THE NATIONAL UNDERGROUND SCIENCE AND ENGINEERING LABORATORY AT HOMESTAKE: PROJECT BOOK, REFERENCE DESIGN STAGE

A Facility for Physics, Astrophysics, EarthLab,
Applied Science and Engineering, and Outreach/Education

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submitted by

The Homestake Collaboration

The Homestake Collaboration

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The Ross headframe, Homestake Mine. Scientific access to the three levels of the proposed National Underground Science and Engineering Laboratory, on the 4850, 7400, and 8000 ft levels, will be via the Ross hoist and No. 6 Winze.

A. PROJECT SUMMARY

This submission is the **Project Book for the National Underground Science Laboratory, Homestake, at the Reference Design stage**. This submission represents a major step beyond the conceptual proposal our group submitted in June 2001. Much of the past two years was invested in strengthening and broadening the science case – an effort that involved not only our collaboration, but many of our colleagues in the broader science community who are interested in underground science. The science case itself has changed, with major new discoveries in neutrino physics occurring since June 2001, and with the development of a compelling program of NUSEL earth science. The community's arguments for NUSEL are summarized in the **Science Book**. In parallel with the science effort, our group has learned a great deal about the Homestake site and how it can be best adapted to meet the science requirements. This has led to the **Science Timeline and Reference Design**, and a facilities development plan much improved over that of the conceptual proposal. We describe this design – the access to underground, the underground and surface campuses, and the options remaining to be explored – and the engineering studies that allow us to assign costs and contingencies. We also describe the work remaining to be done and the program plan for producing a **Baseline Definition** of the Homestake project.

This project began in September 2000, when the INT hosted a group of 200 neutrino physicists in Seattle to discuss, in connection with the NSAC Long-Range Plan (LRP) for nuclear physics, possible priorities for this subfield. The deliberations of one of the meeting's working groups, on Underground Science Laboratories, was dramatically influenced by a proposal Lande made at this meeting, conversion of the Homestake Gold Mine into a National Underground Science and Engineering Laboratory (NUSEL). The availability of this very deep site, with massive shafts and lifts, sophisticated utilities, ventilation, and communications systems, and established operations costs, prompted the NSAC Town Meeting group to make the creation of NUSEL its highest priority. The National Science Foundation and Department of Energy responded by supporting an *ad hoc* study group, the Bahcall Committee, to consider the scientific case for NUSEL and the suitability of possible sites. The Committee's membership included leading underground scientists from particle, nuclear, and astrophysics. Its consultants included experts in earth science and large project management. The Bahcall Report, submitted to NSAC as a LRP White Paper, made a compelling scientific case for NUSEL and identified Homestake as the recommended site. In its final deliberations the NSAC LRP group made creation of a deep underground science laboratory its highest midscale construction priority for the next decade. Because Homestake closure plans limited the window in time when this site would be available, NSAC also wrote the NSF, urging the agency to proceed immediately with NUSEL-Homestake.

Following this decision a national group of underground scientists, several of whom had taken part in the Bahcall Committee and the Seattle, Oakland, and Santa Fe NSAC LRP meetings, collaborated on a NUSEL-Homestake proposal. This MRE proposal was submitted to the NSF in early June 2001, and was reviewed by the Physics Division later that summer. The results of the reviews – the Physics Division conducted two panel reviews in addition to soliciting written reviews – were shared with the proposers in October 2001.

Since submission of the original proposal, the creation of NUSEL and the associated science have generated extensive discussions in the scientific community. In HEPAP's long-range plan, which was debated over the last six months of 2001, neutrino physics, dark matter searches, and other underground science received strong support. Two high-level NRC committees reviewed the science arguments for NUSEL, both concluding that a deep US laboratory is needed. Major changes in the science have resulted from discoveries subsequent to June, 2001, including the

Sudbury Neutrino Observatory demonstration that the solar neutrino flux is dominated by heavy-flavor neutrinos, the KamLAND verification of solar neutrino oscillations, the K2K results, and the identification of thermophilic methanogens at the 8000 ft level of Homestake. New communities, most notably those advocating NUSEL-Homestake as an "EarthLab" for earth science, geomicromiology, and rock mechanics/engineering and those concerned with applications of new detector technologies to a variety of post-9/11 issues, have joined the collaboration. A series of conferences and workshops – the Lead meetings on Underground Science and on Geomicrobiology, the Aspen Workshop on Underground Science, and the NSF-sponsored NESS02 conference – not only contributed to broadening the science, but also clarified the technical requirements (depth, space, utility needs) and readiness of proposed experiments. (These meetings were either organized by the NUSEL-Homestake Collaboration or strongly supported by our members. The materials from these meetings – talks presented, working group white papers – have been preserved on the NUSEL-Homestake web page, **http://int.phys.washington.edu/NUSEL/.**) Major improvements in the NUSEL design have occurred, allowing us to avoid the costly Yates shaft extension while providing a more versatile laboratory that meets the needs of our broader collaboration. Finally, we have continued to develop partnerships nationally and in the region with the goal of enhancing the public outreach potential of NUSEL-Homestake. This includes exploiting Homestake's unique location and history – the US mine most identified with the opening of the American west, located in a major tourist area – and developing links to K-12 and regional and national college and university students and educators. Of particular importance are the opportunities to work with NativeAmerican educators, through both established NSF programs at the tribal colleges and new ones, and to provide a major-science "anchor" for the EPSCoR states of the Northern Great Plains, which currently lack such a focus.

This "version #2" proposal summarizes the progress the Homestake Collaboration has made in developing and broadening the science case for NUSEL; in defining the technical requirements that NUSEL must meet; in integrating this project into national efforts in nuclear and particle physics, astrophysics, earth science and geomicrobiology, outreach and education, and applications to materials science and national security; in formulating a baseline design for NUSEL construction that takes maximal advantage of the extraordinary existing infrastructure of the Homestake Mine; in developing a project management plan; and in producing a Work Breakdown Structure sufficiently detailed to justify project funding in FY06. The version #2 proposal contains the following elements:

- An **Overview** of the project, with special emphasis on our work and that of the community since June 2001. The overview summarizes major changes in the science scope of NUSEL and how these changes impact the technical aspects of the proposal. The overview reviews the conclusions of the various review committees that have dealt with NUSEL, as well as community interactions with the DOE and other agencies relevant to NUSEL. The status of the Homestake site is also summarized.
- The **Science Book**, in which the science case for NUSEL is updated. Important contributions to the Science Book came from community meetings either organized by or strongly supported by our collaboration: the Lead physics, outreach, and geomicrobiology meetings; the Aspen underground science program; and NESS02. The Science Book contains an important chapter on NUSEL as EarthLab, as well as comprehensive discussions of applied science and outreach at Homestake.
- The **Science Timeline** section summarizes the technical needs and readiness of proposed experiments, and thus the schedule and parameters that NUSEL-Homestake should meet. We provide a strawman ``Timeline'' of such experiments, correlating this with our proposed NUSEL schedule.
- A **Program Plan and Reference Design** of the NUSEL-Homestake project, in which we describe the proposed conversion of the Homestake Mine into the world's deepest and most flexible underground science laboratory. We propose a specific plan for meeting the needs of

envisioned and far-future underground science, including optimizing prospects for a megadetector important to very-long-baseline neutrino oscillation experiments and next-generation proton decay searches. We describe the work remaining to be done to arrive at a **Baseline Definition** for the NUSEL-Homestake project, and some of our plans for reaching this milestone. This section concludes with a suggested **Management Plan**, pending future guidance from the NSF on this issue.

- A **Work Breakdown Structure**, including rather detailed description of the underground campus developments at the 8000, 7400, and 4850 ft levels and of the plans for optimizing access to the underground and the capacity for future hall expansions.
- A last short section, independent of the remainder of the proposal, in which we provide a qualitative assessment of the **current status of the mine** (including implications of the flooding that commenced June 2003).

B. PROJECT OVERVIEW

I. NUSEL-Homestake Science and Outreach

What is the physics justification for a National Underground Science and Engineering Laboratory? There is growing recognition that some of the most profound problems in subatomic physics, astrophysics, and cosmology must be attacked with new types of experiments, ones involving massive, ultraclean detectors mounted deep underground to escape backgrounds from cosmic rays. In this overview we outline the prospects for paradigm-shifting discoveries in four areas, neutrino physics, dark matter, nucleon stability, and neutrino astronomy.

Neutrino Physics: Over the past decade experiments done underground have provided some of the most significant new results in physics. The discovery that atmospheric and solar neutrinos oscillate proves that neutrinos have mass, the first demonstration of physics beyond the standard electroweak model. The most naive interpretation of that mass – the so-called seesaw mechanism – suggests we are probing physics characterized by energies ~ 10^{15} GeV, near the grand unified scale and many orders of magnitude beyond the direct reach of accelerators. The discovery that neutrino mixing angles are nearly maximal, unlike those of the quarks, suggests that the neutrino mass generation mechanism differs fundamentally from that of the other fermions. There is every expectation that, as we identify the masses, mixing angles, and CP phases of neutrinos, the emerging pattern will point theorists in the direction of a new standard model, one that explains many of the apparently arbitrary parameters of our low-energy world.

The pace of discovery in neutrino physics is extraordinary. Since the submission of our original proposal in June 2001, the Sudbury Neutrino Observatory has demonstrated that heavy-flavor neutrinos make up two-thirds of the solar neutrino flux. This result eliminates all but one (the large-mixing-angle) proposed oscillation solution to the solar neutrino problem, and vindicates the standard solar model by showing that the total flux (independent of flavor) was correctly predicted. KamLAND showed that the oscillation phenomena responsible for the solar neutrino problem could be tested in a controlled terrestrial experiment, and significantly narrowed the range of neutrino mass differences that could account for the oscillations. These results have had an immediate impact on cosmology. Because of the large mixing angles, Big Bang nucleosynthesis now severely limits neutrino chemical potentials in the early universe, regardless of flavor. We have identified the first component of particle dark matter: neutrinos are at least as important as the visible stars in the universe's matter budget. Yet the allowed range for the absolute scale of neutrino mass – from about 0.05 eV to a few eV – is still too broad. WMAP's very recent measurement and analysis of temperature anisotropies in the cosmic microwave background radiation, probing the structure of our universe 400,000 years after the big bang, proved sensitive to neutrino masses slightly below 1 eV. Thus precision cosmology now is linked to the progress being made in neutrino physics.

One measure of the community's regard for this science comes from last year's Nobel Prize to Raymond Davis, Jr., who founded the field of neutrino astrophysics when he constructed, with the help of the Homestake Corporation, the first solar neutrino detector.

It is important to recognize that these discoveries are the first step in an effort that promises to resolve some of the deepest questions in science. The field's excitement comes from the knowledge that many more steps can be taken. As mentioned in connection with WMAP, we do not know the absolute scale of neutrino mass: the oscillation results provide only a lower bound. We do not know whether the neutrino has a distinct antiparticle. We do not know the mass hierarchy, that is, whether the nearly degenerate pair of mass eigenstates responsible for solar neutrino oscillations is lighter or heavier than the third mass eigenstate. We do not know θ_{13}, the crucial mixing angle that will determine whether neutrino oscillations affect the explosion of and

nucleosynthesis within a core-collapse supernova. Perhaps most exciting, the pattern of neutrino mass now being revealed appears consistent with a novel mechanism that accounts for the existence of matter itself, leptogenesis: CP violation long hidden in neutrinos may account for dominance of matter over antimatter in our universe.

All of these unresolved questions appear answerable. The absolute scale of neutrino mass and the particle-antiparticle nature of the neutrino are connected in a fascinating way. The seesaw mass-generation mechanism exploits the fact that neutrinos, unlike other standard-model fermions, lack charges or other additive quantum numbers that distinguish particles from antiparticles. This allows neutrinos to have, in addition to ordinary Dirac masses, lepton-number-violating Majorana masses. The breaking of this basic standard model symmetry leads to neutrinoless double beta decay, an exotic nuclear decay mode that explicitly violates lepton number. The rates for neutrinoless double beta decay are proportional to the squares of the masses of the neutrinos that couple to the electron. One of the most exciting consequences of recent neutrino physics discoveries is the likelihood, in two of the three most popular neutrino mass scenarios, that neutrinoless double beta decay will soon be discovered if experiments 100 times larger than those currently operating can be mounted. In most scenarios this would then determine the overall scale of neutrino mass. While such experiments are challenging – they generally require ton quantities of an enriched isotope, a very deep underground location, and excellent energy resolution – several of the proposed detectors appear practical. It is likely that a next-generation double beta decay experiment will be one of the early NUSEL-Homestake experiments.

Progress on neutrino mixing angles is expected to come from a combination of solar, reactor, and accelerator experiments. Despite the success of SNO and Super-Kamiokande, 99.99% of the solar neutrino flux has not been seen in direct detection experiments. While there are many reasons for measuring the low-energy solar neutrino flux, one important goal is to better constrain the solar neutrino mixing angle θ_{12}. This requires a well-calibrated neutrino source. Arguably the pp solar neutrino flux is the best candidate, astrophysical or terrestrial, because the normalization is known to 1%. Reactor neutrino experiments using multiple detectors and accelerator experiments using either broad-band or off-axis neutrino beams have been proposed to measure the unknown mixing angle θ_{13}. This crucial measurement will determine in part the size of CP-violating effects in long-baseline neutrino oscillation experiments.

A further step in the above program addresses one of the deepest questions in physics, why does our universe contain matter? The puzzle exists because, in the Big Bang, one would naively expect matter and antimatter to have been produced equally, only to annihilate each other later when the universe cooled sufficiently. Yet our universe (at least locally) contains matter, but virtually no antimatter. Theory tells us that a necessary condition for baryogenesis (an excess of baryons over antibaryons) is the breaking of CP, a symmetry combining parity reversal with charge conjugation. While there is CP violation in the standard model outside the neutrino sector, almost all theorists believe it is too weak to account for the matter asymmetry. However the patterns emerging from recent neutrino physics – the masses and the large mixing angles – suggest that the necessary asymmetry could be produced by CP violation among the neutrinos, which would then be transferred to the baryons, a process call leptogenesis. Very long baseline neutrino oscillation experiments (~ 2000 km) using neutrino superbeams (or ultimately the beam from a neutrino factory) and megaton detectors could measure aspects of the CP violation, providing our first clues to the origin of matter in the Big Bang.

Dark Matter: The results of WMAP and other cosmic microwave background probes, of large-scale structure surveys, and of supernova probes of the Hubble expansion all indicate that the vast majority of matter and energy in our universe is unknown to us, dark and undiscovered. The best global fits to cosmological parameters lead to remarkable conclusions. The total energy density of the universe is very close to the critical value, the minimum energy density guaranteeing that our universe will not recollapse, as inflationary cosmologies predict. And most

of that energy density is in hidden components: 73% is dark energy --usually identified either with Einstein's cosmological constant or with a time-evolving pervasive scalar field -- and 27% is matter. While a small part (~ 4%) of this matter is ordinary baryons (and only part of the baryonic matter is visible in stars and gas clouds), the vast majority is dark, nonbaryonic, and cold, that is, something new, outside the standard model of particle physics. As our cosmological colleagues struggle to understand the nature and equation of state of the dark energy, underground scientists will mount a new generation of detectors to find the particles that comprise the cold dark matter.

The dark matter/dark energy problem is indeed remarkable. We are aware of only a small fraction of the matter/energy in our universe (and therefore in our local region of the Milky Way galaxy). The unseen components nevertheless shaped, through their gravitational and other interactions, the structure of our visible universe. The goal of this field is to identify and understand the properties of the unseen matter and energy, thereby enabling cosmologists to understand how the universe evolved from the Big Bang into its present form.

We have noted that one component of particle dark matter, neutrinos, was recently identified. But we know neutrinos are a bit of a spice in the dark matter mix, not the main ingredient. Perhaps the strongest candidate for the dark matter comes from the predictions of supersymmetry, which is invoked in particle physics to explain the stability of the electroweak scale with respect to radiative corrections. Supersymmetry predicts new particles around the TeV scale, the lightest of which could well be stable. This particle would have been produced in the Big Bang, and would now be affecting the expansion of our universe.

Cross sections for supersymmetric particles interacting with ordinary matter can be estimated, and generally lie between 10^{-6} and 10^{-10} pb. (A 10^{-10} pb cross section corresponds to about one event/100 kg/y.) This is an encouraging result for this young field, as existing detectors can be scaled up to one-ton masses to search all of this allowed range. Experimenters envision detector improvements of about four orders of magnitude. Accompanying these improvements will be the need for deep underground sites, in excess of 4500 mwe, to escape neutron and other cosmic-ray-induced backgrounds.

The particle dark matter quest illustrates a wonderful connection between physics at the largest scales – cosmological structure – and that at the smallest scales, ultra-high-energy accelerator physics. A major goal of the Large Hadron Collider, which will probe particle interactions at distances of $1/100{,}000^{th}$ of a fermi, is to discover supersymmetry directly by producing supersymmetric particles, just as in the Big Bang. The LHC timeline hopefully predicts such a discovery by 2012, about the time particle dark matter experimenters will reach their event rate goal of 1 event/100kg/y.

The Stability of Matter: Almost all of the known elementary particles have finite lifetimes, decaying into other lighter particles. When this does not occur – when a particle is absolutely stable – there is an explanation based on conservation laws. For example, the electron is stable because, as the lightest charged particle, there is no possible decay channel that conserves electric charge. The other component of ordinary matter, nucleons, also appears to be stable, at least on time scales so far measured. The standard model accounts for this stability by assigning to nucleons a conserved charge called baryon number, first introduced by Stuckelberg in 1938.

However, efforts to go beyond the standard model, to unify the strong, electromagnetic, and weak interactions, predict that baryon number is not exactly conserved. That is, ordinary matter will eventually decay at some unimaginably late epoch in the life of our universe. The original predictions of such Grand Unified theories were based on the gauge group SU(5) and predicted lifetimes for the proton between 10^{28} and 10^{32} years. The largest detectors ever built underground were designed to detect favored decay modes, such as $p \rightarrow e^{+}\pi^{0}$: Super-Kamiokande

experimenters have spent a decade watching a dark cylinder containing 50 kilotons of ultrapure water, waiting for the light from the decay of a single nucleon. Their negative results excluded these simplest Grand Unified models.

Modern versions of Grand Unified theories are very attractive, accounting for the masses and mixings of all the quarks and leptons (including the neutrinos) and for the matter-antimatter asymmetry through leptogenesis. They also predict nucleon decay, though at rates suppressed relative to early SU(5) models. In particular, currently popular supersymmetric SO(10) models predict a favored νK^+ proton decay mode within an order of magnitude of present limits, as well as a branch for the $e^+\pi^0$ mode of about 10^{35} years. We have the technology to construct a detector ten times larger than Super-Kamiokande to reach such lifetimes. NUSEL-Homestake would allow us to place this detector at unprecedented depths, where it would be 100 times quieter than Super-Kamiokande. (Low cosmic-ray backgrounds are important in the identification of certain proton decay modes as well as in the ancillary uses of the detector, e.g., supernova, atmospheric, and solar neutrino physics.) Such a megadetector nucleon decay experiment is expected to be a keystone of the NUSEL-Homestake program.

Proton decay is another example of an ultrasensitive low-energy experiment that, while indirect, reaches far beyond current accelerators in its quest for new physics. The processes responsible for proton decay in SO(10) Grand Unified models probe interactions at 10^{16} GeV, corresponding to length scales of 10^{-17} fermis.

Supernova Neutrino Observatories: The nucleon-decay megadetector just described, operating for decades in a multidisciplinary underground laboratory, could serve many communities. We noted that the quest for CP violation in neutrino oscillations has led to several proposals for neutrino superbeams, and requirements for targets placed ~ 2000 km away. (The distances from Homestake to FNAL and BNL are 1290 and 2530 km, respectively.) The requisite target mass for such long-baseline experiments is comparable to that needed for next-generation nucleon decay. Within two decades the international high-energy community will likely produce a neutrino factory and contemplate experiments with even longer baselines, comparable to the earth's radius.

A Type-II (or core-collapse) supernova is one of the most spectacular events in nature. This occurs when a massive star has finished its burning cycles, producing in the final Si-burning stage an iron core. When that core reaches the Chandresekar mass, it collapses under its own gravity to form a hot neutron star, initially on the order of 50 kilometers in radius. Via a mechanism not well understood, but believed to depend on both the hydrodynamic shock wave generated by the collapse to nuclear density and by neutrino heating of the dissociated nuclear matter left in the shock wave's wake, the outer mantle of the star is ejected. This ejection enriches the interstellar medium in the metals produced during hydrostatic burning as well as in rarer elements produced in the explosion itself. Type II supernovae are major engines driving the long-term chemical evolution of the galaxy. In particular, approximately half of the elements heavier than iron are produced in the rapid-neutron-capture process, which requires the explosive conditions and high neutron fluences found in neutrino-driven winds of supernovae.

Just as solar neutrinos allow us to probe the details of the sun's core, complete measurements of the spectrum, flavor, and time evolution of the supernova "neutrino light curve" will provide detailed information on the explosion mechanism, on the behavior of neutron star matter at several times nuclear density, on supernova nucleosynthesis, and on new aspects of neutrino physics that might not be testable elsewhere (such as the effect of an intense neutrino background on neutrino oscillations).

A megadetector of the type discussed for proton decay and long-baseline measurements, located at sufficient depth, would be an incomparable observatory for galactic and extragalactic

supernovae, complementing optical and gravitational wave instruments. A massive detector could follow the "neutrino light curve" of a galactic supernova for tens of seconds, the period in which the puffy protoneutron star radiates its lepton number, becoming a compact neutron star 10 kilometers in radius. At such late times nuclear matter phase transitions might be revealed through sudden changes in the light curve. Such a detector could also see the constant supernova "neutrino background," the integrated effect of all past supernova. There is extraordinary information in the flux and redshifts of this spectrum, to which the earliest stars, now believed to have formed just one billion years after the big bang, contributed. Plausible models of star formation predict first detection is just a factor of three beyond current Super-Kamiokande limits. Such a detector would also reach beyond our galaxy: A supernova in Andromeda would produce a few tens of events.

Supernova neutrino detectors are also crucial to the "supernova watch" program – the plan to correlate optical, gravitational wave, neutrino, and other signals from the next galactic supernova. Supernova neutrino detectors have a 100% detection rate – intervening matter cannot obscure the neutrino signal. This signal is prompt, coming typically several hours to a day before the optical display, which begins when the shock wave reaches the outer envelope.

The **first chapter** of this proposal's **Science Book** describes in detail these and many other important particle, nuclear, and astrophysics experiments that can only be carried out in the shielded environments available very deep underground. These include new solar and atmospheric neutrino experiments to pin down neutrino parameters – particularly θ_{13} crucial to long-baseline searches for CP violation – and to probe for new sterile states, which could generate lepton number asymmetries in the very early universe. There is a fascinating neutrino-earth science connection (distinct from the earth science discussed below): The technologies pioneered by KamLAND and Borexino could soon measure the flux of antineutrinos produced by radioactivity in the earth's core. This would answer questions about the contributions of radioactivity to the terrestrial heat budget, possibly moderating the effects of the ancient sun's much lower solar constant. (The standard solar model predicts a luminosity increase of 44% since the onset on the main sequence five billion years ago.) In addition, the Science Book describes potential opportunities with specialized underground accelerators for nuclear astrophysics, in gravitational physics, and in low-level counting generically.

How will NUSEL contribute to earth science and geomicrobiology? One of the most important developments in the justification for NUSEL-Homestake since the June 2001 proposal has been the recognition of the laboratory's importance to earth science and geomicrobiology. This interest is rather keenly focused on one site, Homestake, because the mine offers extraordinary 3D access to several cubic kilometers of highly folded and fissured ancient hard rock. As was discovered last year, the 8000-ft level of this mine is also home to thermophilic methanogens, temperature-adapted methane-producing microbial colonies. The earth-science component of the NUSEL-Homestake collaboration, led by a steering committee [Brian McPherson (New Mexico Tech), Tullis Onstott (Princeton), Tommy Phelps (ORNL), Bill Roggenthen (South Dakota School of Mines and Technology), Herb Wang (Wisconsin), and Joe Wang (LBNL)], has dubbed this science **EarthLab**.

EarthLab is a proposal to utilize Homestake as a subterranean laboratory and observatory in the study of geomechanical, hydrological, geochemical, and biological processes that modify earth from its surface to the limit of habitable depths. Opportunities for earth scientists to observe directly deep subsurface changes – microbes that precipitate minerals and generate gas, migrating fluids that transport drinking water and weaken earthquake-generating faults, and stresses and strains that cause rock to deform slowly or break catastrophically – are currently very limited. The complex coupling of biogeochemical processes, fluid flow, rock-water interaction, and rock deformation is largely unexplored. A more complete understanding of these processes and their coupling is crucial in advancing disciplinary research ranging from

earthquake engineering to bioremediation. The EarthLab proposers also envision partnerships with industry, including practical applications of its biosphere research to bioremediation, biotechnology, and pharmaceuticals, as well the development of new geophysical and geochemical tools for subsurface characterization and new geological mapping, rock drilling, and other engineering technologies for exploration and construction. By partnering with NASA, these new technologies could be adapted for subsurface life exploration on other planets.

EarthLab's goal of studying complex geologic processes *in situ* with 3D access for continuous observations and controlled experiments requires a very large, instrumented rock volume and access to great depths. As discussed in more detail below, we believe there is only one proposed NUSEL site that satisfies these requirements. The EarthLab science program is focused on five major themes, the nature of life at depth, fluid flow and transport at depth, rock deformation and failure at depth, mineral resources and environmental geochemistry, and scientific and engineering innovation underground. The EarthLab program will explore the interrelation of complex physical, environmental, and microbial processes. For example, tectonic forces bend and fracture rock, in turn altering the permeability and porosity of the rock, and therefore the pressures, directions, and rates of fluid movement. Changes in fluid pressures alter the elastic response of rock to deforming forces, which govern movement along faults and thus the frequency and magnitude of earthquakes. Fluid flow is also important to the distribution of environmentally and economically important minerals and compounds in the crust, many of which are dissolved in and precipitated from hot rocks.

Life at Depth: The relatively recent discovery of a subsurface biosphere – deep subsurface microbial communities – may provide crucial insights into how life on this and other planets may have originated and evolved. The diversity of geologically isolated extremophiles is thought to provide our best guide to possibilities for life beneath the surface of Mars, for example. Subsurface microorganisms also play crucial roles in the dissolution and formation of minerals. Yet the coupling between geomicrobiological and biogeochemical processes and the earth science, chemistry, and physics governing rock masses and fluids is poorly understood. Certain minerals may provide nutrients for microorganisms, and fluids may transport microorganisms to those nutrients. The microorganisms in turn may precipitate minerals or generate gas, altering the permeability and hence the flow of fluids. Fluid flow may dictate the temperature at depth, thereby determining whether thermophiles and hyperthermophiles can survive. If the temperature change is rapid compared to migration times for microorganisms, then the microorganism must adapt or expire. Fracture propagation may also impact fluid flow, exposing fresh mineral surfaces to redox reactions and providing aqueous and gaseous energy sources to the microorganisms.

EarthLab would be the only facility in the world where the coupling of microbial, chemical, and physical processes could be explored from surface to the great depths defining the limits of life.

Fluid Flow and Transport at Depth: Very little is currently known about fluid flow and transport at depth because drill-hole experiments are so limiting, providing small rock samples altered by the drilling process. EarthLab could revolutionize the field by allowing temporal and spatial data far beyond that currently available. The goal would be to achieve a quantitative understanding of recharge and infiltration, fracture permeability, the physics of multiphase flow, flow in fracture networks, verification of well and tracer test models, the coupling of flow, stress, and heat, and the storativity and transmissivity of tight rocks. This science is central to important societal issues, including the stability of water supplies, hazardous waste disposal, and the remediation of contaminated groundwater.

Borehole measurements are fundamentally limited because they provide no direct information about the large volume of rock residing between tested points. Results often erroneously reflect the spatial scale of the separate point measurements. EarthLab would, for the first time, allow

hydraulic, tracer, and geophysical imaging over a 3D array encompassing approximately 9 cubic kilometers of rock, thereby characterizing the structure, fracture connectivity, and transport properties, as well as their variability with scale, depth, and distance across the excavated zone.

Rock Deformation at Depth: Rock deformation deep in the subsurface traditionally has been characterized through proxy methods, such as seismic tomography. Apart from a few deep mines outfitted with extensometers, active rock strain must be deduced from surface methods such as InSAR (satellite-generated Interferometic Synthetic Aperture Radar) and GPS (Global Positioning System) data. EarthLab will allow continuous direct measurements of rock strain and the variables that govern that strain. As with permeability, past studies of strain and stress have generally been compromised because the deep rock being characterized was too small in volume.

EarthLab experiments will be able to test the hypothesis that the Earth's crust is "critically stressed," close to failure by fracture. Repeated shearing of such fractures can keep flow paths open that would otherwise be closed by mineral cementation, enhancing rock permeability. By mapping fractures, stress, and fluid flow within the subsurface, the theory of critical stress can be tested quantitatively.

This research will benefit from the interdisciplinary nature of NUSEL-Homestake: the large detector cavities excavated for physics detectors are ideal laboratories for monitoring 3D+time deformation on unprecedented scales. Hydraulic, tracer, and geophysical measurements of transport parameters will be made during cavern enlargement, and instrumentation arrays will be installed in the finished cavities to monitor the long-term passive response in the stable zone surrounding the detectors.

Mineral Resources and Environmental Geochemistry: Many economically important mineral resources are formed or concentrated by fluid flow in the subsurface. For example, oil, natural gas, and some brines are localized in the crust largely by their physical response to fluid flow. Most metals, such as iron, copper, and gold, are localized chemically, by mineral dissolution and subsequent deposition. Although considerable progress has been made in understanding mineral deposition by observation of fossil systems, opportunities for studying these processes in an active environment are exceedingly rare. For example, most geothermal areas are too hot and deep for direct study. EarthLab would fill this void, allowing direct testing of many aspects of mineral deposition.

Fluid flow through rocks governs the release and concentration of metals and organic compounds of environmental concern. Most such releases are triggered when rock from deep in the crust is exposed to water and oxygen, causing minerals formed at depth to decompose. The most widely known of these processes, acid mine drainage, results when pyrite (FeS_2) is oxidized by near-surface waters. Most studies of acid mine drainage are confined to points where water has reached the surface. EarthLab would permit these processes to be observed at early stages and at depth, perhaps leading to better strategies for control.

Science Technology and Engineering Innovation: The technological and engineering impacts expected from EarthLab include:

- New generic materials, novel microorganisms, and biotechnology applications
- Analytic techniques for geomicrobiology and exobiology
- Natural resource recovery
- Drilling and excavation technology
- Novel uses of underground space
- Mine safety, including large cavern stability analyses
- Subsurface imaging
- Environmental remediation

EarthLab instrumentation itself will break new ground: in the early days of NUSEL-Homestake, when access to most of the 600 km of available drifts is still possible, instrumentation will be installed in coreholes adjacent to excavated blocks, and continuously monitored thereafter for excavation-induced displacements, microseismic activity, temperature, and fluid pressures. Aqueous and particulate samples will be taken from accessible areas. New sensor technologies will be designed for many of these applications.

A specific set of mine engineering research and development issues will be addressed by the **Hard Rock Mining Training and Research Center** of NUSEL. The research component of HRMTRC will focus on experiments in stoping and rock breaking, with the goal of accident reduction and productivity and mine safety optimization; on the application of practical digital mine mapping methods; and on mine engineering, especially advances in stoping methods, long-hole mining, bench mining robotics, and production optimization.

Chapter II of the **Science Book** describes the envisioned experimental program at EarthLab. EarthLab is the community's first opportunity to move beyond borehole and remote sensing experiments, to do advanced earth science and engineering studies in large rock volumes over long times. Much like surgery permits a physician to examine internal bones and organs first identified with X-rays or CAT scans, EarthLab will be a fully instrumented, dedicated laboratory/observatory in which scientists will probe the Earth's active interior.

What is the relevance of NUSEL to post-9/11 challenges and other applied-science issues?
In the past year various advisory committees have stressed the need for the scientific community to help with urgent national security issues. For example, the 2002 National Academy Study "Making the Nation Safer: The Role of Science and Technology in Countering Terrorism," states *"Indeed, America's historical strength is science and engineering is perhaps its most critical asset in countering terrorism without degrading our quality of life."* An important workshop was recently hosted by the Department of Energy on the "Role of the Nuclear Physics Research Community in Combating Terrorism." Research community members from DOE and NSF laboratories and universities met with government counterterrorism experiments to discuss technological solutions to national security challenges. While the scope of the resulting report was quite broad (**http://www.sc.doe.gov/henp/np/homeland/descript.html)**, strong emphasis was placed on the past and future role of low-level-counting techniques – techniques developed for basic underground science.

The active interrogation of luggage, vehicles, and cargo containers for conventional explosives and for special nuclear materials such as highly enriched uranium requires sensitive, large-volume detectors for recording the responses of materials to x-ray, gamma-ray, and neutron probes. Two technologies highlighted in the DOE report are high-resolution intrinsic germanium crystals and very-large-volume scintillation and water Cerenkov detectors. Much of the recent progress in increasing the efficiency and resolution of Ge detectors has come from nuclear spectroscopists and from double beta decay experimentalists – groups that are now collaborating on plans for next-generation double beta decay experiments. The need for rapid imaging of large cargo containers – ships can unload cargo at the rate of a container a minute – has raised the need for very large neutron and photon detectors. The DOE report stresses the kiloton-volume detectors developed by nuclear and particle physicists for neutrino detection as a possible solution. These include detectors modeled after LSND, large scintillation tanks viewed by photomultipliers, as well as water Cerenkov detectors. The report notes that the neutrino physics need for versatile, relatively inexpensive detector technologies has prepared the way for the adaptation and wide application of these techniques to national security problems.

The report also notes that underground experiments to search for extremely rare processes has led to an impressive confluence of techniques that can now be used to monitor our environment for potential hazards:

- few-atom, high-purity chemical separations
- ultra-low-level gas counting systems constructed of materials free of natural radioactive contaminants
- near-zero background germanium and scintillation detectors, and
- deep underground laboratory facilities where cosmic-ray backgrounds are reduced by many orders of magnitude (thereby allowing samples to be counted with high sensitivity).

The applications – sampling high-risk areas, followed by expedited counting in specialized underground facilities – are numerous. The report notes, because of radiochemical solar neutrino experiments, this technology is largely in hand: the applications to national security should be further developed.

One such application was discussed in the pre-9/11 Bahcall Report. There is great concern that a rogue nation could develop nuclear weapons clandestinely, testing low-yield devices deep underground, in enlarged cavities designed to muffle the seismic signal from the explosion. It is believed that such techniques (called cavity decoupling) could reduce the signal by two orders of magnitude, below the seismic detection threshold. However, all nuclear explosions produce large quantities of fission products and their daughters, including radioactive gases vented into the atmosphere. Seismic muffling does nothing to reduce these emissions. (In fact, cavity decoupling tends to enhance venting.) Particularly important are the radioactive noble gases ^{133}Xe and ^{135}Xe, with half lives of 5.3 and 0.39 days, the detection of which (in the proper ratio) would indicate that a nuclear weapon has been detonated. The short half-lives and severe dilution of these gases as they mix in the atmosphere demand a monitoring system with nearly single-atom counting capability. This capability exists because of the chlorine and gallium solar neutrino experiments. The PIsCES group, which is developing the Xe detection technology with the goal of improving our overall nuclear weapons monitoring capabilities by one to three orders of magnitude, uses miniaturized gas proportional counters very similar to those pioneered by Ray Davis to detect another radioactive noble gas, ^{37}Ar. The PIsCES atmospheric samples must be counted deep underground, where cosmic ray backgrounds are tolerable.

An important change from our original proposal is a much expanded **low-level counting facility** for national security and other applications, as well as for many basic science needs (such as determining the activities of materials before they are used in detector construction). **Chapter III** of the **Science Book** describes the crucial roles NUSEL could play in national security and in other applied science fields. Examples of other applications include the development and fabrication of high-purity materials; materials analysis; and the extraction of activities from materials (such as the reduction of Th and U to levels of 10^{-16} g/g in SNO, Borexino, and KamLAND). Such technical steps result in shorter collection times, smaller samples sizes, less restrictive transport times, and much improved sensitivity to short-lived isotopes, impacting both basic science experiments (such as the radiochemical neutrino experiments) and applications, such as atmospheric Xe monitoring for national security and trace-element analysis for materials dating. The microelectronics industry, which currently uses underground laboratory space, is interested in measuring cosmic-ray-induced error rates in chips as a function of depth. Several additional applications – novel microorganisms and their biotechnology applications, resource recovery and environmental monitoring, drilling and excavation technology – connected with earth science are addressed in detail in Chapter III.

What is NUSEL's potential for enhancing science outreach and education? The proposers believe that NUSEL-Homestake has remarkable potential for regional (and national) outreach and education. The reasons include its location (near the geographic middle of five contiguous EPSCoR states); its potential for drawing visitors from among the three million tourists who come to the Black Hills yearly; the links between Black Hill's geology and the region's history (both Native American and mining); access to scientifically underserved K-12 and tribal college students; and Homestake's significance as the birthplace of neutrino astronomy:

- *The opportunity to create a major-science focus for the Northern Great Plains states.* Homestake is located near South Dakota's Wyoming border. The five states within 120 miles of Homestake – South Dakota, North Dakota, Montana, Wyoming, and Nebraska – are **EPSCoR** states. Several others – Idaho, Nevada, Kansas – are within ~ 500 miles. The presence, for the first time, of a major basic research center affords many opportunities to "grow" new research programs in the regional universities. The collaboration's initial success in introducing South Dakota scientists to NUSEL indicates some of the potential. In the conceptual stages of this project (2000 and 2001) several of the senior underground scientists visited state universities to give seminars and to hold discussions with interested faculty. Following submission of the June 2001 proposal, the protocollaboration's first activities were the NUSEL physics and earth science workshops held in Lead. One result was the recruitment of 16 South Dakota scientists as working members of the collaboration, several assuming leadership roles; approximately 30 others have participated in specific collaboration activities, such as formulating NUSEL outreach plans. The collaboration has also contacted key university scientists in neighboring states, expressing our interest in partnering with them. We are encouraging the regional universities to consider an association, perhaps similar to Oak Ridge Associated Universities, in which these institutions can advance more effectively science and education by partnering with NUSEL.

- *Undergraduate and graduate education.* These efforts to integrate South Dakota and regional scientists into the collaboration and to encourage a regional science/education consortium are important to the undergraduate and graduate students in the region. In Chapter IV we describe why we believe a strong NUSEL-regional universities partnership is important to NUSEL's **Research Experience for Undergraduates** and **summer school** efforts, and in follow-up activities that could keep regional undergraduates involved in NUSEL science during the academic year. This partnership is essential in realizing NUSEL's potential for graduate education in the region, as active involvement of graduate faculty advisors is clearly the most efficient way to bring these students to NUSEL. Of course, NUSEL scientists will come from throughout the US and overseas. While NUSEL will endeavor to be of particular help to Northern Great Plains institutions, it will also serve the customary national laboratory role in supporting visiting graduate and undergraduate students from the broader community.

  One program unique to NUSEL will be the training component of the Hard Rock Mining Training and Research Center. Fewer schools are training mining geologists and engineers even though, as US open mines are reaching economic limits with depth and increased stripping ratio, more deep underground mines are being planned to extend mine lifetimes. The HRMTRC would serve as a centralized national training and research center, working to support the educational mission of the nation's mining schools. Many of these schools no longer have the staffing levels or student enrollments to justify the operation of local training mines.

- *Public outreach.* Three million visitors come to the Black Hills annually, some attracted by the outdoor recreation and some by the region's colorful gold mining and Native American history. This opens wonderful opportunities for interesting these visitors in science, particularly if the science is presented well and connected to the region's history and geology. In our original proposal we estimated that a well-designed NUSEL visitor center could draw perhaps 100,000 visitors per year. This was based in part on the success of the Soudan Mine visitor program that, though operating in a smaller and more remote site, attracts 40,000 visitors per year. Regional tourism experts, including the superintendent of Mt. Rushmore, have advised us that our initial estimate may have been far too conservative, with 400,000/yr being a better guess. If the visitor total exceeds 100,000/year, the NUSEL outreach program would be the largest among pure-science research sites. (We distinguish NUSEL from technology centers, such as Cape Kennedy.)

The opportunities for constructing an exciting visitor center seem almost limitless: the geology, cultural history, and science are connected in ways that should fascinate the public. The Black Hills are sacred to the Sioux because of their unique physical features, features that reflect the region's remarkable geology. The Black Hills are literally a peep hole through the Great Plains into the ancient geologic past. The domal uplifts that exposed this island of Precambrian rock, 1.9-2.5 billion years old, occurred 530 and 65 million years ago, the last after the great inland sea retreated. The accompanying erosion scoured off in excess of 5000 feet of the sedimentary rock that covers other parts of the Great Plains, exposing the dome. The extraordinary mineralization that formed the Homestake gold deposit occurred beneath ancient seas as a result of submarine hot springs activity, forming the largest gold deposit of its kind in the world.

Our vision is to explain how this geology influenced the lives of the people who lived in this region, from Native Americans, to the gold rush days and the opening of the American west, to modern times where science now needs the great overburdens provided by Homestake. The NUSEL geomicrobiology program is directly coupled to the geologic history, as isolated pockets of ancient water may hold the most surprising extremophiles. The basic earth science studies – understanding the coupling of subsurface and surface phenomena, the relation between hydrology and mineralization, and environmental science – tie nicely to the history. Part of the history is also the creation of a new field, neutrino astronomy, at Homestake with the start of the chlorine experiment in 1964. This "mining for neutrinos" is then the door to questions such as the origin of the Cosmos, the nature of the dark matter and energy, the stability of matter, supernovae and the origins of the elements, and other compelling questions that interest both the scientist and the public.

Chapter IV of the Science Book describes our plans for the **Visitor Experience Center** program and the near-surface underground tour, as well as an option for deep underground tours to see NUSEL detectors. There is also an important issue of historical preservation. We have had several discussions with Barrick and the State of South Dakota about establishing a **museum/archive** within the existing foundry building at Homestake – a building interesting historically and architecturally. Homestake is arguably the most influential mine in US history, with many important mining inventions originating there. The company wants to preserve this legacy, as well as the library of charts, maps, and employment records dating back to the 1880s. (As many families migrated to the US to work at Homestake, the employment records are an important genealogical resource.) The Barrick Corporation and we have discussed how the company could help support the operations of the museum/archive, and how these operations could be coordinated with those of the visitor center.

- *K-12 education and distance education.* There are many examples of successful **K-12 outreach programs** built around visitor centers, e.g., the Lawrence Hall of Science in Berkeley. NUSEL will host classroom groups and help classroom teachers integrate visits into a broader science experience by making available various preparatory and follow-up science experiences. NUSEL intends to partner with state and regional institutions expert in K-12 education, such as the Black Hills State University's Center for the Advancement of Mathematics and Science Education, to prepare materials appropriate to various age groups. (CAMSE, a South Dakota Board of Regents center of excellence, currently distributes science curriculum kits to about 300 science teachers in western South Dakota.) These materials would be a form of distance education by NUSEL, which could prepare students for their visits to NUSEL. The Laboratory will encourage its scientists and visitors to reinforce these efforts by visiting school rooms, by participating in science fairs as mentors and judges, etc.

The changing demographics of the Great Plains – outward migration has reduced large

portions of the Northern Great Plains to "frontier" population densities of less than six per square mile -- was the subject of the book "Buffalo Commons" by Frank and Deborah Potter, published some 15 years ago. This phenomenon has challenged educators in this region as many school districts fall below a critical mass, and as school closures impose longer student commutes. South Dakota has responded to this challenge by creating one of the most "wired" K-12 educational systems in the nation. NUSEL hopes to build on this opportunity by creating interactive web sites for science students and by encouraging advanced students to join distance education programs utilizing data from ongoing NUSEL experiments.

- *Undergraduates in tribal colleges.* We expect South Dakota and regional tribal colleges to be important NUSEL partners in science outreach to the Native American community. Two of the South Dakota tribal colleges, Sinte Gleska (with about 1000 students) and Oglala Lakota, are well known for their computer science, pre-engineering, and environmental science curriculum. Sinte Gleska University is a partner with the National Science Foundation and the South Dakota School of Mining and Technology in NAMSEL, the Native American Mathematics and Science Educational Leadership, a program that encourages teacher leadership skills, addresses the needs of Native American students, and promotes school cultures which support systemic change. Sinte Gleska and Oglala Dakota are partners in an NSF Model Institutes for Excellence (MIE) grant, which supports the science curriculum developments mentioned above, as well as distance learning efforts involving three other South Dakota tribal colleges (Si Tanka College on the Cheyenne River Reservation, Sitting Bull College on the Standing Rock Reservation, and Sisseton Wahpeton Community College in northeastern South Dakota). Together these five institutions comprise the Oyate Consortium. Currently 94% of OLC and 85% of SGU graduates are employed or seeking graduate degrees; this compares to reservation unemployment rates that frequently reach 80-85%. The goal of the MIE initiative is to integrate traditional tribal values into new programs of study for Native American students. Among these are environmental science, information technology, computer science, pre-engineering, and life science. As several of these programs aim to prepare students for more advanced studies at other institutions, NUSEL-based relationships will help facilitate some of the MIE goals. In short, NUSEL will be located in a center for progressive Native American science and mathematics education and has an opportunity, by partnering with and supporting the tribal colleges, to significantly enhance diversity in science.

  Several tribal college educators discussed possible partnerships with the proposers at the time the initial NUSEL proposal was submitted, then took part in the Education and Outreach Lead workshop. The tribal colleges will be a particular focus of the Research Experiences for Undergraduates Program discussed above.

The topics mentioned above are discussed in more detail in **Chapter IV** of the **Science Book**. Many of the specific ideas discussed were developed in the Lead Workshop as well as in the Education/Outreach parallel sessions of the NESS02 meeting.

