the region's economy and infrastructure is devoted to hosting visitors from around the nation and around the world. The Black Hills tourism industry aggressively markets to European and Asian travelers.

Because of its unique, anthropological, geological, paleontological, archaeological and natural attributes, the Black Hills has played host to countless university expeditions for more than a century. The communities are well aware of the scientific interest in this area, and billboards and signs have been seen to sprout "Welcome Scientists" messages in recent years. We present in Appendix A23 many additional details about recreation, fine arts, and additional aspects of what users can expect when they come to work, study, or visit the Homestake site.

8.10 Facilities, Computers, Libraries

Two state universities, a technical institute, a private university and two tribal colleges offer a wide variety of instruction including degrees and certifications. They also have computer training/laboratories and libraries, many of which are open to the public.

The Devereaux Library on the campus of the South Dakota School of Mines and Technology is open to members of the community.

At the South Dakota School of Mines and Technology the Information Technology Services (ITS) operates and maintains the school's centralized computing resources, the campus Local Area Network and gateways to external wide-area networks, including the state telecommunications network. SDSM&T is a participant in Internet2 and is connected to the Abilene Network through the Great Plains Network.

The E.Y. Berry Library-Learning Center located on the campus of the Black Hills State University is a major resource center available to the community. The facility houses more than 235,000 books and 70,000 government documents. Included is the unique Cox Collection of state, county and local histories spanning from middle of the 19th century through World War II.

The library collection can be searched and accessed using the South Dakota Library Network (SDLN) South Dakota Library Network (SDLN) that the Black Hills State University pioneered for the State of South Dakota. Technical Support Services (TSS) provides computer and network technical support for faculty, staff and students for all university-related business. TSS maintains faculty and staff computers for office use as well as student use lab computers.

In 1996, former Governor Bill Janklow, understood the need for South Dakota's students to compete in a global economy and thus initiated a program to wire each of the schools in the state's 176 school districts for high speed internet access.

8.10.1 Computer Expertise

In order to support the amenities and institutions described throughout this section, the Black Hills region attracts and generates a large population of individuals with expertise in computer programming, software development, systems design and manufacturing. (Detail provided in the labor market summary.) Of particular note is the Sanmina-SCI Corporation, a leading electronic manufacturing services provider that has owned and operated a facility in Rapid City for 35 years. The Sanmina-SCI Corporate plant specializes in assembling printed circuit boards and final systems. The Sanmina-SCI Corporation helps clients introduce new products to market, provide low-volume manufacturing runs, integrate systems, test products, manage the supply chain, deliver product directly to the customer and provide repair service.

8.10.2 Municipal Libraries

Lead's Phoebe Apperson Hearst Lead Library is located on Main Street. The original library, the Hearst Free Library and Reading Room, was a gift to the City of Lead and its citizens by T.J. Grier, Superintendent of the Homestake Mine at that time, on behalf of Phoebe Apperson Hearst on Christmas Day, 1894. The library's original collection had many foreign language books to accommodate the reading interests of the various ethnic groups that made up the population of Lead. Some of these books are still available in the George Hearst Research Room. The City of Lead provides facility and building maintenance and the Lawrence County government and private donations fund the library's operations. The library participates in the shared automation system provided by the South Dakota Library Network consortium.

Neighboring Deadwood, Hill City, Spearfish (the Grace Balloch Memorial Library), Sturgis and Rapid City also have libraries. The Rapid City Public Library has 100,248 books, 5,739 audio materials, 5,493 video materials and several hundred serial subscriptions.

8.11 Labor Market

Table 8.3 summarizes relevant employment within a ~ 340 mile radius of Rapid City.

Table 8.3 Firms and Employees within a 340 mile radius of Rapid City.