II. Why is a next-generation National Underground Science and Engineering Laboratory needed?

In this section we describe why a deep, multipurpose underground science and engineering laboratory is needed by the US and international scientific community. This laboratory must differ from those now in existence. As background requirements in many neutrino and dark matter experiments are improving by more than an order of magnitude per decade, the site must be very deep to accommodate the experiments we foresee in the next twenty years. As detectors an order of magnitude larger than any yet constructed are likely to be housed there, the site must be practical for large cavity construction. It must be suitable for experiments involving large quantities of cryogens or flammables: safety considerations place stringent constraints on ventilation, and make advisable multiple access routes and possibilities for isolating such experiments. Multiple depths can be important, allowing experiments to balance background needs against the additional time and cost to go deeper. The earth science needs are very special. Ideally the laboratory will provide very large volumes of well-characterized rock, with 3D access. The geomicrobiology becomes more interesting with depth, with the age of rock, and with interesting hydrology.

In this section we discuss the existing sites for underground science, the need for a next generation facility, and the many reasons the Homestake Mine presents an opportunity to create a laboratory unequaled in quality and in flexibility.

What underground sites are currently available? The program of science outlined in Section I has a rich heritage. Arguably the field of neutrino astronomy began with the Homestake chlorine experiment, which began in 1964. The interest in this field intensified in the early 1980s, stimulated by the SU(5) predictions of observable proton decay rates. The realization that the solar neutrino problem was a neutrino physics issue, the growing certainty of particle dark matter, and the demonstration in 1987 that supernova explosions could be probed with neutrino detectors all contributed to current excitement in this field.

The three multipurpose underground physics laboratories now operating all were conceived around 1980. The first of these, the Baksan Laboratory in Russia, was excavated in the late 1970s, under the direction of Chudakov and Zatsepin. It was the first deep laboratory built for physics, providing 4700 mwe of cover. The laboratory was built to study the penetrating components of the cosmic rays – muons and neutrinos – and was the site of the SAGE solar neutrino experiment, the first experiment sensitive to the low-energy pp neutrinos. This research continues, though under difficult conditions.

Zichichi proposed the world's largest multipurpose facility, the Gran Sasso National Laboratory in Italy, in 1981. Built off a highway tunnel during the early 1980s, the laboratory provides about 3800 mwe in overburden. Gran Sasso hosts the GALLEX/GNO and Borexino solar neutrino experiments, two long-baseline experiments to detect neutrinos from CERN, the LVD kiloton supernova detector, the double beta decay experiments Heidelberg-Moscow and Cuoricino, the dark matter detector DAMA, and two low-energy accelerators for nuclear astrophysics cross section measurements.

At about the same time Japan began an underground science program that has produced exceptional results. The two sites are an abandoned rail tunnel near Oto (1400 mwe) and the operating Kamioka mine (2700 mwe). The Oto site houses kilogram-scale double beta decay and dark matter experiments. The shallowness of the site will limit future efforts to improve sensitivity. Kamioka housed the Kamiokande water Cerenkov detector, a proton decay experiment that also made historic measurements of the ^{8}B solar neutrino flux and of the neutrinos from Supernova 1987A (along with IMB), and its currently operating successor, the

50-kiloton experiment Super-Kamiokande. Super-Kamiokande confirmed earlier suggestions of an atmospheric neutrino anomaly, providing definitive evidence for massive neutrinos and neutrino oscillations due to the quality of the data it provided. Super-Kamiokande has also established the most rigorous bounds on proton decay and produced an exquisitely precise measurement of the ^{8}B neutrino flux. Recently, the original Kamioka detector was replaced by a kiloton liquid scintillator experiment, KamLAND. By measuring the interactions of antineutrinos produced in distant Japanese power reactors, KamLAND confirmed the solar neutrino oscillation results of SNO, and narrowed the allowed range of neutrino mass-squared differences. Future experiments to be undertaken in Japan include a megaton water Cerenkov detector for long-baseline neutrino and proton decay measurements, and a 10-ton liquid Xe detector for dark matter, double beta decay, and low-energy solar neutrinos.

Smaller laboratories are also making important contributions. In Europe the LSC (Canfranc), LSM (Frejus-Modane), and Gotthard (Mont Blanc) facilities were built off road tunnels. Canfranc (2450 mwe) current houses the IGEX ^{76}Ge double beta decay experiments as well as developmental efforts on dark matter and solar axions. Frejus (4900 mwe) is the site of NEMO3 double beta decay experiment, which hopes to approach 100 milli-eV neutrino mass limits in measurements on several nuclei (including ^{100}Mo, ^{82}Se, and ^{116}Cd). In Finland cosmic ray studies are being done at the Pyhasala Mine at depths up to 900 m, and the lowest level (1440 m, or 4050 mwe) could be developed for future experiments. There are pending proposals for searches for multi-muon events and for a long-baseline (2288 km) experiment with a CERN neutrino beam. In the United Kingdom the UK Dark Matter Collaboration operates a facility in the Boulby potash mine (3350 mwe). The ton-scale next-generation detectors DRIFT and ZEPLIN will follow the smaller dark matter experiments currently housed there.

The world's deepest active facility is the Sudbury Neutrino Observatory in Sudbury, Ontario, Canada. Located at a depth of 6000 mwe in an operating nickel mine, the SNO solar neutrino experiment recently showed that heavy-flavor neutrinos comprise two-thirds of the solar neutrino flux, thereby resolving the long-standing solar neutrino problem. This was established by measuring charge and neutral current neutrino reactions off deuterium, as well as neutrino-electron elastic scattering: SNO consists of an inner vessel containing a kiloton of heavy water, surrounded by seven kilotons of ordinary water. Very recently the Canadian Foundation for Innovation provided funding for a second hall, with a volume of 15000 m^3, for the dark matter experiment PICASSO as well as a future double beta decay detector.

What sites are available in the US? The two operating underground laboratories are Soudan, a former iron mine now operated by the state of Minnesota as a park, and the Waste Isolation Pilot Plant (WIPP), a DOE facility in Carlsbad, New Mexico. Both are relatively shallow, 2080 and 1600 mwe, respectively. Until recently the Homestake Mine was the *de facto* deep facility in the US, housing the chlorine experiment as well as cosmic ray and double beta decay experiments. Because mining has ceased at Homestake, no science experiments are currently active.

US scientists have been prominent in underground science for 50 years. Neutrino astronomy began with the chlorine experiment in 1964. The IMB proton decay experiment, mounted in the Morton salt mine, was the sister experiment to Kamioka, establishing important proton decay limits, providing the first evidence for an atmospheric neutrino anomaly, and seeing neutrinos from Supernova 1987A. US scientists played crucial roles in developing both the $GaCl_3$ (GALLEX/GNO) and metal gallium (SAGE) radiochemical techniques; the pilot experiment for GALLEX was done at Brookhaven. Similarly, Herb Chen and colleagues at UC Irvine developed the conceptual design of SNO.

There have been serious proposals to create a US laboratory similar to Gran Sasso, occurring roughly forty (Luis Alvarez, Aihud Pevsner, and Fred Reines) and twenty (Al Mann and Bob Sharpe; UC Irvine) years ago. Generally the US has had few opportunities, lacking the deep road

and railway tunnels common in Europe. Thus the Mann/Sharpe and UC Irvine proposals of the early 1980s were "greenfield" projects. The former proposed sinking a vertical shaft at a site near Yucca Mountain, Nevada, and the latter advocated excavating a long tunnel beneath Mt. San Jacinto, near Palm Springs, California. Department of Energy officials also encouraged an early EarthLab proposal in the 1980s. These proposals were considered seriously, but ultimately were not funded. Today the situation is qualitatively different: there has been an explosion of interest in underground science, many of the world's current facilities are either too shallow or technically inadequate for the next-generation experiments now under discussion, and a superb existing site has become available in the US.

Why the US needs NUSEL: Collaboration and Community Views. Here we summarize the key arguments for establishing a dedicated, multipurpose deep underground science and engineering laboratory in the US:

The science is compelling: This was summarized in Section I. While the impetus for NUSEL came from the physics community, the laboratory is also important for earth science, for applications such as detector development for homeland security, materials purity, environmental geochemistry, etc., and as an education and outreach center.

There is a lack of deep sites: Gran Sasso, at a depth of 3800 mwe, and Kamioka, at 2700 mwe, were proposed twenty years ago. Since that time the background requirements of underground experiments have typically increased by two to three orders of magnitude. While clever chemistry and careful materials science can eliminate many radioactivity backgrounds, often there is no solution to cosmogenic backgrounds other than depth: the long-lived activities associated with cosmic rays as well as associated "punch-through" neutrons can be impossible to veto effectively. One thus concludes that a next-generation Gran Sasso, built today, ought to strive for a factor of 100 lower cosmic ray muon intensity, corresponding to an additional ~ 3000 mwe in cover. The proposed deep level of NUSEL, at 7400 feet or 6500 mwe, very nearly satisfies this rule of thumb. The deepest level of the Homestake mine is 8000 ft, or 7200 mwe.

The need for such depths is apparent from existing experiments. For example, SNO faced difficult challenges, detecting a charged-current signal that exhibits only gentle angular variation ($1- \cos(\theta/3)$) and a nonspecific neutral current signal, single neutrons. Delayed βs from cosmic ray muon activation of nuclei were the principal background concern in designing the detector. In Kamioka II, where larger backgrounds could be tolerated because elastic scattering events are sharply forward peaked and thus correlated with the sun's position, ~ 1% of muons penetrating the detector produced spallation-product βs above a ~ 10 MeV threshold. The SNO experimentalists wanted to reduce this background by a factor of 200, cutting the number of spallation events above detector threshold to about 1.5/day. This required the collaboration to develop a new site at 6000 mwe in an operating nickel mine, with the cleanroom and access challenges accompanying such a site. While the experiment is a spectacular success, the difficulty of working in an active mine environment contributed to the four-year delay in obtaining first results. If SNO had been done at Gran Sasso depths with the same stringent background cuts, the resulting detector deadtime (40%) would have seriously diminished the experiment.

Our collaboration, the working groups at the Lead and NESS02 meetings, and several review committees, including the NRC Neutrino Facilities Assessment Committee, have studied the depth requirements of future underground experiments. A consistent picture has emerged, described in the Science Book. A few examples:

- Next-generation dark matter searches. These have as their ten-year goal sensitivity to a Weakly Interacting Massive Particle (WIMP) cross section of 10^{-10} pb. Scaling background rates in existing experiments and assuming that an additional factor-of-ten reduction is obtained by vetoing multiple scattering events (by improving detector granularity), a depth of

4500 mwe is required to reduce backgrounds to 50% of the expected signal (10 WIMP events/year in a one-ton experiment). If WIMPS are not observed at 10^{-10} pb, a depth of 6000 mwe might be helpful in establishing the tightest possible limit. If such depths are not available, sophisticated shielding and vetoing might gain back a factor of 10 or more: this would include a thick (1-2m) scintillator active veto around the detector (to tag inward penetrating high-energy neutrons) and instrumentation of the cavity's rock walls to catch some part of the shower associated with the initiating muon. As such mitigating steps are expensive, depth is the simpler solution.

- Double beta decay. The most reliable estimate is likely that for the ^{76}Ge experiment Majorana, as cosmic ray background rates are known for smaller current-generation Ge experiments, such as IGEX. (Approximately one third of the total IGEX count rate in the endpoint region of interest (2038 keV) is correlated with the cosmic muon veto. IGEX is located at 2450 mwe in the Canfranc tunnel.) The principal concern is cosmic ray interactions near but external to the veto shield, producing neutron secondaries which enter the detector. The experimenters have estimated that 4500 mwe is the minimum depth for Majorana, with additional cover being of benefit. The background rates for the Mo double beta decay experiment MOON are more worrisome, with reactions like ^{12}C(n,3n) occurring in the scintillator producing ^{10}C, a positron and γ-ray emitter. While the effectiveness of possible cuts will depend on the position resolution achieved in MOON, a safe depth is considered to be 6000 mwe. In contrast, one study indicates that EXO, a liquid Xe TPC, might require an overburden of only 2400 mwe. EXO experimentalists are developing a laser resonance ionization technique to tag the Ba ion daughter produced in the $\beta\beta$ decay, a novel method of background suppression. The trigger rate for this tagging depends on the background rate, and there are potential cosmic ray neutron backgrounds that have not been fully assessed. Thus EXO experimentalists have proposed a pilot experiment to determine background rates and thus the overburden required for a reasonable trigger rate.
- Proposed solar neutrino experiments to measure the low-energy pp neutrinos, thereby better constraining θ_{12}, include HERON and CLEAN, helium- and neon-based detectors for elastic scattering, and the TPC experiment HELLAZ. The minimum depth for HERON and CLEAN is estimated to be 4500 mwe, though the experimenters would prefer to site these detectors at ~ 6000 mwe: especially in the case of CLEAN, there are significant uncertainties in cosmic-ray-induced activity levels due to poorly known spallation yields for neon. HELLAZ is an exception, capable of operating with a 1% deadtime at a depth of only 2200 mwe.

A fair summary is that 4500 mwe is a minimum depth for most of the background-sensitive underground experiments that are now approaching readiness; but generally "deeper is better" because the background estimates are uncertain. Most of these experiments would be problematic at Gran Sasso depths (3800 mwe).

For EarthLab, the issues are simple. The earth science benefits from access to the greatest range of depths. Homestake is the deepest mine in the US and provides access approximately every 150 ft, from surface to 8000 ft. The geomicrobiology goal is to reach the limits of life, expected at 16,500 ft. Thus 8000 ft is a good starting point for the drilling and coring program the geomicrobiologists will initiate.

There is a lack of space in existing laboratories: Gran Sasso, which is fully subscribed, has tried, over the past five years, to expand. This generated a lively public debate over environmental concerns connected with the water table, recently complicated by a 50-liter pseudocumene spill that reached a local stream. Baksan, the deepest of the multipurpose laboratories, has suffered because of Russian cutbacks in science. In the US, the cessation of mining in Homestake has (temporarily) stopped science there. Remaining are two relatively shallow US laboratories at Soudan and WIPP.

The lack of a US laboratory has inhibited the development of underground science here: Despite the discoveries spawned by the chlorine experiment, no further solar neutrino experiments were

sited in the US. Similarly, all active double beta decay experiments are located overseas. Nevertheless, the US community has remained very active, collaborating on GALLEX, SAGE, Kamioka and Super-Kamiokande, SNO, KamLAND, etc.

Given the growing importance of nonaccelerator physics, we are fortunate that a new window of opportunity for creating a US laboratory has opened. The recognition that very long baseline oscillations are crucial for probing neutrino parameters and new phenomena like CP violation favors the US, where we can mount such experiments. The availability of a site that can easily accommodate megaton experiments while providing incomparable depth should attract international experiments here, if the site is properly developed.

There are important cost advantages in creating a multipurpose laboratory now: We recognize that underground science is a rapidly growing field, and it is apparent that many next-generation experiments will be large, technically demanding, and costly. Viewed in the long-term, there are significant cost savings in planning a multipurpose facility that can facilitate next-generation physics experiments while also serving earth science and various applied fields well. These include:

- Capital costs savings in having a single site with the capacity to manage several generations of new experiments. The capital costs include the physical plant – the shafts and hoists, the experimental halls, sophisticated HVAC systems, dewatering systems, fiber optics and phone communications, and surface office buildings – as well as ancillary services such as the computing system, libraries, and machine, chemical, and glass shops. In general these facilities can be shared by many users, and reused as early experiments are completed and new ones are mounted. The alternative – experimenters operating in a variety of more limited laboratories, or attempting to develop their own infrastructure at a parasitic site – leads to duplication and, generally, a lower standard of support at each facility. For example, the kind of low-level counting facility that we envision for NUSEL was identified by the Bahcall Committee as a key component of NUSEL infrastructure, required (and requested by) many of the groups planning new experiments. Both the facility and the highly trained staff necessary to operate the facility would be beyond the reach of most individual groups. But as a component of common infrastructure, the facility can advance many projects by allowing experimenters to test materials before they are incorporated into new detectors.
- Human cost savings possible with a dedicated, multipurpose facility. Less than ideal sites imply hidden costs because experiments take longer, in effect shortening the useful lifetimes of the nation's most talented experimentalists. For example, factors contributing to the four-year "stretch-out" of SNO included difficulties with mechanical systems and access limitations to the site. Certain access limitations – SNO shifts have been canceled because of seismic activity – may be endemic to a site, regardless of its operations. But other SNO delays, such as an INCO contractor needing exclusive use of the hoist for an extended period, would not arise in a dedicated facility. Access is also a crucial issue in safety: if a fire occurs when an experiment is off limits, the consequences could be catastrophic.
- Operations cost savings. Hoist maintenance and operations and other activities necessary to provide access to depth as well as dewatering costs are essentially independent of the number of experiments conducted at depth.
- Training costs. We believe every experimental group that has used a new site has gone through a painful period when either scientists have had to be trained in underground operations, or miners have had to be trained to help with experimental operations. Similarly, no facility can operate without an experienced safety crew. An important efficiency in creating a multipurpose laboratory now is the opportunity to train these staff once, then have them available to assist many projects with safety and detector installation.

NUSEL will encourage synergies that will advance science generally. One of the great contributions of particle physics has been the creation of laboratories like FermiLab and CERN

that have advanced science and technology beyond what was otherwise possible: the sum is greater than the aggregate parts. During this past decade we have seen the consequences of rapid dissemination of new technology in underground science. KamLAND mounted a difficult experiment in record time in part because of the experience with radiopurification gained in SNO and Borexino. A strong laboratory accelerates the pace of science because it creates and maintains a technology base that eases the way for the next experiment – NASA's goal of faster, cheaper, and better. As with FermiLab and CERN, NUSEL is an essential step in allowing the underground science community to tackle experiments of a qualitatively new scale. NUSEL must provide the infrastructure to support ambitious projects, and it must help focus the community. The expertise that will come to NUSEL includes the large-detector project management skills of particle physics, the low-level counting skills of nuclear physicists and chemists, and the geotechnical knowledge of the earth science community. NUSEL will ensure that these groups interact daily.

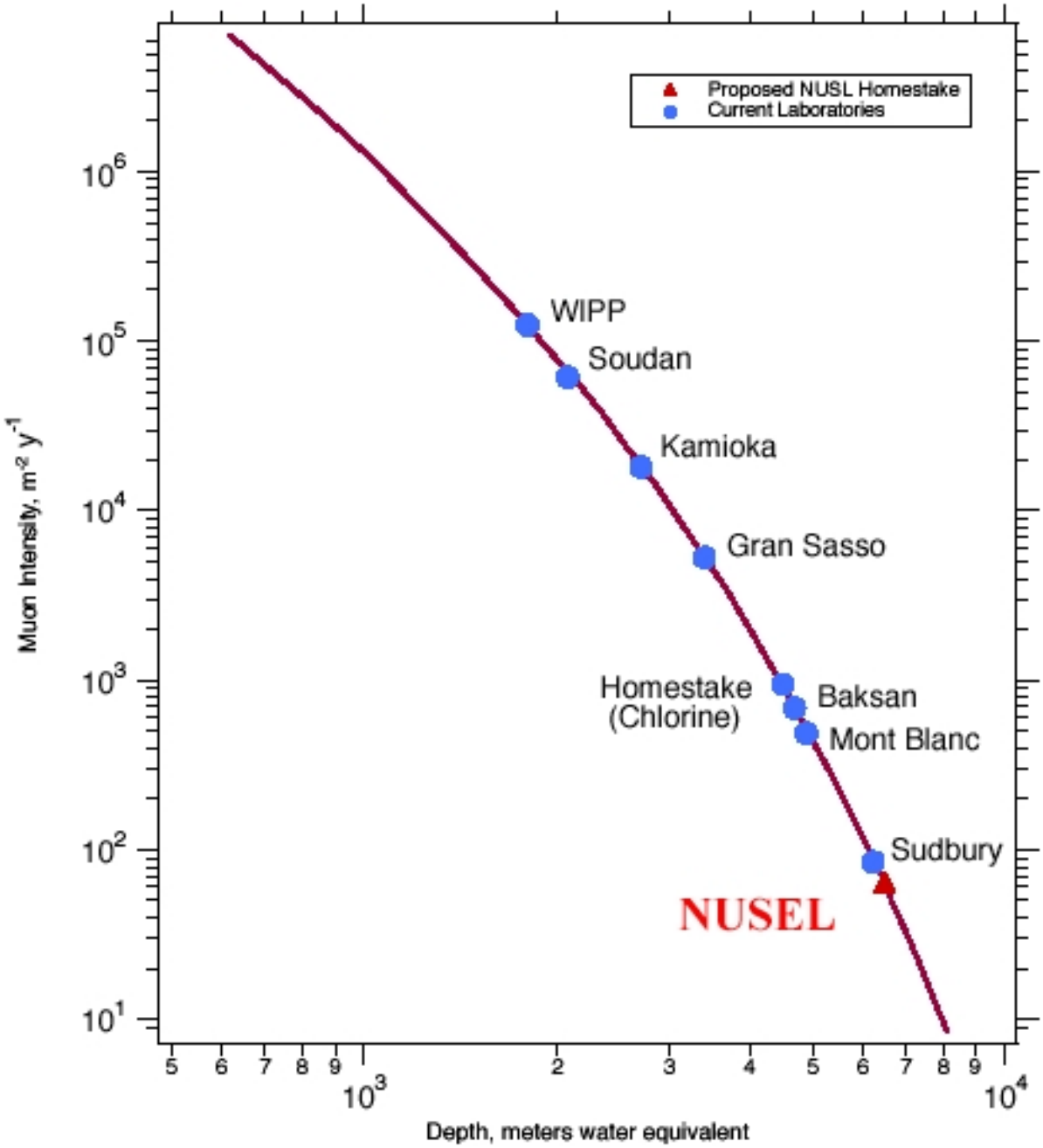


Figure B.1: The depth and muon intensities for existing laboratories and for the produced developments at Homestake. The Homestake main level (shown in the figure as NUSEL) is at 7400 ft, though development will also occur at the 8000 ft (earth science) and 4850 ft (Homestake-chlorine; accelerator physics, megadetector development). Note that the two current US laboratories, Soudan and WIPP, are shallow. The one deep North American site, Sudbury, provides limited space and requires parasitic use, as Sudbury is an active nickel mine.

These and other arguments have been considered by several high-level advisory panels:

The Nuclear Science Advisory Committee*:* NSAC is the standing committee charged with advising the NSF and DOE on nuclear science policy. In NSAC's recent Long-Range Plan process, NUSEL was one of nine mid-scale new construction projects (defined as costing $300M or less) considered for the next decade. The initial push to create NUSEL came from the LRP preTown Meeting on Neutrinos, attended by some 200 community members: Homestake's closing was announced just two weeks prior to that meeting. Creating a US deep underground science laboratory was the #1 recommendation of the preTown meeting, a ranking that was confirmed later in the larger Town Meeting on Astrophysics, Neutrinos, and Symmetries. The Bahcall Committee, formed after the Neutrinos meeting, submitted its report as a White Paper to NSAC. This formed the basis for presentations and discussions at the final LRP summary meeting in Santa Fe, March 2001. NUSEL became the highest midscale construction priority for the field and the third priority overall. (The first priority was support for the existing program, and the second was the one major new construction project proposed, the Rare Isotope Accelerator.)

The final LRP recommendation reads:
We strongly recommend immediate construction of the world's deepest underground science laboratory. This laboratory will provide a compelling opportunity for nuclear scientists to explore fundamental questions in neutrino physics and astrophysics.

Recent evidence for neutrino mass has led to new insights into the fundamental nature of matter and energy. Future discoveries about the properties of neutrinos will have significant implications for our understanding of the structure of the universe. An outstanding new opportunity to create the world's deepest underground laboratory has emerged. This facility will position the U.S. nuclear science community to lead the next generation of solar neutrino and double beta-decay experiments.

Following the LRP process NSAC wrote Dr. Robert Eisenstein, then NSF Assistant Director for Mathematical and Physical Sciences:

This letter is written to express unanimous support by the members of the Nuclear Science Advisory Committee for the creation by the National Science Foundation of a National Underground Science Laboratory at the Homestake Mine site in South Dakota … In view of the compelling nature of the science to be done in a deep underground laboratory, and the potential benefit to the United States of world leadership in this area, we strongly recommend that the NSF undertake an immediate study to assess the feasibility of the Homestake site for a NUSL, and that it invite a detailed proposal and technical design report for serious consideration. NSAC is unanimous that the initiative to create NUSL is very important to further fundamental progress in the physical sciences…

The High-Energy Physics Advisory Panel*:* HEPAP started a similar Long-Range Plan in summer 2001. While the recommendations of the LRP Subpanel's January 2002 report focused on one megaproject, a high-energy electron-positron collider sited either in the U.S. or overseas, NUSEL was addressed in the body of the report:

Worldwide, the program of experiments of interest to particle physicists that require underground locations is broad and technically challenging. Experiments include: searches for neutrinoless double beta decay; searches for weakly interacting dark matter; measurements of solar, atmospheric, reactor, and supernova neutrinos; searches for proton decay; and studies of neutrino properties using beams from distant accelerators.

The subpanel noted that some experiments could be done in shallow sites like Soudan and WIPP, but that only Homestake and the proposed San Jacinto excavation would be deep enough to provide the very low background required for a variety of experiments. The discussion concludes:

Construction of a National Underground Science Laboratory at the Homestake Mine has been proposed to the NSF. A proposal for a laboratory under the San Jacinto Mountain has been submitted to DOE and NSF. These proposals are motivated by a very broad science program, from microbiology to geoscience to physics. Construction of a national underground laboratory is a centerpiece of the NSAC Long Range Plan.

We believe that experiments requiring very deep underground sites will make important contributions to particle physics for at least the next 20 years, and should be supported by the high-energy physics community. Particle physics would benefit from the creation of a national underground facility.

Recently, in response to a request from the Director of the DOE Office of Science, HEPAP examined the scientific merit and readiness of major projects proposed for the next two decades. Their report, "High Energy Physics Facilities Recommended for the DOE Office of Science: Twenty-Year Roadmap," was released March 2003. To achieve the highest science rating, *absolutely central,* HEPAP required "that the intrinsic potential of the science be such as to change our view of the universe. This is an extremely high standard, at the level at which Nobel Prizes are awarded." Of the eleven projects recommended, four would impact the science program of NUSEL: liquid Xe double beta decay; a neutrino superbeam; a megadetector for next-generation experiments on nucleon decay, long-baseline oscillations, supernova neutrino detection, and related neutrino physics; and a neutrino factory. The first three were rated absolutely central. The neutrino factory was considered to be too early in the R&D phase to allow a meaningful evaluation of the physics potential. In NSAC's parallel exercise, two of the seven projects considered require NUSEL: a double beta decay experiment (Majorana or MOON) and a low-energy pp solar neutrino detector. Both were rated absolutely central.

National Research Council Committee on the Physics of the Universe: This committee examined the intersection of physics and astronomy in order to identify opportunities for breakthroughs in understanding the birth, evolution, and destiny of the universe, the laws that govern it, and the nature of space and time. The charge included many interdisciplinary problems of concern to NASA, the NSF, and the DOE. The committee organized its work around 11 unresolved grand questions. In its 2003 report, "Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century," the Committee included recommendations for three new projects: probing aspects of the polarization of the cosmic microwave background that would test the inflationary universe; determining the nature of the dark energy; and underground science. The underground science recommendation states in part:

Three of the committee's 11 questions – the nature of dark matter, the question of neutrino masses, and the possible instability of the proton – must be addressed by carrying out experiments in a deep underground laboratory that is isolated from the constant bombardment of cosmic ray particles. One of the most important discoveries of the past ten years, that neutrinos have mass, was made in an underground laboratory. This discovery has implications for both the universe and the laws that govern it. The mass scale implied by the measurements to date suggests that neutrinos contribute as much mass to the universe as do stars; and neutrino mass points to a grander theory that brings together the forces and particles of nature and may even shed light on the origin of ordinary matter.

The committee believes that there are more opportunities for discovery at an underground

laboratory. Experiments proposed for the near future to address the fundamental questions it has identified require depths up to 4000 meters of water equivalent (mwe). More visionary experiments, as well as the long-term potential of such a laboratory to make discoveries, require even more shielding, to depths up to 6000 mwe …

A North American laboratory with a depth significantly greater than 4000 mwe and adequate infrastructure would be unique in the world and provide the opportunity for the United States to take the lead in "underground science" for decades. Such a laboratory might also be useful for carrying out important science in other disciplines, such as biology and geophysics.

Recommendation: Determine the neutrino masses, the constituents of dark matter, and the lifetime of the proton. The committee recommends that the DOE and NSF work together to plan for and fund a new generation of experiments to achieve these goals. It further recommends that an underground laboratory with sufficient infrastructure and depth be built to house and operate the needed experiments.

National Research Council Neutrino Facilities Assessment Committee: A second NRC committee was charged in 2002 to examine the physics justification for IceCube and NUSEL. The committee's report, "Neutrinos and Beyond: New Windows on Nature" was released in 2003. Its recommendation on underground science states:

Underground research was pioneered 35 years ago in the United States with the detection of neutrinos from the sun. Development of a new underground facility could restore U.S. leadership in this important research area. Such labs are required to study rare forms of penetrating radiation and rare nuclear processes in a low radiation background environment. Two key attributes of an underground laboratory are required: it must be able to site experiments as deep as 4500 mwe with future capability of siting them down to 6000 mwe, and it must be located more than 1000 kilometers from accelerators capable of producing intense beams of neutrinos. The latter would allow the use of such beams to study the properties of neutrinos as they travel over long distances, helping to measure the small but important neutrino masses. Siting the laboratory in the United States would permit the utilization of its powerful particle accelerators already operating. A lab with sufficient shielding could also be a site for various geophysics and geobiology projects. ***A deep underground laboratory can house a generation of experiments that will advance our understanding of the fundamental properties of neutrinos and the forces that govern elementary particles, as well as shedding light on the nature of the dark matter that holds the Universe together. Recent discoveries about neutrinos, new ideas and technology, and the scientific leadership that exists in the U.S., make the time ripe to build such a unique facility.***

III. What are the important attributes of a next-generation underground laboratory?

The following are among the key considerations in planning for the next-generation underground science and engineering laboratory:

Depth: If the facility is to accommodate the background-sensitive experiments now being planned (as well as those that will arise in the next two decades) a depth of at least 6000 mwe is needed. Other experiments may prefer intermediate depths for (a) more convenient access, (b) lower lithostatic pressure and thus easier and less costly large-cavern construction, and (c) a non-vanishing muon flux for detector calibration or other purposes. Thus a versatile facility must be able to offer a range of depths.

Detector Halls: One key element of the laboratory is the underground halls. There are two models now employed. The Gran Sasso excavation produced three large detector halls, each approximately 20 m wide by 100 m long by 20 m in height. The director, aided by an advisory committee, allocates space in these halls based on the strength of the proposed experiments. Some small detectors at Gran Sasso are sited in various access tunnels and ancillary spaces. This large, multipurpose hall approach has worked well. The planned second SNO hall is in the tradition of those at Gran Sasso (though about 3/8ths as large). The Kamioka and original SNO excavations are quite different. First, the constructed cavities are upright cylinders with hemispherically-domed ceilings and primary access near the top. This is an attractive design for very large water detectors like SNO (8 ktons) and SuperK (50 ktons). Second, the excavation was specialized, not general purpose, designed to optimize a specific experiment.

The "hybrid" model to which SNO is evolving is an attractive one. Certain classes of experiments – such as dark matter searches and double beta decay – have very similar needs in terms of floor space, ventilation, background requirements, utilities, and depth. Thus several smaller halls or one general-purpose hall could be optimized for this class of experiment, and reused for successive efforts. But NUSEL must have the flexibility to construct customized space for detectors with special requirements, including large volumes of water, electrical isolation, and physical isolation and venting for safe use of flammables, cryogens, toxic materials, and suffocating gases. This requires a very special site both physically and in terms of the capacity and flexibility of its ventilation system.

The capacity to customized cavities for challenging experiments implies the retention of mining capability throughout the laboratory's lifetime. As these excavations will occur while other experiments are operating, the ventilation system (and other barriers) must be adequate to keep dust out of occupied halls.

The capacity to excavate a megadetector at depth: If a megadetector is to serve multiple purposes – e.g., proton decay, long-baseline neutrino physics, and a supernova neutrino observatory – it must be located at a reasonable depth and be operable for a period ~ 50 years. The Bahcall Committee specifications for such construction were inspired by UNO: a "rural mailbox" hall with gross volume of at least 0.9 million m^3 (0.5 million m^3 of liquid) at depths of at last 4000 mwe, specifications necessary for a next-generation water Cerenkov detector to be factors of 10 more sensitive and quieter (in terms of background rate) than SuperK. This places very stringent constraints on the host site. As such an experiment is crucial part of the NUSEL program, it must be **known** that rock in the vicinity of the laboratory is sufficiently competent to permit such an excavation. The only accepted technique for doing this is coring of the site, followed by laboratory testing of the core samples. A geotechnical site history, particularly one in which other large cavities have been excavated and monitored for stability, is also helpful.

Another issue is the feasibility of rock disposal. The "rural mailbox" excavation will produce about 2.5 megatons of rock, which is considered solid waste when brought to the surface. Thus,

in addition to the civil engineering challenge of mining this volume, NUSEL must solve the transportation and permitting/waste disposal issues.

Cleanliness. While depth is the optimal solution to troublesome cosmic ray backgrounds like "punch through" neutrons and delayed spallation-product activities in the detector volume, good ventilation engineering and infrastructure are important in combating natural radioactivity backgrounds. A great deal has been learned about the necessary engineering. For example, radon can be controlled by mineguard (polyurethane sealant) coating of rock walls (which can provide reductions of ~ 10^6) and proper ventilation. The scrubbed air in contact with experiments should have residual radon levels of no more than 1 Bq/m^3. Some detectors have a critical volume needing to be completely purged of radon, which can be accomplished by using boil-off gas from radon-free liquid nitrogen. A radon-free materials storage area is also important. Experiments such as Majorana and MOON are sensitive to activities induced when materials are exposed on the surface, including ^{68}Ge, ^{60}Co, ^{93}Mo, ^{99,100}Nb, and ^{91}Mo. For this reason Majorana requires an underground Cu electroforming facility, and is interested in the possibility of underground Ge crystal growth and detector preparation. In experiments like SNO, Borexino, and KamLAND, low-level counting techniques capable of measuring U and Th at levels of 10^{-16}g/g are an important part of background control. NUSEL must maintain the infrastructure necessary to address these background issues. The low-level counting facility is one example. NUSEL will help raise the overall level of background reduction expertise: it brings experimentalists into contact with one another, so that new background reduction methods are quickly disseminated.

The importance of 24/7 access: Observers familiar with how experimental science is really done understand that very few factors are as important as personnel access to detectors, 24 hours a day and seven days a week. Such access may be necessary in construction and operations phases of experiments, and the ability to visit any hall at any time is an important safety issue.

Safety, special materials, and materials handling: Next-generation experiments will require safe use and handling of flammables, cryogens, certain toxic chemicals, suffocating gases, and possibly even mega-Curie neutrino sources for detector calibration. NUSEL should have the physical and operational systems necessary to guarantee safe storage and transport of such materials. The required facilities include isolated laboratories, ventilation systems capable of isolating and separately venting certain areas, and effective sensor and suppression systems. Cavities housing large quantities of liquids must be located below grade. The operations requirements include safety teams capable of handling hazards from both conventional mining and construction and from exotic detector materials. Also included are all possible preventative measures: the laboratory must be able to guarantee that each experiment is being conducted responsibly, and that all regulatory and licensing constraints are respected.

Access for large and heavy equipment: The cost of detector assembly escalates if one encounters a "ship in the bottle" problem: hoists or other access that requires detectors to be broken down into very small modules, then reassembled at depth. NUSEL must have the capacity to transport standard modules of significant size and weight from a cleanroom in the surface laboratory (or from a loading dock) to an underground hall. It must have a trained staff that can manage such transport in minimal time and effort, without risk of equipment damage. The standardization of module sizes will allow experimentalists in any laboratory to preassemble their equipment in the most efficient way, knowing that NUSEL has the capacity to handle the modules. NUSEL should retain the capacity to handle special loads, such as long steel I beams, oddly shaped sections of tanks, etc. (Mining companies frequently handle large, odd-dimensioned loads by slinging them beneath the hoist cage.) A pumping system with the capacity to empty a water megadetector, either for maintenance or decommissioning, is important.

Quietness and stability: electrical, mechanical, seismic: Many underground detectors use sensitive transducers that produce signals at very low levels. While sensitive pre-amplifiers can

be protected with electrical shielding and good grounding, experimenters will benefit from well-designed and well-isolated clean power sources, and from electrical isolation and grounding systems that minimize ground loops and cross-talk. Electrically and mechanically noisy equipment should be isolated in specialized underground rooms. The NUSEL power supply should be stable, with a history of infrequent power outages, and uninterruptible power supplies should be in place to keep critical equipment operating during power spikes or failures. The laboratory should be in a seismically quiet region, and rock bursts should be rare, as detectors respond to both.

Adequate support facilities and a strong scientific environment: The scientific environments in which many underground experiments have been conducted in the past have been far from ideal. Scientists far from their home universities need shop services. They also benefit from the intellectual atmosphere that accompanies a critical mass of experimentalists and theorists. Therefore, if NUSEL is to be a national and international center, we believe the right model is Gran Sasso, which strives to provide significant services to the experimentalists in a setting not unlike a university physics department. The technical services include machine, chemical, and glass shops, and administrative services include shipping and receiving, computing, maintaining inventories, libraries, and visitor services. Gran Sasso employs approximately 33 staff for these functions. The low-level counting and underground materials facilities envisioned for NUSEL would be additional examples. For below-ground operations, the hybrid model for NUSEL – initial excavation of multipurpose halls coupled with continued development of special-purpose cavities throughout the lifetime of the laboratory – will require the laboratory to maintain adequate engineering and excavation capabilities (permanent or contract staff), in addition to operations/maintenance and safety/environment groups. Gran Sasso has a theory group and a vigorous seminar program. It frequently hosts conferences or workshops, and is playing a leadership role in IUPAP-sponsored underground science activities.

Quality of life issues: These begin in the workplace, with efficient layouts, good lighting, well-controlled temperature and humidity, and pleasing aesthetics – in contrast to some of the difficult (and occasionally dangerous) conditions experimentalists have endured in certain parasitic sites. The goal is to minimize fatigue that scientists and staff experience because of long hours of work, and thus accidents connected with fatigue. The underground campus should be designed with the same attention to workplace ergonomics that is now routine in surface laboratories. Support services that contribute to the quality of life include a library, access to electronically-archived literature, a cafeteria and vending machine areas, comfortable accommodations for visitors (laboratory or privately operated), seminar rooms, and reciprocal agreements with area universities. The community context, good housing and schools and cultural and recreational opportunities, affect the quality of life outside the laboratory.

Outreach and education: The Kamioka, Soudan, and Gran Sasso laboratories all conduct successful outreach and educational programs. They host regular, ongoing tour programs for K-12 students. The Soudan Laboratory, as part of a state park, provides both historical and scientific tours to the lowest level of the Soudan Mine. The outreach and educational opportunities depend on site-specific factors like regional K-12 student and visitor populations, whether NUSEL is a regional science focal point or one of many, and historical or other connections that help to interest the general public.

Neutrino beams: Proposals for next-generation neutrino oscillation experiments to probe phenomena like CP violation favor baselines of 1000-3000 km. Thus the distance between accelerator laboratories and NUSEL is relevant.

IV. Why is Homestake the preferred site for NUSEL?

This section is broken into two parts. The first is a rather complete description of the physical plant available at Homestake, at no cost to the public: the mine owner, Barrick Gold Corporation, has agreed in principle to donate the needed portions of the Homestake campus to the state of South Dakota. The second section is a point-by-point discussion of the advantages of Homestake, addressing each of the issues raised in Section III as well as others we feel are pertinent.

As an introduction, it is important to be able to distinguish what is purposed here – a multipurpose, next-generation underground science and engineering laboratory that will facilitate new physics experiments of unprecedented size and complexity, meet the goals of EarthLab proponents, contribute to a variety of important applied-science fields, and conduct a vigorous outreach program -- from past practices in underground science.

In the past, site preparation, access, and operating costs associated with going underground often had the potential to account for a large fraction of an experiment's budget. The cost-benefit analyses have led experimenters to seek shared facilities, even if those facilities are less than ideal. Homestake, Kolar Gold Fields, Kamiokande, Super-Kamiokande, SNO, and WIPP share/shared facilities with mining operations, where the key limitations have been access/capacity restrictions (Homestake, Kolar, SNO), safety (Kolar), or lack of depth. Generally these mine environments have been the locations where specialized cavities were built, however, utilizing the host's in-house mining expertise. Facilities sharing with motor or railways include Gran Sasso, Frejus, Mont Blanc, Canfranc, and Oto. These facilities have offered excellent access, and particularly in the case of Gran Sasso, have further reduced costs per experiment by hosting multiple experiments. The limitations of these facilities include lack of depth (Oto, Canfranc, and perhaps soon Gran Sasso) and size (Frejus, Mont Blanc, Oto), when viewed in the context of experiments planned for the next ten years. To date these laboratories have not tackled the specialized cavity excavations that were central to the key discoveries by Super-Kamiokande and SNO: the tunnel laboratories are of the experimental-hall type, with the space excavated at the time of initial construction. (The possibility of an UNO-like new construction at Frejus, however, has been discussed.)

One exceptional case is Baksan, a "greenfield" project in which a tunnel was excavated to considerable depth (4700 mwe) for the purpose of creating a scientific laboratory.

The motivation for parasitic use is cost. For example, the hard-rock mining costs of sinking new shafts are typically $10,000-20,000 per mwe overburden. Thus the creation of dual access to a site at 6000 mwe represents an initial investment of $120-240M, **after which** one must invest in hoists, utilities, ventilation, hall construction, and other facilities necessary to a laboratory. Thus most experimental groups have elected to share space and facilities with nonscientific hosts. In mine environments parasitic use has generally increased science operations costs due to the resulting longer "time to physics." Capacity on the lifts for personnel and materials is limited and the host's prime function (mining) has priority. Lifts optimized for mining generally are divided in ways that make transport of large experimental modules very difficult. The mine environment is dirty. Whether a mine or tunnel, the need for more exotic detector materials and large volumes of flammables, compressed gases, and asphyxiates may make relations between host and scientists increasingly complicated in future experiments.

This context helps one to appreciate the opportunities Homestake provides:

- The existing physical plant is remarkable. Massive shafts and hoists provide dual access to every level. The ventilation, air conditioning, water supply, dewatering system, phone and

radio communications systems, fiber optics network, compressed air supplies, and sensor and safety systems are in place. **No major construction** is required underground to convert Homestake into an unmatched scientific laboratory, apart from hall excavation. Experiments using flammables, cryogens, etc., can be isolated because of the physical extent of the site and of the utilities systems.

- The geotechnical attributes are equally remarkable. Homestake is the **deepest site in the US** (8000 ft, or 7100 mwe). (The density of Homestake rock is 2.91.) It provides a variety of levels and great flexibility is optimizing sites for experiments. The region is seismically quiet and the rock exceptionally competent, with rock bursts rare even at 8000 ft. The areas proposed for experimental halls (6600 mwe and 4300 mwe) can be cored and evaluated before construction. There is an extensive geotechnical database, including studies of the stability of large cavities at depths up to ~ 7000 ft. The site is ideal for earth science, as it provides 3D access to approximately 9 km^3 of well-characterized and interesting rock. Thermophilic methanogens have been identified at the 8000 ft level. The **existing mining capacity** of either main shaft to the 4850 ft level is sufficient to excavate an UNO-size cavity in 2.5 years.
- Highly skilled workers – engineers, geologists, miners, administrators – who **know how to operate a complex facility efficiently and economically** are available. They are part of an established operations system. Thus nonscientific operations costs are known. As an operating facility the many permitting obstacles facing greenfield sites – construction, environmental, safety, waste rock disposal – have been addressed. There is an on-site location for waste rock that avoids surface transport (e.g., in the case of UNO).

Homestake's Physical Attributes: A summary of the site's present physical characteristics, hoist capacity, utilities, and operations is given below.

Site physical characteristics (underground): Levels at Homestake have been developed from the surface to the mine's bottom, at 8000 ft, roughly every 150 feet. Personnel and equipment access to the underground is primarily through the Ross and Yates shafts, both of which terminate at the 4850 ft level (4300 mwe). The shaft cross sections are very large, 19.3 by 14.0 ft and 27.7 by 15.3 ft, respectively. The shafts, separated by about 1000 m, are connected at their bases by major drift, 13-15 ft wide and arching to 12 ft, equipped with an electric trolley line. This drift is one of two main levels that will be developed for NUSEL.

Below this level there are three ways to access lower levels. The No. 6 Winze begins 100m horizontally from the bottom of the Ross shaft and continues to the base of the mine, at 8000 ft. With the installation of a convenient transfer station between the Ross and No. 6, these two shafts will serve (in the development plan we prefer) as the main scientific (clean) access to the mine, serving the 4850 ft, 7400 ft, 8000 ft, and other levels. A series of sloped ramps provides a second access route to levels between the 4850 ft and 8000 ft levels, and the No. 4 Winze a third route between 4850 ft and 7400 ft levels. On the 4850 ft level the base of the Yates, the Ross/No. 6, and the top of the No. 4 shaft form a triangle, with the No. 4 approximately 1900 m from the Yates and 1600 m from the Ross. On the 7400 ft level another major drift, with cross section 9 by 9 ft, connects the base of the No. 4 shaft with the No. 6 shaft. It is along this drift, beginning at the No. 6 shaft end, that the deep level of NUSEL will be developed.

Thus the existing Homestake layout allows development along the main drift at 4850 ft (4300 mwe, 500 mwe below the level of Gran Sasso), with the Yates and Ross providing direct access to the surface. This is the level recommended for megadetector construction (e.g., UNO) and for other experiments wanting to simplify construction and transport, assuming moderate overburden needs. The deep level at 7400 ft (6600 mwe) is the choice for experiments needing great overburdens. No shaft construction is required in this plan, and new drift construction is limited to the immediate areas near the experimental halls. Access to the 8000 ft level, where the geomicrobiology program will be based, is also through the Ross and No. 6 shafts, with the ramp

system providing secondary access.

Later, in the **Homestake Facilities Development Plan** section, we will describe how the existing access and other mine infrastructure will be optimized for NUSEL. One goal is to exploit the existing dual access to all levels to sequester mining from scientific access. A second goal is to retain mining capability on all levels, so that specialized cavities can be constructed at any time during the lifetime of NUSEL. We discuss adjustments that can be made to optimize massive detector construction projects. The plan also describes how earth science needs – for instance, the desire to instrument much of the available 9 km^3 of rock – will be addressed.

Capacity and condition of shafts and hoisting equipment: Currently the Yates hoist is configured with four hoisting compartments, two for people and two skips for rock. The Ross is divided into two skips and a double-decker compartment for people and equipment. The No. 6 is very similar, but is not double-decker.

The hoisting equipment for the Yates and Ross shafts are pre-World War II, manually operated drum hoists with mechanical Lilly speed controls. Both hoists require mechanical motor-generator (MG) sets. The No 6 Winze hoist is approximately 30 years old and is semi-automatic. It also uses a MG set.

The hoists are powered by sets of 1250 hp DC Nordberg motors. The shafts and hoisting systems are serviceable and, with continued proper maintenance, will last indefinitely. The maximum cage load is 6 .7 tons, though the load is normally limited to 6 tons.

The Facilities Development Plan includes a series of important improvements to these hoists to make them suitable for scientific use, to increase the "footprint" (to 11 ft by 12 ft) and load limits, and to reduce operating costs. These include replacing the wooden Yates sets with steel sets; replacing the MG sets with semiconductor power supplies; replacing the manual and semi-automatic controls with fully automatic controls; and an option for upgrading to Kevlar ropes to increase the cage load.

Dewatering system: The Homestake Mine dewatering system is extensive, with excess capacity that could be very useful in filling or draining detectors. The Ross pumping system comprises major pumping stations on the 8000 ft and 6800 ft levels of the No. 6 shaft and on the 5000 ft, 3650 ft, 2450 ft, and 1250 ft levels of the Ross shaft. The total capacity of this system to the surface is approximately 2300 gpm through a 12-in-diameter pump column. Most of the water pumped from the mine is industrial water introduced from mining operations. The mine itself is quite dry, with just 470 gpm from groundwater. There is a small additional pump station located at the 1100 level of the B&M No. 2 shaft.

Ventilation: Three separate intake and exhaust circuits deliver 860,000 cubic feet per minute (cfm) of ventilation air to the headings of the underground mine. The surface fans include the Oro Hondo fan (3000 hp American-Davidson centrifugal with backward-curved airfoil blades) and the Ellison Fans (two Trane 89" DWDI centrifugal fans with 700 hp motors). The mine has also used five 100 hp section booster fans. Principal intakes include the Yates, Ross, and No. 5 shafts, with capacities of 270,000, 220,000, and 150,000 cfm. All of these intakes will be within the surface "footprint" inherited by NUSEL from the mine owners.

The Oro Hondo fan will be used for ventilating the underground drifts during NUSEL construction. The facilities development plan calls for a new fan system to be installed for permanent operations, while the Oro Hondo fan will be repositioned and reserved for emergency laboratory purging needs.

Air conditioning: The mine employed 2480 nominal tons of cooling in the deep levels. Cooling

is delivered to the headings via nineteen 30-ton and two 60-ton spot-coolers, 290-ton and 350-ton water chillers with cooling coils, and a 2300-ton vent plant located at the 6950 ft level, which bulk-cools air and circulates it to the headings. This system exceeds considerably the airflow and cooling requirements of NUSEL. As the vent plant is expensive to operate, a replacement air-cooled chilling system will be implemented during NUSEL construction.

Compressed air: Current capacity of the Yates compressors is 20,000 cfm at 100 psi. Installation of local filter/dryer units will be required to obtain instrument quality air from this system. While the Yates compressors will be used during initial construction of NUSEL, we intend to install new compressors on both of the main experimental levels, and may use skid-mounted compressors for later underground excavation.

Water supplies: The mine has both potable and industrial water supplies. The potable water system is fed from several storage tanks located in Lead and meets all federal Safe Drinking Water Act requirements. A majority of the supply is fed through a 4" pipeline that extends from the surface to the 5000 ft level in the Ross shaft. Each level off the Ross has a 2" pipe branching off the 4" main. The No. 6 and No. 4 shafts are served from the Ross system by a 2" pipeline with outlets on each station. The capacity of this system is up to 400 gpm. This system will satisfy NUSEL potable water needs and will require minimal updating.

The industrial water is very high quality. It comes directly from Homestake's surface water collection system gathered from local streams. The water is stored in a surface 1.2-million-gallon reinforced concrete storage tank. A minimal amount of treatment is provided by a chlorinating system. The industrial water is gravity fed to the underground through a 6" pipeline in the Ross shaft and a 4" pipeline in the Yates shaft. The Ross and Yates pipelines feed 4" pipelines in the No. 6 and No. 4 shafts, respectively. The Ross and Yates pipelines are rated at 1400 and 400 gpm, respectively. The industrial water system will be sufficient for NUSEL needs, with some specialized treatment of water for experiments provided on the laboratory levels.

Telecommunications and computing: Homestake has a Bell-based telecommunications touch-tone phone system that includes voice mail, a surface radio system, and a pager system. The mine has state-of-the-art communications and data transmission systems throughout the Ross and Yates shafts. Barrick intends to pass all of these systems on to NUSEL. Much of the wiring for phone, control, security, and intercom communications surface system was upgraded in 1999.

<u>Voice</u>: The current Bell system can support in excess of 600 lines. The surface and underground voice communications (telephone) use copper Category 3 cabling. The subsurface cabling consists of two 100-pair phone lines (one serving the 4850 ft level and No. 4 Winze and the second serving the No. 6 Winze area) and one 50-pair phone line (serving the Yates shaft stations). All are routed down the Yates shaft. During the 1999 surface upgrade new Category 3 cables were installed, primarily as buried cables or as bundles in the tunnels. These new cables replaced older wires that had been hung overhead.

<u>Voice/radio</u>: An existing leaky-feeder system extends the entire length of the Yates and Ross shafts for redundancy and for emergency communications. This system is just a few years old and is one of the most flexible and reliable mine-ready radio communications systems on the market.

<u>Internal data</u>: The mine has internal and external data communications systems. Both systems have hardware and connectivity that can be expanded to increase redundancy and speed to more remote locations in the mine. Mine computers are linked by fiber optics, with the subsurface serviced from a vertical fiber down the Yates shaft. This fiber is routed to a concentrator outside the 4850 ft electrical shop and then down the No. 6 shaft to the 6950 ft vent and across to the 7400 ft LHD shop. Currently all pumping controls and carbon monoxide monitoring between the

4850 ft level and the surface interfaces locally to the fiber system by copper line, so that these functions can be monitored from the surface. PC interfaces are located on the 6500 ft, 6950 ft, and 7400 ft levels. NUSEL plans include complete redundancy for data communications between internal facilities, including redundant fibers in the primary shafts.

External data: Black Hills FiberCom provides connectivity to the mine with a direct fiber connection. The current speed is OC-1 (51.84 Mbps) supported by a SONET (Synchronous Optical Network) hierarchy. Black Hills FiberCom ensures redundancy through alternate fiber paths should the direct fiber be severed in any location. Future expansion to OC-3 (155 Mbps) speed is possible. This would allow outside users to obtain speeds equal to that possible for inside users operating over the internal data network.

Controls and monitoring: The mine's infrastructure control and monitoring system is well-tested and thoroughly reliable. The system has four nodes, with one operator interface in the surface mine office and another underground. The existing operations staff installed and programmed the system, so that all necessary expertise is available locally.

FIXDMACS system: The FIXDMACS system is used to monitor, throughout the mine, the control pumps, fans, and other essential equipment, as well as carbon monoxide levels. The system operates on uninterruptible power. The control area where facility operators monitor the output includes 50 process control screens, as well as several equipment status screens and control interface templates. The graphics displays are high quality, based on the operator interface software Intellution.

Subsurface gas detection: There are approximately 20 carbon monoxide monitoring stations located throughout the mine. As new ventilation paths will be set up to optimize NUSEL, many of these monitors will be relocated.

Personnel and operations: As we will argue in the next section, there is no mine attribute more important to NUSEL than the existence of an efficient operations infrastructure manned by highly trained personnel, many of whom desire to remain with NUSEL. Mine operations are carried out by five groups:

- Operations/maintenance group: This group is responsible for the operations and maintenance of plant infrastructure including the hoisting facilities, crushing operations, ventilation and pumping systems, power, compressed air, water and communications services, surface grounds and buildings, and the main underground haulage and access drifts. This group supports underground excavation and construction activities by transporting supplies, materials, waste rock, and personnel. At NUSEL this group would help with the transport of experimental equipment between the surface and the experimental halls. This group is responsible for the installation of new services and equipment, such as power and communications, air handlers, fans, and other hardware.
- Underground excavations/construction group: This group is responsible for the drill, blast, muck, and ground control functions for all underground excavations. Construction activities include track, concrete, and shotcrete placement, wall coatings and paint finishes, wall and barricade construction, and excavation support installations (e.g., construction of rock dumps and bypass gates).
- Engineering group: This group is responsible for the evaluation and design of all underground excavations including technical support for ongoing excavation and construction activities. Technical support includes rock mechanics analysis, design and monitoring, surveying, scheduling, blast design and materials, and equipment testing. At NUSEL these responsibilities would include the scheduling of facilities used in transport of experimental equipment and the oversight of transport and underground installation. Plant engineering responsibilities include preventative maintenance, systems engineering, equipment replacement and procurement, and plant upgrades.

- Safety/environmental group: This group evaluates all work done on the site to ensure safety and environmental protection. It has specific reporting, database, permit, inspection, monitoring, and compliance responsibilities. It formulates emergence response plans, policy books, and training materials, and is responsible for training site personnel, contractors, the mine rescue team, and for NUSEL, the visiting scientists. The group is responsible for security functions and the occupational health program, including documentation, operation, and maintenance of the mine operating system.
- Administrative group: This group is responsible for all personnel functions, public relations, legal review, accounting, and purchasing. Purchasing functions include competitive bid preparation, contract agreements, legal review, the documentation and accounting interface, inventory management, supply ordering, and warehouse and yard supervision. Thus the NUSEL shipping and receiving, computing, inventory, library, and visitor services would fit within this group, as would all funding agency reporting requirements.

Figure B.2: A view of the Yates (left) and Ross (right) headframes. The distance between the two shafts is approximately one kilometer. These shafts/hoists provide the principal access to the 4850 ft level. In the facilities development plan, the Ross and the No. 6 Winze provide scientific access to all laboratory levels. The Yates would normally be used as the excavation shaft (together with the No. 4 Winze to reach the 7400 ft level), but could also be dedicated to megadetector construction, to give this experiment maximum access.

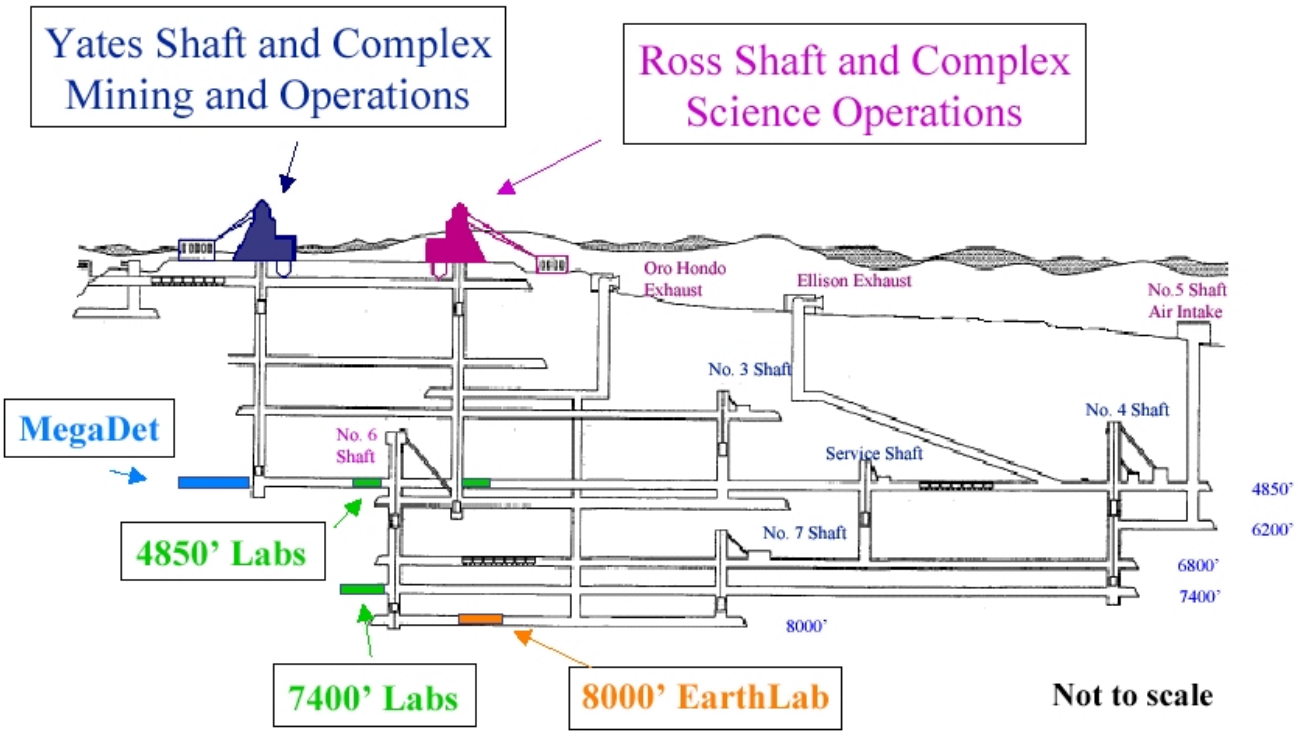


Figure B.3: The same view as in Figure B.2, but from underground. This schematic shows the principal shafts and a few of the major drifts in the Homestake Mine, as well as the planned laboratory development. The specific developments on the 7400 ft, 4850 ft, and 8000 ft levels are discussed in the Facilities Development section, later in this project book. The proposed megadetector location (near the base of the Yates) and the 7400-ft development are both in the exceptional competent rock of the Yates Unit.

Figure B.4: The Yates hoist engines.

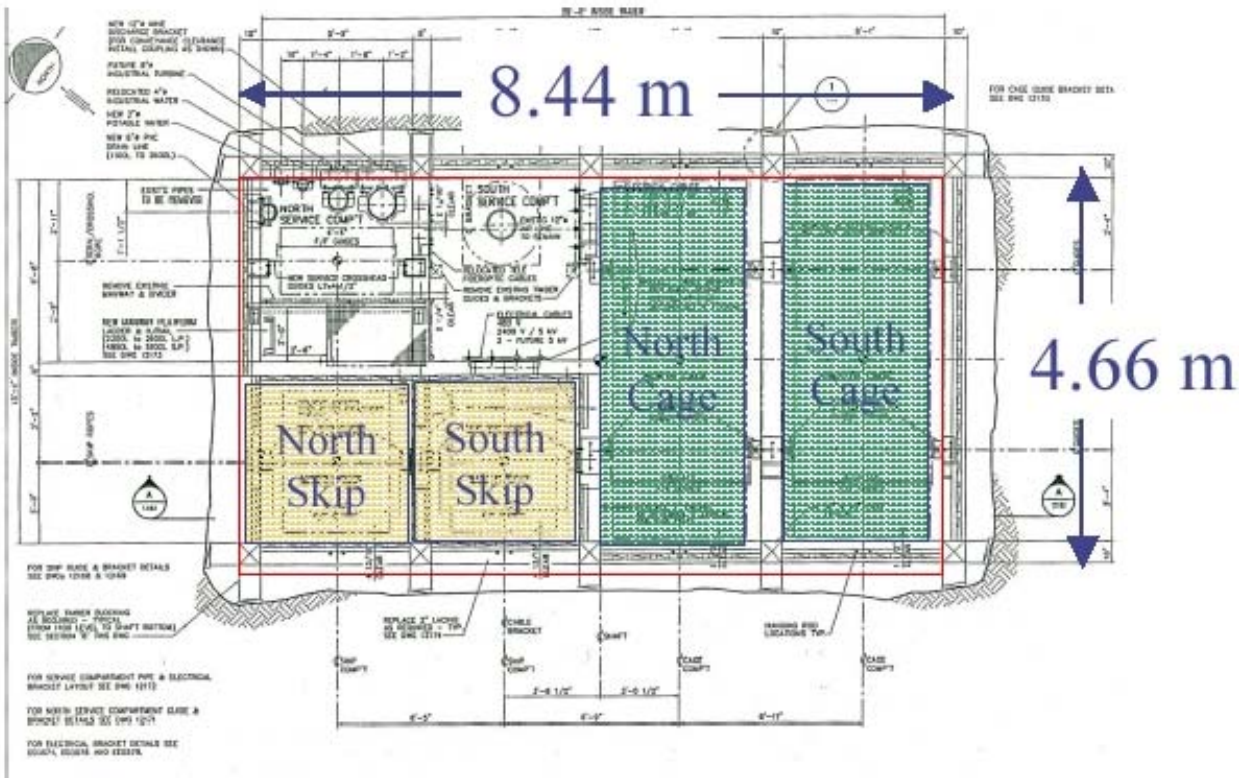


Figure B.5: The Yates shaft cross section, showing how the space is divided into smaller cages (for people) and skips (for rock). The facilities development plan discusses how this hoist will be modernized, though its basic configuration will not be changed until megadector construction begins. In contrast, the Ross and No. 6 will be redesigned, at the beginning of NUSEL construction, for clean scientific access, with a single large enclosed cage, 11ft × 12 ft, and a separate automated man hoist for 24/7 access.

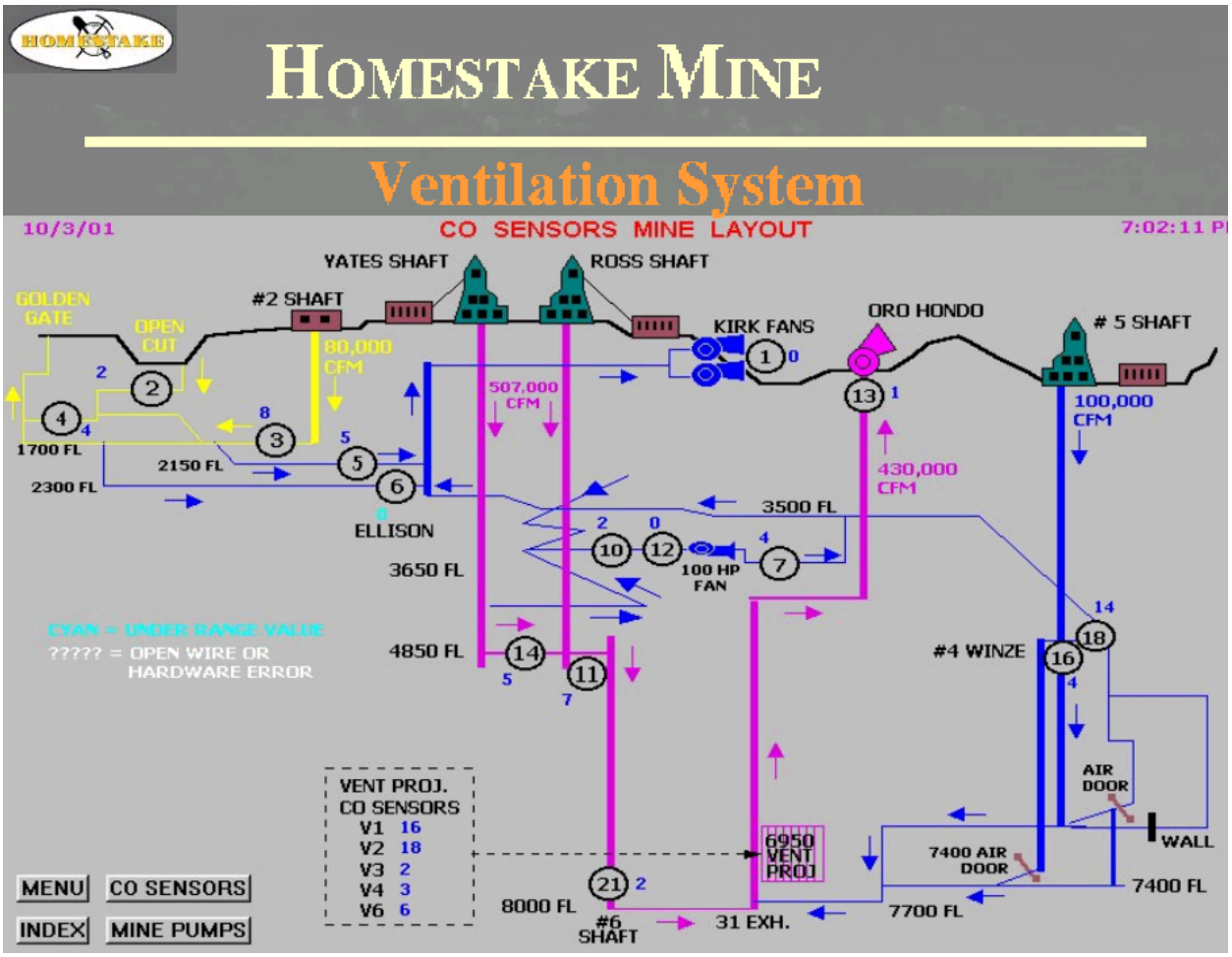


Figure B.6: The current ventilation and gas (carbon monoxide) sensor system at Homestake. This Facilities Development section describes how this system will be reconfigured to provide independent ventilation circuits for the 4850-ft and 7400-ft laboratory levels. This high-capacity system is a major asset of the Homestake plant. The proposed ventilation scheme for the 7400-ft level exhausts through the No. 7 shaft into higher drifts, so that any accidental gas discharge will be safely routed away from occupied areas. This is an important safety feature possible (at reasonable cost) only because of the existing ventilation shafts and drifts at Homestake.

<u>Why Homestake is the optimal site for NUSEL</u>: Later, in the Facilities Development Plan section of this version #2 proposal, we present a detail plan for exploiting the existing site and infrastructure of Homestake to produce an underground science laboratory unique in its potential and flexibility. The plan is more efficient than that offered in the version #1 proposal, a result of a year of discussions between the collaboration's scientists and engineers (including two with a total of 40 years of experience as head engineers at Homestake). It achieves the following goals:

- A two-level laboratory divided between intermediate (4850 ft) and deep (7400 ft) levels, which is attractive scientifically (allowing experimentalists to balance great depth and easy of access) and from the engineering perspective (distributing ventilation loads). Some activities will use other parts of the mine, such as the geomicrobiology center at 8000 ft.
- Clean, efficient scientific access with large-load capabilities (module weights of at least 8 tons and footprints of at least 11 ft by 12 ft) from surface to 8000 ft.
- All hall excavations occur in rock that is immediately accessible, and thus where rock quality is known.
- Dual access is maintained for all levels, enhancing safety. Because of this access, future expansion of both the 4850 and 7400 ft levels is possible while keeping all excavation sequestered from all science operations.
- The plan optimizes both excavation and detector construction possibilities for a megadetector on the 4850 ft level.

The Bahcall Committee recognized the potential of Homestake long ago:

- The **existing infrastructure** at Homestake will allow us to produce a facility at very **low cost** that has **capabilities beyond any other envisioned laboratory**. The important attributes include the multiple shafts and thus the multiple access, the ability to sequester potentially hazardous experiments, the depth and range of depths available, the existing mining capacity (sufficient to excavate the UNO cavity in 2.5 years), and the reliable facilities (hoists, ventilation, air conditioning, water, dewatering, data and communications, controls and monitoring systems, and local hydroelectric capacity).
- The Homestake site offers **low risk**: a) the overall site geology and hydrology are very well understood and very favorable; b) the rock structures designated for hall development are directly accessible; c) Homestake is an operating, efficient facility with a highly trained staff, many of whom would remain at NUSEL; d) mining and operations costs are known; e) the area is seismically quite; f) the area has a long history of support for mining; and g) as an operating facility, Homestake does not face the substantial permitting obstacles confronting proposed greenfield sites.
- The Homestake site requires very little development, greatly **shortening the time to first physics**. The facilities development plan envisions the low-level counting facility operating at 7400 ft within one year of initial funding. The earth science program will commence immediately.
- Homestake is an **ideal site for EarthLab and for geomicrobiology,** and is likely the only site that could serve both the physics and earth science communities well.
- Homestake presents **exceptional opportunities for education and outreach**. The mine is located in a major tourist area and in a region of the US that currently lacks a major science focus. NUSEL will be an important partner of the universities and tribal colleges in South Dakota and in surrounding EPSCoR states, working to strengthen science and education in the region. Distance education and other K-12 outreach activities are crucial to this region because of the demographic problems facing school districts.

Below we expand on the first two bullets above by relating Homestake's physical attributes to the discussion in Section II:

Depth: Both of the NRC committees noted that proposed next-generation experiments require

overburdens of 4000-4500 mwe, and that NUSEL must be able to provide depths up to 6000 mwe to meet scientific needs over the next two decades. The proposed Homestake development plan provides main levels at 4400 mwe and 6500 mwe, and potential access to any depth from surface to 7200 mwe. The rock in Homestake is of excellent quality (the results of geotechnical studies are cited below), believed by our engineers to be superior to any of the 50 hard-rock North American mines with which they are familiar. All areas planned for hall development are immediately accessible for coring. The site is seismically quiet and very dry.

Unlike any other proposed NUSEL sites, Homestake meets the needs of EarthLab proponents and of the geomicrobiology community, as well. Important attributes include its 3D extent (9 km^3 are accessible through 600 km of drifts), a massive geotechnical data base including 3D computerized models of the site, and complex, highly-folded preCambrian rock with an interesting geothermal history. The microbiologists have found interesting extremophiles at the 8000 ft level and propose to study deeper layers, to 16500 ft.

Detector halls: Because of the excellent access provided underground by the existing system of hoists and ramps, a uniquely flexible laboratory is possible, one that merges the best elements of Gran Sasso and Kamioka. Initial construction will produce a series of halls similar to those of Gran Sasso, though specialized somewhat to meet the needs of the low-level counting facility and other experiments described in the Science Book. But because the existing hoisting system provides dual access to all levels, NUSEL-Homestake will be a **living** facility, one where Super-Kamiokande-style specialized cavities can be constructed in future years, without interfering with ongoing science operations. As noted below, this includes the construction of megacavities much deeper and much larger than any attempted to date.

Homestake is unique among the sites proposed because experiments using large quantities of cryogens and flammables can be sequestered and separately vented. Provisions will be made in NUSEL construction to reserve such sites, and to anticipate how the existing ventilation system can be adapted for those sites.

Megadetector capabilities: This version #2 proposal was profoundly influenced by very recent neutrino physics developments. With the realization that very long baseline experiments might be able to probe new sources of CP violation relevant to leptogenesis, great attention has been drawn to neutrino superbeams and to megadetectors designed as distant neutrino detectors, but also serving as proton decay, supernova physics, and precision atmospheric neutrino detectors. There is growing recognition that such a detector, located at depth, will support a much richer science program than one located just below the surface. While such a detector is far outside the scope of this proposal, the new NUSEL-Homestake configuration prepares the way for such a project by preserving an ideal site for the construction.

Proposed megadetectors include water Cerenkov detectors like UNO and Hyper-Kamiokande, variations where an array of Super-Kamiokande-like modules is excavated, and new-technology detectors like SuperIcarus. As the rural mailbox design of UNO may be the most difficult geotechnically, we focus on this.

Among the challenges posed by such a detector are:

- Is it demonstrated that the excavation is geotechnically practical in the proposed site?
- What are the permitting or practical obstacles to disposing of the associated 2.5 megatons of waste rock?
- Is the excavation cost known reliably?
- After excavation, can the detector construction be done efficiently?
- Can one efficiently fill and drain (for periodic maintenance/decommissioning) the detector?

<u>Stability</u>: The geotechnical stability of large caverns at Homestake has been established through

construction and measurement as well as through laboratory testing and modeling. Among the "permanent" deep large chambers the Homestake Mining Company constructed are an equipment repair shop at 7400 ft and an air conditioning plant at 6950 ft. In addition, HMC has carried out extensive Vertical Crater Retreat (VCR) mining at depths below 7000 ft. VCR involves the excavation of 150 to 200 ft high cylindrical regions by drilling vertical holes for explosives into the volume from above, then blasting out progressive horizontal sections from the bottom of the region.

In 1985, as VCR mining was being developed at Homestake, HMC arranged to have the Bureau of Mines evaluate a test VCR excavation at 7100 ft. This involved premining stress tests of the site to fix parameters in a rock mechanics model, followed by postmining measurements of rock shifts. The model predicted the postmining behavior accurately (W. G. Pariseau, "Research Study on Pillar Design for Vertical Retreat Mining," Bureau of Mines Report J0215043, October 1985). The rock stress and shear characteristics utilized in these calculations were determined by Z. Hladysz (now a NUSEL-Homestake collaboration member). Additional rock mechanics studies of Homestake shaft stability were carried out by W. Pariseau, J. Johnson, M. McDonald, and M. Poad in 1995 (Bureau of Mines Report of Investigations 9531, 9576, and 9618). These involved both 2D and 3D models.

In fall 2000 Johnson and Tesarik of the National Institute of Occupational Safety and Health (NIOSH), employed numerical models similar to those of Pariseau to evaluate the stability of a 200 ft diameter by 400 ft cylindrical excavation at various Homestake depths. They concluded that such an excavation would be stable with stresses below the rock limit at both the 4850 and 6800 ft levels, but could be problematic at the 8000 ft level. In February 2001, in response to the Bahcall Committee interest in rural mailbox excavations for experiments like UNO, Callahan, Osnes, and Vlankenship of RESPEC (Rapid City, SD) carried out stability analyses for various deep chambers, including a rectangular configuration with a 50 by 50 m cross section at 4850 ft. Their conclusions were consistent with those of Johnson and Tesarik.

The summary from these studies is that, with normal ground support, megacavities of the type proposed for UNO can be constructed at depths up to 6500 ft, with the expectation that they will be stable for several decades. However, as there is no strong science justification for going below 4850 ft, this is optimal depth for an UNO-style cavity in Homestake. (The Callahan et al. study concluded that the construction would then have a safety factor of 10, where 3 is considered acceptable.) Both excavation and detector construction can be optimized by locating the detector near the base of the Yates shaft. No cost savings results from siting UNO at a shallower depth – any additional hoisting costs at 4850 ft are offset by the improved haulage and support infrastructure on this level.

There have also been studies of the stability of an alternative design, an array of VCR cylinders 50 m in diameter and 50 m long. With a center-to-center separation of the cylinders of 100 m, the excavation is within Homestake rock limits. Increasing this separation to 150 m increases the safety factor significantly.

Much less is known about the suitability of the rock in competing proposals. In one case the rock cannot be tested prior to constructing the 6 km tunnel to the proposed laboratory location. (The national monument status of the site prevents coring prior to construction.)

<u>Rock waste disposal</u>: The excavation of a 0.9 million m^3 volume for a 0.5 megaton water detector will produce approximately 2.5 megatons of displaced rock, a solid waste. A disposal site must be found, and the noise and dust accompanying trucking of the rock can lead to public opposition and permitting difficulties. Assuming 20 ton loads, the task corresponds to 100 truck round trips per day, 365 days a year, for 3.5 years.

This very difficult problem is avoided at Homestake. A large open pit exists on site where the waste rock can be deposited. This can be accomplished without any surface transport, by installing an underground conveyor on the 600 ft level, connecting the Yates shaft to the open cut, a distance of about 800 m. The anticipated cost of the conveyor system is approximately $5M.

Excavation costs: The track record in physics for correctly predicting the cost of large excavations is not a good one. In contrast, at NUSEL the excavation would be done with the same equipment, personnel, and techniques that Homestake used for mining, and in familiar rock. The Homestake rough mining cost for the 4850 ft level is $34.46/ton.

Detector construction plan: The facilities development plan anticipates that work on a megadetector would commence after scientific halls on the 7400 and 4850 ft levels have been completed, and after the Ross and No. 6 hoists have been modernized and upgraded for science access to these levels. At this point the Yates hoist could be dedicated to the excavation, which could be completed in as little as 2.5 years if mining is done at capacity. After excavation is completed, the Yates cage could be modified – very much as the Ross and No. 6 were to enhance science access – to make detector construction as easy as possible. Because of the very large Yates shaft cross section, it is possible to have a single-cage configuration as large as 5.5 m by 4.5 m, so that a large cargo container could be lowered to the detector site. Dedicating the Yates in this way to megadetector excavation and construction would give this project maximum flexibility, and avoid any interference with other laboratories activities, which would be conducted through the Ross and No. 6.

The cost of megadetector construction is not part of the NUSEL proposal, though our proposal is designed to make such a project feasible at a later date.

Filling and draining the detector: The mine's dewatering system may be very helpful in filling and draining the detector. The excess pumping capacity of the system (that in excess of the 470 gpm from groundwater) is about 2000 gpm, or 11.5 ktons/day. Thus a detector comparable to SuperK could be drained in 5 days, while UNO could be emptied in about three months. As the ground water is of good quality, it may be possible to filter it for use in the filling stage, as well. This source could fill SuperK in 20 days and UNO in one year, timescales that might well be adequate.

Cleanliness: The cleanroom environment – a variety of rooms varying from Class 100 to 1000 would be useful – is important on both the detector assembly and detector operations ends. For example, some groups will use NUSEL's surface laboratory cleanroom facilities to prepare detector modules. Transport of large, precleaned, and carefully wrapped instrumentation assemblies from the surface to depth will be via the Ross and No. 6 hoists, which will be fitted with enclosed lift cages resembling an elevator. While not a cleanroom environment, the lifts will be dedicated to science. There will be facilities for washing and cleaning the assemblies before re-entering the cleanroom environment at depth. This is the SNO model, with an important improvement: SNO transport was through an active and thus very dirty mine environment. At NUSEL the transport leg, while not a cleanroom environment, will be isolated from the mining environment to minimize contamination during transport.

The standard facilities described in Section III – underground materials storage areas, the low-level counting facility, necessary underground fabrication facilities – will be part of NUSEL-Homestake infrastructure.

24/7 access: During major excavations and detector construction NUSEL hoists would likely operate 24 hours and seven days a week. At other times access might be limited at night. To provide access NUSEL will install an automatic man-hoist – a small elevator – on the Ross and

No. 6 that can be operated by an individual and controlled by a keycard. There must be an operator, however, who can be called in an emergency. This might be addressed by combining this job with others (e.g., night security).

Safety, special materials, materials handling: The FIXDMACS system for mine monitoring and the safety experience accumulated by Homestake operators form an important baseline for safety oversight and procedures at NUSEL. The Homestake Mine fully complies with all MSHA regulations (one provision of these regulations being two means of escape from each level). All operating shafts have fresh, incoming air (fumes will not follow workers attempting to exit the mine).

The sensor system described earlier permits rapid detection of carbon monoxide excesses, fires, etc. We plan certain control and monitoring upgrades for NUSEL. One of these is a new addressable fire detection and alarm system that is fiber linked to the main fire alarm panel at the surface, which serves as the fire alarm command center for the entire Homestake facility. The subsurface fire detection system will also include a remote fire alarm annunciator, door holders/closers, manual pull stations, and smoke detectors and audio/visual notification in the corridors, labs, and shops. The carbon monoxide detection system will be upgraded to a multi-gas system in the detector areas. The subsurface PA system will provide paging coverage for all normally occupied subsurface science areas.

Surface security and access will be controlled by a card reader system, with card readers installed at all new-structure exterior doors. Access to the facility will be monitored by relocated video cameras. We have been asked about the possibility of a higher-security area for national security work. There are possibilities for developing a separate drift for such work, with tightly controlled access, should the agencies decide a need exists.

MSHA oversees all mines that produce commercial materials, and thus was the responsible agency during mine operations. OSHA oversees all other underground construction as well as most surface facilities. OSHA is familiar with the activities in standard university, industrial, and national laboratories, while MSHA is not. However, MSHA regulations governing hoist operations, ventilation, and mine rescue teams are well tested and successful. A reasonable approach would be to place NUSL under OSHA oversight, but have the laboratory follow MSHA regulations with respect to mine rescue and hoist operations.

Homestake's mine rescue team is outstanding, generally regarded as the best in the US. All team members are regular employees, but they donate their time when training for mine rescue. The only facility cost is their equipment and training materials. NUSEL would like to retain this team and expand their training to include potential problems in the scientific areas.

NUSEL will establish a safety office to oversee all safety and security issues, and to guarantee that experimental operations are carried out in a responsible way. In addition to its internal responsibilities, the safety office will be responsible for coordination with local police, fire, and medical personnel. It will also be responsible for a safety review of new experiments before they are formally considered, and for control of all flammable materials, radioactive materials, noxious gases and liquids, and asphyxiating gasses. Before any new experiment is approved, the report of the safety office will be reviewed by an independent operations safety oversight committee that includes mine safety experts, experimentalists, and a representative of the South Dakota Department of Environment and Natural Resources. This committee will report to the Director.

Access for large and heavy equipment: The key element in the Ross and No. 6 hoist upgrades is to enable efficient transport of standardized detector modules, 11 by 12 feet and up to 8 tons, from surface to 8000 ft. In addition, Homestake personnel have experience transporting very

large or awkwardly shaped cargo underground by slinging the load beneath the cage. We noted, in the discussion of UNO, that the Yates could be adapted for a module footprint of about 14 ft by 18 ft, should this be helpful to that experiment.

Quietness and stability: electrical, mechanical, seismic: There are two issues specific to Homestake. First, the area is very quiet seismically, and the mine has very few rockbursts. Second, there are several hydroelectric plants on the site that could provide power to NUSEL at very low cost. This would give NUSEL a backup power supply should Black Hills Power suffer an outage. One plan would have Barrick Gold retaining ownership of the hydroelectric facilities, but selling the power to NUSEL at rates substantially below market. There is about 2.5 MW of generating capacity that interests NUSEL. The cost of power generation is $0.01/kW-hour.

Adequate support facilities: We feel the Gran Sasso model of strong in-house support facilities – library, shops, visitor support, etc. – is the right model for any underground laboratory that aspires to be a national and international center. For Homestake the argument for following this model is even stronger, as the universities within 40 miles of the site, Black Hills State College and the South Dakota School of Mines and Technology, do not have the research infrastructure typical of large research universities.

Quality of life: There are several site-specific issues affecting the quality of life. The town of Lead (population 3500, elevation one mile) has a sunny, semi-arid, high-plains climate, warmed by the compression of air down-drafting from the Front Range of the Rocky Mountains. Mean January and July temperatures (high/low) are 25°/10°F and 75°/69°F, respectively. Lead retains much of its mining heritage. A major civic project now underway is the reconstruction of the 1914 Lead Opera House, following faithfully the original architectural drawings. The city webpage can be found at http://www.leadmethere.org.

The nearest city is Rapid City (population 57,500), a 45 minute drive on very good roads. Rapid City has a very convenient modern airport with jet and air commuter service to Denver, Minneapolis, etc. The Black Hills offers exceptional outdoor recreational opportunities, including skiing, hiking, boating, trout fishing, horseback riding, and mountain biking (including on the 114 mile long Mickelson Trail): this is the main reason for the area's strong tourism industry. The area offers many campgrounds. Spearfish Canyon, an area preserved for the past 100 years by the Homestake Mining Company, is just a few miles south of Lead. This US Forestry Service Scenic Byway is the location where the winter scenes in "Dances with Wolves" were filmed.

Various services give a cost-of-living index for Rapid City of 89.3-100.2, depending on the choice of weighting factors.

Outreach and education: This is addressed in Section IV of the Science Book.

Neutrino beams: Homestake is 1290 km from FermiLab and 2530 km from Brookhaven.

C. THE NUSEL-HOMESTAKE SCIENCE BOOK

The **NUSEL Science Book** describes the physics, earth science, applications, and education/outreach opportunities that can be realized at Homestake. The corresponding four sections are developed around project areas, such as double beta decay or geomicrobiology. For each project area we describe the **importance of the science**, the **readiness** of the project, and the project's **facility requirements** (e.g., the space and supporting infrastructure needed underground). The results of this chapter are then summarized in Section D, the **Science Timeline**, on which our Homestake Facilities Development Plan of Section E is then based.

The Science Book discussion of NUSEL science is not complete. Rather, it reflects the major science themes that were developed by the science community during the Lead Physics, Outreach, and Geomicrobiology workshops, during the Aspen Underground Science program, and during NESS02 (including collaboration responses to the NRC Neutrino Facilities Committee). We are aware of several research directions that have not yet been explored adequately in these workshops. For example, there have been recent suggestions of gravitational drop tests (using the 5000-ft shafts of Homestake in place of drop towers, which are typically limited to 3000 ft or less and are influenced by wind) and of underground gravitational wave antennas. (In Japan's Oto Underground Laboratory a 300m laser interferometer TAMA operates for gravitational wave detection: the underground location provides a "quiet" location.) Underground experiments have been mounted for magnetic monopoles and other exotic objects produced in the early universe. While some materials science is included in the Applications sections of the Science Book (section III), this discussion so far has been limited to radiopurity issues in microelectronics. However, techniques for isolating a few atoms within a macroscopic sample, creating materials of extreme purity through underground manufacturing, and single-atom counting have much broader applications in materials science.

While most of the Science Book is based on materials produced by our collaboration, we have also had important help from others in the science community. In particular, following the collaboration's Lead meeting and other early work on earth science, an independent earth science group was organized by the NSF to develop the case for EarthLab. We are very grateful to them for making the results of their study available to us (section II). We intend to maintain the Science Book as a living document, updating it as the science moves forward. We invite any community member to contribute to its development.

I. Science Book: Physics

Neutrino Physics: Several Nobel Prizes in the last 15 years (Lederman, Schwartz, and Steinberger, 1988; Reines, 1995; Davis and Koshiba, 2002) celebrate the fundamental contributions neutrino physics made in two areas: the development of the electroweak "standard model" of particle physics and the inauguration of a new field, neutrino astrophysics. What is more remarkable, however, is that during this period, a series of new discoveries have been made in neutrino physics and astrophysics – discoveries that may help resolve some of the deepest questions in physics. The demonstration that neutrinos are massive provided the first proof that the standard model is incomplete. In fact, most theorists believe that the pattern of neutrino masses is providing our first window on new physics residing at the Grand Unified Scale, an energy 100 billion times that of our most power accelerators. We now know that neutrinos are a component of particle dark matter, at least as important as the visible stars in their contribution to the universe's mass-energy budget, but not the dominant component.

But like a detective who has found valuable clues but cannot yet resolve the mystery, current discoveries have posed important new questions. We do not yet know the absolute scale of neutrino mass, as the solar and atmospheric results probe m^2 differences, not absolute masses. The absolute mass scale is central to understanding what neutrinos imply about beyond-the-standard-model physics, and to the role of neutrinos in cosmology. Crucial in understanding the mechanism responsible for neutrino mass is the nature of this particle under particle-antiparticle conjugation: we do not yet know whether the antineutrino is identical to (Majorana) or distinct from (Dirac) the neutrino. While we know the first and second neutrino generations mix, as do the second and third, we have not yet measured the mixing of the first and third generations. This mixing is important in the astrophysics of supernova explosions and will determine whether future long-baseline oscillation experiments will succeed in measuring neutrino properties important to the very early universe. The long-standing problem of why we are here – why our primordial universe was not symmetric in its matter and antimatter composition, with these two components later annihilating – may very likely have to do with CP violation among neutrinos. The "seesaw" mass pattern suggested by experiments fits nicely into models where the baryon number asymmetry was created through the process of leptogenesis.

The current status is often summarized in this way. We know, within experimental accuracies that must be greatly improved, $m_2^2 - m_1^2$ and the magnitude of $m_3^2 - m_2^2$, but not the overall scale $(m_1+m_2+m_3)/3$. We do not know if these three masses are (dominantly) Majorana. The mixing matrix describing the relationship between flavor and mass eigenstates is

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \begin{pmatrix} \nu_1 \\ e^{i\phi_2}\nu_2 \\ e^{i\phi_3}\nu_3 \end{pmatrix}$$

$$= \begin{pmatrix} 1 & & \\ & c_{23} & s_{23} \\ & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & & s_{13}e^{-i\delta} \\ & 1 & \\ -s_{13}e^{i\delta} & & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & \\ -s_{12} & c_{12} & \\ & & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ e^{i\phi_2}\nu_2 \\ e^{1\phi_3}\nu_3 \end{pmatrix}$$

where $c_{12} = \cos\theta_{12}$, etc., and where the second line represents the successive solar, 13, and atmospheric mixings. We know $\theta_{12} \sim 30°$ and $\theta_{23} \sim 45°$, but have only the limit $\theta_{13} < 10°$. Furthermore, we have no information on the CP violating Dirac phase δ and the Majorana phases

ϕ_2 and ϕ_3.

Most significant to neutrino sleuths is that nature has been kind: the wonderful discoveries that have come from neutrino astrophysics imply that new experiments can be done on earth, with terrestrial neutrino beams, as well as with astrophysical neutrino sources. This means that two communities, underground scientists who build ultraclean detectors and accelerator physicists who create new neutrino beams, can work together to resolve many of the open neutrino questions. The required experiments are difficult, requiring a new generation of cleaner, deeper, and larger underground detectors for neutrino physics, as well as unprecedented neutrino superbeams. But with the right combination of experiments, the questions that need to be answered can be answered: most of the unknown parameters can be determined.

Figure C.1: Ray Davis's Homestake chlorine experiment.

A.1 Double Beta Decay: The Importance of the Science: Double beta decay arises from a special feature of the nuclear force: nuclei with even numbers of protons and neutrons are more tightly bound than other nuclei. This frequently produces a mass pattern where an even-even nucleus with N protons and Z neutrons, N+Z=A, denoted (A,Z), as well as the nucleus (A,Z+2) are well bound, but the intermediate odd-odd nucleus (A,Z+1) is less so, and thus has a larger mass. Consequently, the ordinary first-order β decay process $(A,Z) \rightarrow (A,Z+1) + \nu_e + e^-$ is energetically forbidden, while a second-order-weak process in which (A,Z) decays spontaneously to (A,Z+2), with the emission of two electrons, is allowed. Thus nature isolates a very rare phenomenon – there is only one other example of a measurable sensitive to second-order weak effects.