Industry Segment	Firms	Employees	Relevant Categories
Machinery, Machining & Fabrication	192	13,598	die casting /extrusion, electroplating/plating, fabricated metals-pipes and plate, industrial machinery: pumps and valves, machining and machine tools, and power transmission
Electronics, Instruments& Computing	101	6,610	computer integrated systems designs, custom programming, software development, industrial instruments and electronic systems
Transportation Equipment& Repair	28	1,275	aircraft body, wing assemblies, repair, parts auto body, electrical and hardware

9 Summary and Conclusions

The Homestake site is the best location for DUSEL: outstanding opportunities for multiple sciences (and the resulting synergies); freedom from competing commercial priorities; existing infrastructure; and a receptive community, which includes not only good will but also a remarkable financial commitment from the state and from a philanthropic donor.

Uncompromising Opportunities: Homestake means access to the deep underground under near-ideal circumstances for science. It combines depth, low background environments, and the structural integrity to support large cavities, and it is completely dedicated to research.

This is an opportunity unique in all the world, and a large, multidisciplinary team of scientists, with a core of nationally recognized physicists and leaders in biology, geology, and engineering in the underground environment is poised to take advantage of it. Our phased approach begins with an Early Implementation Program (EIP) and is already underway under the auspices of the Homestake Interim Laboratory using South Dakota Science and Technology Authority funds. The EIP represents rapid access for science, education and engineering and assures that facilities will be available for experiments. Deeper levels will be developed as needed, thereby matching facility development with experimental requirements. Throughout its phased development, Homestake DUSEL will support an extremely diverse and comprehensive suite of experiments.

Homestake DUSEL will address many of today's most important scientific challenges, including the origin, evolution, and fate of the universe; a vast array of earth sciences and geoengineering research; and biology under extreme conditions. Many of these questions are relevant to high-profile societal issues, including ground water, carbon sequestration, and geothermal energy.

Built into the plans are education and outreach (including an ambitious science education center). These plans serve the community—particularly through K-12 and collegiate educational systems—and also visitors to the Black Hills. The E&O opportunities are seen by state and local governments as a major asset, and enjoy encouragement at every level.

A Running Start on a Safe and Productive User Facility: Approximately $116M is available through state funding and private donations to support the construction of the Homestake Interim Laboratory and its Early Implementation Program. This commitment represents a significant portion of the DUSEL facility construction costs. Leveraging this investment will make Homestake DUSEL a leader in cost-effectiveness and "time to science" as well as in results.

The Interim Laboratory's management and operational structures, including a customized safety program that integrates the requirements of an underground environment and multidisciplinary research (informed by extensive experience with large user facilities), will phase into DUSEL.

The preliminary cost estimate ($FY07 without contingency) for the MREFC application is $410M (including $225M in experiments and $91M in design and outfitting for underground laboratories). Other funding totaling $180M, including the Authority-controlled funds, will provide nine years of pre-operations support and underground lab preparation.

Room to Grow, and a Knowledge Base to Grow On: The design provides >100,000 ft^2 of underground lab space, and the site readily accommodates future expansions, including extending to greater depths and providing additional above- and below-ground infrastructure. Preliminary risk evaluations and geotechnical studies show that risks are manageable; there are no show stoppers. Earth science, geomicrobiology and several physics experiments, in particular, can be established expediently due to excellent underground access and existing documentation.

The result will be the world's largest, deepest, and most comprehensive underground laboratory.

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11 Appendices Cited in the Report

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A2 ***"Guidelines for Planning and Managing the Major Research Equipment and Facilities Construction (MREFC) Account"*, 22 November 2005 (29 pages) http://www.nsf.gov/bfa/docs/mrefcguidelines1206.pdf**

A3 **Summary of South Dakota Legislation**

A4 ***"Deep Science – A Deep Underground Science and Engineering Initiative"*, 12 October 2006 (48 pages) http://www.dusel.org/DUSEL_101706.pdf**

A5 **Homestake Interim Laboratory Letters of Interest, http://www.lbl.gov/nsd/homestake/LOI.html**

A6 ***"Property Donation Agreement between and among Homestake Mining Company of California, the State of South Dakota and the South Dakota Science and Technology Authority"*, 14 April 2006 (259 pages)**

A7 ***"Report of the Homestake DUSEL Program Advisory Committee"*, 12 March 2006 (with charge, membership, evaluation criteria, listing of Letters of Interest in Appendices, 49 pages)**