The rates for such "double beta decay" are exceedingly tiny, corresponding to nuclear life times many orders of magnitude greater than the age of our universe. Interest in this process comes from its connections to neutrino physics. Nature appears to obey a symmetry, CPT, than assigns to each particle an antiparticle, a particle with the same mass and spin, but with opposite charge (or more correctly, with all of the particle's additive quantum numbers reversed). If we consider standard-model fermions – quarks, charged leptons, neutrinos – it is clear that the quarks and charged leptons have distinct antiparticles: under particle-antiparticle conjugation, the electron becomes a positron, clearly distinct because its charge is positive, opposite that of the electron. However, this question is more difficult for the neutrino.

The neutrino carries no charge (and has no other obvious additive quantum numbers). Thus its behavior under particle-antiparticle conjugation is unclear – one could imagine the neutrino having a distinct antiparticle, one that behaves in reactions in a way that distinguishes the antineutrino from the neutrino. (In this case one would invent an additively conserved quantum number, called lepton number, to distinguish the two particles, perhaps with the neutrino and electron assigned $l = +1$ and the antineutrino and positron $l = -1$.) Or the neutrino could be identical to the antineutrino. The first case corresponds to a Dirac neutrino, the second to a Majorana neutrino.

If neutrinos are Dirac particles, similar to other standard model fermions, then one would expect these particles would share a common mechanism for generating masses. Efforts to generalize the standard model then lead to a puzzle. For example, many grand unified theories (GUTs) enlarge the first-generation doublets of the standard model, (e,ν_e), to include the other first-generation particles. Then one would expect that these first-generation Dirac particles would couple to the mass-generating fields similarly (up to group theory factors), and thus have comparable masses. However, while the u and d quarks and electron all have masses ~ 1 MeV, tritium beta decay studies tell us that the electron neutrino mass is less than 2.2 eV. An attractive resolution to this puzzled was offered by Gell-Mann, Ramond, and Slansky and by Yanagida some years ago. If neutrinos also have Majorana mass terms, then it becomes natural to generate a light neutrino mass of size

$$m_\nu = m_D \left(\frac{m_D}{m_R} \right)$$

where m_D is the Dirac mass and m_R the right-handed Majorana mass. Thus, if the right-handed Majorana mass scale is large, perhaps at the GUT scale, then (m_D/m_R) is the needed small parameter explaining why the neutrino is so light. This seesaw mechanism – the higher the scale m_R, the smaller the neutrino mass m_ν -- then relates small neutrino masses to new physics residing beyond the standard model. The Majorana mass terms explicitly violate lepton number conservation.

Double beta decay probes this physics. If neutrinos are Dirac particles, then only the standard-

model two-neutrino process contributes to double beta decay: two correlated single beta decays occur, with virtual excitation of the intermediate nuclear state, producing two electrons and two electron antineutrinos in the final state. Thus the final-state total lepton number $l = 0$ and lepton number is conserved. If lepton number is violated – as it would if Majorana mass terms are included – then neutrinoless ββ decay can also occur, producing a final state with $l = 2$. That is, the antineutrino produced in the first β decay is (at least partially) identical to the neutrino, and thus can be reabsorbed on a second nucleon, with the emission of a second electron. The final state contains just two electrons, which carry off the total nuclear decay energy. This is a very distinctive experimental signal: plotting the summed energy spectrum, neutrinoless double beta decay produces a line at the endpoint energy, while two-neutrino ββ decay produces a continuous spectrum peaked at an intermediate energy, with the phase space going to zero at the endpoint.

The neutrinoless process measures the Majorana neutrino mass. If parity is violated maximally, as in the standard model, the antineutrino produced in β decay is righthanded, while the neutrino that induces the (ν_e, e^-) reaction on the second nucleon must be lefthanded. Thus the exact V-A character of the weak interaction would, for massless neutrinos, forbid neutrinoless ββ decay, regardless of lepton number conservation. But if the neutrino is massive, the neutrinoless process is not forbidden, but merely suppressed by the factor m_ν/E_ν, where E_ν is the typical energy of the exchanged neutrino. Because phase space favors the neutrinoless process, searches for neutrinoless ββ decay are very sensitive probes of small Majorana masses, despite this suppression.

Experimental progress in this field has been rapid. Thirty years of effort were required before the standard model two-neutrino process was finally observed in 1987. Now accurate lifetimes and decay spectra are known for about a dozen nuclei. The standard-model process is crucial to theory, providing important benchmarks for the nuclear physics matrix element calculations that are done to relate neutrinoless double beta decay limits to the underlying neutrino mass.

Progress in neutrinoless ββ decay has been even more impressive. Extraordinary efforts to reduce backgrounds through ultrapure isotopically enriched materials, improved energy resolution (important in distinguishing 0ν from 2ν decay), and siting experiments in deep underground locations (to avoid cosmogenic backgrounds) has produced a "Moore's Law" for double beta decay, a factor-of-two improvement in lifetime limits every two years. The bound from the nucleus ^{76}Ge, $\sim 2 \times 10^{25}$ years, corresponds to a Majorana mass limit of (300-1300) meV (milli-eV), depending on the nuclear matrix elements employed. The goal of the next generation of experiments is very ambitious, pushing lifetimes by $\sim 10^3$ and probing masses as low as 10-30 meV.

These ambitious new efforts are driven by the recent discoveries of Super-Kamiokande, SNO, KamLAND, and K2K that establish neutrinos are massive. The questions remaining:

- **Are light neutrinos Majorana particles?** There are strong theoretical prejudices that this is the case, but the observation of neutrinoless double beta decay is the proof of Majorana masses and lepton number violation.
- **What is the absolute scale of neutrino mass?** The measured oscillations determine mass differences, but not the overall scale of neutrino mass. Neutrinoless double beta decay is our most promising tool for determining that scale. As a virtual process it probes all neutrinos that couple to the electron. The neutrino mass scale is a crucial parameter in cosmology and astrophysics: without this parameter, the interpretation of current (e.g., WMAP) and future cosmic microwave background and large-scale structure surveys will be less certain. (The initial WMAP analysis quoted a mass sensitivity of 0.7 eV, though later analyses have claimed significantly less sensitivity.) The Majorana mass tested in ββ decay is the sum over $2n$ mass eigenstates, weighted by the coupling probability to the electron and by the relative

CP eigenvalue λ (assuming CP conservation), where *n* is the number of generations:

$$< m_{\nu}^{Maj} >= \sum_{i=1}^{2n} \lambda_i U_{ei}^2 m_i$$

- **What is the neutrino mass hierarchy?** Assuming three light neutrinos, the oscillation results allow three possible mass patterns: a standard seesaw hierarchy; a degenerate scheme where the various mass splittings are small compared to the overall scale; and an inverted hierarchy, where the (nearly degenerate) neutrino pair responsible for solar neutrino oscillations is heavier than the third neutrino. Assuming Majorana neutrinos, both of the later would produce neutrinoless ββ decay within the reach of next generation experiments. In fact, the next experiment could settle this issue, with a large Majorana mass indicating a degenerate scheme, and a null result indicating a standard seesaw hierarchy (or a Dirac neutrino).
- **CP violation in ββ decay.** Many theorists believe that the lepton number violation probed in double beta decay, together with CP violation, are the key to understanding baryogenesis. The mass pattern emerging from recent oscillation experiments, which suggests a seesaw Majorana mass scale ~ 0.3×10^{15} GeV ~ M_{GUT}, is quite consistent with leptogenesis models. While leptogenesis occurred at very high energies early in the big bang, the low-energy neutrino phases can be related to leptogenesis through models. The three-neutrino mass matrix contains three phases, one of which can be probed in long-baseline experiments, and two of which can only be probed in double beta decay. Extraction of these phases is a great challenge, made difficult by the nuclear structure uncertainties.
- **Nuclear physics.** Aside from its significance in neutrino physics, double beta decay is a fundamental nuclear decay mode for about 50 otherwise stable nuclei. The nuclear decay amplitude, a two-nucleon matrix element involving a sum over virtual intermediate nuclear states, is a challenging many-body problem. The quality of neutrino mass limits, or neutrino mass values, depends on the accuracy with which matrix element can be calculated. Double beta decay has stimulated important advances in nuclear structure theory, including Monte Carlo and Lanczos shell model techniques and quasiparticle RPA.

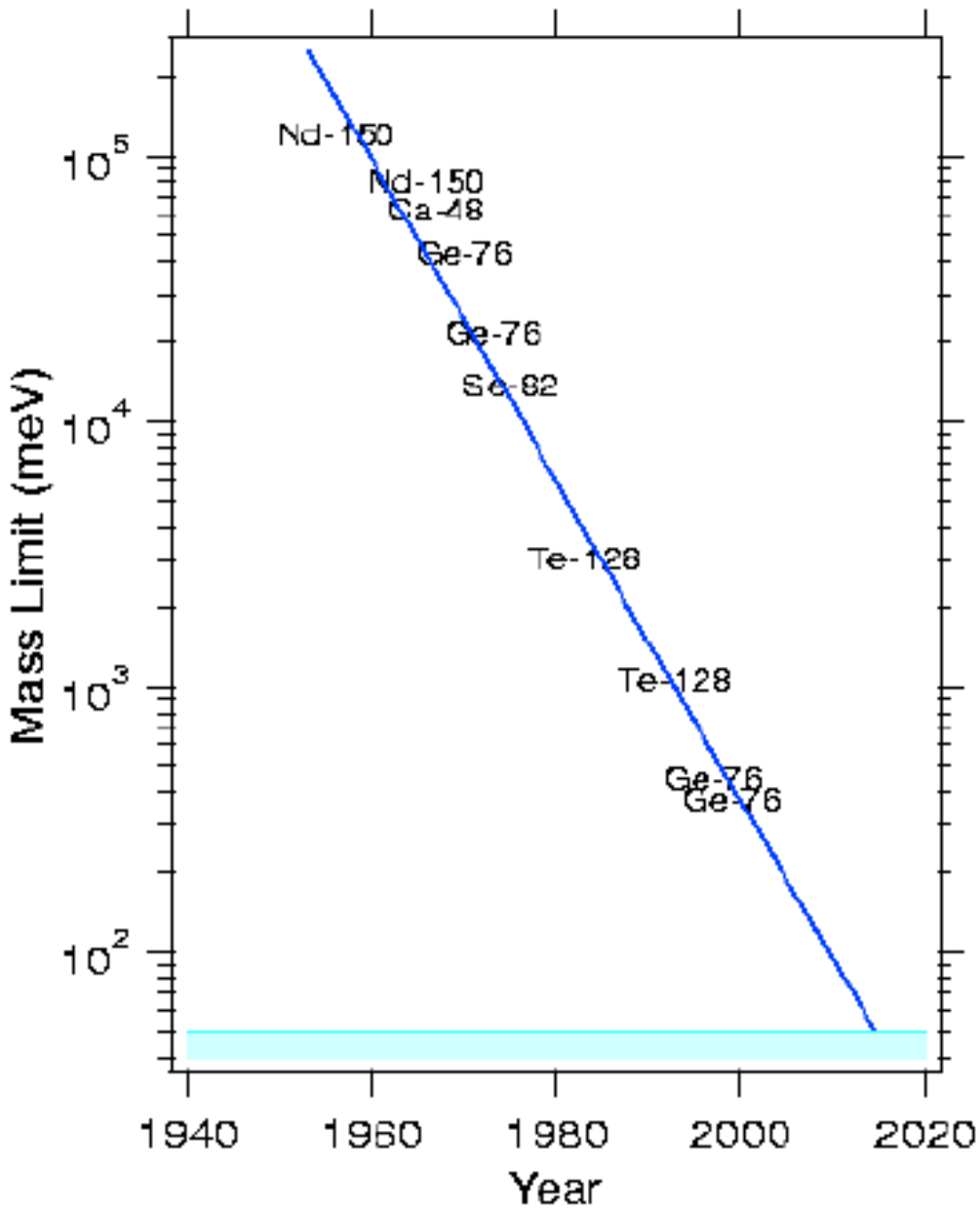


Figure C.2: Improvements in the Majorana mass limits from neutrinoless double beta decay experiments. As the half life is proportional to the square of this quantity, the trend represents a improvement in experimental sensitivity of five orders of magnitude over four decades. Next-generation experiments employing ton quantities of enriched isotopes have the potential to push sensitivities two or three orders of magnitude further.

Double Beta Decay Experiments								
Experiment	Isotope	Technique	Isotope Mass (kg)	Enriched	$Q_{\beta\beta}$ (MeV)	$\langle m_{ee} \rangle$ (eV) 90%CL	Overhead (mwe)	Location
Heidelberg-Moscow	^{76}Ge	5 Ge crystals	9.9	86%	2.04	< 0.40	2700	Gran Sasso, Italy
IGEX	^{76}Ge	6 Ge crystals	~9	86%	2.04	< 0.44	2450	Canfranc, Spain
UCI	^{82}Se	TPC with foils	0.014	97%	2.99	< 7.7	290	Hoover Dam, US
ELEGANT	^{100}Mo	drift chamber - scintillators	0.20	94.5%	3.03	< 2.7	1800	Oto, Japan
Kiev	^{116}Cd	$CdWO_4$ crystals	0.09	83%	2.8	< 3.3	1000	Slotvinia, Ukraine
Missouri	^{128}Te	Geochemical	Te Ore	No	.87	< 1.5	N/A	N/A
Milano	^{130}Te	Cryogenic 20 TeO_2 crystals	2.3	No	2.53	< 2.6	2700	Gran Sasso, Italy
Cal-UN-PSI	^{136}Xe	High Pres. TPC	2.1	62.5%	2.47	< 3.5	3000	Switzerland
UCI	^{150}Nd	TPC foils	0.015	91%	3.37	< 7.1	290	Hoover Dam, US
NEMO3	^{82}Se, ^{100}Mo, ^{116}Cd, ^{150}Nd	drift chamber-scintillator	1, 10, 1, 1	Yes	3.0, 3.0, 2.8, 3.4	~0.1	4800	Frejus France
CUORICINO	^{130}Te	Cryogenic 56 TeO_2 crystals	11.5	No	2.6	~ 0.1	2700	Gran Sasso, Italy
GENIUS	^{76}Ge	400 Ge crystals	1000	Yes	2.04	0.01		Gran Sasso, Italy
MAJORANA	^{76}Ge	210 Ge crystals	500	Yes	2.04	0.02	≥ 4000	
CAMEO	^{82}Se, ^{100}Mo, ^{116}Cd	Borexino CTF	~1, 1, 1	Yes	2.99, 3.0, 2.8	~1		Gran Sasso, Italy
MOON	^{100}Mo	Scint+Foils	3400	No	3.03	0.03	≥ 2500	
CUORE	^{130}Te	Cryogenic 1020 TeO_2 crystals	210	No	2.53	0.02		Gran Sasso, Italy
EXO	^{136}Xe	High Pres. TPC	10000	Yes	2.47	0.01	≥ 2000	
DBCA-II(2)	^{150}Nd	Drift chamber	18	Yes	3.37	~0.05		Oto, Japan

Figure C.3: A table of operating (blue), developing (red), and proposed (black) double beta decay experiments. The most noticeable change is the large masses proposed for future experiments, motivated by the mass scales deduced from atmospheric neutrino oscillation experiments.

A.2 Double Beta Decay: The Readiness of Next-Generation Experiments. Over the past 30 years a variety of experimental techniques for double beta decay searches have been developed and applied to favorable cases. Early work relied heavily on geochemical measurements; there are a couple of cases amenable to radiochemical techniques, as well. A great deal of progress has been made in recent years in experiments where the ββ decay source is also the detector. In particular, the most stringent limits have come from Ge detectors enriched in the double beta decay isotope of interest, ^{76}Ge (natural abundance 7.58%). The two most recent experiments, by the IGEX and Heidelberg-Moscow collaborations, have produced the most restrictive lifetime limits, and thus the best constraints on $<m_\nu^{Maj}>$, less than 300-1300 meV, with the range reflecting nuclear matrix element uncertainties.

The next-generation detectors now under consideration have as their goal mass sensitivities of 10-50 meV. All such experiments must have the following characteristics:

- Sufficient mass, ~ 1 ton, to acquire reasonable statistics.
- Good energy resolution, in order to separate the 0ν line (in the summed energy of the two electrons) from the tail of the 2ν ββ decay spectrum.
- Extremely low backgrounds: the detector must be located at sufficient depth to reduce cosmogenic backgrounds to an acceptable level and be made of sufficiently pure materials to render natural radioactivity backgrounds tolerable.

Several other considerations are important:

- The cost of next-generation experiments is such that the proposed technology must be thoroughly demonstrated before a full-scale experiment is undertaken.
- Although the use of an abundant natural isotope would be ideal, there are very few candidates. Experiments at the one-ton scale are practical with enriched isotopes, reducing the detector volume.
- A small detector volume generally minimizes internal backgrounds, which scale as the detector volume (provided the enrichment process does not concentrate some troublesome activity). It also minimizes external backgrounds by reducing the shielding volume necessary for the detector. By designing an apparatus where the detector is also the source, the detector size can be further reduced.
- A large Q value increases the phase space for ββ decay, and thus generally the rate. A large Q value also places the two-electron energy above many potential low-energy backgrounds.
- For a fixed 0ν ββ decay rate, nuclei with smaller 2ν ββ decay rates are favored, as this reduces possible confusion from 2ν events near the endpoint.
- Identifying the daughter nucleus in coincidence with the produced electrons is a very effective background suppression technique, eliminating virtually all backgrounds except 2ν ββ decay.
- Event reconstruction, providing kinematic data such as opening angles and the single-electron energy spectrum, can aid in the elimination of backgrounds.
- Good spatial resolution (detector granularity) and timing information are also effective in rejecting backgrounds.
- Certain nuclei – lighter isotopes or nuclei near closed shells – may be more tractable for nuclear structure studies. In such cases experimental limits (or an observation of double beta decay) can be more reliably translated into neutrino mass bounds (or results).

No experiment, past or proposed, has succeeded in optimizing all these characteristics simultaneously. Currently there are approximate 15 proposals for experiments hoping to achieve next-generation sensitivity. Of these proposals, there are four where the level of effort could, in the near term, result in a proven technique capable of reaching the 10-50 meV mass sensitivity goal. Each of these efforts has significant US involvement, and three of the four have indicated their desire for an underground location in the United States:

Majorana (^{76}Ge): Majorana is a next-generation enriched ^{76}Ge experiment that, in the view of many experts, is ***now ready for construction***. The experimenters propose to reach the 0.5-1.0 ton detector mass goal by staging, building additional modules as the enriched Ge becomes available. The readiness is based on the demonstrated success of very similar detectors at the 10 kg scale: the technical extrapolations required in scaling up to a multi-crystal array of the necessary mass are modest. The staging is important, allowing the experimenters to verify their techniques as detector mass is added. The results from the first modules, however, will quickly surpass current Moscow-Heidelberg and IGEX limits.

Worldwide there are two schemes being studied. The Majorana collaboration has proposed a 0.5-ton detector of segmented, 86% enriched ^{76}Ge diodes in multi-crystal arrays. A group at the Max Planck Institute, Heidelberg, is investigating a scheme for suspending the Ge crystals in a liquid nitrogen shield (GENIUS). The Heidelberg group has a small test facility operating at Gran Sasso, while the Majorana group is testing a prototype enriched segmented detector and is constructing an 18-crystal array of natural Ge diodes.

Several hundred enriched ^{76}Ge crystals, all segmented and instrumented for pulse-shape analysis, will reside in Majorana's modules. The modular design allows for easy access to the crystals while still minimizing the detector footprint. Although alternative methods are being explored, the low-risk baseline cooling method is conventional (unlike the GENIUS design). While the detector segmentation and improved pulse discrimination are advances over past designs, the vast bulk of the technology has been taken from earlier Ge experiments. The IGEX members of the Majorana collaboration have 25 years of experience in collaborating with industry on custom-designed Ge detectors and cryostats. The collaboration has previously fabricated electroformed copper parts for the cryostats and the shield that meet the activity limits for Majorana. The proposed Majorana electronics scheme has been used previously in Ge detectors, and the pulse-shape analysis algorithms have been tested in numerous detector installations. The ECP in Karsnoyarsk, which previously produced the enriched Ge used in IGEX, is the isotope supplier for Majorana. Thus the bulk of the technology necessary for Majorana has been tested and, in most cases, used in previous $\beta\beta$ decay experiments.

The Majorana collaboration – approximately 50 scientists from 12 institutions – intends to submit its proposal in spring, 2003. Within 1.5 years of initial funding the group will have at least one 50 kg module commissioned underground and operating. One year of data will produce a half-life limit one order of magnitude beyond current experiments. The cost to complete the full array is estimated to be $75-100M. The experiment requires a deep underground site, with an overburden of at least 4500 mwe, as discussed below.

Cuore (^{130}Te): The success of the MIBETA experiment, an array of TeO_2 cryogenic detectors with a total mass of 6.8 kg, led to the CUORE proposal (Cryogenic Underground Observatory for Rare Events). In CUORE 1000 750-g TeO_2 crystals will be operated as a collection of bolometers. The detectors will be grouped into 25 separate towers of 40 crystals, with each tower arranged in 10 planes of four crystals each. One such plane with a mass of 40 kg has now been successfully tested and a single tower prototype, called CUORICINO, began operations at the Gran Sasso laboratory in January 2003. CUORICINO will provide an important test of backgrounds and other experimental parameters.

The energy resolution at the $0\nu\ \beta\beta$ decay peak (2.529 MeV) is expected to be about 5 keV FWHM (~ 0.2%). The background measured in the first plane is ~ 0.5 counts/(keV kg y). However a major contributor to this background was surface contamination arising from the use of a cerium oxide polishing compound high in thorium. With this problem eliminated, the experimenters anticipate that backgrounds will be reduced below ~ 0.1 counts/(keV kg y).

A major advantage of CUORE is that the isotope of interest, ^{130}Te, has a natural abundance of

34%. Thus no enrichment is needed, resulting in lower costs. The MIBETA results indicate that cosmogenic activities within the TeO_2 crystals are not a serious concern. On the other hand, the crystal mounts and cryostat form a significant amount of material close to the bolometers. Much of the cryostat is shielded with low-activity lead from Roman times, but quantities of copper and Teflon remain close to the crystals.

CUORE is likely **close to being ready for construction**. If CUORICINO is not background limited and reaches it design sensitivity goals, the group will then be ready to proceed with CUORE construction. This evaluation should be possible after about a year of CUORICINO operations, which places the CUORE decision point early in 2004. The CUORE collaboration is led by Italian groups, but there are members from the US (LBNL and Univ. of South Carolina), Spain, and the Netherlands. The collaboration estimates construction costs of $8-10M. The proposed site for CUORE is Gran Sasso.

EXO (^{136}Xe): The Enriched Xenon Observatory (EXO) is a proposal to use up to 10 tons of 60-80% enriched ^{136}Xe in a scintillation detector. The unique aspect of the experiment is the proposed detection of the ^{136}Ba daughter ion in coincidence with the decay event. If this technique were perfected, it would eliminate virtually all background except that associated with 2ν ββ decay. The real-time optical detection of the daughter Ba ion might be possible if the ion can be localized and probed with lasers. This spectroscopy has been used for Ba^+ ions in atom traps. However the additional technology to detect single Ba ions in a condensed medium or to extract single Ba ions from a condensed medium and trap them has yet to be demonstrated. The optical detection of the Ba^+ ion is accomplished by pumping the ion from the $6^2S_{1/2}$ ground state to the $6^2P_{1/2}$ excited state via a 493-nm laser. As the excited state has a 30% branching ratio to the $5^4D_{3/2}$ metastable state, the ion can be detected by re-exciting this metastable state to the 6P state via a 650-nm laser, then observing the decay back to the ground state. The procedure can be repeated millions of times per second on a single ion to produce a significant signal.

EXO will use liquid Xe scintillator, as a gaseous TPC would require a larger detector to accommodate the same Xe mass. However, at liquid densities the laser light scattering is too great to permit optical detection of the Ba ions *in situ*. Thus the proposed technique, once the candidate ββ decay event is localized via its scintillation and ionization, is extraction of the ion via a cold-finger electrode coated in frozen Xe. The ion is electrostatically attracted to the cold finger, which later can be heated to evaporate the Xe, releasing the Ba ion into a radiofrequency quadrupole trap. At this point the Ba^{++} ion is neutalized to Ba^+, laser cooled, and optically detected. The focus of current research is to demonstrate each of the steps in this procedure.

Achieving sufficient energy resolution to avoid interference from 2ν ββ decay is important to EXO. The collaboration recently demonstrated, by measuring scintillation light and ionization simultaneously, that the necessary resolution could be achieved. The EXO collaboration has received DOE HEP funding to proceed with a 200-kg enriched Xe detector without Ba tagging. This initial prototype, which will be sited in the Waste Isolation Pilot Plant (WIPP) in New Mexico, will help the collaboration evaluate backgrounds and other aspects of the experiment.

While the EXO experiment still has **technical issues remaining to be resolved**, the possibility of nearly background-free observation of ββ decay in a very large (10-ton) detector is exciting. As in the case of the experiment discussed below, this new technology may ultimately prove to have greater reach that any currently existing, and thus could provide the foundation for next-to-next-generation efforts, too.

MOON (^{100}Mo): The MOON (Mo Observatory of Neutrinos) collaboration will use ^{100}Mo as a 0ν ββ decay source and as a target for solar neutrinos. These two science goals (as well as the sensitivity to low-energy supernova electron neutrinos) make the detector an enticing idea. ^{100}Mo has a high Q-value (3.034 MeV), enhancing the phase space for ββ decay and placing the

summed electron energy peak well above most radioactivity backgrounds. It appears to have favorable matrix elements for 0ν and 2ν ββ decay, which will enhance the neutrino mass sensitivity, provided sufficient resolution is achieved to reduce 2ν backgrounds. Energy and angular correlation measurements in the detector will be used to identify 0ν ββ decay events and reject backgrounds. The initial MOON concept was a supermodule of scintillator and Mo ensembles. One option is a module of plastic fiber scintillators with thin (0.03 g/cm^2) layers of cladded Mo, arranged to achieve position resolution comparable to the fiber diameter (2-3 mm). A total of 34 tons of natural Mo would provide ~ 3.3 tons of ^{100}Mo (abundance 9.63%).

As a solar neutrino detector ^{100}Mo has a low threshold (168 keV), a known and favorable cross section, and a charged-current event rate of ~ 160/(^{100}Mo ton y) (without neutrino oscillations). The subsequent delayed decay (15.8 s) of the daughter nucleus ^{100}Tc to ^{100}Ru provides a coincidence. The primary background to this coincidence is thought to be 2ν ββ decay.

Radiopurity levels of better than 1 mBq/ton must be achieved in the Mo and scintillator. Plastics of this cleanliness can be produced, while the Mo requirements can be met with carbonyl chemistry. However, the total surface area of the Mo-scintillator modules, ~ 26000 m^2, poses difficulties. Dust, being electrostatically charged, tends to garner Rn daughters and become radioactive. Keeping these surfaces free of dust during production and assembly will be a challenge. Another challenge is the resolution. Simulations indicate that energy resolution for the 0ν ββ decay peak will be ~ 7%, which is at the upper end of the range of feasibility for sub-50-meV sensitivity to neutrino mass.

A more attractive option may be a bolometer, yielding improved energy resolution and a smaller surface area. This would likely require an insulating compound substituting for the pure Mo. MOON is in an R&D phase with **significant technical challenges not yet resolved**. The Japanese-US collaboration that is developing MOON has not yet developed a firm cost estimate, but the experiment will require funding in excess of $50M. It will require a very deep site, preferably in a US underground laboratory.

A.3 Double Beta Decay: Facility Requirements. This section summarizes the facility requirements for double beta decay: what must an underground laboratory provide to optimize the prospects for next-generation experiments?

Cosmogenic backgrounds and depth requirements: Current double beta decay experiments generally employ active shields to reduce cosmic ray backgrounds. MOON and Majorana background estimates include the use of such shields in combination with rather stringent data cuts. This will reduce backgrounds to an acceptable but not negligible level: Majorana anticipates seven background events in the region of the double beta decay peak, assuming a 10-year exposure. For this reason there is concern about backgrounds not yet identified and/or that evade the veto. Of particular worry are cosmic-ray-associated high-energy neutrons, which can induce spallation, capture γs, recoils, and inelastic reactions.

An important benchmark for Majorana comes from the current IGEX ^{76}Ge experiment, which is located in the Canfranc tunnel at a depth of 2450 mwe. Approximately one-third of the total count rate in the endpoint region of interest (2038 keV) is correlated with the cosmic ray muon veto. From this rate the Majorana collaboration has estimated that similar events occurring near (but outside) the veto shield could, via neutron secondaries, double the anticipated Majorana background rate. Increasing the depth is significantly easier than other possible mitigating steps, such as direct detection of high-energy neutrons. A site at 4000 mwe will reduce cosmic-ray muon levels to 2×10^3/m^2/y, about a factor of 12 below Canfranc levels. Today this would require siting Majorana outside the US.

Proposed double beta decay experiments involve a variety of heavy nuclei including Ca, Ge, Se,

Mo, Cd, Te, and Xe. A detailed catalog of potential radioisotope production from such targets is not presently available. This has placed an additional burden on experimentalists, who individually must estimate cross sections and identify isotopes of concern. Ultimately crucial reactions must be tested with accelerator experiments. The associated uncertainties make deep sites attractive.

Spallation reactions on carbon in the scintillator used in MOON may be the most serious depth-related background in this detector, affecting both double beta decay and pp neutrino detection. A worrisome activity is ^{10}C produced by (n,3n). ^{10}C produces a positron and a 718 keV γ after 0.71 ns. (Recall that the pp signal is a prompt low-energy electron followed by a β decay delayed by ~ 15 s.) The effectiveness of possible cuts will depend on the position resolution achieved in MOON; estimates of the depth required to reduce this background to a negligible level currently range from 5000-6000 mwe.

EXO may have less stringent depth requirements. The published (hep-ex/0002003) background study of EXO considered a penetrating muon flux of $0.01/m^2/s$, which corresponds to an overburden of about 2400 mwe. Based on the Gothard group's experience with TPC muon rejection, it is estimated that the laser system would be needed less than once per hour for muons entering the detector but not otherwise rejected. Muons interacting outside the detector can produce neutrons that would enter EXO undetected. The discussion in hep-ex/002003/ noted that many of the resulting spallation reactions would be rejected by the associated high-ionization short-track events. We are not aware of detailed discussions of (n,2n) and similar neutron reactions that could evade such detection.

The backgrounds that have received the most attention from the EXO collaboration are not depth related. These include γ rays associated with radon or other radioactive gases leaking into the detector volume and 2ν $\beta\beta$ decay. For an assumed energy resolution of $\sigma \sim 44$ keV, considered to be conservative, 23 2ν events would occur within 2σ of the endpoint per ton-year. The ultimate sensitivity of the EXO technology may depend on improvements in the resolution that come from the additional event kinematics cuts possible in a TPC.

In summary, Majorana background estimates suggest that 4500 mwe would be an adequate depth, though the collaboration favors a deeper site, if available, to provide some margin of safety. MOON depth requirements are still quite uncertain, with the possibility that very great overburdens of 6000 mwe will be necessary. Provided the laser tagging is perfected and the prototype experiment reveals no unanticipated cosmogenic backgrounds, EXO could function at depths as shallow as 2000 mwe.

Double beta decay space requirements: The space requirements for the experiments, given as length × width × height, are:

- Majorana: $5\times 4 \times 3$ m^3 apparatus and $4 \times 4 \times 3$ m^3 control systems.
- EXO: $5 \times 5 \times 5$ m^3 apparatus, $5 \times 4 \times 3$ m^3 control systems, and $4 \times 4 \times 3$ m^3 cryogenic purification systems.
- MOON: $5 \times 8 \times 5$ m^3 apparatus and $8 \times 11 \times 6$ m^3 lab area and control systems.

Basic facilities needs: Most of the general site requirements of double beta decay experiments are modest. They include:

- Power requirements of 10-25 kW.
- Stable temperatures, usually 20°C or less, with air conditioning.
- Scrubbed air, with residual radon levels below $1 Bq/m^3$.
- A clean room for preparations, assembly and cleaning.
- DI water system.
- Cranes for assembly and manipulation of detector and shielding elements.
- Radon-free materials storage area.

- Machine shop, both general and for ultra-low background work.
- Low-level counting capabilities for materials screening.
- A source of radon-free liquid nitrogen or nitrogen gas. (Most experiments have a critical volume needing to be purged of radon. Pure nitrogen purge gas is commonly used, e.g., boil-off N_2 gas from liquid nitrogen.)

Special facilities needs (experiment specific): Majorana and EXO have identified special facilities needs and special safety concerns.

- An underground copper electroforming facility. The acids and plating baths used in the electroforming require special safety procedures. (Majorana)
- Possibly, underground Ge crystal growth and detector preparation facilities. (Majorana)
- Large-volume liquid Xe containment. Large quantities of liquid cryogens present an oxygen displacement hazard. (EXO)
- A system for continuous cryogenic purification. (EXO)

A.4 Double Beta Decay: Summary. The importance of the science and the readiness of key next-generation experiments like Majorana argue that NUSEL must be able to host such experiments as early as possible. In addition there are exciting new technologies under development that could exceed existing techniques in reach. Thus NUSEL should be prepared to host at least two such experiments. There are many shared resources that would benefit all $0\nu\ \beta\beta$ decay experiments and R&D efforts, as well as other activities within NUSEL. These should be part of basic NUSEL infrastructure. There are also some technical needs and safety concerns that are experiment specific.

B.1 Solar Neutrinos: The Importance of the Science. The field of neutrino astrophysics began in 1965 with the efforts of Ray Davis Jr. and his colleagues to measure solar neutrinos, a byproduct of thermonuclear energy generation in the solar core. The subsequent history of this subject demonstrates the rapidly accelerating pace of technical innovation in underground science, the increasing breadth of the scientific issues, and the deepening connections with both conventional astrophysics and accelerator experiments.

Solar neutrinos offer unique opportunities for testing both electroweak physics and the nuclear reactions occurring in the interior of our best known star. The neutrino flux predictions come from the standard solar model (SSM), an application of the theory of main-sequence stellar evolution to our nearest star. The SSM traces the evolution of the sun over the past 4.6 billion years, thereby predicting the present-day temperature and composition profiles of the solar core that govern neutrino production. The SSM is based of four assumptions:

- The sun evolves in hydrostatic equilibrium, maintaining a local balance between the gravitational force and the pressure gradient. To implement this condition in a calculation, one must specify the equation of state as a function of temperature, density, and composition.
- Energy is transported by radiation and convection. While the solar envelope is convective, radiative transport dominates in the core region where thermonuclear reactions take place. The opacity depends sensitively on the solar composition, particularly the abundances of heavier elements.
- Thermonuclear reaction chains generate solar energy. The SSM predicts that the energy is produced from hydrogen burning, $4p \rightarrow {}^4He + 2e^+ + 2\nu_e$, through the pp chain (98% of the time) and CNO cycle. The core temperature, $\sim 1.5 \times 10^7$ K, results in typical center-of-mass energies for reacting particles of ~ 10 keV, much less than most of the Coulomb barriers inhibiting charged particle reactions. Thus cross sections are small, and generally must be estimated from laboratory data taken at higher energies.

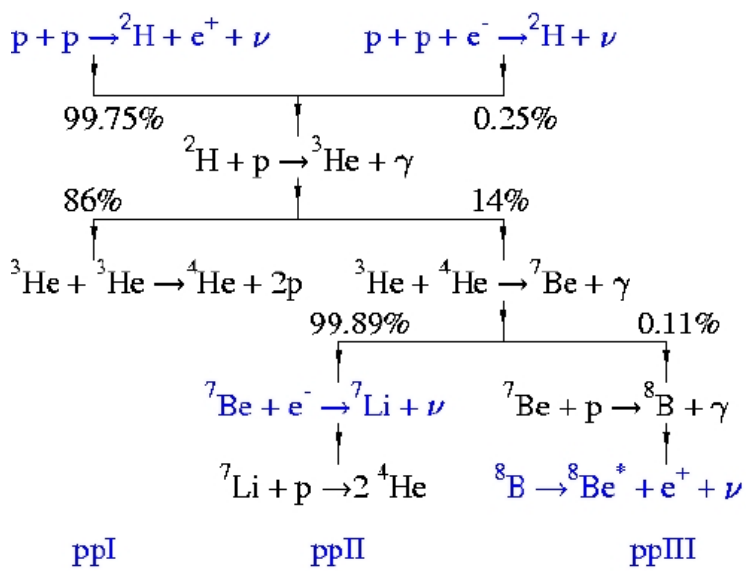


Figure C.4: The pp chain, showing the three cycles and the neutrino-producing reactions that probe the competition between the cycles.

- The SSM is constrained to produce today's solar radius, mass, and luminosity. The sun is believed to have been highly convective when it first entered the main sequence. Thus, with the assumption that the surface abundances of metals (A>5) were undisturbed by the subsequent evolution, the SSM equates the initial core metalicity to the observed surface abundances. The remaining parameter, the initial abundance ratio ^{4}He/H, is adjusted until the model reproduces the present solar luminosity after 4.6 b.y. of evolution.

Experimental tests of the standard model, including measurements of the sound speed throughout most of the solar interior, are in good agreement with the SSM. Thus we can use this model with some confidence in predicting the flux of ν_es from the sun. The principal neutrino sources come from p+p β decay (maximum neutrino energy of 420 keV), from p+p+e^- (producing a line source of neutrinos at 1.44 MeV), from ^{8}B β decay (maximum energy ~ 15 MeV), and from electron capture on ^{7}Be (producing line sources at 860 and 380 keV). There are also significant fluxes from CNO cycle reactions.

Davis used 610 tons of perchloroethylene (C_2Cl_4) in a radiochemical experiment to look for the solar-neutrino- induced reaction ^{37}Cl(ν_e,e^-)^{37}Ar. The experiment, which was sensitive primarily to the high-energy ^{8}B and ^{7}Be neutrino fluxes, was mounted at the 4850 ft level of Homestake. The results led to the recognition of the "solar neutrino problem" – the observation of an electron neutrino flux substantially (~ factor of three) below the predictions of the SSM. The Davis experiment was followed, in the 1980s, by the Kamiokande experiment in Japan, where solar neutrinos were observed in a 4.5-kiloton water Cerenkov detector. Solar neutrinos elastically scatter (ES) off of electrons in the water, with the recoiling electron then detected because of the Cerenkov radiation it produces. The direction of the recoil electron – away from the sun – is an important aid in separating events from background. This event-by-event direct detection experiment was sensitive to the high-energy portion of the ^{8}B solar neutrino flux. In the 1990s two new radiochemical experiments, SAGE and GALLEX, used ^{71}Ga as the target to make integral measurements primarily sensitive to the low energy pp and ^{7}Be neutrino fluxes. SAGE was mounted in the Baksan Laboratory in Russia, and used gallium metal, which is a liquid slightly above room temperature. GALLEX was performed in Gran Sasso and used a $GaCl_3$ solution. In each of these experiments substantially lower neutrino fluxes were found than predicted by the SSM. The pattern of discrepancies was difficult to explain by making plausible adjustments to the SSM, such as changes that might lower the core temperature.

An elegant particle-physics solution to these discrepancies is provided by neutrino oscillations – a phenomenon requiring massive neutrinos and mixing (that is, mass eigenstates not coincident with the flavor eigenstates). The oscillation of solar electron neutrinos into ones of another flavor would result in reduced detection rates in all of the detectors discussed above. As massive neutrinos are not allowed in the standard electroweak model – a consequence of the lack of a right-handed neutrino field and the requirement of renormalizability – neutrino oscillations would imply new physics.

The sun is an extraordinary neutrino source for investigating neutrino oscillations. The long baseline (~ 10^8 km) between the source (the solar core) and the earth, combined with the low energies of solar neutrinos, implies sensitivity to the differences in the squares of neutrino masses of $\delta m^2 \sim 10^{-12}$ eV^2. Such a value is many orders of magnitude beyond the reach of terrestrial experiments. Moreover, as the neutrinos pass through ~ 10^{10} g/cm^2 of matter before exiting the sun, their interactions can lead to great enhancements in oscillation probabilities. This phenomenon, the Mikheyev-Smirnov-Wolfenstein (MSW) mechanism, arises because the effective masses of neutrinos are altered by the presence of matter. In particular, the electron neutrino mass increases relative to those of the other neutrino flavors, producing a level crossing (nearly degenerate neutrino masses) at some critical solar density.

The most decisive solar neutrino experiments were mounted recently. Super-Kamiokande is the successor to the Kamioka experiment, with a mass of 50 kilotons of ultrapure water and a solar neutrino ES event rate of many thousands per year. This detector is primarily sensitive to electron neutrinos as the heavy-flavor cross section is only 0.15 that for electron neutrinos. This experiment provided a very precise constraint on the flux, on the spectrum of recoil electrons, and on day-night differences arising from MSW effects in the earth. The Sudbury Neutrino Observatory is using 1 kiloton of heavy water to distinguish electron and heavy-flavor solar neutrino reactions. The heavy water is contained within a central acrylic vessel, which is surrounded by seven kilotons of ordinary water. SNO detects ν_es via the charged-current (CC) reaction $\nu_e+d\rightarrow p+p+e^-$ and neutrinos of any flavor by the neutral-current (NC) breakup reaction $\nu_x+d\rightarrow p+n+\nu_x$. The first reaction provides excellent spectral information, as the electron carries off most of the energy of the incident neutrino, while the NC measurement is an integral one (only the neutron is measured). By comparing the CC and NC rates, one can separately determine electron and muon/tauon neutrino components of the solar neutrino flux (measured at Earth). The CC results show a reduced flux and a spectral shape consistent with matter-enhanced neutrino oscillations. SNO's NC measurements yielded a total ^{8}B neutrino flux (summed over flavors) in good agreement with the predictions of the SSM. The comparison of the CC and NC results shows that approximately 2/3rds of the solar neutrinos arrive on earth as heavy-flavor neutrinos.

These new results are quite spectacular. With very high confidence the solar neutrino problem is due to flavor oscillations with parameters in the so-called large-mixing-angle (LMA) region of the δm^2-$\sin^2 2\theta$ plane. The SNO NC agreement with the SSM is gratifying because this flux depends critically on the solar core temperature, varying approximately as T_c^{22}, where T_c is the solar core temperature. The LMA solution has recently been verified by a terrestrial experiment, KamLAND, which measures the electron antineutrino flux produced by Japanese power reactors at various distances from the detector. The KamLAND results further restrict the values of δm^2 allowed within the LMA region.

Because of the importance of the solution uncovered – massive neutrinos and neutrino oscillations are the first phenomena we have found that require physics beyond the standard electroweak model – there is great interest in extending such measurements to lower solar neutrino energies. The primary goal of the field is to make precise measurements of the fluxes and flavors of the lower energy solar neutrinos, particularly the pp neutrinos, the dominant solar neutrino flux (90% of the total) produced in the initial step of hydrogen burning. Arguably the pp neutrino flux, at its solar source, is known more precisely than any other, terrestrial or astrophysical. This opens possibilities for probing fundamental questions in both astrophysics and physics:

Physics

For the foreseeable future, solar neutrinos will provide the only intense source of electron neutrinos. These neutrinos are essential in efforts to understand the properties of neutrinos and in probing new phenomena like CPT violation.

A low-energy solar neutrino measurement provides an important test of the LMA solution. One feature of this solution is that the survival probability for low energy neutrinos is substantially higher than that for the ^{8}B neutrinos measured in SNO. Verifying this prediction is important. A low-energy measurement, when combined with SNO data, will also help to narrow the uncertainty on δm_{12}^2.

Future high-statistics pp solar neutrino experiments provide the best opportunity for improving our knowledge of θ_{12}. Assuming that there are only three active neutrino flavors, solar neutrino oscillations are dominated by the mixing of two mass eigenstates, ν_1 and ν_2. Solar neutrino experiments are the primary source of information on δm_{12}^2 and θ_{12}. While KamLAND has

helped to narrow the LMA solution region in δm_{12}^2, neither it nor Borexino will appreciably improve our knowledge of the mixing angle. A pp solar neutrino measurement with an uncertainty of 3% would constrain θ_{12} with an accuracy comparable to that possible with the entire existing set of solar neutrino data. Thus a goal of next-generation pp solar neutrino experiments is to achieve 1% uncertainty, thus substantially tightening the constraints on θ_{12}.

Precision flux measurements of the low-energy (pp and ^{7}Be) solar neutrinos will substantial improve limits on sterile neutrinos coupling to the electron neutrino. Sterile neutrinos with even small couplings to active species can have profound cosmological effects. The coupling of ν_es to sterile states can be limited by CC and NC measurements with an accurately known neutrino source. KamLAND (together with the SNO CC and NC data) should ultimately limit the sterile component of ^{8}B neutrinos to ~ 13%. This bound can be improved by measuring the NC and CC interactions of pp and ^{7}Be neutrinos to accuracies of a few percent. In general one expects the sterile component of solar neutrino fluxes to be energy dependent. Thus low-energy solar neutrino experiments are an important part of such searches.

Future pp solar neutrino experiments will be able to probe CPT violation with an order of magnitude more sensitivity than has been achieved in the neutral kaon system. As neutrinos are chargeless, they provide an important testing ground for CPT violation. If CPT is violated, the neutrino mass scale and mass splittings will differ between neutrinos and antineutrinos. A high precision measurement of the pp ν_e survival probability is an important component of CPT violation searches. In some models this will test CPT violation at a scale $< 10^{-20}$ GeV, which can be compared to the present bound from the neutral kaon system, $< 4.4 \times 10^{-19}$ GeV.

Preliminary estimates indicate that limits on the neutrino magnetic moment could be improved by an order of magnitude in future pp neutrino ES experiments. A neutrino magnetic moment will generate an electromagnetic contribution to neutrino ES, distorting the spectrum of scattered electrons. The effect, relative to the usual weak amplitude, is larger at lower energies, making a high-precision pp solar neutrino experiment an attractive testing ground for the magnetic moment. The strongest existing laboratory limit, $\mu(\nu_e) < 1.5 \times 10^{-10}$ Bohr magnetons, could be improved by an order of magnitude in a 1% experiment.

Solar neutrino detectors are superb supernova detectors. Many of the most interesting features in the supernova neutrino "light curve" are flavor specific and occur at late times, 10 or more seconds after core collapse. Because of their low thresholds, flavor specificity, large masses, and low backgrounds, solar neutrino detectors are ideal for following the neutrino emission out to late times. Solar neutrino detectors will likely be the only detectors capable of isolating the supernova ν_e flux during the next supernova. The 3 ms deleptonization burst, important in kinematic tests of neutrino mass, is mostly of this flavor. Electron-flavor neutrinos also control the isospin of the nucleon gas – the so called "hot bubble" – that expands off the neutron star. The hot bubble is the likely site of the r-process. Currently we lack a robust model of supernova explosions. The open questions include the nature of the explosion mechanism, the possibility of kaon or other phase transitions in the high density protoneutron star matter, the effects of mixed phases on neutrino opacities and cooling, possible signatures of such phenomena in the neutrino light curve, and signals for black hole formation. Supernovae are ideal laboratories for neutrino oscillation studies. One expects an MSW crossing governed by θ_{13}, opening opportunities to probe this unknown mixing angle. The MSW potential of a supernova is different from any we have explored thus far because of neutrino-neutrino scattering contributions. Oscillation effects can be unraveled because the different neutrino flavors have somewhat different average temperatures. All of this makes studies of supernova neutrino arrival times, energy and time spectra, and flavor composition critically important. Finally, the detection of the neutrino burst from a galactic supernova will provide an early warning to optical astronomers: the shock wave takes from hours to a day to reach the star's surface.

Some proposed solar neutrino detectors serve as double beta decay and particle dark matter detectors. Examples are MOON (double beta decay) and CLEAN and Majorana (WIMP dark matter).

Astrophysics

Solar neutrino experiments provide crucial tests of the SSM. The delicate competition between the ppI, ppII, and ppIII cycles comprising the pp chain is sensitive to many details of solar physics, including the core temperature, the sun's radial temperature profile, the opacity, and the metalicity. This competition can be probed experimentally by measuring the ^{7}Be flux (which tags the ppII cycle), the ^{8}B flux (which tags the ppIII cycle), and the pp flux (which effectively tags the sum of ppI, ppII, and ppIII). The pp neutrino flux is a crucial test of the SSM due to the accuracy with which it is predicted (~ 1%). Present experiments have left substantial uncertainties in flux determinations. While the situation will improve with new data from SNO and Borexino, future high-precision pp flux measurements (~ 1%) are crucial, as the table indicates.

	pp	^{7}Be	CNO	^{8}B
Present experiments	18%	35%	100%	13%
Near-term experiment	12%	8%	100%	8%
Future experiments	1-3%	2-5%	5-10%	2-5%

Table IB.1 Present and anticipated precision of solar neutrino experiments.

The CNO neutrino flux is an important test of stellar evolution. Approximately 1.5% of the sun's energy is produced through CNO-cycle hydrogen burning. The CNO cycle is important in the early evolution of the sun as out-of-equilibrium burning of C, N, and O powers an initial convective solar stage, thought to last about 10^8 years. Furthermore, one of the key SSM assumptions equates the initial core metalicity to today's surface abundances. A measurement of CNO cycle neutrinos would quantitatively test this assumption.

B.2 Solar Neutrinos: The Readiness of Next-Generation Experiments. The difficulty of proposed new experiments to characterize the low-energy solar neutrinos is high. The requirement is to develop new-generation detectors with high statistics, thresholds in the 100 keV range, and abilities to reject backgrounds that rise exponentially as thresholds are lowered. There are excellent R&D programs, some of which are quite mature, focused on meeting these requirements. But no project has resolved all of the questions of background suppression, systematics, and cost-effective detector design, and thus none is ready for construction.

The proposed detectors include both ES and CC schemes in which the end goal is sensitivity to low-energy neutrinos with 1-3% uncertainty. Both types of detectors are needed to determine the flavor content of the solar flux. Both types of experiments generally require specialized underground sites, with the depth requirements for ES detectors being particularly stringent (~ 6000 mwe, according to the recent NRC Neutrino Facilities report).

The ES pp neutrino experiments discussed below are HERON, TPC, and CLEAN, the leading US R&D efforts. There is also an important Japanese effort, XMASS. The XMASS detector will record scintillation light produced by ES in a few tons of isotopically enriched liquid Xe. XMASS will also be used in double beta decay and dark matter searches, though with different Xe isotopes as the source/target. An important advantage of ES experiments is the certainty with which the ES cross section is known. This makes it possible to contemplate a 1% measurement of the pp flux, which would substantially narrow the uncertainty on θ_{12}, without calibration by an artificial neutrino source.

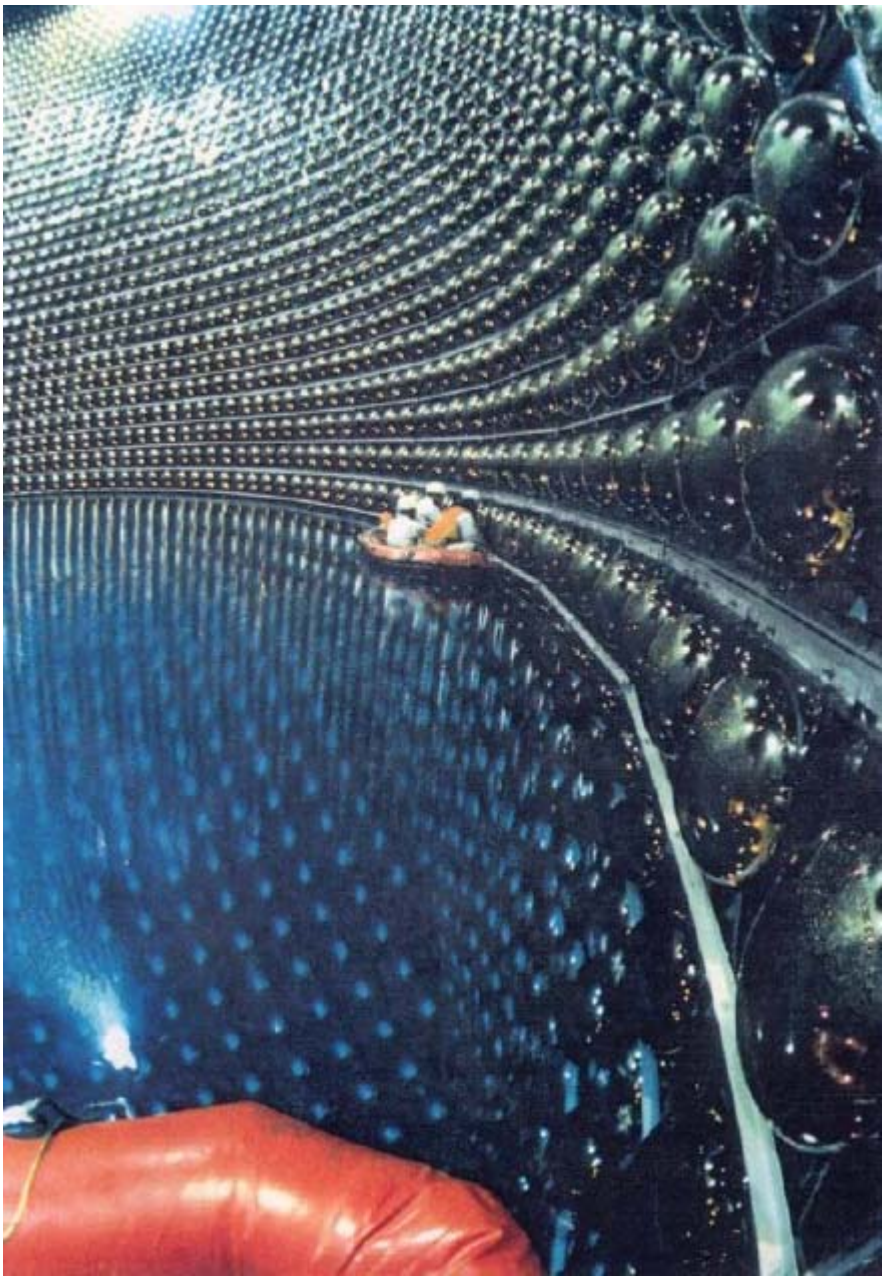


Figure C.5: The Super-Kamiokande detector, as it was being filled for the first time. This is an example of a large (50 kton) underground detector requiring a specialized excavation. Next-generation experiments now under consideration are an order of magnitude larger and must be sited at a depth of at least 4000 mwe, so that the cosmic ray muon background is an order of magnitude smaller than in Super-Kamiokande.

LENS and MOON are the two CC R&D efforts discussed below. These use inverse β decay in combination with a delayed decay of the daughter nucleus, with this coincidence helping to distinguish events from background. Both detectors employ highly segmented designs in order to reduce backgrounds from accidental coincidences.

CLEAN (ES in Liquid Neon): The goal of CLEAN is a 1% measurement of the ES of pp and ^{7}Be solar neutrinos in liquid neon. CLEAN will also search for particle dark matter by observing the recoil of neon nuclei after the scattering of weakly interacting massive particles (WIMPs). The recoil electrons produced by neutrino ES produce about 15000 extreme ultraviolet photons/MeV, split between two components: two-thirds are in the short (5 ns) singlet state and one-third is in the long (3.9 μs) triplet state. This yields an estimated 1.4 photoelectrons detected per keV, implying 17% energy resolution for a 100 keV β. The expected threshold for CLEAN is ~ 20 keV. The scintillation light is isotropic and thus provides no directional information. The position of an event can be reconstructed with a resolution of 20-30 cm, thus allowing one to use fiducial volume cuts effectively.

The proposed detector consists of a cylinder, 6m in diameter and 6m high, containing liquid neon at 27K. A spherical array of PMTs is suspended within the cylinder. The neon-filled cylinder is housed in a liquid nitrogen shield and surrounded by an ultrapure water shield to reduce the external gamma ray flux (e.g., from the rock walls in NUSEL). The detector and shield together fill a cylindrical volume, 12m in diameter and 12m high. The fiducial volume of 10 tons is defined to be a 2.5m diameter sphere at the center of the detector.

The advantages of liquid neon include the absence of long-lived radioisotopes, high density (1.2 g/cm^3), high scintillation yield, low cost of the target material ($40K/ton), and the ease with which neon can be purified by distillation and cold traps. The dominant background in CLEAN is expected to be γs from the PMTs. The wavelength shifter employed in the detector can be coated on a low-radioactivity substrate well removed from the PMTs, allowing a very low total count rate. The fiducial volume cut (the restriction to the 2.5m diameter sphere at the center) yields an estimated background/signal ratio of a few percent. It has been estimated that a depth of 4500 mwe is sufficient to reduce cosmic backgrounds to less than 1% of the signal. (However, uncertainties in this estimate are discussed in the next section.)

CLEAN also has potential as a supernova neutrino and particle dark matter detector. Supernova neutrinos could be recorded by ES and by nuclear recoil, following coherent scattering of the neutrino off a neon nucleus. A comparison of the two rates will provide important information on the energy spectrum of heavy flavor supernova neutrinos. WIMP scattering on neon also produces observable recoil energies. If CLEAN reaches its background goals, it will be fully competitive with the next generation of ~ 1 ton dedicated dark matter detectors.

While **significant R&D issues remain to be resolved** in the CLEAN project, progress has been very good. The collaboration has purchased and successfully tested low-background PMTs at liquid-neon temperatures. Measurements of the photon yield and attenuation lengths in liquid neon are underway. A proposal for a 1-ton prototype will be submitted in 2003. The collaboration will study light attenuation and detector cryogenics with the prototype, and may convert the prototype into a particle dark matter detector by refilling it with liquid xenon. The collaboration is expanding as the R&D is carried out. With good progress the group expects to submit a construction proposal a few years from now. While a careful cost estimate cannot be made at this time, expectations are in the $40-60M range.

HERON (ES in Helium): HERON is a proposal to observe the ES of pp and ^{7}Be solar neutrinos in superfluid liquid helium. The recoil electron produces both ionization and rotons that

propagate throughout the detector. Recombination of the ionization cloud produces in excess of 30,000 photons/MeV of extreme ultraviolet (16 eV) photons. The photons are detected in a set of bolometers mounted above the surface of the liquid helium. The rotons that reach the superfluid surface eject a burst of energetic ^{4}He atoms, which then condense onto the silicon bolometers mounted above the surface, producing a temperature rise in the bolometers. The energy resolution is extremely good, ~ 6 eV for a 6 keV x-ray, and the threshold is expected to be no more than 50 keV. Position information is provided by a system of coded apertures mounted in front of the array of Si bolometer wafers.

HERON will use 20 tons of superfluid liquid helium, a volume 5m in diameter and 5m high. This volume is surrounded by a liquid nitrogen cryostat, which also serves as passive shielding, and by an ultrapure water shield to reduce the gamma ray flux from the underground site's rock walls. As foreign materials immediately precipitate out of the superfluid, the liquid helium is free of any internal radioactive contaminants. The detector requires an overburden of approximately 4500 mwe to reduce cosmic ray backgrounds to an acceptable level.

The dominant background in HERON are the γs external to the superfluid, particularly from the cryostat. Using the position information available from the coded aperture system, a fiducial volume cut can reduce this background. In addition, many of the γs Compton-scatter multiple times in the detector, enabling one to reject the events. The estimate background rejection efficiency is a promising 3×10^{-3}. A final cryostat design and an assessment of materials radiopurity is needed before one can assess the adequacy of this rejection. The necessary engineering studies are underway.

The counting rate for a 10-ton fiducial volume will be ~ 5000 pp events/y. Angular information is not available, but the rate is sufficient to allow measurement of the 7% annual flux variation due to the earth's orbital eccentricity, thereby establishing the solar origin of the events.

Significant R&D issues remain to be resolved before HERON is constructed. The HERON collaboration is carrying out experiments on scintillation and drifted charges, to determine whether single electrons that drift to the surface under an applied electric field can be extracted in He "bubbles" and detected using the Si bolometers. The collaboration is also developing larger Si wafers that are sensitive to single photons and optimizing the coded apertures for improved position information and background pattern recognition. Studies of systematics are being made to determine whether systematic uncertainties can be made commensurate with the SSM pp flux uncertainty. The collaboration plans to construct a prototype within the next two years, in order to prepare the way for a full construction proposal. The estimated cost of HERON is uncertain, but is in excess of $40M.

Time Projection Chamber (ES in He): TPC is a proposal to observe pp and ^{7}Be solar neutrinos in a high-pressure time projection chamber. The recoil electrons produce ionization tracks that are drifted to a set of anode wires, where the signals are amplified and read out. The scattering angle can be reconstructed from the TPC's three-dimensional tracking data. The recoil electrons are concentrated in a 15-20° forward cone with respect to the direction of the sun. The incident neutrino energy can be determined from the reconstructed angle and the energy deposited along the track. The difference in the ES NC and CC recoil spectra can be used to separate the flux into its electron and heavy-flavor components.

The TPC target is a He/CH_4 mixture at 10 atmospheres. The detector's central region is 14m in diameter and 20m in length. The recoil tracks are drifted distances up to 10m to anode planes at the ends of the detector. Extensive Monte Carlo simulations have shown that TPC can reconstruct 100 keV electron tracks.

Two sources of background must be addressed. External γs enter the detector, producing

Compton recoil electrons. As the detector is not self-shielding, fiducial cuts are not effective in reducing this background. Instead, the detector components must be fabricated from radiopure materials. Previous experience (most notably the MUNU experiment) suggests the structural elements can be made sufficiently pure. External shielding is also required to reduce γs from the rock walls of the chamber. The second background is due to internal contaminants, with tritium, ^{14}C, ^{40}Ar, ^{85}Kr, and Rn being among the most serious activities. These activities can be reduced by using gases produced from very old petrochemicals from deep underground, by purifying the gases used, and by carefully sealing the detector from the atmosphere. It is known that methane from certain deep wells is depleted in ^{14}C. Background rates of 100-200/day (20-40/day in the signal region) are expected, while the pp rate is about 5/day after cuts. The experimenters plan to subtract the background using tracks in the hemisphere opposite the forward event cone, resulting in a subtraction error of 6%/√yr.

The detector response will be calibrated using delta rays generated by cosmic ray muons and double Compton scattering. These events are kinematically constrained, providing redundant information that can be used in the calibration, and have rates exceeding the signal rate by two to three orders of magnitude, if the detector is sited between 1500 and 3000 mwe. (In this range the cosmic ray background is sufficient for calibration, but not overwhelming.) By using the two classes of events, the experimenters can measure the detector's energy scale and threshold, its fiducial volume, and its tracking resolution to 0.1-0.2%.

With a target mass of 7 tons, TPC will record about 1500 pp events/y after cuts. As the experiment would then be statistics limited, a much larger detector (70 tons) has been discussed. The increased counting rate would provide a better determination of $\sin^2 2\theta_{12}$, provided systematic uncertainties are small, and of the ^{7}Be and CNO neutrino rates (with 1% and 4% accuracy, respectively).

Significant R&D issues must be resolved before TPC is ready for construction. Current research includes developing the readout systems and electronics, determining attenuation lengths for drifting the ionization tracks, testing gas purification, and mechanical design. An R&D proposal has been submitted. With continued good progress, a full proposal might be ready in a few years. It is believed that costs will be less than $150M, though no formal cost estimate has been made.

LENS (CC in ^{115}In): The LENS (Low Energy Neutrino Spectroscopy) collaboration is an international group that includes members from Borexino, SAGE, GALLEX, Chooz, Bougey, and SNO. While several targets have been considered, current efforts are focused on ^{115}In. As the ^{115}In CC threshold is 114 keV, LENS samples most of the pp spectrum. The signal is a prompt electron in spatial and time-delayed coincidence ($\tau = 4.7$ μs) with a 116 keV event. A triple coincidence with a 497 keV cascade γ in an adjacent cell completes the CC signature. The event rate is ~ 99 pp events/y/ton of In. The primary background in LENS arises from the natural beta decay of ^{115}In (endpoint energy of 495 keV), which produces a singles rate of ~ 250 kHz/ton. Suppression of the resulting accidental coincidence backgrounds requires good energy and position resolution. An overburden of at least 3000 mwe is necessary to reduce cosmic ray backgrounds to an acceptable level.

Two major technical advances have helped LENS: 1) the development of indium-loaded liquid scintillators based on indium-carboxylates with a light output 3-4 times that of previous scintillators, and 2) a detector architecture with indium-loaded liquid scintillator modules interspersed with indium-free modules. The latter detect the 497 keV tag γ with sufficient energy resolution that only moderate granularity is required to suppress accidental coincidences from indium decays.

The basic architecture of LENS is a closed-packed array of linear modules of indium-loaded

liquid scintillator (10% indium by weight), 10cm × 10cm × 300cm, with active indium-free liquid scintillator buffers, 100cm in length, on the two ends. Each module is viewed from the ends by a pair of PMTs. The indium-free modules have a larger cross section, 20cm × 20cm, and are arrayed to envelop each indium-loaded module. With time-of-flight event location, the design produces an overall granularity of ~ 2000 cells/ton In. Monte Carlo simulations predict detection efficiencies of 25-30% for pp neutrinos and ~ 80% for the higher energy ^{7}Be and CNO neutrinos.

The LENS collaboration has installed a low background counting facility in Gran Sasso and is now assembling a prototype modular array within that facility. The experimenters will measure the *in situ* detector response for the prototype indium-loaded modules and the level of intrinsic and external backgrounds.

To achieve a 1.5% statistical uncertainty for pp neutrinos after five years of operations, 40 tons of indium is required. The corresponding 200 ton-y uncertainties for the ^{7}Be and CNO fluxes are 5% and 10%, respectively. The dominant systematic uncertainty in LENS is the ^{115}In(ν_e,e^-) cross section. This could be calibrated with 2% accuracy if a very intense (8 MCi) ^{51}Cr neutrino source can be produced.

Significant R&D issues must be resolved before LENS construction commences. The full detector will have ~ 25000 modules containing ~ 400 tons of indium-loaded scintillator, two kilotons of indium-free scintillator, and 100,000 PMTs. The approximate detector dimensions are 9m × 32m × 32m. The total estimated cost is in the $150M range. The LENS goal is to submit a construction proposal in two years.

MOON (CC in ^{100}Mo): MOON's solar neutrino response is the CC reaction ^{100}Mo(ν_e,e^-)^{100}Tc. The threshold for this reaction is 168 keV. The signal is the prompt electron followed by the delayed β decay (15.8s half life) of ^{100}Tc. The MOON detector will contain 34 tons of natural molybdenum, yielding three tons of ^{100}Mo and a solar neutrino event rate ~ 360/y. The most troublesome background is ^{100}Mo 2ν ββ decay. High spatial resolution, good energy resolution, and the ability to distinguish two β tracks from a single track will help in suppressing this background. The established technical requirements for MOON include U and Th activities of less than mBq/ton of molybdenum, timing resolution of 2ns, spatial resolution of ±3mm, energy resolution of ~ 7% at 3 MeV, and a dynamic range of 0.1-40 MeV.

The MOON collaboration is investigating three detector systems to achieve the design goals. The first uses 6m × 6m × 50 mg/cm^2 thick Mo foils sandwiched between 2.5mm scintillator planes, with signals read out through wavelength shifting fibers connected to a total of 13,600 16-anode segmented PMTs. The primary concern in this design is due to scattering and losses in the Mo foils. The second uses Mo-loaded liquid scintillator with 0.3-0.7% Mo by weight viewed by avalanche photodiodes, connected to a wavelength-shifting fiber optics readout. Additional R&D must be carried out to increase (by a factor of a few) the photon yield of the scintillator. The third option is the construction of a cryogenic calorimeter loaded with Mo. While this design offers the prospect of very good energy resolution, significant R&D will be needed before technical feasibility can be assessed.

All three approaches would be simplified if MOON were to use Mo enriched in ^{100}Mo. It appears possible to produce several tons of enriched Mo in Russian facilities, but the associated costs have not been assessed.

The primary backgrounds are ββ decay, impurities within the Mo, and cosmic ray backgrounds. The estimated signal/background from ββ decay is ~ 2/1 for the Mo foils design. R&D on Mo purification are ongoing, though it appears the purity requirements can be met. Cosmic ray backgrounds can be reduced to a negligible level by siting the experiment at depths of 5000-6000 mwe.

Significant R&D must be done in order to assess competing design options and the ultimate sensitivity of MOON. The MOON collaboration anticipates that this will take a few years. At that point a full detector could be designed and a proposal for funding submitted. Because the design is not fixed, it is difficult to offer even a crude cost estimate at this point.

B.3 Solar Neutrinos: Facility Requirements. This section summarizes the facility requirements for future solar neutrino experiments: what must an underground laboratory provide to optimize the prospects for next-generation experiments?

Cosmogenic backgrounds and depth requirements: The depth requirements for the ES detectors HERON and CLEAN are estimated to be ~ 4500 mwe, though there are significant uncertainties because the spallation yields from neon, in particular, are poorly known. CLEAN may be susceptible to delayed activities from isotopes of Ne, F, O, and N, some of which have lifetimes of several tens of seconds. A conservative design would site these experiments at ~ 5500 mwe, providing an order-of-magnitude safety margin. In the ββ decay discussion of MOON it was noted that a conservative design would place this detector at great depths, 6000 mwe.

The HELLAZ stated depth requirement is ~ 1900 mwe. However our estimates indicates a 1% deadtime in this experiment would not be achieved without an overburden in excess of 2200 mwe. If cosmic ray calibration were not an issue, HELLAZ would be sited at 4400 mwe in Homestake, to make use of the ground support available on the 4850 ft level. However, many other levels in the Yates formation at lower overburdens are readily accessible from the Yates shaft. HELLAZ requires quite a large room, so an excavation in the Yates formation, with its excellent rock strength, would minimize construction costs.

LENS has relatively modest depth requirements, 3000 mwe, due to the triple coincidence of the signal. The natural site at Homestake would be on the 4850 ft level (4400 mwe).

Finally, we note that Raghavan has recently suggested a 1 kton liquid scintillator detector (similar to Borexino or KamLAND) with directional sensitivity to measured the terrestrial antineutrino flux coming from the earth's core. Such a detector would also be used for a variety of solar neutrino measurements. In the energy region corresponding to the *pep* line and CNO neutrinos, a difficult background is the cosmic ray spallation product ^{11}C, produced at ~ 50 times the rate of another spallation product, ^{7}Be, that has been of concern to Borexino experimentalists. Half of the ^{11}C positrons fall in the *pep* window. A depth of ~ 7000 mwe reduces this background to ~ 5% of the SSM *pep* signal. Thus if a detector for geophysical neutrinos is constructed, a site on the deeper of the two proposed NUSEL main levels (7400 ft, or 6500 mwe) might increase the reach of the experiment.

Solar neutrino space requirements: The two cryogenic experiments, HERON and CLEAN, require customized cylindrical cavities ~ few 10^3 m^3 in volume. The remaining experiments can be accommodated nicely in standard "breadloaf" halls. The volumes needed are in the range $(0.5\text{-}27) \times 10^3$ m^3, easily within Homestake specifications for both the 4850 ft and 7400 ft levels.

These cavity dimensions take into account the significant amounts of water shielding, for most of the detectors, needed to provide the local shielding from γs and neutrons emanating from the rock walls. The possible need for auxiliary space (usually adjacent to the detector) is also included. In general this space has few aspect ratio constraints on its dimensioning as the intended uses include staging during assembly, locations for auxiliary equipment such as refrigerators, pumps, water handling, electronics, storage, etc.

Basic facilities needs:

- Power requirements of a few hundred kW.

- Stable temperatures, usually 20°C or less, with air conditioning.
- Scrubbed air, with residual radon levels below 1-10 mBq/m^3 (depending on the experiment). This is not a concern for cryogenic detectors because of the lack of diffusion into them.
- A clean room for preparations, assembly and cleaning, and various levels of clean-room conditions in the detector cavity during construction and operations.
- DI water system.
- Cranes for assembly and manipulation of detector and shielding elements. Significant hoist capacity (both weight and volume) during construction. (It is recognized that there will be some compromise between NUSEL desires for experimentalists to "modularize" their designs and collaboration desires to move very large and possibly awkward loads underground.)
- Twenty-four-hour personnel access to detectors.
- A storage area for radon-free materials and to "cool" cosmogenics.
- Machine shop, both general and for ultra-low background work.
- Low-level counting capabilities for materials screening.
- Space for R&D work (surface and underground).

Special facilities needs (experiment specific):
- Special materials preparation areas (e.g., electroforming).
- Containment, external dumping, oxygen deficiency equipment, and emergency evacuation procedures to enhance the safety of experiments employing large quantities of flammable gases or scintillation materials, high-pressure gases, and cryogenic liquids such as neon, helium, and nitrogen.
- The necessary permits to allow transportation and importation of intense neutrino calibration sources. (These sources are easily shielded and present no personnel hazard from external radiation.)

B.4 Solar Neutrinos: Summary. There is a great deal of ongoing R&D activity, both in the US and overseas, focused on next-generation high-statistics solar neutrino detectors capable of characterizing the flux, spectrum, and flavor of low-energy solar neutrinos. The most advanced experiments appear to be 2-3 years away from construction. Thus NUSEL should be prepared to accommodate such experiments very early in its lifetime. The facilities requirements of such experiments are significant, with some requiring specialized excavations, and many requiring specialized procedures for flammables, cryogens, and compressed gases. NUSEL should be prepared to host R&D efforts immediately on opening. Many of the proposed experiments are now engaged in, or plan to mount in the near future, underground prototype experiments.

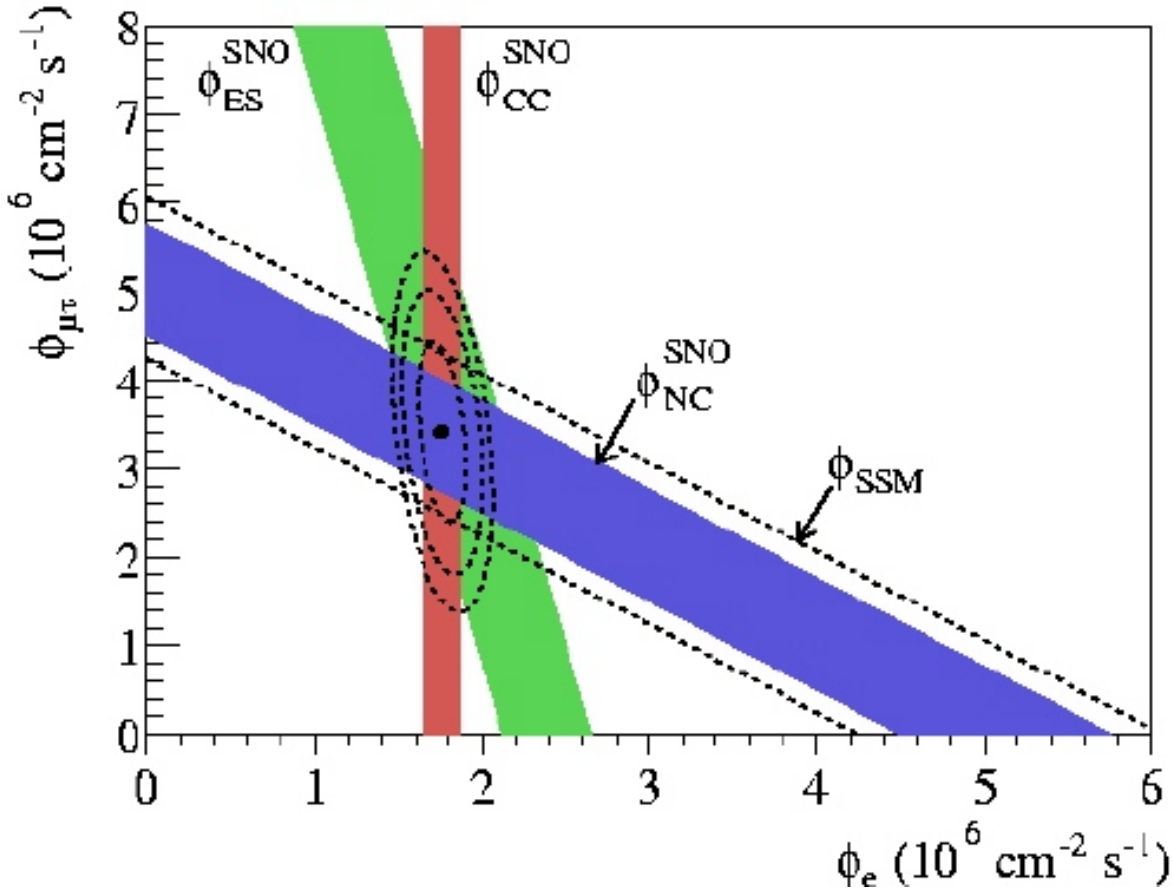


Figure C.6: The Sudbury Neutrino Observatory results, charged-current, neutrino-current, and elastic scattering rates, show that heavy flavor neutrinos account for two-thirds of the solar neutrino flux. The total flux is in remarkable agreement with the predictions of the standard solar model (the area between the dashed lines). Once these data were added to other solar neutrino constraints, the large-mixing-angle (LMA) solution emerged. SNO measures the high-energy portion of the solar neutrino flux, 0.01% of the total.

C.1 Long-baseline Neutrino Oscillations: Importance of the Science. As noted earlier, one of the fortunate aspects of recent solar and atmospheric neutrino oscillation discoveries is the neutrino mass scale. The neutrino m^2 differences for atmospheric and solar neutrino oscillations are within the reach of terrestrial experiments using accelerator and reactor neutrino sources. This opens up marvelous opportunities for more precise measurements of poorly known parameters, such as (δm_{12}^2, θ_{12}) and ($|\delta m_{23}^2|$, θ_{23}), for measuring new neutrino parameters, such as the sign of δm_{23}^2 and θ_{13}, and for probing new phenomena, such as CP violation, CPT violation, and matter effects on oscillations. The neutrino mass-matrix parameters are currently our only experimental indication of the physics that lies beyond the standard electroweak model. New phenomena such as CP violation could lead to profound discoveries, such as the mechanism responsible for the creation of matter in the early universe.

Terrestrial neutrino experiments offer many advantages. The neutrino propagation distances we can probe are arbitrary (up to the earth's radius), limited only by our ingenuity in creating powerful neutrino beams and sensitive detectors. By using combinations of near and far detectors, beams and detectors can be carefully tested. Systematic effects can be controlled and evaluated, resulting in known uncertainties.

Terrestrial experiments have already had significant impact. The KamLAND reactor neutrino (baseline ~ 180 km) experiment has verified the LMA solution to the solar neutrino problem, while narrowing the allowed range for δm_{12}^2. The K2K experiment – muon neutrinos of energy ~ 1.5 GeV from the KEK accelerator are observed in the Kamiokande detector, baseline ~ 250 km – has found a reduced flux consistent with the atmospheric neutrino oscillation parameters. Two additional accelerator experiments with baselines ~ 750 km, MINOS (FermiLab to Soudan) and CNGS (CERN to Gran Sasso), will run within the next five years with the goal of narrowing uncertainties on the atmospheric oscillation parameters. The science goals of future experiments include:

Precise measurements of δm_{12}^2 and θ_{12}: It appears unlikely that long-baseline accelerator neutrino experiments will provide precise measurements θ_{12}. KamLAND's results on reactor electron antineutrino disappearance have reduced the LMA allowed range for δm_{12}^2, however. KamLAND will produce more data, and it is conceivable that future long-baseline reactor experiments could improve on KamLAND's results. Because the SSM pp flux prediction is so precise, high statistics (~ 1%) pp solar neutrino measurements are a promising strategy for further constraining θ_{12}.

Precise measurements of δm_{23}^2 and θ_{23}: In the case of the "atmospheric" parameters the open challenges include definitive observation of oscillatory behavior and a precise measurement of δm_{23}^2 and θ_{23}, with one question being the extent to which θ_{23} differs from 45°. Certain models have been offered where the θ_{23} is precisely 45° as a result of symmetry, so that deviations from this value are a measure of the symmetry breaking.

Detection of the appearance signal $\nu_\mu \rightarrow \nu_e$: The appearance of ν_es in a ν_μ beam at an atmospheric length scale would provide a measure of a subdominant oscillation governed by θ_{13}. This mixing angle is currently unknown but limited by the Chooz reactor experiment to < 10°. As the Jarlskog invariant that governs CP violation in neutrino oscillations is proportional to sin $2\theta_{13}$ cos θ_{13}, the size of this mixing angle is crucial to plans to measure leptonic CP violation (and the hope of relating this observation to theories of leptogenesis). Even a very small θ_{13} (10^{-3} or greater) is important in supernova physics because of the MSW mechanism: this angle governs the high-density crossing between electron and heavy-flavor neutrinos, thereby producing a hotter electron neutrino flux. Note that the sign of δm_{23} determines whether electron neutrinos or antineutrinos experience an MSW crossing. The charge-current interactions of electron neutrinos in a supernova influence the proton/neutron ratio important to the r-process and other nucleosynthesis.

Detection of the matter effects in the appearance signal $\nu_\mu \rightarrow \nu_e$*:* The matter effects, as noted above, depend on the sign of δm_{23}^2. Thus a long-baseline experiment in which the beam penetrates a significant distance through the earth will resolve the hierarchy question: is the neutrino pair that dominates solar neutrino oscillations lighter (normal hierarchy) or heavier (inverted hierarchy) than the third neutrino?

Detection of CP violation in neutrino oscillations: In the introduction to the neutrino physics discussion of this section we noted that the "Dirac" CP phase – the phase observable in neutrino oscillations – appears in the combination $\sin\theta_{13}\, e^{i\delta}$. This produces a difference between the oscillation probabilities when neutrinos and antineutrinos are interchanged,

$$P(\nu_\mu \rightarrow \nu_e) \Leftrightarrow P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$$

As the CP-violating signal grows with the length of the baseline (though of course the flux is decreasing as $1/L^2$), very long baselines are helpful in such experiments. The expected effects are small and, of course, depend crucially on $\sin\theta_{13}$. It is also difficult to unravel many of the parameter ambiguities associated with matter effects and with uncertainties in the CP-conserving neutrino parameters. Thus some of the proposals to measure δ require measurements with multiple baselines, while others depend on the distinctive oscillation "fingerprint" that is implanted on a well-characterized broad-band neutrino beam.

The existence of light sterile neutrinos: The short-baseline neutrino oscillation experiment LSND conducted the appearance experiment using neutrinos from stopped pion decay

$$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$$

The experimenters found a nonzero oscillation probability of ~ 0.3% and a region of allowed oscillation parameters centered on $\delta m^2 \sim 1\ eV^2$. As this δm^2 is distinct from the solar and atmospheric values, LSND requires a fourth light neutrino in a mass range that would influence large-scale structure. No evidence has emerged for such a "sterile" neutrino from other experiments, but neither does any experiment contradict the claim (though the KARMEN and Bugey results limit the allowed range of the LSND oscillation parameters). The FermiLab experiment MiniBoone, now in the commissioning stage, will check the LSND result. If MiniBoone confirms LSND, the pattern of light neutrinos is considerably more complicated than that of three active species. Even if the LSND parameters are ruled out, sterile neutrinos with very small couplings to active species can be important in the early universe. Thus tightening the limits on sterile neutrinos is important, regardless of the validity of LSND claims.

Tests of CPT violation: A possibility for accommodating the solar, atmospheric, and LSND results that does not require a fourth neutrino is CPT violation. CPT violation allows different masses for neutrinos and antineutrinos. A CPT-violating oscillation observable is an asymmetry in the probabilities

$$P(\nu_\alpha \rightarrow \nu_\beta) \Leftrightarrow P(\bar{\nu}_\beta \rightarrow \bar{\nu}_\alpha)$$

C.2 Long-baseline Neutrino Oscillations: The Readiness of Next-Generation Experiments. The long-baseline oscillation program is quiet complex because it connects to so many other issues. Arguably **the discovery of leptonic CP violation will remain the single most important goal of neutrino physics** for the near future. To reach this goal a number of intermediate steps must be taken, some to clarify the difficulty of the search for CP violation.

The observation of CP violation will require two major advances, the creation of powerful new neutrino beams and the construction of an underground detector of unprecedented size, approaching a megaton. This megadetector is likely to be **the most ambitious and most important project NUSEL undertakes**. Its justification rests not only on long-baseline physics, but also proton decay, supernova neutrino physics, atmospheric neutrinos, and other science. Certain detector parameters, particularly depth, may be governed by these other uses. For this reason, we will delay our discussion of the megadetector to later in the Science Book, after the chapters on proton decay, supernova physics, etc. As the cost of the megadetector is likely ~ $0.5B, a decision to proceed will require very careful consideration by the physics community, independent of NUSEL. The megadetector is not part of the present proposal. However, in our view one of the strongest arguments for Homestake is its obvious suitability as a site for the megadetector, should the community decide to proceed. The Facilities Development Plan shows that the most logical and cost-effective plan for NUSEL-Homestake naturally **preserves an ideal, deep site** for the megadetector – one in the thoroughly studied, exceptionally competent rock of the Yates formation. It also allows NUSEL to provide the megadetector collaboration with a **dedicated hoist** capable of mining (and disposing on site) one megaton of rock/year. That hoist, the largest at Homestake, could later be dedicated to and optimized for construction.

Some of possible steps in a coherent program of long-baseline neutrino physics include:

Completion of current experiments: Additional data from KamLAND (and also new data from SNO in the salt and ^{3}He NC detection modes) will further narrow uncertainties on the solar neutrino mixing parameters. MINOS and CNGS will start to provide data ~ 2005 and K2K will complete its data taking, narrowing the uncertainty on the atmospheric δm^2 to ~ 10%. MiniBoone will produce results, and if LSND is verified, many new directions for new neutrino experiments will need to be explored.

Efforts to measure θ_{13}: There are at least three suggestions for either measuring θ_{13}, or showing that it is much smaller than the Chooz limit of 10°. One is to exploit the NuMI beam (FermiLab to Soudan, expected to be available in 2005) to measure the appearance of ν_es in a ν_μ beam. The kinematics of the reactions used to produce the neutrino beam provide a relative clean ν_μ beam with a well-defined energy at a specific angle "off-axis" from the beam's center. Thus, at the cost of some loss in flux, one gains knowledge of the neutrino energy. This is important in reducing various backgrounds that might be mistaken as signals for ν_e appearance (e.g., CC ν_μ events where the muon is misidentified as an electron, or CC ν_τ events where the tauon decays into an electron). The experiment does not require an underground detector. The off-axis angle is chosen to select energies of 1.5-2.0 GeV, so that the detector sits at one oscillation length for the atmospheric mass difference, given the Soudan to FermiLab distance of 735 km. A ~ 50-kiloton detector at this location will be used to identify ν_e events, and a ~ 500-ton near detector will be used for calibration. The detector options include fine-grained calorimeters, water Cerenkov detectors, and liquid argon detectors. The goal is sensitivity to $\sin^2 2\theta_{13}$ approaching 0.01 – though, because of correlations with δm_{13}^2, the sensitivity deteriorates if the true δm_{13}^2 differs from the atmospheric best value. Data could be taken as early as 2007. There is a very similar off-axis proposal involving a neutrino beam from the Japanese Hadron Facility and Super-Kamiokande as the far detector.

A second proposal is a reactor neutrino experiment with either two or three detectors. To circumvent the neutrino spectrum uncertainties, the ratio of event rates is studied as a function of energy. With detectors arranged in a near-far configuration – distances of 0.5 and 3.0 km will encompass the atmospheric mass difference – electron antineutrino disappearance imprints on the ratio an oscillatory pattern. The magnitude of the oscillation depends on the size of $\sin^2 2\theta_{13}$. A third detector further helps with systematics. It appears that the reach of such an experiment in quite competitive with that of off-axis proposals and likely could be mounted in a relatively short time, given the success of KamLAND. The optimal detector sizes depend on the power of the

reactor, but 10-100 tons is typical. Most important, the combination of off-axis and reactor antineutrino experiments appears to be considerably more sensitive than either individually, due to different dependencies on uncertainties in quantities like the atmospheric m^2 difference.

A third possibility is a very-long-baseline neutrino oscillation experiment with a broad-band neutrino superbeam. This proposal aims at determining parameters like θ_{13}, removing parameter degeneracies, seeing matter effects, and measuring or limiting CP violation (if other parameters are favorable) in one experiment. This idea is discussed below.

Very long baseline searches for CP violation: The program to observe CP violation includes the determination of θ_{13} and the use of matter effects to determine the mass hierarchy (normal vs. inverted). The basic strategy requires intense neutrino beams (superbeams) and very long baselines (greater than 1200 km, so that one can exploit significant matter effects) for comparing

$$P(\nu_\mu \to \nu_e) \Leftrightarrow P(\bar{\nu}_\mu \to \bar{\nu}_e)$$

But to disentangle all of the mixing parameters, multiple measurements are required. Two approaches have been discussed seriously. One is a program of measurements with multiple baselines. Multiple beamlines at different distances to the same detector is an attractive possibility because the detector (~ 0.5 Mtons) may be the most costly part of the program. For Homestake the natural choices are the complementary baselines to FermiLab (1290 km) and Brookhaven (2530). Longer distances (or higher energy beams) allow one to probe oscillations beyond the first oscillation maximum, which provides information simultaneously on the CP phase and the sign of δm_{23}^2.

Another possibility is the observation of ν_μ oscillations, in appearance and disappearance modes, using a single baseline, but employing a wideband neutrino beam. The wideband beam allows one to observe the effects of multiple oscillation lengths as an energy dependent modulation of the beam spectrum. This strategy has been explored in detail by a Brookhaven group, though the approach is general and could be applied elsewhere.

There are two components to this program, the superbeam and the detector. Superbeams have been under study at Brookhaven and FermiLab, as well as overseas. A superbeam requires an intense high-energy proton beam, a high-power target for pion production, and a pion decay channel to produce the neutrinos. The Brookhaven proposal is an upgrade of the AGS to produce a 1 MW proton beam, with a possible future upgrade to 4 MW. FermiLab is exploring two options, one based on a new 8 GeV proton synchrotron, and one based on a new 8 GeV superconducting proton linac, feeding the Main Injector. The detector most often discussed is a multi-100 kiloton water Cerenkov detector like UNO (or an array of small water detectors), but smaller scintillation and liquid argon detectors are also being explored.

Of course, if MiniBoone confirms LSND, there will be (at least) three distinct δm^2 values, and a more complicated set of long- and short-baseline experiments will be required to understand the associated phenomena.

The Neutrino Factory Future: A Neutrino Factory is designed to create very intense, pure beams of electron and muon neutrinos and antineutrinos at relatively high energies. The primary purpose of the facility would be to enable very accurate measurements of the parameters of the neutrino mixing matrix. In particular, if θ_{13} were very small, this would be the next step in the effort to find leptonic CP violation. The neutrino factory would allow measurement of $\sin^2 2\theta_{13}$ as small as ~ 0.0001, and to see maximal CP violation at that limiting θ_{13}.

C.3 Long-Baseline Neutrino Oscillations: Facility Requirements. The issue for NUSEL is the requirements for constructing the megadetector, which depend not only on long-baseline uses of the detector, but also the demands of proton decay, supernova neutrino detection, etc. We address this issue in our later megadetector discussion.

C.4 Long-Baseline Neutrino Oscillations: Summary. The above program is exceedingly rich. It promises to answer many of the unanswered questions we have about the neutrino mass matrix, including the crucial question of CP violation. It makes excellent use of the facilities at FermiLab and Brookhaven, and takes advantage of the very long baselines to Homestake. And as will be apparent in later discussions, the megadetector needed for this program will advance studies of proton decay, supernova physics, and other underground science fields.