A8 ***"Technical Report: Geo-Science and Geo-Engineering Research at DUSEL"*, D. Elsworth and C. Fairhurst. Based on materials supplied by Coordinators, Working Groups 7, 8, 9: L. Costin, F. Heuze, B.J. McPherson, J.-C. Roegiers, E. Sonnenthal, R.P. Young, 9 October 2006 (59 pages)**

A9 ***"Infiltration Schematic DWG No. 601W006"*, Homestake Mining Co., 7 February 1990**

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A16 **Adam's Museum Letter of Collaboration**

A17 ***"DENR Underground Inspection, May 28 and 29, 2003"*, M. Cepak, M. Keenhihan, M. Nelson**

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A20 ***"DENR Report on Homestake Mine Underground Inspections Water Quality Summary"*, M. Nelson, July 2003**

A21 *"Geochemical Evolution of Water Quality During Re-filling of the Homestake Mine"*, Geochima, Inc., 13 June 2003
A22 Cyberinternet Appendix from the State of South Dakota
A23 Additional Users' Environment Information

12 Glossary, Abbreviations and Terms

ADA: Americans with Disabilities Act
A/E: Architectural and Engineering
ALS: Advanced Light Source
AM&H: Adams Museum and House
ANSI: American National Standards Institute
APS; American Physical Society
AST: Above Ground Storage Tank
ASTM: American Society of Testing and Materials
ATLAS: A Toroidal LHC ApparatuS
ATS: Automated Transfer Switch
BCCB: Baseline Change Control Board
BCP: Baseline Change Proposal
BHSU: Black Hills State University
B-L: Baryon - Lepton
BNL: Brookhaven National Laboratory
BOO: Board of Overseers
BOR: South Dakota Board of Regents overseeing the state's six regental universities
BSL: BioSafety Level
CA: National Science Foundation Cooperative Agreement
CAMSE: Center for Advancement of Mathematics and Science Education
CCB: Configuration Control Board
CDR: Conceptual Design Report
CFR: Code of Federal Regulations
CL: Confidence Level
C/M: Construction Management
CP: Charge-Parity symmetry
CY: Calendar Year
D&D: Decontamination and Decommissioning
DARHT: Dual Axis Radiographic Hydrodynamic Test
DENR: South Dakota Department of Environment and Natural Resources
DGGE: Denaturing Gradient Gel Electrophoresis
DNA: DeoxyriboNucleic Acid
DOD: Department of Defense
DOE: Department of Energy
DUSEL: Deep Underground Science and Engineering Laboratory
E&O: Education and Outreach
EIP: Early Implementation Program
EH&S: Environment, Health, and Safety or ES&H
EMO: Energy Management Office
EMP: Environmental Management Program
EMCS: Energy Monitoring and Control Systems
EPA: Environmental Protection Agency
EPSCoR: Experimental Program to Stimulate Competitive Research
EROS: Earth Resources Observation and Science
ESA: Environmental Site Assessment
EVMS: Earned Value Management System
FISH: Fluorescent In-Situ Hybridization
FMEA: Failure Modes and Effects Analysis
FNAL: Fermi National Accelerator Laboratory
FTE: Full-Time Equivalent
FUA: Facility Use Agreement
FY: Fiscal Year (Oct. 1 to Sept. 30)
GB: Giga Byte
GeV: Giga-electron Volt
GPC: Great Plains Collaboration
gpm: gallons per minute
GPS: Global Positioning System
GUTs: Grand Unification Theories
HARC: The Homestake-Adams Research Center
HAZMAT: Hazardous Materials
HIL: Homestake Interim Laboratory
HMC: Homestake Mining Company,
HRB: Homestake Reference Book
HSC: Homestake Scientific Collaboration
HVAC: Heating, Ventilating, and Air-Conditioning
IRIS: Incorporated Research Institutions for Seismology
ISE: Initial Suite of Experiments for Homestake DUSEL
ISM: Integrated Safety Management
IT: Information Technology
keV: kilo-electron volt
kt: kton kiloton
LBNL: Lawrence Berkeley National Laboratory
LDRD: Laboratory Directed Research and Development
LHD: Load-Haul-Dump
LHS: Large Hadron Collider
LIGO: Laser Interferometer Gravitational-Wave Observatory
LLR: Lunar Laser Ranging
LOI: Letter of Interest
LSND: Liquid Scintillator Neutrino Detector
LUNA: Laboratory Underground Nuclear Astrophysics situated in Gran Sasso, Italy