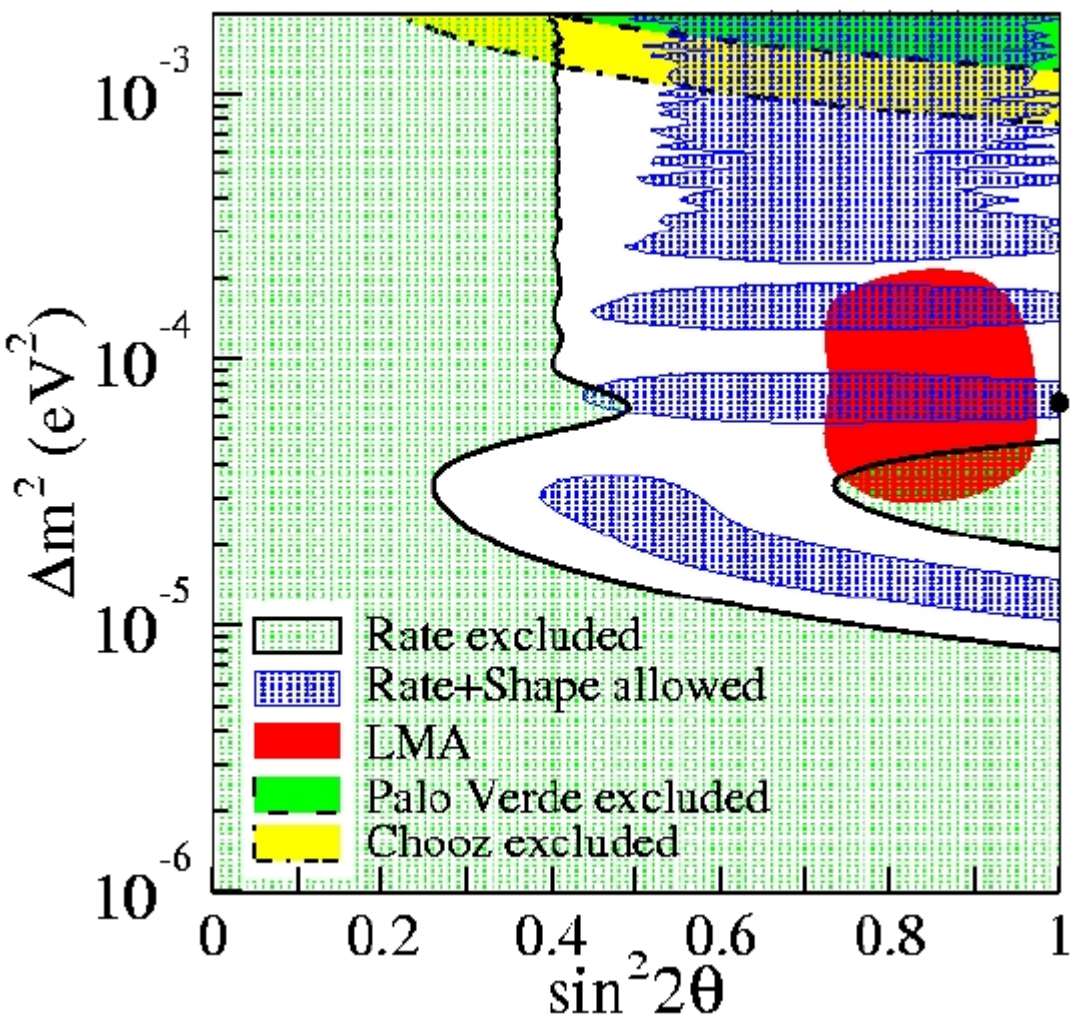


Figure C.7: Results from the KamLAND long-baseline reactor neutrino oscillation experiment. The data show that the LMA solar neutrino allowed region (in red) is now further restricted to two smaller areas centered on larger and smaller mass differences. Future long-baseline experiments will accelerator and reaction neutrinos will measure unknown neutrino parameters such as θ_{13} and the CP-violating phase δ.

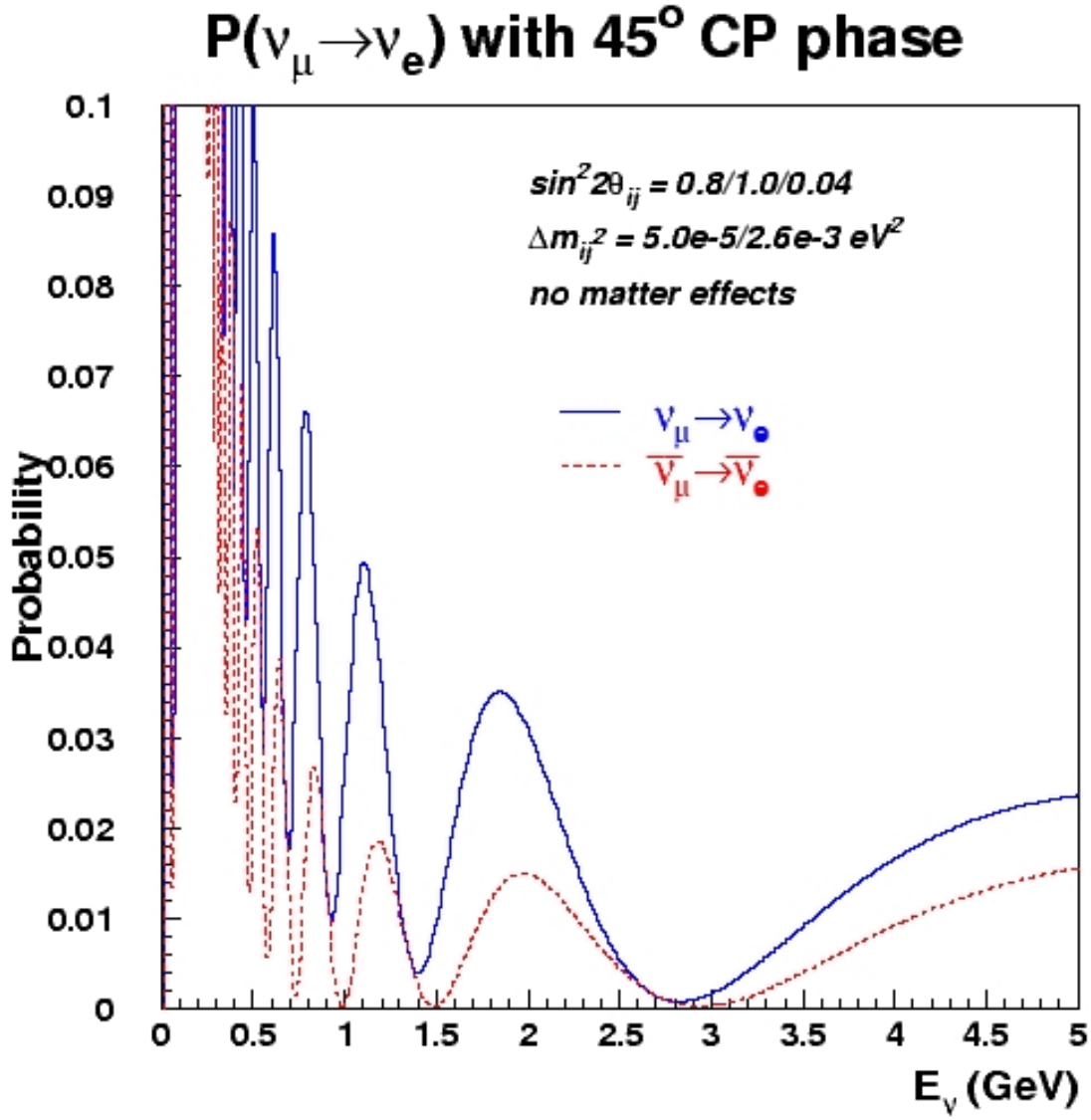


Figure C.8: An example of the possible outcome of oscillation tests of CP violation. This simulation comes from the Brookhaven broad-beam proposal.

D.1 Atmospheric Neutrino Oscillations: Importance of the Science. When primary cosmic-ray protons and nuclei enter the upper atmosphere, the resulting hadronic interactions produce secondary cosmic rays. The spectrum of these secondaries peaks at about 1 GeV, but distribution's tail continues to high energy, falling off approximately as a power-law. One frequent product of hadronic interactions is the pion, which then decays

$$\pi^+ \to \mu^+ + \nu_\mu \to e^+ + \nu_e + \bar{\nu}_\mu + \nu_\mu$$

Thus the atmosphere is a source of cosmic ray neutrinos, which then travel downward and through the earth. An underground detector can observe neutrinos coming from above, as well as those coming from below after traversing the earth. In effect, such a detector, through the zenith angle of the neutrino event, can sample neutrino events with baselines ranging from 10 km (the thickness of the atmosphere) to 13000 km (the diameter of the earth). The latter distance, for GeV neutrinos, implies sensitivity to oscillations with δm^2 as small as 10^{-4} eV^2. That is, atmospheric neutrinos provide a marvelous laboratory for studying neutrino oscillations.

Studies of atmospheric neutrinos awaited the advent of the large underground detectors necessary for their detection. In particular, in the 1980s the water Cerenkov detectors Kamiokande and IMB were used to study atmospheric neutrino events producing electrons or muons in the tanks. In 1988 and 1989 these collaborations reported that they were recording too few ν_μ events – the first hint of a profound discovery. (The expected ratio of ν_μ/ν_e is not too different from the 2/1 value given by π decay above. However, rather sophisticated calculations are done to estimate the incident ν_μ and ν_e fluxes, based on measured laboratory cross sections and including effects like the earth's magnetic field.) By 1990 results were available from a different kind of proton decay detector, the fine-grained iron detectors Frejus and NUSEX. While the results from these smaller detectors had substantial error bars, they did not appear to confirm the atmospheric neutrino anomaly. The program continued with the Soudan 2 fine-grained iron tracking calorimeter, the MACRO detector, and the 50-kton successor to Kamiokande, Super-Kamiokande.

One of the comforting aspects of atmospheric neutrinos is that the measurements are self-normalizing: apart from small geomagnetic effects, the source is isotropic. Thus one can look for new physics by determining whether the muon/electron event ratio depends on zenith angle (or baseline). The data produced by Super-Kamiokande was definitive. Normalizing to the Monte Carlo calculations of the expected ratio of muon to electron events, Super-Kamiokande found for the sub-GeV sample of events, after 1489 days of data, the ratio of ratios

$$\frac{\left(N_\mu / N_e\right)_{data}}{\left(N_\mu / N_e\right)_{M.C.}} = 0.688 \pm 0.016 \pm 0.050$$

The up-down asymmetry for multi-GeV muon sample was not zero, but

$$\frac{N_{up} - N_{down}}{N_{up} + N_{down}} = -0.303 \pm 0.030 \pm 0.004$$

In contrast, the corresponding asymmetry for electrons is consistent with zero. The up-down muon asymmetry deviates from the expected zero by 10σ, independent of any Monte Carlo input. The Super-Kamiokande binning of these events by zenith angle shows a systematic depletion of the muon events as one sweeps toward downward angles, with the upward-going

flux lower than the downward flux by a factor of two. This led to the announcement in 1998 by the Super-Kamiokande collaboration of the discovery of massive neutrinos and neutrino oscillations. Careful analysis shows that the data are consistent with $\nu_\mu \rightarrow \nu_\tau$ oscillations with $\theta_{23} \sim 45°$ and $\delta m_{23}^2 \sim 2 \times 10^{-3}$ eV^2.

The properties of atmospheric neutrinos – the large baseline/energy or L/E range accessible (from 1-10^5 km/GeV), the self-normalizing properties of up-down comparisons, and the propagation through large amounts of matter – make these neutrinos an attractive source for future studies. In particular, megadetectors built for long-baseline accelerator neutrino studies and for nucleon decay will produce very large data sets. Such detectors will also fully contain higher energy events, which provide better angular resolution. Given an order of magnitude increase in event samples, several goals would be in reach:

- *Detection of the oscillation pattern:* With the improved energy reach and angular resolution, observations of neutrino oscillations should reveal a sinusoidal survival probability. No existing atmospheric neutrino experiment has succeeded in measuring such a pattern. For example, the Super-Kamiokande pattern as a function of L/E, while suggestive of neutrino oscillations, can be fit almost as well by certain neutrino decay models, once one takes into account detector resolution. One would like to see, as a function of increasing L/E, neutrino disappearance and then reappearance.
- *Detection of* ν_τ *appearance:* The favored fit to the Super-Kamiokande results is $\nu_\mu \rightarrow \nu_\tau$ oscillations. Subsequent interaction of the ν_τ in the detector will result in τ appearance at a rate of about 1/kton-y.
- *Detection of matter effects:* In the standard three-flavor scenario matter effects are present if there is a nonvanishing θ_{13}: the $\nu_e \leftrightarrow \nu_\mu$ oscillation can become resonant in matter and significantly modify the oscillation probabilities of electron and muon neutrinos. Matter effects can also arise because of coupling to a sterile neutrino. (Super-Kamiokande uses the absence of matter effects to exclude the pure $\nu_\mu \rightarrow \nu_{sterile}$ oscillation at 99% c.l.) Finally, in detectors sensitive to the sign of the produced lepton, matter effects can lead to different oscillation patterns for neutrinos and antineutrinos. This, as noted in the previous chapter, results in sensitivity to the sign of δm_{23}, and thus to the mass hierarchy (regular or inverted).
- *Precision measurements of oscillation parameters:* Larger data sets will clearly narrow the allowed ranges for the mixing parameters. At 99% c.l. the Super-Kamiokande results determine δm^2 only to ~ factor of three, for example. It has been argued that a detector with sensitivity to the sign of the lepton might be able to probe $\sin^2 2\theta_{12}$ to ~ 0.02, a result competitive with future long-baseline goals, after 1 Mton-y of data.
- *Study of multi-GeV neutrino interactions in nuclei:* Nuclear response functions and spallation yields are of interest to nuclear structure theorists.

D.2 Atmospheric Neutrinos: Readiness of Next-Generation Experiments. Most of the proposed future detectors that will significantly improve over Super-Kamiokande will be multi-purpose experiments, often primarily focused on proton decay and long-baseline accelerator neutrino physics, but also used as supernova detectors, for studies of atmospheric muons, and for certain solar neutrino physics, such as day-night comparisons.

Water Cerenkov detectors: Proposed detectors include UNO, Hyper-Kamiokande, and AQUA-RICH. The first two detectors are qualitatively similar to Super-Kamiokande. For example, UNO would be divided into three cubic compartments, $60 \times 60 \times 60$ m^3, with the walls fitted with PMTs sensitive to low-energy neutrinos. One possibility with this detector would be observation of τ appearance.

The AQUA-RICH detector is based on the ring imaging Cerenkov technique. The proposers envision two spherical detectors equipped with hybrid photodetectors (HPDs) and immersed in a large tank of water. The water in the upper part of the tank is a shield against low energy cosmic

rays. The inner surface of the outer sphere is a mirror, focusing the Cerenkov light onto the outer surface of the inner sphere. The inner sphere is densely covered with HPDs to detect the focused Cerenkov rings.

Though some R&D concerns remain, **the technology of water Cerenkov detectors is well developed**.

Magnetized tracking calorimeters: While the water detectors are a demonstrated technology for very-large-scale efforts, they also have some drawbacks. One is the lack of sensitivity to the muon charge. Thus an interesting alternative is a large magnetized tracking calorimeter. The muon charge sensitivity allows one to separate neutrino and antineutrino events, and thus to extract the matter effects discussed above. The energy of the hadronic system and the momentum of semi-contained muons can be measured, yielding very good neutrino energy reconstruction. As the angular resolution – the handle on L – is also good, L/E can be well determined. This is helpful in the oscillation pattern extraction.

The long-baseline MINOS detector at Soudan and the NOE part of the ICANOE detector at Gran Sasso will employ this technology. The detector that is planned for atmospheric neutrino oscillation studies at Gran Sasso, MONOLITH, is about an order of magnitude larger (34 ktons, with a fiducial volume of 26 ktons). Thus it will have a fiducial volume similar to Super-Kamiokande, but improved L/E resolution and sensitivity to the muon sign. MONOLITH **employs established technology** and, its proponents argue, could be quickly constructed.

Liquid argon time projection chambers: Liquid argon TPCs are sensitive to τ appearance and to both electron and muon neutrinos down to very low energies. A drawback is the higher cost per kton, compared to iron detectors. Argon TPCs have better angular resolution than water detectors. The 600-ton ICARUS detector is being installed in Gran Sasso, and plans exit to enlarge it to 3.0 ktons. It will be used for ν_e and ν_τ appearance in the CNGS beam from CERN to Gran Sasso. Though limited for atmospheric neutrino studies because of its size, there are proposals to construct super-detectors of mass ~ 30 ktons. Thus this technology is **being demonstrated at a small scale, with plans to extend the technology to Super-Kamiokande masses soon.**

D.3 Atmospheric Neutrinos: Facilities Requirements. We will address facility requirements for very large detectors in the megadetector section.

D.4 Atmospheric Neutrinos: Summary. There are important goals not yet realized in atmospheric neutrino studies, including the observation of the oscillation pattern, increased precision on mixing angles, observation of τ appearance, and investigation of matter effects in detectors with sensitivity to the sign of the charged lepton. Thus atmospheric neutrino studies will be an important component of the physics program of future underground megadetectors (or Super-Kamiokande-class detectors with new capabilities, such as lepton charge sensitivity).

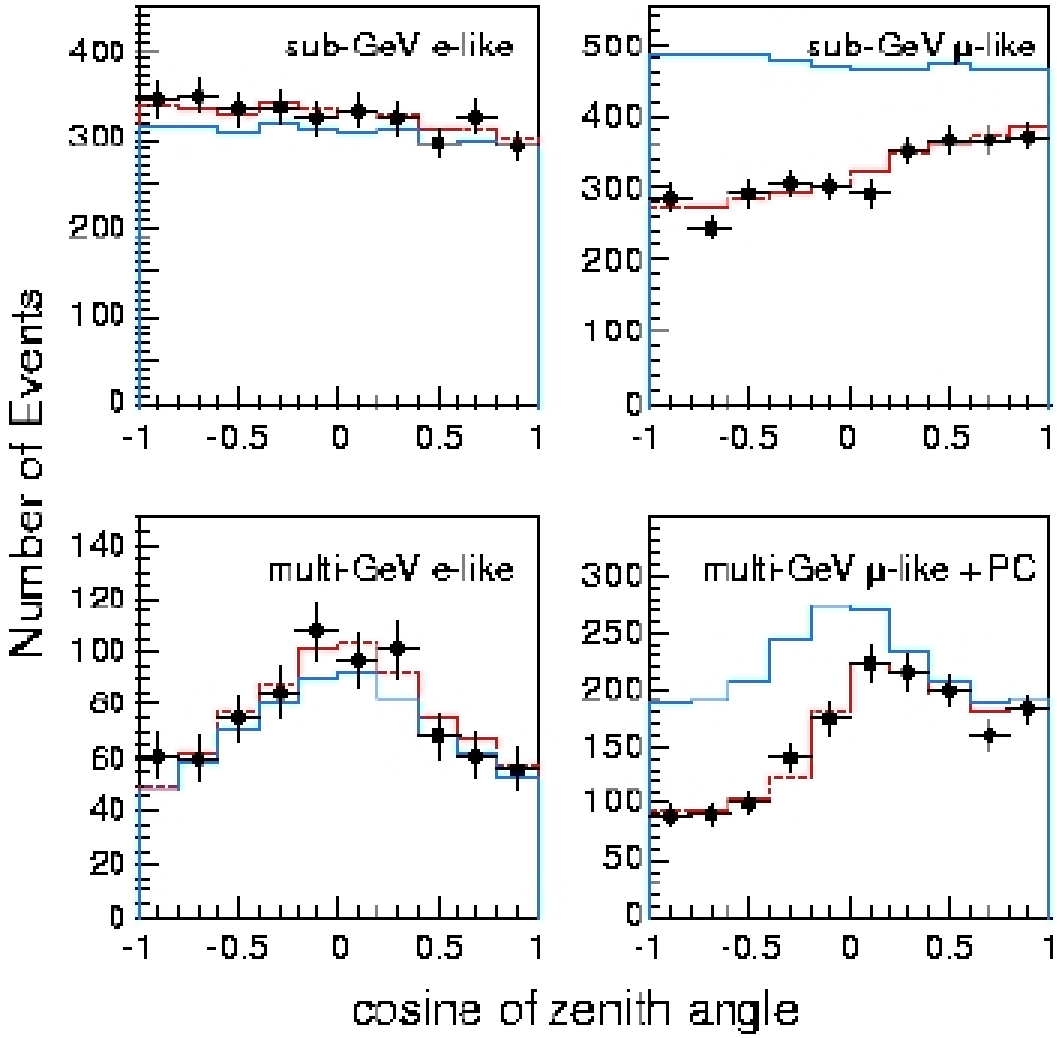


Figure C.9: The Super-Kamiokande atmospheric neutrino results showing excellent agreement between the predicted (blue line) and observed electron-like events, but a sharp depletion in the muon-like events for neutrinos coming from below, through the earth. This depletion at large baselines is seen in both the sub-GeV and multi-GeV data. The results are fit very well by $\nu_\mu \rightarrow \nu_\tau$ oscillations with maximal mixing (red line).

Cosmology and Astrophysics: In the past decade cosmology and astrophysics have undergone profound changes. With new ground- and space-based instrumentation these fields have become far more quantitative, and the connections between the underlying nuclear and particle microphysics and astrophysical phenomena far more critical to our understanding. This has produced a fertile intersection of cosmology, astrophysics, and nuclear and particle physics. The recent National Research Council study on "Quarks and the Cosmos" was inspired by the deepening microphysics-macrophysics connections, as well as by the associated sociological changes: many scientists trained in particle and nuclear physics are now applying their skills to cosmological problems.

Underground science has a central role to play in cosmology and astrophysics. Arguably the most important new mystery in physics is the matter/energy budget of our universe. Precision measurements of the cosmic microwave background, large-scale structure, and the light curves of distant supernovae have forced us to accept that the cosmos is filled with dark energy and dark matter, producing a universe very close to critical density. The visible universe open to conventional observations accounts for only ~ 1% of the total matter/energy budget. Deep underground experiments provide our best hope for identifying particle dark matter, and thus for relating dark matter to candidate theories for a more complete "standard model" of subatomic physics.

Core-collapse supernovae are important astrophysical laboratories. They produce prodigious neutrino fluences in all flavors, and these neutrino travel to us over galactic "baselines." The matter effects on oscillations are unique due to the high matter density and the important contributions of neutrino-neutrino scattering to the MSW potential. These neutrinos are a fascinating probe of the deep interior of the supernova. The neutrino light curve provides our best hope for identifying exotic phase (strangeness condensation, quark matter) transitions that might occur during protoneutron star cooling. Such transitions could alter the high-density equation of state, leading to unexpected mass/radius relationships in neutron stars. The neutrino burst as well as correlations between the burst and the gravitational wave signal could help us understand the explosion mechanism. The neutrino light curve controls the neutron-proton chemistry of the hot nucleon gas that is blown off the neutron star, where the r-process likely takes place. Thus neutrino observations would eliminate many current uncertainties in nucleosynthesis calculations. It is very important to have an array of supernova observatories underground to map out the flavor and light curves of the neutrinos from the next galactic supernovae.

Laboratory measurements of nuclear cross sections were vital to the solar neutrino problem, as they allowed astrophysicists to construct a quantitative standard solar model that accurately predicted even the highly temperature-dependent ^{8}B neutrino flux. The new stellar laboratories we hope to exploit for fundamental physics – core-collapse supernovae, thermonuclear supernovae like SNIas (the cosmological standard candles crucial to studies of the dark energy), novae, and red giants – similarly need to be understood as well as possible. Energy production in stellar environments occurs through networks of low energy nuclear reactions. Measurements of such reactions in the laboratory are often severely limited by cosmic ray backgrounds. An underground laboratory provides an ideal site for a low-energy accelerator to measure nuclear astrophysics cross sections, free of backgrounds.

E.1 Dark Matter: Importance of the Science. A combination of astrophysical measurements – maps of the cosmic microwave background, large-scale structure surveys, SNIa measurements of the Hubble expansion, gravitational lens maps of galaxy matter distributions – have progressed to the point of providing a reliable inventory of the composition of the universe. Energy densities are usually quoted in terms of the critical density, the density at which a test's particle's kinetic energy due to the Hubble expansion is compensated by the potential energy due to gravitational attraction

$$\rho_{crit} = \frac{3H^2}{8\pi G} \approx 1.88 \times 10^{-29} h^2 g / cm^3$$

Here $h \sim 0.71 \pm 0.04$ is the Hubble constant H in units of 100 km/s/Mpc and G is the gravitational constant. Thus the universe is closed if $\rho < \rho_{crit}$ and open otherwise. Measurements of the first acoustic peak in the angular power spectrum of the cosmic microwave background (CMB) indicate that the universe's total energy density is near the critical value, $\Omega_{tot} = \rho/\rho_{crit} = 1.0 \pm 0.04$, consistent with the prediction of inflation. The various measurements provide a very consistent inventory of the universe, a dark energy density of $\Omega_\Lambda \sim 0.73$, a total matter density of $\Omega_M \sim 0.27$, and a baryonic contribution to the matter density of $\Omega_b \sim 0.044$. The fact that the stars and other measured, luminous matter account for only ~ 1% of the total density means that majorities of both the total matter and the baryonic matter consist of unidentified dark components.

The most direct determination of the cosmological density of baryonic matter comes from the theory of big-bang nucleosynthesis and measurements of primordial light-element abundances. In particular, accurate determinations of the primordial deuterium abundance in low-metalicity gas clouds have been made from the absorption spectra of background quasars. The nucleosynthesis calculations reproduce the observed deuterium abundance only if $\Omega_b h^2 = 0.020 \pm 0.001$. The ratio of amplitudes of odd to even acoustic peaks in the CMB anisotropy spectrum provides an independent determination of $\Omega_b h^2 = 0.0224 \pm 0.0009$, in stunning agreement with the nucleosynthesis value. Thus physics at the time of recombination confirms a result from the nucleosynthesis epoch, three minutes after the big bang. The discrepancy between these determinations and the mass seen in stars and other luminous structure requires most of baryonic matter to be dark. Possibilities include matter hidden in condensed objects – there have been extensive gravitational microlensing searches for massive compact halo objects (MACHOS) near our galaxy, with too few being found to account for mass in the halo – and matter hidden in gas clouds.

Several measurements give consistent results for the total matter density. CMB measurements, particularly the height of the first acoustic peak, require $\Omega_M h^2 = 0.135 \pm 0.009$. Red-shift survey measurements of the shape of the power spectrum for large-scale matter inhomogeneities yield $\Omega_M h^2 = 0.20 \pm 0.03$. These results agree well with those obtained by combining measurements of the baryon density and the baryon-to-total-mass density ratio in clusters, as determined by X-ray measurements or by measurements of the Sunyaev-Zel'dovich distortion of the CMB. The results are consistent with Hubble-expansion observations of distant Ia supernovae, which indicate $\Omega_\Lambda - \Omega_M \sim 0.4$.

The excess of matter over baryonic matter strongly suggests that some type of nonbaryonic particle was produced in the early hot universe, and now exists as background matter, affecting the expansion and large-scale structure of our universe. One possibility is massive neutrinos. If a neutrino has a mass much smaller than 2 MeV, it decouples thermally from other matter while still relativistic. Their current number/energy densities can be related to those of the photons (the

cosmic microwave background), which are given by Stefan's law

$$\begin{Bmatrix} n_\gamma \\ \rho_\gamma \end{Bmatrix} = 2\int \frac{d^3q}{(2\pi)^3} \frac{1}{\exp(q/T_\gamma)-1} \begin{Bmatrix} 1 \\ q \end{Bmatrix} = \begin{Bmatrix} 2\zeta(3)T_\gamma^3/\pi^2 \\ \pi^2 T_\gamma^4/15 \end{Bmatrix} \approx \begin{Bmatrix} 408/cm^3 \\ 4.6\times 10^{-34} g/cm^3 \end{Bmatrix}$$

That is, the background photon number and energy densities are fixed by today's CMB temperature, which has been measured to be $T_\gamma \sim 2.72$K. Clearly ρ_γ/ρ_{crit} is very small. That would also be the case for neutrinos were it not for neutrino mass. For neutrino masses small compared to the temperature at coupling (so that the neutrinos have a relativistic distribution) but large compared to today's temperature (so that the mass dominates the present energy density) one finds

$$\rho_\nu = 2\sum_i m_\nu(i) \int \frac{d^3q}{(2\pi)^3} \frac{1}{\exp(q/T_\nu)+1} = \frac{3}{4} n_\gamma \left(\frac{T_\nu}{T_\gamma}\right)^3 \sum_i m_\nu(i)$$

The sum extends over the light neutrino masses. T_γ is higher than T_ν due to photon reheating by $e^+ + e^- \rightarrow \gamma + \gamma$ after weak interaction freezeout

$$\frac{T_\nu}{T_\gamma} = \left(\frac{\rho_\gamma}{\rho_\gamma + \rho_{e^-} + \rho_{e^+}}\right)^{1/3} = \left(\frac{4}{11}\right)^{1/3}$$

Thus one finds

$$\rho_\nu = \frac{3}{11} n_\gamma \sum_i m_\nu(i) = 0.0106 \frac{\rho_{crit}}{h^2} \sum_i m_\nu(i)/eV$$

For the three known light neutrinos, the minimum ρ_ν is obtained for a standard seesaw hierarchy: only one generation is important, with $m_\nu \sim \sqrt{\delta m_{23}^2} \sim 0.055$ eV. The maximum ρ_ν is obtained for a degenerate hierarchy, three neutrinos each with a mass ~ 2.2 eV (the tritium β decay bound), yielding for $h \sim 0.71$

$$0.0011 \le \rho_\nu / \rho_{crit} \le 0.14$$

The lower bound is not too much less than the mass density in the visible stars, while the upper bound (corresponding to three degenerate light neutrinos with $m_\nu \sim 2.2$ eV) is some 100 times larger. In fact, though the exact bound is somewhat in debate, very recent CMB results from WMAP when combined with large-scale structure and supernova Ia data appear to lower the upper bound from 0.14 to 0.026. (We use the analysis of Hannestad, which is somewhat more conservative than the original WMAP analysis.) That is, the bound on ρ_ν derived from laboratory data is now significantly less restrictive than that imposed by cosmology. (Perhaps a better statement is that tritium β decay mass bounds must be improved in order to avoid the neutrino mass scale becoming a significant uncertainty in cosmological analyses.)

One concludes from the excess of matter over baryonic matter that most of the universe's matter is non-baryonic and (given constraints on light neutrino masses) must involve one or more particles outside the standard model of particle physics.

One important possibility is the axion, a light pseudoscalar predicted in extensions of the standard model in which the strong CP problem is solved by the Peccei-Quinn mechanism. Axions have couplings to **E•B,** and can be produced by fluctuations in this pseudoscalar source term. Axion couplings are severely limited by laboratory searches, red giant and other stellar cooling arguments, and by the duration of the neutrino burst from SN1987A. The primary "open window" corresponds to very weakly coupled axions, with masses of 10^{-2} to 10^{-5} eV, where the lower bound is established by requiring the cosmic axion contribution to dark matter not exceed ρ_{crit}. Thus light axions near this lower limit are most interesting cosmologically.

Axions are produced in the early universe by a nonthermal mechanism in which classical axion field oscillations are excited, yielding a highly degenerate axion Bose condensate that acts as cold dark matter. The production mechanism becomes more effective for lighter axions, so the contribution to Ω_M increases as the axion coupling and mass drop. A sea of axions of mass 10^{-5} eV and typical velocity ~ 10^{-3} is thus a candidate for the bulk of Ω_M. The technique of choice to search for cosmological axions is the conversion $a \rightarrow \gamma$ in a microwave cavity placed in a strong magnetic field. This resonant process requires tuning the cavity to step through the allowed range of axion masses, looking for the microwave photon. This program is partially completed, with new and more sensitive experiments in the construction stage. The microwave cavity experiments do not require underground sites.

Perhaps the leading particle cold-dark-matter candidate comes from supersymmetric extensions of the standard model. Although the energy scale where supersymmetry should appear is not fixed *a priori*, the mass hierarchy problem – the stability of the electroweak scale with respect to radiative corrections – suggests that superpartner masses must be ~ 1 TeV. As explained below, the lightest supersymmetric particle most likely is stable and could account for the nonbaryonic dark matter.

Several arguments favor weak-scale supersymmetry. The gauge coupling strengths measured in accelerator experiments unify at the scale of grand unified theories (GUTs) if the masses of supersymmetric particles are ~ 1 TeV. Precision elecroweak data favor a light Higgs boson, as predicted by the minimal supersymmetric extension of the standard model (MSSM).

In order to prevent baryon- and lepton-number violation in supersymmetric particles, the conservation of R parity is imposed on theories. The R-parity quantum number is +1 for standard-model particles and –1 for the supersymmetric partners (sparticles). Conservation of R parity requires sparticles to be produced in pairs, heavy sparticles to decay into lighter sparticles, and the lightest sparticle to be stable. Thus the lightest supersymmetric particle (LSP) is a leading particle dark matter candidate. The LSP must be a neutral, weakly-interacting massive particle (WIMP), as LSPs with strong or electromagnetic interactions would become bound in anomalously heavy isotopes. Severe bounds exist on the possible abundances of such isotopes.

A natural possibility for the LSP in the neutralino, a linear combination of the wino, bino, and the two higgsinos, the superpartners of the neutral gauge and Higgs bosons. If the neutralino is the stable LSP, it would be present today as a cosmological relic from the early big bang, when temperatures were sufficiently high to produce pairs of supersymmetric particles. Like other weakly interacting particles, WIMPs will fall out of thermal equilibrium with the rest of the universe when the temperature drops to the point that weak rates, which typically vary as T^5, can no longer keep up with the Hubble expansion. The result at late times is cold dark matter, massive particles moving nonrelativistically at the time of structure formation. The relic density of any WIMP depends on its annihilation cross section, which by assumption is weak scale. Detailed calculations for the neutralino, in a variety of supersymmetric theories, suggest that the relic density will be sufficient to account for a significant fraction of the dark matter, *i.e.*, ~ 0.1–0.3 of the critical density.

Most direct-detection particle dark matter experiments search for nuclear recoils produced in elastic scattering of neutralinos from nuclei. Searches for inelastic nuclear excitations have also been done in targets where a low-lying excited state can be reached. The subsequent γ-decay provides the signal. The predicted rates depend on the neutralino cross section and the density and velocity distribution of neutralinos in the vicinity of the solar system.

There are many variables affecting neutralino-nucleon cross sections. Candidate supersymmetric models are classified according to the mechanism by which the supersymmetry breaking is communicated from the hidden sector to the visible sector. The most basic mechanism is provided by minimal supergravity (mSUGRA), which arises as a low-energy limit of a supergravity theory. In mSUGRA the broken supersymmetry is communicated to the visible sector via gravity, leading to soft SUSY-breaking masses at the TeV scale. Among the parameters are a universal gaugino mass $m_{1/2}$ and $\tan\beta$, a ratio of the vacuum expectation values of Higgs fields. Parameter variations define a range for mSUGRA spin-independent neutralino-nucleon cross sections ~ 10^{-6}–10^{-11} pb. Frameworks more general than mSUGRA broaden this range.

Experiments limit the WIMP scattering rate, and thus the neutralino-nucleon cross section as a function of the WIMP mass. Some 20 dark matter experiments are currently operating, with all but one of the world's underground laboratories hosting at least one. The current detection limit (90% c.l. sensitivity) is ~ 0.3 events/kg/day, corresponding to a cross section ~ 10^{-6} pb. This sensitivity was achieved by the Edelweiss experiment, in which no nuclear recoil events above 20 keV were observed after 7.3 kg-days of exposure of a single 0.33 kg Ge cryogenic detector. Similar sensitivity has been achieved by the ZEPLIN I group, which has 230 kg-days of data using a single-phase liquid Xe detector with a fiducial mass of 3.1 kg. Next-generation improvements to target masses of 10–50 kg should reach cross section sensitivities of ~ few 10^{-8} pb within 5 years, while next-to-next generation efforts may reach 10^{-10} pb sensitivities (or event rates of 1/100 kg y) in 10 years.

E.2 Dark Matter: Readiness of Next-Generation Experiments. Several 100-1000 kg dark-matter experiments are in the planning or proposal stages, some with smaller-scale versions already running or currently under construction.

All of these experiments have very stringent background constraints that require deep underground sites and careful attention to sources of ambient radioactivity. Many of the experiments allow rejection of the otherwise dominant electromagnetic background by determining whether the interacting particle produced an electron recoil or a nuclear recoil. Such discrimination is possible because the energy loss per unit track length is much higher for nuclear recoils than for electron recoils. Experiments may also be able to exploit the expected time dependence of the WIMP signal. If the experiment's energy response, efficiencies, and backgrounds can be kept stable and if a sufficient number of WIMP events is detected, it may be possible to detect a ~ 5% modulation in the WIMP scattering rate and energy spectrum due to the Earth's orbital motion. The presence of this annual modulation could confirm a signal, while the absence can be exploited to identify background, thereby improving an upper bound.

GENIUS (Ge): The GENIUS collaboration plans to operate an array of 40-400 high-purity Ge detectors (100kg-1 ton) immersed directly in liquid nitrogen. The liquid nitrogen is stored in a tank 12m in diameter and 12m in height, surrounded by 2m of insulating material (polystyrene foam). The Ge detectors are suspended at the center of the inner tank on a polyethylene support. Several concentric layers containing up to 37 detectors each are envisioned. The detector is designed for both dark matter and double beta decay searches. The signal for WIMP scattering is ionization in the Ge crystals. One of the GENIUS design goals is a reduction of backgrounds by a factor of 1000, relative to best current measurements. This will be achieved by removing almost all materials from the immediate vicinity of the detectors (the crystal mounts and cryostat

system are the main background sources in current experiments) and by the immersion in very pure liquid nitrogen. The compact arrangement of Ge crystals provides significant self-shielding.

Preliminary studies suggest high purity Ge detectors work reliably under such conditions: low energy thresholds (2.5 keV) and good energy resolution (1 keV at 300 keV) were achieved for 300-400g crystals operating for up to three weeks in liquid nitrogen. Monte Carlo estimates indicate the background goal is feasible if care is taken to bring the crystals quickly underground, avoiding activation, and if Ge crystal surfaces are kept clean.

The expected sensitivity of GENIUS for spin-independent WIMP scattering is about 10^{-9} pb, assuming an exposure of 100 kg y and a background of 1 event/100 kg y/keV.

A small test version, GENIUS-TF, is currently under construction in Gran Sasso. Fourteen natural Ge crystals (40 kg) will be mounted within a 0.064 m^3 volume of ultrapure liquid nitrogen. The entire experiment fits within a volume of 2m × 2m × 2m. GENIUS-TF will determine whether "naked" Ge detectors work reliably in liquid nitrogen for extended periods (at least a year) and will be helpful in testing materials radiopurity. **GENIUS is in the research and development stage**.

Majorana (Ge): Majorana was discussed previously as a double beta decay detector. The enriched Ge crystals will be arranged in 10 21-crystal modules in order to provide a high amount of self-shielding. Each detector will be axially (2) and azimuthally (6) segmented so that single-scatter events, which are almost always contained in one detector segment, can be distinguished from multiple-scatter events, which usually deposit energy in more than one segment. Two preliminary phases are anticipated, one with a single enriched ^{76}Ge crystal and a second with 14-18 enriched crystals in one cryostat system.

Estimates of Majorana's performance as a WIMP detector are based in part on experience with currently running Ge diode experiments. The ionization signal from WIMP scattering will be similar to current detectors, but the background rate should be reduced due to the segmentation and to the close packing of the modules. Both of these changes with significantly reduce Compton backgrounds and help with neutron rejection. (Neutrons have a mean free path of several centimeters in Ge and thus can be identified because of scattering in multiple sites.) Pulse shape analysis is expected to provide position information that can be use to reject events on the surfaces of the detectors: surface contamination of the crystals may be a limiting background for this type of dark matter experiment. Another expected advantage of segmented Ge detectors is reduced capacitance and thus a threshold below 1 keV ionization energy.

Majorana plans to run for 10 years with a mass of 500 kg. The long duration will increase sensitivity because of the predicted annual modulation of the event rate and energy spectrum. The necessary detector stability over several years has already been demonstrated in smaller Ge crystal arrays.

Assuming a flat background of 0.005 counts/(keV kg day) between threshold and 20 keV ionization energy, Majorana's cross section sensitivity for spin-independent WIMP-nucleon interactions should be ~ 10^{-9} pb. This assumes a 1 keV threshold and an exposure of 5000 kg years. **Majorana is in the latter stages of research and development.**

CryoArray (Ge, Si): CryoArray is a large array of germanium and silicon detectors cryogenically cooled to ~ 25mK, the same technology used in CDMS (Cryogenic Dark Matter Search). Simultaneous measurements are made of the ionization in the Ge diodes and the phonon energy produced in an interaction. Together these two measurements allow rejection of electron-recoil background events. Cryogenic detectors share the excellent energy resolution of conventional Ge diodes. In CDMS I the resolution achieved in the phonon and charge channels was less than 1

keV. For events above 10 keV recoil energy the rejection efficiencies for photons and low-energy surface electrons was greater than 99.95% and 95%, respectively. CryoArray is expected to have improved discrimination against surface electrons (>99.5%) because the phonon measurement provides information of the location of the interaction: comparison of phonon-pulse arrival times in a detector's four independent channels localizes interactions in the detector's xy-plane. Events occurring near detector surfaces result in phonon pulses with shorter rise times, allowing their rejection. Si detectors, which are less sensitive to WIMPs than Ge detectors, will be valuable in confirming that a possible signal is due to WIMPs.

CDMS I, with a active fiducial mass of Ge of ~ 0.3 kg, was mounted at a shallow site on the Stanford campus. CDMS II, which will have a total mass of ~ 7 kg and 42 detectors, is currently being deployed at a depth of 2080 mwe in the Soudan mine. This experiment will run through 2006. The detectors for CryoArray will be close packed within a cryostat, with the full experiment likely consisting of several identical cryostats, each with a volume less than 1 m^3. Simplifications introduced since CDMS II construction should allow ten times more detector mass to be mounted within a given cold space. This will make materials screening easier. A challenge in constructing a one-ton array at reasonable cost will be developing mass-production techniques for the ~ 1000 detectors. The cold and warm electronics systems developed for CDMS II lend themselves well to mass production.

To reach its goal, sensitivity to 10 WIMP interactions per year or, equivalently, to a WIMP-nucleon cross section of 10^{-10} pb, CryoArray requires relatively modest improvements in the technology of CDMS II, provided that the experiment is placed at sufficient depth to render the fast neutron background negligible. The photon background must be improved by approximately a factor of fifty, through a combination of better materials screening and better self-shielding. This goal should be achievable, as it is a factor of three beyond what is currently achievable with Ge diodes. More difficult will be the task of reducing β background by a factor of ~ 300. Better self shielding will be particularly effective for βs, but screening materials for low-energy surface βs will be a challenge. **CryoArray is in the research and development stage**.

ZEPLIN IV (liquid Xe): Liquid xenon has some excellent properties as a dark matter detector. It has a high density, 3 g/cm^3, so detectors can be compact. It has a high atomic mass (A=131.3), which is favorable for WIMP scalar interactions provided that a low threshold energy can be achieved.

Liquid xenon is an intrinsic scintillator, having high scintillation (λ = 170 nm) and ionization yields because of its low ionization potential (12.13 eV). There are no long-lived radioactive Xe isotopes, and other impurities (such as ^{85}Kr) can be reduced to very low levels by centrifugation or with a distillation tower and cold trap. Krypton contamination levels as low as 1ppb have been achieved. Liquid xenon is available in large quantities.

The formation of excimer states, bound ion-atom systems, produces scintillation in liquid Xe. If the electrons are drifted in a high electric field (10^5-10^6 V/cm), a secondary process, called proportional scintillation, can be detected. If the electrons are drifted out of the liquid into Xe gas, the secondary process is electroluminescence, which takes place at much lower fields of a few kV/cm. Electron and nuclear recoils can be distinguished by measuring both the primary scintillation signal and a secondary process.

The recoiling Xe atom loses its energy through both ionization and scintillation. The number of fast scintillation photons is only about 25% of the number of electrons associated with an electron or gamma with the same energy. The number of released free electrons is also small, as the ionization electrons recombine very quickly. The strong recombination leads to the emission of more UV photons. Under a high electric field a nuclear recoil will thus yield a small charge signal and a much larger light signal, while an electron recoil has the opposite behavior. The

ratio of charge to light is thus the basis for separating nuclear from electron recoils.

The ZEPLIN IV project, with ZEPLIN II as a prototype, is a proposed one-ton two-phase (liquid and gas) Xe detector. The goal is to measure both scintillation and electroluminescent photons to separate electron from nuclear recoils. Experiments with a 1 kg liquid Xe test chamber have achieved recoil energy thresholds below 10 keV and factors of 1000 in electron discrimination.

Due to the high purity of liquid Xe, the scintillation photons can be collected with a high efficiency while the electrons can be drifted to an anode region for readout. To maintain background discrimination at low energies, it is crucial to detect the few electrons produced in a nuclear-recoil event. The efficiency of this process is better in two-phase Xe than in the single phase. PMTs detect the primary scintillation photons a few nanoseconds after the event, while the electrons are drifted to the gas phase, where electroluminescence occurs. The same PMTs detect the electroluminescent photons after a few tens of microseconds, depending on the electron drift distance.

ZEPLIN II, the prototype for ZEPLIN IV, is under construction at UCLA and will be installed at the Boulby mine, UK. The 35 kg liquid Xe fiducial volume is viewed by seven PMTs placed above the gas phase. The static electric field to drift the free ionization electrons up to the gas phase is shaped by ten copper rings. Two wire frames form the electron extraction field at the liquid-gas phase surface and the electroluminescence field above the surface. The detector is vacuum-insulated with a double-layer chamber made of cast copper vessels.

The one-ton ZEPLIN IV detector will be modeled after ZEPLIN II. Eighty 5-inch PMTs will be placed above the liquid and gas phases, with special care taken to reduce any dead regions in the detector. The insertion of an internal CsI photocathode is being considered for signal amplification. The projected sensitivity of ZEPLIN IV is $\sim 5 \times 10^{-9}$ pb for a background of 2 events/(kg day keV) and 360 days of data.

XENON (liquid Xe): XENON is a proposal for a modular liquid Xe experiment with ten time-projection chambers (TPCs), each containing 100 kg of active target Xe. An additional 150 kg of liquid Xe surround the target, providing a veto shield for background events generated in the containment vessel and other materials. XENON will be a two-phase experiment, with detection of both the primary and proportional scintillation signals. The electrons produced in a nuclear or electron recoil are drifted to the gas phase, where they produce proportional scintillation light in a strong electric field.

The primary UV photons are detected by an array of PMTs placed above the liquid-gas interface. To increase the detection efficiency, a CsI photocathode is placed in the liquid and used to convert downward-going photons into photoelectrons. To increase the primary light collection efficiency, the TPC walls will be made of 90% Teflon, which has a 90% diffuse reflectivity at 178 nm. Three signals are thus expected from one event: the prompt scintillation signal, the electroluminescence signal, and the proportional scintillation signal from the CsI photocathode. The difference in arrival time between the first two signals gives the z-coordinate of an event, while the xy position can be determined by reconstructing the spot where the proportional scintillation pulse is produced. The 3D event localization allows background discrimination by fiducial volume cuts. The overall efficiency for background rejection is expected to exceed 99.5%, with visible energy thresholds of a few keV, corresponding to recoil energies below 10 keV.

The liquid Xe TPCs are cylindrical, with a height of 30 cm and an inner diameter of 38 cm. The cylinder, formed by a sandwich of Teflon spacers and thin copper rings for field shaping, contains the active liquid Xe target. The cylinder is closed at the bottom by a thin Cu plate. The inner surface of the plate is coated with CsI. A larger Cu cylinder housing the wire structure for

the proportional scintillation field and 37 PMTs in a close-packed hexagonal pattern close the top. The entire cylinder is enclosed in a copper vessel containing the liquid Xe for active shielding. Two rings of 16 PMTs detect the scintillation light from the shield. While the baseline detector design uses low-radioactivity PMTs to read out light, readout schemes based on large-area avalanche photodiodes or gas electron multipliers are also under study.

The extrapolated sensitivity of XENON for one ton of target material and three years of exposure is 4×10^{-10} pb. This assumes a background rate of 0.039 events/(ton day keV) (corresponding to a nuclear recoil discrimination of 99.5%) and a visible energy threshold of 4 keV (corresponding to a 10 keV recoil energy in liquid Xe). Depending on the detector readout scheme and the efficiency of the self-shielding, another factor of 4 improvement is expected. A prototype with 7 kg of active material is planned to test all design aspects and to determine backgrounds and the event threshold. **XENON is in the research and development phase.**

DRIFT-3: The DRIFT (Directional Recoil Identification From Tracks) experiment uses a negative-ion TPC. The negative ions are created by the slightly electronegative gas attaching to the electrons produced by a recoil track. Because negative ions diffuse much less than electrons do, no external magnet is needed to inhibit diffusion, and sub-millimeter resolution can be achieved even after drifting the ions for meters. Measurement of the range of the recoil together with the total ionization should allow nearly perfect rejection of background photons and electrons.

A one-cubic-meter prototype with 2-mm resolution and 250 g of CS_2 gas is currently running at a depth of 3000 mwe in the Boulby mine. A second-generation version with 0.5-mm resolution and higher pressure (and thus greater mass) has been proposed. DRIFT-3 would be a larger version of the second-generation experiment, with 100 m^3 of gas at 160 torr, for a total active mass ~ 100 kg. The small mass will likely limit the experiment's sensitivity to cross sections of ~ 10^{-9} pb, corresponding to 10 events/y, depending on the Z of the gas that is used.

DRIFT's primary advantage is in providing the directional axis of the recoil, and quite possibly the direction of the recoil as well. Because WIMPs should have a strong directional asymmetry due to the movement of the sun with respect to the galaxy frame, the directional information can confirm that events are due to WIMPs. The diurnal modulation due to the earth's rotation produces a 10% asymmetry, significantly larger than the annual asymmetry and less subject to possible systematic effects. Were a WIMP signal detected, directional information would provide information about their galactic distribution. **DRIFT-3 is in the conceptual stage.**

E.3 Dark Matter: Facility Requirements. This section summarizes the facility requirements of next-generation dark matter experiments. What should an underground laboratory provide in order to optimize these experiments?

Depth requirements: The most important cosmic-ray muon background for direct dark matter detection experiments is due to fast neutrons (20-500 MeV) produced outside the detector shielding. These high-energy "punch-through" neutrons are difficult to tag with a conventional local muon veto system, as they can originate several meters within the cavern's rock walls. They scatter in the materials surrounding detectors, generating low-energy neutrons that produce signals in central detectors quite similar to those of WIMPS. Countermeasures currently under study include thick active shields and wide umbrella veto systems deployed in the tunnel rock.

In contrast, current experiments very successfully discriminate against backgrounds that deposit energy through electromagnetic interactions, reducing rates by many orders of magnitude. Consequently fast neutrons have become the limiting factor.

Good benchmarks are provided by existing experiments. The sensitivity of CDMS at the shallow

Stanford Underground Facility (16 mwe) is limited by external neutrons, despite a muon veto system that is more than 99.9% efficient. EDELWEISS is an experiment similar to CDMS, but located at depth in the Laboratoire Souterrain de Modane in the Frejus Tunnel (4800 mwe). Because of its depth, EDELWEISS has detected no WIMP candidates during 7.4 kg-days of exposure. This experiment is currently the most sensitive direct dark matter search. As discussed above, the ten-year goal of several experimental groups is to reach a sensitivity of one event/100 kg/year, more than four orders of magnitude beyond current limits. Thus there is a need to extrapolate backgrounds far beyond current experience.

Estimates of the size of "punch through" neutron backgrounds depend on the muon flux and neutron production cross sections. The former is well measured. At the earth's surface the muon flux is about $170/m^2/s$ and the average energy is ~ 4 GeV. The attenuation at 4500 mwe is nearly a factor of 10^7: the penetrating flux is $800/m^2/y$ and is much harder, with a mean energy of ~ 350 GeV. (For comparison, the flux at 1700 mwe (the WIPP depth) is 100 times higher, while at 6500 mwe (corresponding to the 7400 ft level at Homestake) it is ~ 25 times lower.)

The neutron cross sections are far more uncertain. Energetic muons produce neutrons in rock through quasielastic scattering, evaporation of neutrons following nuclear excitation, photonuclear reactions associated with the electromagnetic showers generated by muons, muon capture, and secondary neutron production in such processes. The neutron yield as a function of the mean muon energy is approximately a power law, $N \propto \langle E_\mu \rangle^{0.75}$. While various theoretical estimates of the high-energy neutron spectrum at depth have been made, few experiments have been done. An empirical function that is in use, derived from the Monte Carlo muon shower propagation code FLUKA, works reasonably well, with deviations from measurements being a factor ~ 3, particularly at greater depths. This factor is a reasonable estimate of uncertainties in fast neutron predictions.

When such estimates are combined with Monte Carlo simulations, one finds that CDMS-II at the Soudan Mine (2080 mwe) should detect no more than eight single-scatter events due to external high-energy neutrons, during an exposure of 6.8 kg-y. This will not adversely impact the experiment's sensitivity goal of 3×10^{-8} pb. But backgrounds will be an issue for subsequent experiments. For example, a one-ton Ge experiment designed to reach a sensitivity of 10^{-10} pb would yield about 10 WIMP events/y. Detection at this level would probe a majority of the parameter space of currently favored SUSY models, complementing searches that will be done at the LHC. If performed at Soudan depths, one would expect up to 1170 neutron events/y. Neutrons often can be distinguished by their multiple scattering in experiments with good granularity – detailed Monte Carlo simulations are necessary to estimate the rejection possible because of multiple scattering. If one assumes this technique will provide a factor of ten suppression in the fast neutron background, the resulting signal/noise would still only be 1/10.

Depth reduces the neutron background to an acceptable level. The factor of 25 that would be achieved by going from Soudan to a site at 4500 mwe would reduce the neutron background rate to 50/y. If an additional factor of ten is obtained by vetoing multiple scattering events, the resulting background would be a factor of two below the target WIMP rate (corresponding to a cross section of 10^{-10} pb). An additional factor of 25 would be obtained by going to 6500 mwe, the NUSEL-Homestake 7400 ft level, reducing the background to one event per several years. If WIMPS are not observed, this reduction might be important in establishing the tightest possible limits.

While depth is the simplest, most certain, and least expensive solution to the fast neutron background, sites shallower than 4500 mwe could be acceptable with proper attention to background reduction. Sophisticated shielding and vetoing could reduce this background by one to two orders of magnitude. A thick (1-2m) scintillator active veto around the detectors could tag high-energy neutrons as they penetrate inward. In addition the cavern rock, or an outer heavy

passive shield, could be instrumented with additional veto detectors in order to catch some part of the shower associated with the initiating muon. Finally, increased granularity in detectors could enhance the multiple scattering rejection rate. While only preliminary studies of the efficacy and cost of these steps have been made, it is likely that the cost would not exceed that of the central dark-matter detectors.

In summary, the goals of experiments envisioned for the next ten years (corresponding to WIMP cross sections no smaller than 10^{-10} pb**) could likely be met with shielding of 4500 mwe**. A deeper site (e.g., 6000 mwe) would provide an additional safety net against residual muon-related backgrounds, and may be necessary for next-to-next-generation experiments that plan to reach beyond 10^{-10} pb. Shallower sites may be satisfactory if additional investments are made in the detector, including carefully designed shields and high granularity. However, there remains some concern that a possible systematic leakage of muon-related neutron events could render a shield less effective than required, though no specific mechanism for such leakage has been identified, to our knowledge.

Materials handling issues: During fabrication and transport of detector components at the earth's surface, high-energy cosmic-ray-induced neutrons, protons, and muons can activate materials through spallation reactions. Knowledge of the cosmic ray spectrum and spallation cross sections is required to calculate activation rates. The flux of cosmic rays and its variation with geomagnetic latitude is well known. The nuclear spallation cross sections are far more uncertain. Neutrons dominate nuclide production at the earth's surface (~95%), with protons (~5%) and muons (~1%) of some importance. There are only a few (n,x) and (p,x) cross sections measured as a function of target mass and energy. Cosmogenic activation programs like SIGMA and COSMO use compiled cosmic ray intensities and semiempirical formulas fitted to available nuclear data to estimate cross sections.

Isotope	Decay	Half life	Energy deposition in Ge (keV)	Activation (μBq/kg)
^{3}H	β^-	12.33 y	E_{max}=18.6	2
^{49}V	EC	330 d	$E_{K(Ti)}$=5, no γ	1.6
^{54}Mn	EC,β^+	312.3 d	E_γ=840.8, $E_{K(Cr)}$=5.4	0.95
^{55}Fe	EC	2.73 y	$E_{K(Mn)}$=6, no γ	0.66
^{57}Co	EC	271.8 d	E_γ=128.4,142.8, $E_{K(Fe)}$=6.4	1.3
^{60}Co	β^-	5.27 y	E_{max}=318, E_γ=1173.2,1332.5	0.2
^{63}Ni	β^-	100.1 y	E_{max}=66.95, no γ	0.009
^{65}Zn	EC,β^+	244.3 d	E_γ=1124.4, $E_{K(Cu)}$=9	9.2
^{68}Ge	EC	270.8 d	$E_{K(Ga)}$=10.37	172

Table IE.1 Cosmogenically-produced isotopes in Ge for an exposure of 30 days at sea level, followed by one year of exposure under ground.

In principle calculations or measurements of cosmogenic activation rates in all WIMP detector target materials (and potentially in surrounding materials) must be performed in order to accurately estimate allowed exposure times on the earth's surface and required "cool-down times" below ground. Here we discuss Ge as an example, a proposed target material in several experiments, as extensive calculations have already been done.

The Table above shows cosmogenically produced isotopes in natural Ge after exposure for 30 days on the surface followed by storage below ground for one year. Only isotopes with half-lives longer than 200 days are shown. For ^{68}Ge a saturation activity is taken, as this isotope cannot be separated during the zone melting process. The calculations were done with a variation of the COSMO program. Limits on ^{68}Ge and ^{3}H activation from the CDMS-I 1999 data run are consistent with these calculations. These are the two most troublesome activities. ^{68}Ge decays by electron capture to ^{68}Ga, which emits a 10.4 keV X-ray. ^{3}H β^- decay has an endpoint of 18.6 keV.

To estimate expected counting rates due to ^{68}Ge and ^{3}H, we take the two extreme cases of GENIUS (which has a background goal of 0.01 events/(kg y keV), with only the charge signal recorded) and CryoArray (which has an electron-recoil rejection efficiency goal of 99.95% and a γ-ray background goal of 4.75 events/(kg y keV)). Two μBq of ^{3}H would produce ~ 5 events/(kg y keV), which is tolerable for CryoArray but much too high for GENIUS. A ^{68}Ge activity of 172 μBq produces ~ 2500 events/(kg y keV) in the 10.4 keV line. Although this is a much higher event rate, the excellent energy resolution of Ge detectors will concentrate most of these events in a few keV-width bins centered on 10.4 keV. The activity will also subside after a few years underground. Thus the ^{68}Ge activity is less problematic.

While limiting surface exposure times to 30 days or less is possible – and while shielded production and transportation schemes are being discussed – it would be preferable to produce the Ge detectors in a shielded facility directly at the NUSEL site. Modest cover of 10-20 mwe is sufficient to eliminate the hadronic component of cosmic-ray-induced showers, which dominates the activation. Thus Ge detector fabrication could be done on a level much shallower than that required for the experiment itself.

Most of the dark matter experiments discussed above use copper. The table below lists the cosmogenic activities in Cu after a surface exposure of 90 days followed by underground storage of one year. The activities, again calculated using a modified version of the COSMO code, must

Isotope	Decay	Half life	Q-value (keV)	Activity (μBq/kg)
^{3}H	β^-	12.33 t	18.6	6.3
^{22}Na	EC,β^+	2.6 y	2842.2, E_γ=1274.5	0.7
^{49}V	EC	330 d	601.9	7.8
^{54}Mn	EC,β^+	312.3 d	1377.1, E_γ=840.8	125
^{55}Fe	EC	2.73 y	231.4	10.1
^{57}Co	EC	271.8 d	836, E_γ=128.4,142.8	28.5
^{60}Co	β^-	5.27 y	318, E_γ=1173.2,1332.5	8.33
^{63}Ni	β^-	100.1 y	66.95	1.02
^{65}Zn	EC,β^+	244.3 d	1351.9, E_γ=1124.4	123.8

Table IE2: Cosmogenically produced isotopes in Cu for an exposure of 90 days at sea level followed by one year of below-ground storage.

be considered in the context of specific experimental designs. The quantity and location of copper will vary, as well as the degree to which the indicated activities will interfere with specific signals.

Basic facility needs: The basic facility needs of dark matter experiments are quite similar to those for double beta decay:

- The space required to set up any one of the next-generation detectors is no more than 10×50 m^3. It could be advantageous to mount several dark matter experiments in a single larger hall because of common needs for cranes, water shielding, and a muon veto.
- Experimental rooms must be cleanable, that is, upgradeable to clean-room standards during initial assembly and later operations, with air scrubbed to reduce radon levels. Some experiments require constant radon purging.
- Each experiment requires additional underground laboratory floor space to house data acquisition (~ 50 m^2). Modest surface laboratory space (~ 30 m^2) and a surface control room with computer links to the laboratory (~ 30 m^2) are needed. A surface (or underground) laboratory clean room (class 1000-10000) for staging and assembly of experiments is important.
- Because stability during extended periods of data-taking is critical, air condition is necessary in both the experimental and data acquisition areas.
- Power requirements are modest, no more than 50 kW.
- Access to NUSEL common facilities – machine shops (below and/or above ground), the low-level counting facility, and the radon-free clean storage area – is important.
- Nearly all dark-matter experiments would benefit from an underground facility for electroforming copper. The germanium experiments would be helped by underground facilities for crystal growth and detector manufacturing.
- The typical size of underground experimental crews during installation is 5-10 people. Standard running requires only one or two people accessing experimental areas, with larger numbers during upgrade periods and run commissioning. The principal laboratory requirement is 24/7 access in case of emergency.

Special facility needs (experiment specific): Each experiment has specific additional needs not covered in the general list above:

- GENIUS requires room space of about 16 m in diameter and 19 m in height in its conventional configuration, with the liquid nitrogen tank above the ground level of the hall. A two-ton crane, a platform, and a crown wheel would provide access to a class 100 clean room on top on the tank. An alternative configuration would submerge the tank completely below the laboratory floor level, requiring excavation of a hole and coating of the hole with water-proof concrete. This alternative configuration is attractive because the clean room would be at ground level, so that no extra platform or crown wheel would be required. This configuration would be simpler and would be safer in case of a leak or an earthquake. In either configuration, a liquid nitrogen filtering system using active charcoal beds, a nitrogen gas liquefaction system, and a liquid nitrogen supply would be required.
- Majorana's special needs are discussed in Section A.3.
- CryoArray will require an additional room for cryostat pumps and plumbing (25 m^2 footprint), a few He liquifiers (~ 20 kW each of power consumption), and storage for a few hundred liters of liquid nitrogen and liquid helium.
- Zeplin IV requires a crane rated for at least two tons and a liquid nitrogen supply.
- XENON electrical power needs are 100 kW, with 3-phase lines. Liquid nitrogen consumption is estimated to be 3000 liters/d, requiring a large on-site tank, with nitrogen lines to the underground laboratory.
- DRIFT III space needs are somewhat larger: configurations of $10 \times 50 \times 6.5$ m^3 and $15 \times 15 \times 10$ m^3 are under consideration. A 5-ton crane is needed, with enough space above the apparatus for operations. A large gas TPC requires gas-handling equipment, exhaust

treatment, and possibly other safety measures.

E.4 Dark Matter: Summary. Direct WIMP searches are motivated by the possibility that the majority of dark matter in the universe consists of long-lived or stable, weakly interacting particles produced in the big bang. The field is relatively young and developing rapidly, with larger next-generation experiments to follow current efforts. The detector techniques under development – conventional Ge diodes, liquid xenon scintillation detectors, Ge and Si phonon-mediated detectors, gaseous TPCS – are quite varied. In addition to measuring the nuclear recoil spectrum of the WIMP, all experiments provide some additional signature more specific to WIMPS, e.g., the spectral form and event rate in multiple materials or signal modulation due to the motion of the sun and earth about the galactic center. Several current-generation experiments are operating in underground laboratories, while others would like to move to some facility like NUSEL soon. Most experiments could operate successfully at 4500 mwe. Generally the space and power requirements are modest. All projects would benefit from shared infrastructure, particularly low-level counting facilities, materials handling facilities, and underground storage and fabrication facilities.

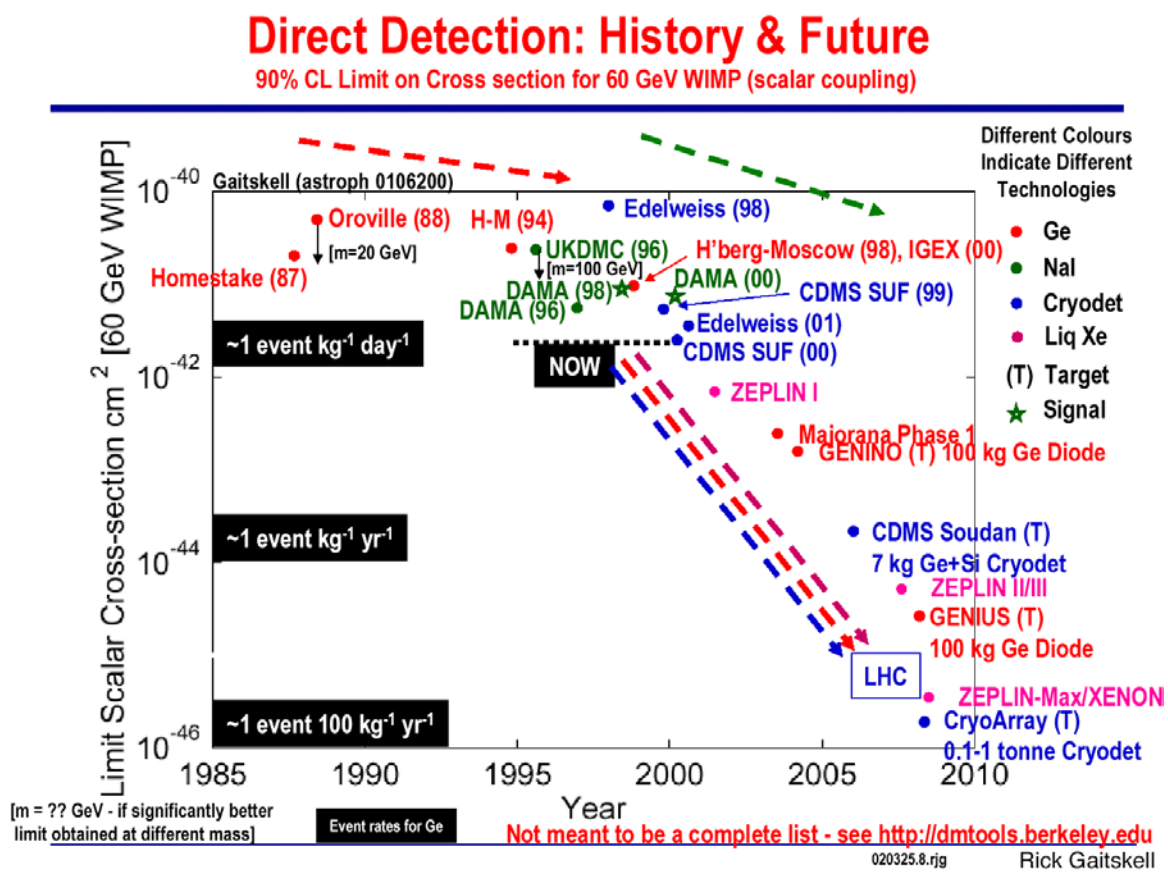


Figure C.10: Projected improvements in dark matter detection limits, given the next-generation efforts now being planned.

F.1 Supernova Neutrino Detection: Importance of the Science. One of the spectacular achievements that resulted from the development of large active solar neutrino and proton decay detectors was the recording of the neutrino burst from Supernova 1987A, which occurred in the Large Magellanic Cloud some 150,000 light years from earth. The coincident detection of events by the Kamioka and IMB collaborations showed that our gross picture of collapse and subsequent protoneutron star cooling – neutrino energy release of ~ 3×10^{53} ergs and a cooling time of ~ 3 seconds – was correct. This observation provided many important constraints on particle physics and astrophysics, including bounds on the neutrino mass and neutrino magnetic moment, constraints on anomalous cooling mechanisms such as axions and large Dirac neutrino masses, and even tests of extra-dimension theories.

Core collapse supernovae occur at the end of the life cycle of a massive star, e.g., one of 20 solar masses or so. Such massive stars evolve rapidly through their various hydrostatic burning cycles, until reaching the final stage where explosive Si burning begins to produce an inert iron core. When the iron core reaches the Chandresekar mass it becomes unstable to gravitational collapse. This collapse proceeds rapidly, typically as about 0.6 times the freefall velocity, as the electron gas quickly becomes ineffective in supporting the star: electron capture converts some of the trapped lepton number into escaping neutrinos. The gravitational work done on the collapsing matter also produces nuclear excitations, which further robs energy from the electron gas.

At a density of about 10^{12} g/cm^3 the neutrinos become trapped: the random-walk diffusion time for an escaping neutrino becomes greater than the collapse time. Thus the remaining lepton number and gravitational energy is locked within the star, trapped until after core bounce.

The collapse of the inner iron core, where the sound speed in nuclear matter exceeds the matter velocity, is homologous. When the central region of the core reaches several times nuclear matter density, the nuclear equation of state abruptly halts the collapse. The resulting trampoline-like rebound produces a pressure wave that moves outward, through the infalling matter and towards the edge of the homologous core (the sonic point). Surrounding infalling shells of matter subsequently reach the same density, rebounding to produce pressure waves that "chase" those already produced. When the edge of the homologous core reaches nuclear density, the compression and subsequent release of the pressure waves result in shock wave formation. The shock wave moves out through the outer iron core and beyond.

The passage of the shock wave through the outer iron core melts the nuclei into a nucleon gas, sharply reducing the neutrino opacity. (The opacity is dominated by coherent neutral current scattering. As the weak charge is approximately the neutron number N, the melting of the nuclei effectively reduces this contribution to the opacity by 1/N.) This and the accompanying enhanced electron capture off free nucleons produces a ν_e deleptonization pulse, a sharp peak in the neutrino luminosity that lasts for about 3 ms. However, 99% of neutrino emission is associated with the slower cooling of the hot, puffy protoneutron star: neutrinos of all favors leak out on a timescale of about 3 s.

Deep in the interior of the protoneutron star the neutrinos are in flavor equilibrium. As they leak out, however, their decoupling from the matter is flavor-dependent. The heavy-flavor neutrinos, which lack charge current reactions with the nucleons and have reduced cross sections for elastic scattering off electrons, decouple from deeper within the star, where it is hotter. The "neutrinospheres" for electron neutrinos and antineutrinos are further out; the ν_es are most strongly coupled to the matter because the matter has undergone substantial electron capture, and is thus neutron rich, enhancing ν_e charged current scattering. Though there is some debate on this matter, the result is a neutrino temperature hierarchy of 8, 4.5, and 3.5 MeV for the heavy-flavor, electron antineutrino, and electron neutrino flavors, respectively. (The corresponding mean neutrino energies are about 3.1 times the temperatures.) This provides an important neutrino oscillation diagnostic, as there is the potential for oscillations to produce a distinctive

temperature inversion.

While investigators agree, at least on a qualitative level, in their predictions of the neutrino fluxes, the supernova mechanism is far more controversial. Almost without exception simulations that employ accepted nuclear equations of state and treat the microphysics (such as neutrino diffusion) reasonably (e.g., multigroup flux-limited diffusion or even a full Boltzmann calculation) fail to produce explosions. The initial hydrodynamic shock wave stalls at or near the edge of the iron core, having lost too much energy in melting nuclei and in neutrino emission. The hope has been that strong charge-current neutrino interactions in the hot nucleon soup left in the shock's wake could provide an extra push to force the shock wave outward again. The reasoning is that, since 99% of the released energy resides in neutrinos, this is the place to look for help. But neutrino heating is less effective than one might hope because the distance between the neutrino-emitting protoneutron star surface and the stalled shock wave represents many scale heights. Furthermore, neutrino heating of the matter near the neutron star quickly raises the matter temperature to ~ 2 MeV, where neutrino emission then competes with neutrino heating. That is, no further net energy deposition can occur.

There are hopes that this neutrino-driven "delayed" model will yet prove correct. One can produce an explosion by artificially hardening the neutrino spectrum. Qualitatively it is also appreciated that convection could enhance neutrino energy deposition. By sweeping heated matter to large radii (where the matter expands and cools, before it has a chance to radiate neutrinos), and replacing it with cold matter from larger radii, convection can circumvent the "gain radius" limitation to total neutrino heating. Great effort is currently being invested in 2D and 3D supernova simulations, though the numerical complexity forces shortcuts in the treatment of the neutrino diffusion and other important microphysics. Some of these simulations yield explosions for certain progenitor star choices, though it is unclear whether these results will survive when neutrino diffusion is handled more realistically. Currently there are several terascale supernova simulation efforts underway that have multiD simulations with realistic microphysics as one of their goals. Thus it may soon be known whether convection is a possible solution to the supernova mechanism puzzle.

Understanding supernovae is crucial to many aspects of astrophysics. They are among the most important engines driving the galaxy's long-term chemical evolution. It is believed that about half of the heavy elements are synthesized in the r-process (rapid neutron capture process), with the hot bubble above the protoneutron star being the most likely site. Wonderful new data on r-process nucleosynthesis is coming from observations of metal-poor halo stars, making this field very exciting. Other important nucleosynthesis is associated with the shock wave heating of material in a supernova, a process called explosive nucleosynthesis. Supernova neutrinos are believed to directly synthesize elements like ^{11}B and ^{19}F through spallation reactions in the carbon and neon zones. This is known as the neutrino process.

Some unusual core-collapse supernovae – suggestive of SNIc explosions, but unusually energetic – have been associated with gamma ray bursts. The nature and origin of gamma ray bursts is one of the key problems in observational cosmology.

As already mentioned, supernovae are marvelous neutrino sources. The detection of these neutrinos in an array of underground detectors could yield important new physics:

- Supernovae produce neutrinos of all flavors, with a temperature hierarchy that may allow us to look for oscillation effects. The matter effects on oscillations – the MSW effect – are especially rich. Because of the higher density, the 1-3 crossing that is not probed by solar neutrinos will cause flavor conversion in supernovae. It is possible that a limit – either an upper bound or a lower bound – on θ_{13} could be established by a careful measurement of supernova neutrino fluxes. (Flavor conversion requires an adiabatic level crossing, which in turn requires a minimum value for the mixing angle.) In addition, there are important

locations in the star where neutrino-neutrino scattering, rather than neutrino-electron scattering, dominates the MSW potential. The effects of this nonlinear coupling are just now being explored theoretically. Supernovae are very likely our only laboratories for studying this interesting aspect of the MSW effect.

- The neutrinos are an important diagnostic of the supernova mechanism. They provide a direct measure of the gravitational binding energy of the neutron star: by following the neutrino light curve observers can monitor the process by which a puffy protoneutron star, perhaps ~ 40-50 km in radius, cools to a compact object of radius ~ 10 km. Similarly, the difference in the total number of electron neutrinos and antineutrinos measures the total lepton number radiated by the core. One of the fascinating questions regarding neutron matter at several times nuclear density is the possibility of new phases, such as kaon condensation or deconfined quark matter. It was recognized several years ago that such a phase transition will normally produce a region of mixed phase, e.g., where droplets of strange matter might coexist with ordinary nuclear matter. (This is a consequence of the two conserved charges, electric and baryon number.) This produces inhomogeneities in the weak charge distribution governing neutral current neutrino scattering, the main reaction trapping the neutrinos. This in turn can alter the neutrino light curve. Thus if a phase change occurs as the protoneutron star cools, it might be detected as a change in the rate of neutrino emission.
- As the protoneutron star cools (and as additional mass falls on to its surface) an interesting possibility is collapse to a black hole. This would appear in the neutrino light curve as a sharp cutoff.
- The neutrinos control conditions crucial to nucleosynthesis. For example, the neutron-proton chemistry of the "hot bubble" above the protoneutron star surface is controlled by the competition between the electron neutrino and antineutrino charge current reactions. Thus measuring the neutrino light curves (and knowing the neutrino parameters governing oscillations) will eliminate uncertainties in models of this nucleosynthesis. Similarly, neutrino process nucleosynthesis depends sensitively on the spectrum of the heavy-flavor neutrinos, which was not measured in SN1987A.
- Important constraints on neutrino masses, including the mass of the ν_τ, can be derived from supernova neutrino oscillations. Neutrino mass causes a kinematic spreading of the neutrino burst. Several possible sharp time structures in the neutrino light curve – the 3 ms deleptonization burst, the initial sharp rise in the neutrino luminosity, and the abrupt termination of the neutrino flux that would accompany black hole formation – have been discussed as possible "clocks" against which the spreading could be measured. For a galactic supernova the potential mass sensitivity is 1-2 eV. This is no longer so impressive – it is competitive with current tritium mass limits of 2.2 eV, given that we know the mass splittings among the three light flavors, and is less stringent than the WMAP bound. However a supernova constraint has the virtue of being tied directly to the kinematic effects of mass.
- Many supernovae in our galaxy may be obscured optically by the intervening matter. Neutrinos thus provide an early warning that an optical display may soon follow. (It may take hours to a day for the shock wave to reach the outer mantle of the star.) No supernova has ever been observed from such early times, as the light curve turns on. The environment immediately surrounding the progenitor star is probed by the initial stages of a supernova. For example, any effects of a close binary companion upon the blast would occur very soon after shock breakout.
- The simultaneous observation of the gravitational wave, optical, and neutrino signals from a galactic supernova could be very important, placing multiple constraints on the collapse mechanism.
- We will discuss, in the megadetector chapter, exotic possibilities, such as detecting the relic flux of neutrinos from all past supernovae and detecting collapses in our neighboring galaxy Andromeda.

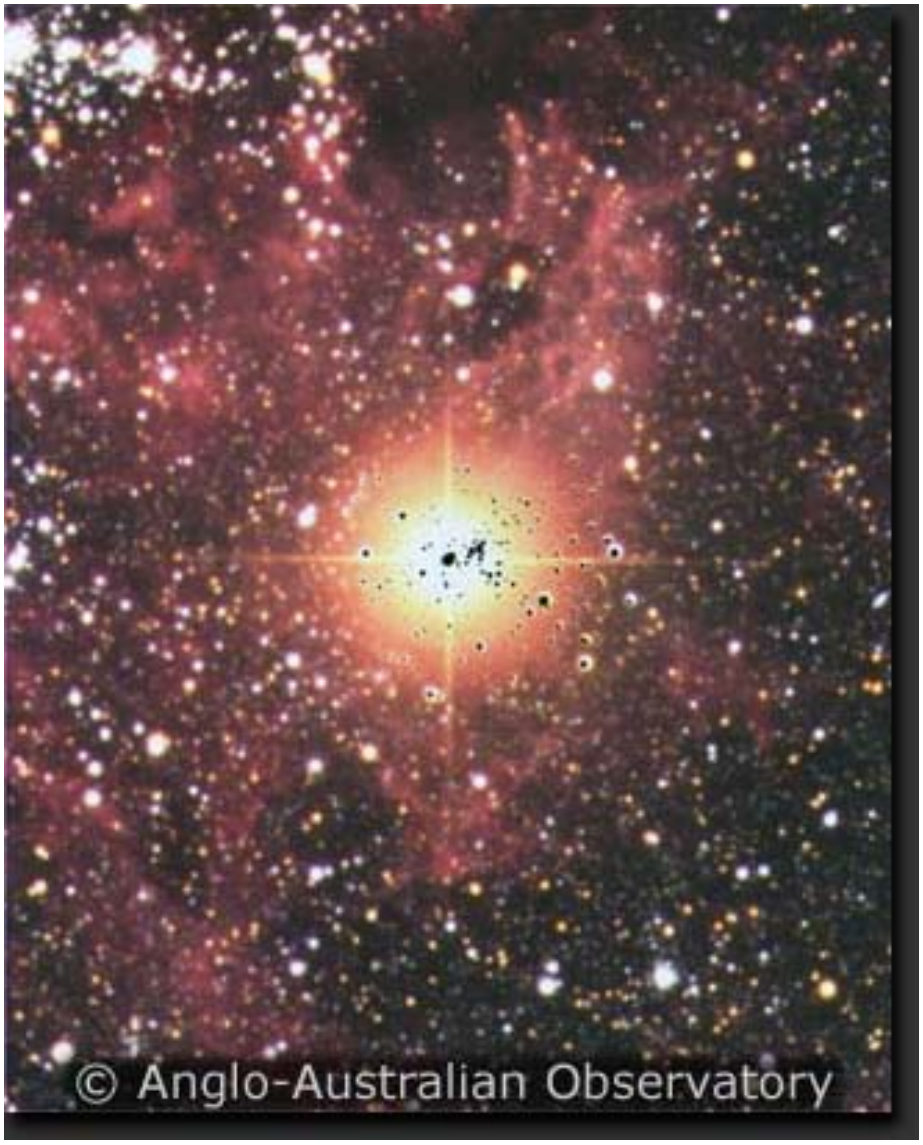


Figure C.11: The optical display of Supernova 1987A, which was observed on earth both optically and via its neutrino burst. The superimposed negative image shows the same star region prior to core collapse. While the optical display and kinetic energy of the explosion are impressive, less than 1% of the energy released in the gravitational collapse is released in this way. The bulk of the energy, ~ 99%, is carried by the neutrino burst.

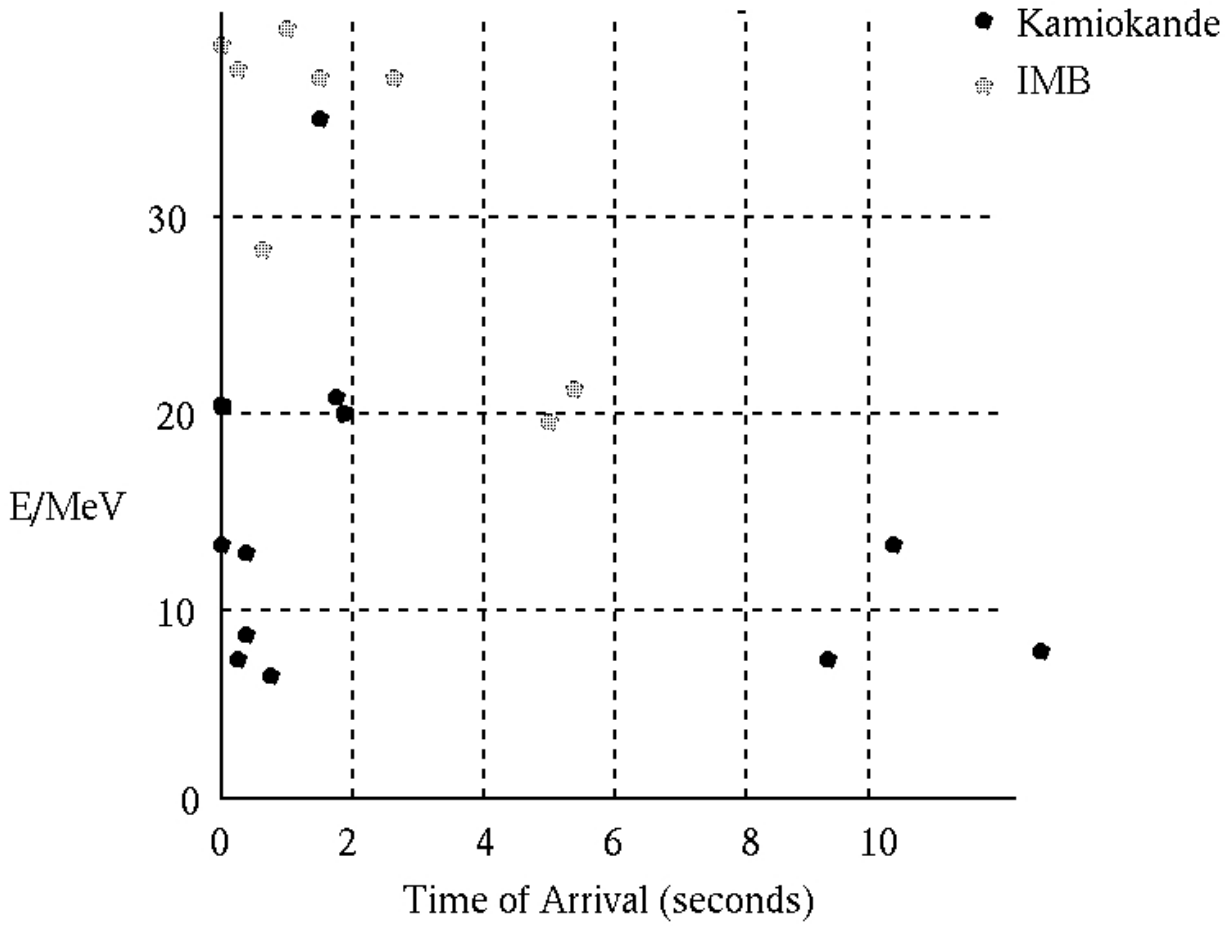


Figure C.12: The IMB and Kamioka neutrino events from SN1987A.

F.2 Supernova Neutrinos: Current and Future Observatories. The most important consideration in preparing for the next galactic supernova is to appreciate that an opportunity presents itself once in a lifetime: the best estimate of the galactic supernova frequency is 1/30y. There are two consequences. First, we need to be prepared at all times with detectors capable of measuring the spectrum, including the flavor and time development, of the next supernova, which could occur at any time. The minimum requirements are detectors operating in both charge-current modes as well as some scheme for measuring neutral current interactions. Second, most (though not all) supernova observatories are likely to be detectors with additional physics goals, such as proton decay or solar neutrinos. Thus a theme of this field is the "supernova watch" – the notion that we should try to coordinate the world's program of underground neutrino detectors to guarantee that the necessary supernova capability is always in place.

Directional sensitivity is also important, as this could help optical observers locate the supernova quickly. Detectors exploiting elastic scattering off electrons provide some directional information. Another possibility, if several detectors are able to measure enough events to determine the turn-on time of the neutrino pulse to millisecond accuracy (or if the deleptonization burst could be used as a clock), is to determine the direction by triangulation.

Detector type	Target reaction	Spectrum	Timing	Pointing	Flavor
Scintillator	H (CC) C (15.11MeV γ)	Y N	Y Y	N N	Anti-ν_e All flavors
Water Cerenkov	H_2O (CC,ES)	Y	Y	Y	Anti-ν_e
Heavy water	D (NC) D (CC)	N Y	Y Y	N Y	All flavors ν_e, anti-ν_e
Long-string water Cerenkov	H (CC)	N	Y	N	Anti-ν_e
Liquid Ar	Ar (CC,ES)	Y	Y	Y	ν_e
High-Z neutron	NaCl,Pb,Fe (CC)	N	Y	N	All flavors
Radiochemical	^{37}Cl,^{127}I,^{71}Ga (CC)	N	N	N	ν_e

Table IF.1 Supernova neutrino detectors and their principal capabilities.

The table shows the supernova neutrino attributes of the major detector types now in operation. Water detectors are dominated by the charge current (CC) reactions of electron antineutrinos on protons, though the elastic scattering (ES) of neutrinos of any flavor is important because it provides directional sensitivity. Scintillator detectors are also dominated by the CC reaction off protons, though the neutral current (NC) reaction exciting the 15.11 MeV level in ^{12}C is interesting as a high-threshold process dominantly sensitive to heavy-flavor supernova neutrinos. The signal is the subsequent 15.11 MeV γ-ray. The CC reactions off deuterium in heavy water detectors produce either an electron or a positron plus two neutrons, the latter a triple-coincidence for antineutrino reactions. The gentle backward peaking of the CC signal provides some directional sensitivity. The deuterium NC signal is a single neutron. Liquid argon detectors can exploit the ^{40}Ar(ν_e,e$^-$)^{40}K reaction as well as ES. High-Z targets like Pb have enhanced charged current cross sections for ν_es because of the Coulomb effects on the outgoing electron and because of the neutron excess. The signal is excitation of states in the continuum that then decay by neutron emission. The NC channel also produces spallation neutrons. Finally, various radiochemical detectors like chlorine, iodine, and gallium are good supernova ν_e detectors. The specifications for various operating or soon-to-be-operating detectors are given below, along with the events expected from a supernova at the galactic center.

Detector	Type	Mass (kton)	Location	Events @ 8.5 kpc	Status
Super-Kamiokande	H2O	32	Japan	8000	running
SNO	D_2O/ H_2O	1/1.4	Canada	450/300	running
LVD	scintillator	0.7	Italy	170	online
AMANDA	long string	~ 0.4/pmt	Antarctica		running
Baksan	scintillator	0.33	Russia	50	running
Borexino	scintillator	0.3	Italy	100	~late 2003
KamLAND	scintillator	1.0	Japan	300	running
Icarus	liquid Ar	2.4	Italy	200	2005

Table IF.2 Sensitivity of operating detectors to supernova neutrinos.

Several new detectors with supernova neutrino sensitivity have been proposed. Most have other primary physics goals, but a few are dedicated supernova neutrino observatories. In most cases, depth is not a major issue for detecting the early burst neutrinos, but detector thresholds and depth can influence how long a detector can follow the neutrino light curve. Detector mass is also crucial.

Lead-based dedicated observatories: Most of the dedicated observatories are based on the observation that neutrino-induced spallation neutrons could be detected in relatively inexpensive and easily maintained large detectors. These generally exploit the rapid increase in CC cross sections with Z: a heavy nuclear target often has a CC ν_e rate that is not too much smaller than the NC rate, despite the three flavors of neutrinos and antineutrinos contributing to the latter. Lead is the choice of detectors like OMNIS because it is a plentiful, inexpensive high-Z material.

Lead-based detectors are sensitive to the higher energy portion of the supernova neutrino flux capable of exciting the nucleus above the neutron-emission threshold. This threshold, in the absence of oscillations, thus favors the hotter heavy-flavor neutrinos. The CC reaction $^{208}Pb(\nu_e,e^-)^{208}Bi^*$ can produce either single or two-neutron emission, with the ratio sensitive to the temperature of the ν_e spectrum. The NC reaction $^{208}Pb(\nu_x,\nu_x)^{208}Pb^*$ is observable via the n, 2n, and γ emission channels.

One interesting form of lead is lead perchlorate. A water-based solution is a good neutron moderator, and the presence of Cl provides an attractive (n,γ) signal, 8.6 MeV in γ-rays. Because lead perchlorate is transparent, it has been considered for Cerenkov detectors, which would provide spectral sensitivity.

The current OMNIS design uses two ktons of lead-slab detectors and 0.5 ktons of lead perclorate, which would produce several thousand events following a supernova at the galactic center. The lead-slab design alternates vertical slabs with planes of scintillator for detecting the neutrons from the lead. OMNIS will have intrinsic timing of better than 100 μs, so that fine structure in the neutrino burst (such as the neutronization burst or black hole formation) can be resolved.

Construction of the lead slab modules for OMNIS could begin immediately, although some research to optimize the detector is still underway. Monte Carlo simulations have been used to determine the optimum slab thickness, balancing neutron detection efficiency against cost, and preliminary engineering designs of these modules have been completed. Considerable R&D must be done to optimize the lead perchlorate detector. The experimenters plan to site the lead-slab modules in the WIPP laboratory and the lead perchlorate modules in NUSEL.

Cosmic-ray-induced neutrons are of some concern, so greater depth is helpful in minimizing this background. However, extreme depths are not needed. The safety of lead perchlorate in an underground laboratory must be studied.

Radiochemical quasi-real-time detectors: CC radiochemical detectors may be of interest for supernova neutrino detection because of their low cost and ease of maintenance, and because of their sensitive to a single neutrino flavor, ν_e. Though one would normally favor an active, real-time detector, our best current ν_e detector SNO is of moderate size and may not run for many more years. An accurate integral measurement of the neutrino fluence in this channel is important because, when combined with the results from water Cerenkov detectors, the net lepton number radiated by the protoneutron star can be determined.