M&O: Management and Operations or Maintenance and Operations
MEMS: Micro ElectroMechanical Systems
MeV: Million-electron Volt
MOU: Memorandum of Understanding
MPS: Mathematical and Physical Sciences
MSW: Mikheyev-Smirnov-Wolfenstein effect
MSHA: Mine Safety and Health Administration
MWE (mwe): meters water equivalent
NASA: National Aeronautics and Space Administration
NEPA: National Environmental Policy Act
NGI: Norwegian Geotechnical Institute
NIH: National Institutes of Health
NSF: National Science Foundation
NuSAG: Neutrino Science Assessment Group
ORNL: Oak Ridge National Laboratory
OSHA: Occupational Safety and Health Administration
PA: Public Address
PAC: Program Advisory Committee
PANS: Photo-Activated Nanostructured Systems
PCR: Polymerase Chain Reaction
PEP: Project Executive Plan
PI: Principal Investigator on the NSF award(s)
PM: Project Manager
PMF: Probable Maximum Flood
PMT: PhotoMultiplier Tube
PPE: Personnel Protective Equipment
QA: Quality Assurance
R&D: Research and Development
R&RA: Research and Related Activities
RCP: Research Centers Program
REU: Research Experiences for Undergraduates
RFP: Request for Proposal
RIA: Rare Isotope Accelerator
RII: Research Infrastructure Improvement
S-1, S-2, S-3: Solicitation steps in the revised NSF process for establishing DUSEL
SD: State of South Dakota
SDGS: South Dakota Geological Survey
SDLN: South Dakota Library Network
SDSM&T/SDSMT: South Dakota School of Mines and Technology
SDSTA: South Dakota Science and Technology Authority
SDSU: South Dakota State University
SECUREarth: Scientific Energy/Environmental Crosscutting Underground Research for Urgent Solutions to Secure the Earth's Future
SF: square feet
SLR: Satellite Laser Ranging
SNO: Sudbury Neutrino Observatory
SNOLAB: Underground laboratory situated in connection to the SNO experiment
SSM: Standard Solar Model
STEM: Science, Technology, Engineering and Mathematics
State: State of South Dakota
SUSY: Supersymmetry
TDR: Technical Design Report
TDS: Total Dissolved Solids
TPC: Time Projection Chamber
TSS: Technical Support Services
TUNL: Triangle Universities Nuclear Laboratory
UCB: University of California, Berkeley
U/G: Underground
UIC: Underground Injection Control
URA: Universities Research Association
URL: Uniform Resource Locator (web link)
USD: University of South Dakota
UST: Underground Storage Tank
USGS: United States Geological Survey
VLBI: Very Long Baseline Interferometry
WBS: Work Breakdown Structure
WDT: Western Dakota Tech
WIMPS: Weakly Interacting Massive Particles
WIPP: Waste Isolation Pilot Plant

Horizontal Levels in the mine are denoted by the vertical elevation below the Yates Collar, thus the 4850 level is 4850 feet below the Yates Collar on the surface. We refer to levels using the abbreviation xxxxL, where xxxx is the elevation in feet and L refers to "Level".

Homestake Interim Laboratory is the state funded facility including surface facilities and 4850L developments. Access to the Homestake Interim Laboratory is provided by the Ross and Yates conveyances as well as surface adits and ventilation shafts.

Homestake DUSEL will be the NSF-sponsored multidisciplinary laboratory that will assume management and operation responsibility for the Homestake Interim Laboratory as well as then expanding this into a deep facility. The SDSTA will maintain some roles in Homestake DUSEL, such as maintaining the terms and conditions of the property donation agreement, but will cede M&O responsibility to the new facility.