As GNO and SAGE are small detectors and chlorine has been dismantled, the most attractive proposal is one based on the reaction $^{127}I(\nu_e,e^-)^{127}Xe$. This detector has been suggested as a modern version of the chlorine detector, but with a considerably larger cross section and with an

automated system for flushing the noble gas Xe out of the xenon. Unlike the chlorine experiment, the Xe extraction (99% of the Xe could be removed in a 15 minute purging with helium) would be done twice daily and counted ($\tau_{1/2} \sim 36.3$ d), so that the experiment could also look for solar neutrino day/night effects. This would also mean that the detector would be kept free of Xe, awaiting a galactic supernova, the detector's main purpose. The proposed 3-kiloton detector, with the iodine deployed as a NaI solution, would record approximately 700 ν_e events from a supernova occurring at the galactic center. The detector could be maintained by a single investigator working part time, and would be active 100% of the time.

A more sophisticated version of this experiment has been suggested where the purging is triggered by an observation of the Cerenkov light produced by the emitted electron. The detector would be arranged as an array of upright cylindrical modules, roughly one meter in diameter, separately flushed, with each viewed by surrounding phototubes. The modular geometry reduces the purging time to ~ 1 minute. Thus a Cerenkov signal could be verified by extraction and counting of a Xe atom – a technique similar to the EXO double beta decay scheme. The timing capability of this detector for supernova neutrino detection would be determined by the electron detection.

Water Cerenkov megadetectors: Large water Cerenkov detectors such as UNO will have excellent supernova neutrino detection capabilities, including very high statistics and excellent directional sensitivity. Their mass would allow detection of supernovae in Andromeda (though these are infrequent) and observation of the relic supernova neutrinos produced over the entire history of star formation – capabilities beyond the reach of most other proposed detectors. These issues are discussed in the proton decay/megadetector chapter.

Liquid argon detectors: The most important supernova neutrino channel in a liquid argon detector is the CC reaction $^{40}Ar(\nu_e,e^-)^{40}K^*$. The cross section is known accurately. (The model-dependent Gamow-Teller contribution has been determined by the same technique used for ^{37}Cl, observation of the β-delayed protons following the decay of ^{40}Ti, the isospin analog of ^{40}Ar.)

A liquid argon drift chamber such as Icarus can detect the primary electron track as well as the secondary tracks from the $^{40}K^*$ γ decay, with approximately a 5 MeV threshold. Elastic scattering events are also visible. The 2.4 kton Icarus detector is to be sited at Gran Sasso. Icarus would record ~ 200 events for a supernova occurring at the galactic center. The proposed LANNDD detector (Liquid Argon Neutrino and Nucleon Decay Detector), with 70 kilotons of liquid argon in a single chamber, would record thousands of events. The signal would be strongly enhanced by flavor oscillations. The LANNDD detector is a second possibility for detecting the relic supernova neutrinos.

F.3 Supernova Neutrinos: Facility Requirements. As the detectors mentioned above are discussed elsewhere in this Science Book, we focus here on common, general requirements for supernova neutrino physics within NUSEL.

Detector up-time must be virtually 100%. Therefore it is highly desirable for experimenters to have 24/7 access to the detectors, enabling them to respond immediately to any difficulties. Excellent network conductivity is essential for the same reason.

Relative timing of events among different neutrino experiments is crucial for event location by triangulation. Precise timing within each experiment is important in correlating sharp features (like the deleptonization burst or black hole formation) with other detectors or with gravitational wave detectors. During the peak of the burst, the average time between consecutive events in UNO would be less than 100 μs. Therefore one must maintain this kind of timing accuracy within the underground laboratory.

Though discussed elsewhere in the Science Book, we note that almost all massive detectors require specialized excavations. In the case of UNO, the NUSEL-Homestake plan calls for a dedicated hoist and shaft (the Yates) and underground transport of the ~ two megatons of excavated rock into the open cut, using a specially constructed conveyor. The iodine detector is ideal for a vertical crater excavation of a type commonly done at Homestake, with the cavity afterward flooded by water to isolate the array of 1m cylindrical modules from the rock walls. LANNDD and the lead perchlorate detectors involve hazardous materials that will require careful handling; LANNDD should be isolated and separately vented.

F.4 Supernova Neutrinos: Summary. Supernova neutrino detection has the potential to provide important new information on neutrino properties (including the effects of neutrino background on the MSW potential), the supernova mechanism, the properties of superdense nuclear matter, the conditions under which r-process, ν-process, and other nucleosynthesis occurs, and black hole formation. Neutrino detection is important to gravity wave and optical observations, verifying that a galactic supernova has occurred (crucial if it is optically obscured) and providing an early warning to optical astronomers that an explosion is imminent. The most massive detectors may detect supernovae in our neighboring galaxy Andromeda and the relic supernova background neutrinos that will constrain the history of star formation.

The general detector requirements include very large masses and flavor sensitivity (requiring multiple channels or multiple detectors). Some detectors must provide good energy resolution, low thresholds, good timing, and pointing capability. It is crucial that detectors be capable of operating for very long times, or that the community arranges for a succession of detectors to provide continuous coverage. As the galactic supernova rate is about 1/30 y, missing the next event would be tragic.

The depth requirements are generally modest, though the most challenging issues (measuring the relic neutrinos, following the neutrino light curve out to very long times) require very quite detectors. Most supernova detectors will serve several purposes, with the ancillary uses (proton decay, solar or atmospheric neutrino detection) often determining the needed depth. Detector stability and reliability, and 24/7 access to guarantee that reliability, are essential.

G.1 Nuclear Astrophysics. Experimental nuclear astrophysics is the study and measurement of nuclear processes in astrophysics, especially those driving both the steady evolution and explosions of stellar systems. The importance of this field is illustrated by the solar neutrino problem: precision nuclear astrophysics measurements were combined with careful modeling, yielding a standard model of main-sequence stellar evolution that accurately predicted solar neutrino fluxes. The credibility of these predictions ultimately led the community to recognize that fundamental new neutrino physics was responsible for the deficits in counting rates.

New neutrino discoveries are part of a broader revolution underway in astrophysics, one driven by marvelous new instrumentation: new-technology earth- and space-based telescopes, underground neutrino observatories, the Compton Gamma Ray Observatory, the Chandra X-Ray Telescope, the Space Infrared Telescope Facility, WMAP, and new large-area cosmic ray detectors. These instruments are now providing information of unprecedented detail on objects within and outside our galaxy. These data often reflect the underlying nuclear and atomic microphysics governing these objects. The nuclear astrophysicist tries to determine that microphysics from laboratory experiments, thereby enabling modelers to deduce the properties of the astrophysical systems being studied.

One major goal of nuclear astrophysics is to understand hydrostatic nuclear burning through the different phases of stellar evolution, determining the lifespans of the stars and the initial conditions at the onset of stellar explosions. Another is the understanding of nuclear processes far from nuclear stability, which characterize nucleosynthesis in novae, X-ray bursts, and supernovae. These also determine the elemental and isotopic abundances observed in stellar atmospheres and in the meteoritic inclusions that have condensed in stellar winds, or detected with gamma ray observatories.

The laboratory measurement of nuclear processes in stellar explosions requires the development of a new generation of radioactive beam facilities to produce exotic short-lived nuclear species and to observe the reactions of these nuclei on the split-second timescales of stellar explosions. This physics is being and will be pursued above ground with large accelerators at facilities like ISAC II, RIA, and Riken. Different techniques are needed for the study of reactions important in the quiescent periods of stellar evolution. A new generation of high intensity, low-energy accelerators for stable beams are needed in order to simulate within human timescales the processes that occur in nature over stellar lifetimes.

While more than thirty years of intense experimental study have helped define the major features of nuclear burning during hydrostatic stellar evolution, so far only two fusion reactions have been studied at the relevant stellar energies. One of these measurements was made with the first underground accelerator experiment, LUNA I conducted at Gran Sasso. Many other rates crucial to stellar modeling have been deduced indirectly from extrapolations of higher energy laboratory data. These extrapolations can be off by orders of magnitude in cases where the underlying nuclear structure is poorly constrained. Furthermore, to obtain empirical information on the effects of stellar plasmas on fusion rates, experimenters must make measurements at very low energies where the screening effects of atomic electrons become most important.

The associated uncertainties complicate the modeling of important phases of stellar evolution, such as the CNO reactions within massive main sequence stars and the reactions on heavier species that govern the later stages of nuclear burning (e.g., the production of the γ-ray source ^{26}Al in massive stars and novae). Descriptions of the red giant and the asymptotic giant helium- and carbon-burning phases, where the slow neutron capture (s-) process responsible for the origin of more than half of the elements likely occurs, are also limited by nuclear physics uncertainties. Many of these uncertainties can be reduced or eliminated if a suitable low-background underground accelerator facility were established. The problems that could be effectively addressed with such a facility include:

$^{12}C(\alpha,\gamma)^{16}O$: The rate of this reaction determines the $^{12}C/^{16}O$ ratio produced by helium burning. This in turn determines the masses within the carbon and oxygen zones of a Type II supernova progenitor, thereby influencing the outcome of the core collapse (whether a neutron star or black hole is formed) and the explosive nucleosynthesis associated with the passage of the shock wave. While calculation of the reaction rate for conditions typical of helium burning requires knowledge of the cross section near $E_{cm} \sim 300$ keV, data exist only above 1 MeV. The extrapolation to lower energies is complicated by two states just below the $^{12}C + \alpha$ threshold. Present data and extrapolations fall far short of the 10% precision at 300 keV necessary to meaningfully constrain astrophysical calculations.

Cosmic-ray background in γ-ray detectors, beam-induced backgrounds (which diminish at the lower energies), and low beam currents have limited past experiments. Several different techniques have been applied to this reaction with comparable levels of success. Two general strategies are under consideration for the future: an intense ^{12}C beam in conjunction with a ^{4}He gas jet target, γ-ray detectors, and a recoil separator, or a ^{12}C target, an intense ^{4}He beam, and γ-ray detectors. In either case the γ detection requires a large-solid-angle array of either scintillator or high-purity germanium detectors. A high-current accelerator facility located deep underground would clearly address the factors that limited previous experiments.

S-process neutron sources, $^{13}C(\alpha,n)^{16}O$ and $^{22}Ne(\alpha,n)^{25}Mg$: In intermediate-mass AGB stars the $^{13}C(\alpha,n)$ reaction is thought to be the main s-process neutron source, operating at temperatures ~ 1×10^8 K. The $^{22}Ne(\alpha,n)$ reaction operates at somewhat higher temperature ~ $(2–3) \times 10^8$ K and is the dominant s-process neutron source in more massive stars. The rates of these reactions determine the neutron fluence during the s-process, and are important to arguments that identify site or sites for the s-process. S-process nuclei contribute significantly to the production of elements between Fe and the transuranics: the origin of the heavy elements was one of the urgent scientific questions recently identified in the NRC Report on "Quarks and the Cosmos."

Although measurements of the $^{13}C(\alpha,n)$ cross section have reached down to $E_{cm} \sim 300$ keV, the extrapolation to the astrophysically important region of 150-200 keV is hampered by poorly constrained subthreshold resonances, yielding a reaction rate uncertain by an order of magnitude. The $^{22}Ne(\alpha,n)$ reaction is thought to be dominated by narrow resonances. The rate is highly uncertain due to the possibility of unobserved weak resonances just above threshold: according to the NACRE compilation the uncertainty at $T \sim 2 \times 10^8$ K exceeds two orders of magnitude. In previous measurements the neutrons produced in these reactions were moderated in polyethylene and then detected, at thermal or epithermal energies, with ^{3}He-filled proportional counters. This method yields a high neutron detection efficiency (20–50%) and is insensitive to γ rays or charged particles, but is affected by any background neutron source, including those produced by cosmic rays. While previous experiments exploited active and passive shielding extensively, all were limited in sensitivity by cosmic ray neutrons. A repetition of these experiments in an underground facility thus should yield greatly improved results. The $^{13}C(\alpha,n)$ cross section measurements could be extended to lower energies, while the lower-energy resonances affecting $^{22}Ne(\alpha,n)$ could either be measured or more tightly constrained. In addition, the development of ^{3}He-filled proportional counters free of α emitters on the inside walls might be helpful in reaching ultimate sensitivities.

Light nucleus reactions $^{3}He(\alpha,\gamma)^{7}Be$ and $^{2}H(\alpha,\gamma)^{6}Li$: The $^{3}He(\alpha,\gamma)$ reaction governs the pp chain branching to the ppII and ppIII cycles, leading to the production of ^{7}Be and high energy ^{8}B solar neutrinos in the sun. The Q-value for the $^{3}He(\alpha,\gamma)$ reaction is 1586 keV and the γ-ray spectrum consists of lines at ~ 1.6, 1.2, and 0.43 MeV. The energy of the lowest data point so far measured is $E_{cm} \sim 107$ keV, while the most effective energy (the Gamow peak) for this reaction in the sun is ~ 22.9 ± 12.8 keV. The $^{2}H(\alpha,\gamma)^{6}Li$ reaction is responsible for ^{6}Li production in the big bang. Laboratory measurement extend only to 600 keV, while the energy range relevant for big bang

nucleosynthesis is ~ 50–200 keV. An accurate cross section at big-bang energies will be important if ^{6}Li is observed in future studies of abundances in metal-poor halo stars. (The primary process by which galactic ^{6}Li is thought to be produced is cosmic-ray spallation, a secondary process that becomes much more effective at late times, when the interstellar medium is richer in C and O.) Non-standard big-bang models, such as those postulating inhomogeneities, tend to produce more ^{6}Li, and thus can be constrained by observational limits on big-bang ^{6}Li nucleosynthesis, if the production cross section is known accurately.

Hydrogen-burning scenarios: There are significant resonant and nonresonant cross section uncertainties at low energies for several hydrogen-burning reactions occurring in the CNO, NeNa, and MgAl cycles (or chains). These reactions are important in both main sequence and more evolved stars. The required studies include (p,γ) and some (p,α) reactions on isotopes of N, O, Ne, Na, Mg, and Al. The CNO cycle operates in the sun, producing 1.5% of solar energy as well as neutrino fluxes that, if measured, would directly determine the metalicity of the solar core. A comprehensive understanding of the CNO, NeNa, and MgAl cycles is important in interpreting isotopic abundance anomalies (^{17}O, ^{22}Ne, and ^{26}Al) reflecting nucleosynthesis prior to solar system formation.

G.2 Nuclear Astrophysics: Readiness of a Next-Generation Facility. The advancements in precision astrophysics put continual pressure on the nuclear astrophysics community to improve cross section measurements, a few of which were discussed above. The one underground accelerator now operating, LUNA II at Gran Sasso, is limited in a number of ways: most of the recommendations for improving LUNA I were not implemented because of space and other constraints at Gran Sasso. This has restricted LUNA's impact to pp-chain reactions. The study of stellar He burning processes requires substantially higher beam energies than those available at LUNA. At NUSEL-Homestake the US nuclear astrophysics community would combine the passive shielding provided by depth with the latest detector technology for active event identification and background rejection. New, commercially available accelerator technology will provide a one to two orders of magnitude improvement in the beam intensity. The Homestake facility would be developed in three stages:

- The first-stage development will concentrate on γ ray and neutron detector development (moderated neutron detector, differential large scintillation detector) to identify optimal strategies for lowering the intrinsic background in facility detectors. This would include selecting materials for chamber, target, and shields.
- In second-stage development a 0.6-1.0 MeV 1-10 mA light-ion (p and α) accelerator will be set up for a variety of experiments and for target development (focused on reducing beam-induced background). As every reaction produces unique background problems, it is likely that each reaction will require 6 months to a year of effort.
- In the third stage, and in parallel with the efforts described above, a heavy ion linear accelerator with recoil mass separator and gas jet targets will be developed for reaction measurements requiring reverse kinematics. Note that the study of stellar He-burning processes requires substantially higher beam energies than those available at LUNA II. This stage will include the development of a high-intensity ECR source. Measurements with inverse kinematics generally have lower beam-induced backgrounds. Stage three developments are crucial to the measurement of the ^{12}C(α,γ)^{16}O reaction as well as for selected proton-induced reactions.

A final proposal for the NUSEL underground accelerator facility will require about three years of effort. A US collaboration has been formed to complete this work. The study of underground detection techniques will be performed in collaboration with the LUNA group, and the development of active shielding and event-tracking techniques will be carried out with at several existing US low-energy accelerator facilities. While a final proposal will require two to three additional years of effort, NUSEL plans call for finished space to be available on the 4850 ft level no earlier than FY07. Thus it is anticipated that **an underground accelerator will be one**

of the earliest facilities installed at NUSEL.

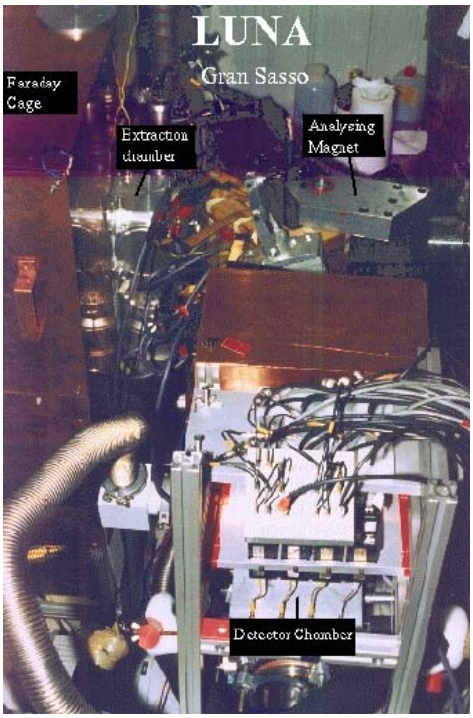
G.3 Nuclear Astrophysics: Facility Requirements. The following are the basic requirements for completing the three-stage program:

- Stage I: Space requirement 5m ×10m × 3m high; 50 kW of electrical power; ventilation and chilled water.
- Stage II: Space requirement 15m × 10m × 5m high; 200 kW of electrical power; ventilation and chilled water; an overhead crane.
- Stage III: Space requirement 15m × 30m × 5m height; 900 kW of electrical power; ventilation and chilled water; an overhead crane.

The desired location within NUSEL-Homestake is 4850 ft, as this provides ample shielding. The technical aspects of the proposal are currently being developed, with a core group of investigators meeting regularly. All three of the stages will need strong technical and infrastructure support from the participating accelerator laboratories.

G.4 Nuclear Astrophysics: Summary. There remain significant uncertainties in the reaction rates for the pp chain, affecting the precision of standard solar model neutrino flux predictions. The uncertainties in many charge-particle reactions that drive late stellar evolution, including the helium-burning reaction $^{12}C(\alpha,\gamma)^{16}O$ crucial to the evolution of Type II supernova progenitors, are much larger. A better understanding of these reactions would be of great help to astrophysics, with a more quantitative model of the SNIa "standard candle" being one possible outcome. Charged particle reactions are thought to provide the neutron fluences necessary to s-process nucleosynthesis, which is responsible for about half the heavy elements between Fe and Pb.

The installation of an accelerator laboratory deep underground, utilizing recent advances in accelerator, detector, and data-handling technologies, could lead to major improvements in our understanding of the nuclear reactions that power the stars and drive explosive astrophysical environments. Such a facility would have no counterpart elsewhere in the world.



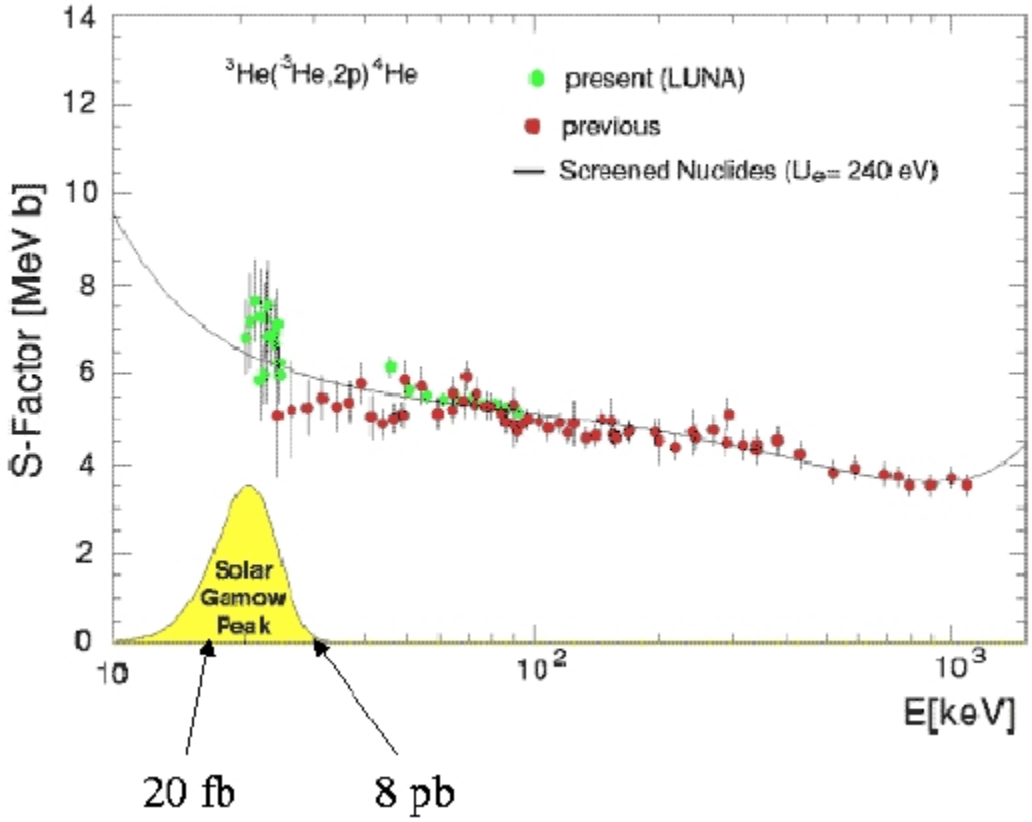


Figure C.13: The LUNA II facility at Gran Sasso and a pp chain Gamow peak measurement.

Megadetector Physics: The capacity to excavate a stable, deep megacavity for a next-generation proton decay experiment is one of the strongest arguments for the NUSEL-Homestake site. Homestake provides access to the extremely stable Yates rock formation through the Yates shaft, which could be dedicated to the excavation and construction of a detector like UNO. As noted in the Overview, the integrity of Homestake rock for such an excavation has been established: there is a long history of studies of large-span excavations at Homestake. The proposed site has already been studied thoroughly and is directly accessible, available for additional coring and rock mechanics studies. As the Yates mining capacity is one megaton/year, a UNO-sized excavation would require less than two years. The rock would be disposed on site, through a conveyor built on the 600 ft level that would transport the rock from the Yates shaft to the Open Cut. The excess pumping capacity (through the Ross pump column) could drain UNO in about 90 days. It is unclear to us that whether any other site could meet the excavation, stability, rock disposal, and pumping requirements of UNO.

The driver for a megadetector is the physics, particularly the opportunity to do a next-generation nucleon decay experiment while at the same time meeting the needs of the very-long-baseline neutrino oscillation program aimed at detecting CP violation. Furthermore there is a long list of other important physics – atmospheric, solar, and supernova neutrino measurements – that would be advanced by the construction of the right detector at the right depth.

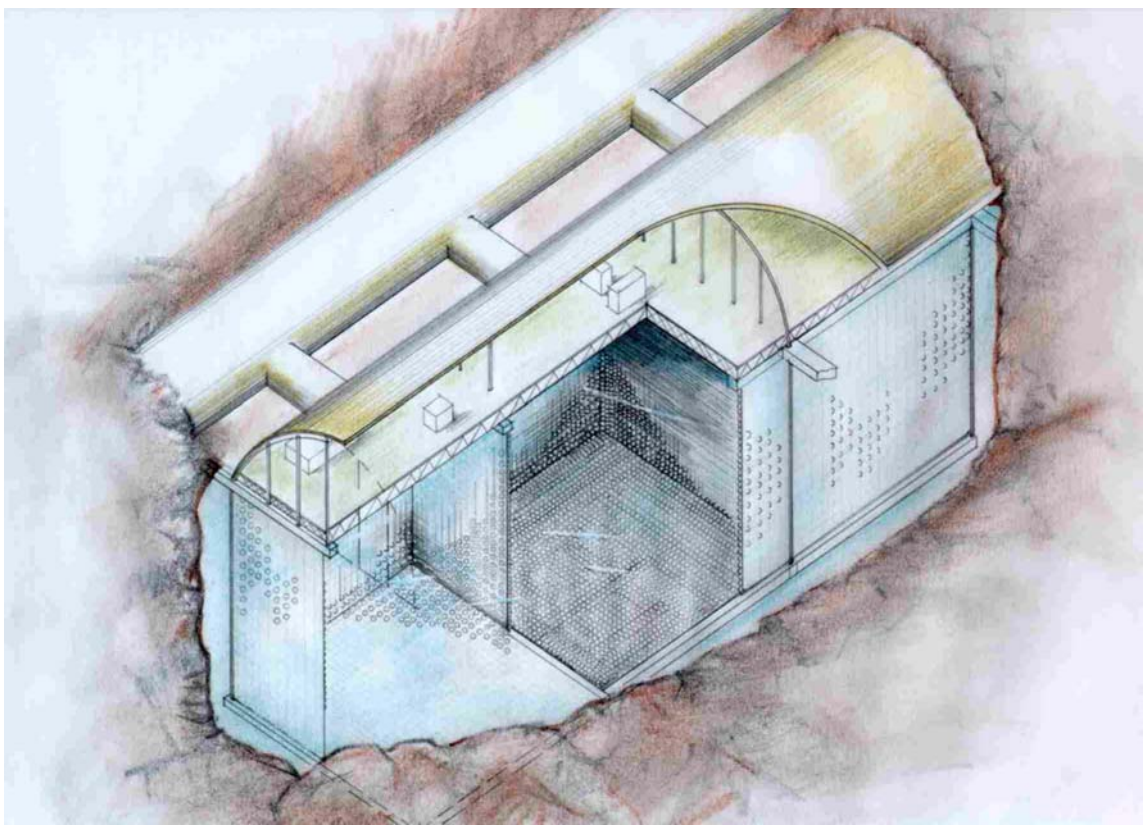


Figure C.14: Artist's rendering of UNO, a planned 0.5 megaton water Cerenkov detector for proton decay, long-baseline neutrino physics, and atmospheric and supernova physics.

H.1 Nucleon Decay: Importance of the Science. While current experiments show that the proton lifetime exceeds ~10^{33} years, its ultimate stability has been questioned since the early 1970s. At that time theorists began the development of Grand Unified Theories (GUTs) to extend the standard model, an effort to unify three fundamental forces, the strong, electromagnetic, and weak, operating between the quarks and leptons. The dramatic meeting of the strengths of the three forces at ~ 10^{16} GeV in supersymmetric GUTs greatly encouraged this effort. It is also consistent with the pattern of masses that is emerging from recent neutrino discoveries, which implies a right-handed Majorana seesaw mass ~ 0.3×10^{15} GeV, close to the GUT scale. But perhaps the most generic and crucial prediction of GUTs is that nucleons will decay into leptonic matter such as a positron and a meson, revealing quark-lepton unity. That is, the matter comprising our universe is not absolutely stable.

Certain early versions of GUTs based on the gauge group SU(5), including minimal supersymmetric SU(5) models, predict relatively short lifetimes for the proton, such as branches to the $e^+\pi^0$ and νK^+ modes with partial lifetimes of 10^{28} to 10^{32} years. These predictions have been excluded by the IMB, Kamiokande, and Super-Kamiokande experiments. A class of well-motivated GUT theories based on the gauge group SO(10) and supersymmetry are now the focus of interest. These successfully describe the masses and mixings of all the quarks and leptons, including neutrinos, and also account for the origin of the excess of matter over antimatter through the process of leptogenesis, as discussed in the neutrino section of the Science Book. These theories place a conservative upper bound on the proton lifetime that is within a factor of ten of the current lower limit. This makes the discovery potential for proton decay in a next-generation experiment – one that exceeds Super-Kamiokande by at least an order of magnitude – rather high.

From a broader perspective, the discovery of proton decay would provide physicists with a unique window on physics at truly short distances, less than 10^{-30} cm. Such distances cannot be probed by any other means: current high-energy accelerator experiments probe to 10^{-17} cm. The discovery of proton decay would provide crucial support to the notion of unification and to ideas like leptogenesis. Because the predictions of a well-motivated class of theories are not far above current limits, the need for next-generation proton decay experiments is compelling. Those theories include supersymmetric SO(10), flipped SU(5), and string-derived SU(2)×SU(2)×SU(4) models. The modes most favored are νK^+ and $e^+\pi^0$ with lifetimes less than ~ 2×10^{34} and 10^{35}, respectively. Should proton decay be discovered in these channels, searches for related modes, including $\mu^+\pi^0$ and μ^+K^0, could provide additional constraints on GUTs.

The "classical" proton decay mode $p \rightarrow e^+\pi^0$ can be detected efficiently with low background. The present best limit on this mode, $\tau/\beta > 5.7 \times 10^{33}$ y (90% c.l.), comes from the 92 kton-y exposure provided by Super-Kamiokande. The detection efficiency of 44% is dominated by final-state π^0 absorption and by charge-exchange for protons decaying in ^{16}O. The expected background is 2.2 events/Mton-y.

The mode $p \rightarrow \nu K^+$ is more difficult to detect in water Cerenkov detectors due to the unobserved neutrino. The present limit in Super-Kamiokande is the result of combining several channels, the most sensitive of which involves observation of the K^+ through $K^+ \rightarrow \mu^+\nu$ in coincidence with a γ ray from the deexcitation of ^{15}N (produced because a proton in ^{16}O decayed). Monte Carlo studies suggest that this mode should remain background free for the foreseeable future. The present limit on this mode is $\tau/\beta > 2.0 \times 10^{33}$ y (90% c.l.).

H.2 Nucleon Decay: Readiness of Next-Generation Experiments. Both the lifetime and decay modes of the nucleon are unknown *a priori*. Thus the lifetime could range from just above present limits to values many times larger. It follows that it is appropriate to measure progress logarithmically, motivating order-of-magnitude improvements in detector size. The efficiency for detecting 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 be achieved by running Super-Kamiokande for an additional 30-40 years, or by constructing an order-of-magnitude larger experiment.

The favored decay modes of the nucleon are also unknown *a priori*, and the signatures of possible decay modes are generally quite distinct. Thus detectors have to be sufficiently versatile to achieve good sensitive to most or all of the kinematically allowed channels. The need for long running times requires a detector technology that is reliable, so that repairs are infrequent. The long running time also makes it important for the proposed detector to be able to address other physics questions, while the proton decay search is ongoing.

A variety of proton-decay detector technologies have been discussed:

Water Cerenkov detectors: Water Cerenkov detectors enjoy several advantages over alternatives. The medium is inexpensive, the technology is mature and well tested, and the ability to deploy the technology on very large scales is demonstrated, due to the long experience with Super-Kamiokande. Currently there is an international collaboration exploring a next-generation version of Super-Kamiokande. The Japanese project is Hyper-Kamiokande, while the US version is UNO (Underground Nucleon Decay and Neutrino Observatory). There have been discussions in Europe of mounting such a detector in the Frejus tunnel. The total mass of the proposed UNO detector is 650 kilotons. A veto shield makes up the outer 2.5m of the detector; the fiducial volume cut is 2m inside of that boundary. The active volume is 440 kilotons, 20 times larger than the Super-Kamiokande detector. The structure is "rural mailbox" style, a rectangle 60m × 60m ×180m, divided into three cubic sections. The inner section has higher phototube coverage, 40%, while the coverage over the remainder of the detector is 10%. The inner section is important for solar neutrino physics and also for detecting the 6 MeV γ accompanying $p \rightarrow K^+\nu$ for a proton bound in ^{16}O.

Detailed Monte Carlo studies, including full reconstruction of simulated events, indicate that water megadetectors 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 ~ few × 10^{35} y, if selection criteria are tightened to reduce background counts. For example, with a detection efficiency of 18%, the expected background is only 0.15 events/Mton-y, ensuring a signal/noise of 4/1 even for a proton lifetime of 10^{35} y. Any of the proposed megadetectors would provide a decisive test of supersymmetric SO(10) GUTs by reaching a sensitivity of ~ few × 10^{34} y for the νK^+ mode.

HEPAP recently classified the science potential of such a next-generation detector as **absolutely central**. The report noted that the UNO technology is well tested and **may not require significant R&D**. However, it noted that a rigorous professional civil and mechanical engineering design of UNO depends on the choice of final site. The report concluded that the detector could be completed within 10 years of ground breaking.

Modular water Cerenkov detectors: An alternative design that has been suggested for a megaton water Cerenkov experiment is an array of ten 100 kton cylindrical detectors, 50m in diameter and 50m in height. Studies indicate that these could be placed as deep as 6950 ft at Homestake, on the circumference of a 250m circle centered on the No. 6 shaft. This location accesses another section of the Yates formation, rock known for its high integrity. (This is the same area of the formation where the 7400 ft main laboratory development would be done.) The construction of such chambers has been rather thoroughly investigated: the rock is removed through a tunnel near the cylinder base. When construction is completed, the connection between the chamber and this tunnel is closed, and the chamber is finished with a concrete liner and with an inner water-tight plastic liner.

The proposal excavation plan utilizes the No. 6 Winze and Ross for excavation. In current NUSEL planning this would not be available. However excavation through the No. 4 Winze and Yates is still quite practical. While there is additional transport of rock, the cost is not large. Nor does the use of the smaller No. 4 Winze limit the rate at which the excavation could proceed. The argument for the deeper location is that the background needs of new detectors have been underestimated historically. In the case of Homestake, the placement of the detectors at 6950 ft is feasible, in the rock mechanics/engineering sense, and the fractional increase in the cost is small. The gain is more than an order of magnitude additional suppression in the background from cosmic rays.

Liquid argon detectors: It has been noted elsewhere in the Science Book (see, for example, the supernova neutrino discussion) that the feasibility of very large mass liquid argon detectors is being explored. Such detectors have advantages over water detectors. The sensitivity to the supersymmetry-favored $p \rightarrow K^+\nu$ mode is enhanced by about an order of magnitude due to the extraordinary bubble-chamber-like pattern recognition capabilities. Thus the three-kton ICARUS detector is projected to be as sensitive to this mode as Super-Kamiokande. Due to the pattern recognition quality, a single observed event could be convincing evidence of proton decay. The proposed massive successor to ICARUS, the 70-kton LANNDD detector, has been discussed previously. The drawback of liquid argon detectors is the smaller mass, which limits the sensitivity to modes like $e^+\pi^0$ that are readily observed in water.

Very-large-scale liquid argon detectors are not yet a demonstrated technology. Thus there is **significant R&D remaining to be done**. A serious engineering issue is ensuring safety if detectors like LANNDD are placed in a multipurpose underground laboratory.

Scintillation detectors: The feasibility of a very-large-mass scintillation detector for proton decay has been discussed. The KamLAND experiment is considered a prototype for such applications. It will have enhanced sensitivity to the $p \rightarrow K^+\nu$ mode by directly observing the K^+ by dE/dx and observing the subsequent $K^+ \rightarrow \mu^+$ decay. KamLAND will also have sensitivity to very difficult modes like $n \rightarrow \nu\nu\nu$ by observing associated nuclear γ rays, though their limit will be sharply limited by background.

H.3 Nucleon Decay: Facility Requirements. Among the facility requirements for next-generation nucleon decay experiments are:

- Civil engineering/rock mechanics: The civil engineering facility requirements for a detector like UNO are formidable. They include the identification of a site capable of sustaining a massive cavern and of mining, transporting, and disposing of at least 2 Mtons of rock. We believe Homestake is the only US site that has demonstrated that such construction is clearly feasible.
- A recent HEPAP report on future large DOE projects concluded that the optimal depth for the full proposed scientific program of UNO is at least 4000 mwe. Many arguments leading to this conclusion are connected with the use of UNO for atmospheric, solar, and supernova neutrino physics. However depth is important for some proton decay modes. The use of nuclear γ rays as a tag for $p \rightarrow K^+\nu$ requires sufficient depth so that accidental spatial and temporal coincidence of a low-energy event due to cosmic ray muon spallation products is avoided. A study of this background as a function of depth for the $K^+\nu$ mode has not yet been done, though it is clear that the muon background is reduced by about an order of magnitude for every 1600 mwe below Super-Kamiokande depths (2700 mwe). (The difference between the 4850 ft level at Homestake and Super-Kamiokande's depth is approximately 1700 mwe.)

  There are arguments for siting low-threshold detectors even deeper. The signature for the mode $n \rightarrow \nu\nu\nu$ is a very low energy coincidence (a 2 MeV γ ray from a bound-state decay in ^{11}C followed by the β decay of the ground state (20.4m); or neutron emission from ^{11}C

followed by the β decay of ^{10}C (Q = 3.65 MeV, 19.3 s)). The planned KamLAND search for this decay is inhibited by the cosmic-ray-induced fast neutron rate of 5000/d, as fast neutron knockout reactions on ^{12}C mimic the decay. If a large scintillation detector were located at 7000 mwe, the resulting 10^3 suppression (relative to KamLAND) of the fast neutron background would result in a proportional improvement in the ννν mode limit.

- There must be a reasonable method of filling the detector. A possibility at Homestake would be to use the water seeping into the mine, which is very clean. A water purification system could be installed. The fill could proceed at 500 gpm, corresponding to 210 days for a 0.6 Mton detector.
- The laboratory must be able to handle a large-scale construction project. One would expect several hundred physicists to be involved. A Homestake advantage is the possibility of dedicating the Yates hoist to the experiment, and of optimizing that hoist for the construction.

H.4 Nucleon Decay: Summary. The stability of matter is clearly one of the deepest question in nature. Recent neutrino mass discoveries hint of grand unification, and GUTs generically predict nucleon decay. The favored theories predict lifetimes within about an order of magnitude of current bounds. We have the capacity to do a next-generation experiment that extends limits by an order of magnitude. One possibility uses an established technology, large water Cerenkov detectors. Other ideas include massive liquid argon or scintillator detectors, which offer advantages for certain favored decay channels.

A megadetector for nucleon decay, long baseline neutrino experiments, and for astrophysical neutrino studies is likely to be the signature project for NUSEL. Homestake provides an ideal site, and with the creation of a modern laboratory, designed to facilitate construction and operations, would be the ideal venue.

I. Other Megadetector Uses. This section summarizes and extends previous discussions about ancillary uses of a megadetector – other than proton decay or long-baseline physics. Most of these uses benefit from a relatively deep site.

One natural application of a large proton decay detector is to study the zenith-angle dependence of the solar neutrino rate. Such day-night studies are possible even with the energy calibration difficulties of very large detectors. Dividing the events into only day and night bins, Super-Kamiokande measures a D/N asymmetry of 0.33 ± 0.22 (statistical error only). Thus ~ 20 Super-Kamiokande-years will be required to measure a 3σ effect if current indications persist. A detailed determination of the zenith-angle dependence, especially the crucial effect of Earth's core, is probably out of reach. A megadetector would provide the needed event rate and might be designed to keep potential systematic effects small. As muon-induced delayed β activities tend to be the most serious background in solar neutrino experiments, significant depth is important.

As discussed in the atmospheric neutrino section of the Science Book, several of the outstanding challenges in this subfield require very large detectors. This includes the measurement of the oscillation pattern (disappearance and then reappearance as a function of L/E), the observation of ν_τ appearance, and precision measurements of the parameters governing the oscillations.

Because nucleon decay detectors are designed to operate for long periods, an ideal second application is to supernova neutrino physics. (Recall that the rate of galactic supernovae is about one in 35 years.) There is keen interest in measuring the neutrino "light curve" out to very long times, due to processes like kaon condensation that may occur only after the protoneutron star has radiated most of its lepton number. Such a phase change can alter the neutrino opacity of the star, changing the neutrino emission rate. Another example is a delayed collapse into a black hole, which would lead to a sharp termination of neutrino emission. The ability of a detector to follow the neutrino light curve depends on the detector's mass (the event rate) and the detector threshold (whether late, low-energy events can be detected). Ideally one would like a "smart" detector that could respond to an initial burst by preparing to trigger on very low energy events that, otherwise, might be discarded.

A second possibility is the detection of the constant flux of relic supernova neutrinos, a quantity that would be of great significance cosmologically in that it integrates over the earliest generation of massive stars to now. Recently it has been argued that the Super-Kamiokande limit is already significant, approaching within a factor of three the range of fluxes that come from plausible models of star formation. This is an example of a problem where any detection is important, but where a great deal of additional information resides in the spectrum and its redshifts. Background rates, and thus depth, are crucial because this is an isotropic low-energy signal.

The detection of extragalactic supernova neutrinos is also within reach of a megaton detector: event counts for a collapse in Andromeda would be a few tens. (But Andromeda collapses occur less than once per century.) Scintillation detectors would be capable of measuring terrestrial antineutrinos of interest to geophysicists.

II. Science Book: Earth Science and Geomicrobiology – NUSEL as EarthLab

EarthLab is a proposal to exploit NUSEL as a deep subsurface observatory and laboratory for the study of geomechanical, hydrologic, geochemical, and biological processes that modify Earth from its surface to the limit of habitable depths. Currently we have few direct opportunities to view, within the deep subsurface, the principal agents of this change, including microbes that precipitate minerals and generate gas; migrating fluids that transport drinking water, weaken earthquake-generating faults, and change rock compositions; and stress and strain that cause rock to deform slowly and break suddenly. Furthermore, biogeochemical processes, fluid flow, rock-water interaction, and rock deformation are all coupled in complex ways. A better and more complete understanding of this coupling is critical to advancing disciplinary research ranging from earthquake engineering to bioremediation.

EarthLab requires a large-scale underground excavation where drilling, coring, and tunneling can access a variety of structural, hydrological, biological, and geochemical environments. EarthLab's underground operations should encompass a crustal volume of tens of cubic kilometers and should extend to several kilometers depth to permit studies of how these complex phenomena scale with distance, depth, and time. Such a facility would be a unique resource for multidisciplinary and multi-institutional investigations for the international geological and biological science and engineering communities. These requirements are well met by NUSEL-Homestake. Its 600 km of tunnels in 3D provide direct access to more than 9 km^3 of complex, highly folded, well characterized rock, reaching to a depth of nearly 2.5 km. Borehole studies initiated by EarthLab scientists will extend this initial footprint to a depth of 5 km.

Most Earth processes are coupled in complex ways. For example, tectonic forces cause rocks to bend and fracture, in turn altering the permeability and porosity of the rock, and therefore the directions and rates of fluid movement. Changes in fluid pressures cause changes in the elastic response of rocks to deforming forces, which control movement along faults and, ultimately, the frequency and magnitude of earthquakes. Fluids also distribute environmentally and economically important elements and compounds in the crust, many of which are dissolved in and precipitated from geothermally heated water. By providing three-dimensional access to large volumes of rock in the shallow subsurface and at depths up to several kilometers, EarthLab will permit scientists to address interactive geologic and life processes, many of which cross disciplinary boundaries.

In addition to pursuing its primary research agenda, EarthLab will also seek partnerships with the bioremediation, biotechnology, and pharmaceutical industries to develop practical applications of its subsurface biosphere research. Other potential industry applications include developing new geophysical and geochemical tools for characterizing the subsurface and new geological mapping, rock drilling, and other engineering technologies for subsurface exploration and construction. By partnering with NASA, these new technologies could also be adapted to explore for subsurface life within our solar system. An important part of EarthLab's plan, which crosses all basic research and engineering disciplines, is to support a very active program to educate and train future generations of scientists and teachers from pre-college to post-graduate, in partnership with the other users of NUSEL. EarthLab scientists will be active in NUSEL public outreach and education programs for K-12, undergraduate, tribal college, and graduate students.

To take full advantage of shared technological infrastructure, intellectual breadth, and education and outreach potential of NUSEL, EarthLab's activities will be closely linked and integrated with those of other scientists who use NUSEL. For example, areas of common interest between earth scientists and physicists include techniques for low-level counting, the rock mechanics

relevant to large underground excavations, and the measurability of the antineutrino flux arising from the earth's natural radioactivity.

Because EarthLab will be unique in scale and in offering long-term access, its users will be able to perform a wide range of experiments and record observations with economic efficiency and minimal duplication. These capabilities and the on-site access to cutting-edge technologies for real-time detailed biological, geophysical, mechanical, and geochemical interrogations, will establish EarthLab as the world leader in subsurface science and engineering research. We expect EarthLab to become the leading earth science center internationally, with its scientists helping to integrate EarthLab research with subsurface research and development at underground laboratories in other countries, including Canada (Sudbury and Underground Research Laboratory), Sweden (Aspo), Italy (Gran Sasso), and South Africa (various mines).

The following discussion of EarthLab possibilities is based on the report by B. J. McPherson and the EarthLab Steering Committee, "EarthLab: A Subterranean Laboratory and Observatory to Study Microbial Life, Fluid Flow, and Rock Deformation."

The EarthLab Science Questions

Some of the major research themes of EarthLab include:

Microbial Life at Depth. One of the great frontiers in the life sciences in the coming decades is the study of life in extreme environments, such as the deep subsurface. Fluid flow, energy transfer, and nutrient fluxes control the distribution of life at depth. We know surprisingly little about these processes, especially under conditions of high pressure, temperature, and environmental stress in complex geological environments. A better understanding of the feedbacks among key processes is critical to understanding how microbial life survives and proliferates at depth. Microbial activity, in turn, generates gas and mineral precipitates that in turn affect rock permeability, fluid flow, and rock strength. Detecting these byproducts of life and distinguishing them from abiological processes is the key to developing life detection technologies for exobiology. For the first time, these connections can be explored in EarthLab where the growth, activity, and transport of microorganisms can be observed in situ.

Hydrologic cycle. Groundwater is the most important source of clean drinking water for most of the planet. There is increasing need to tap more and deeper aquifers, as surface water supplies cannot keep up with the growing world population's thirst. To take full advantage of groundwater supplies, we need to know more about how it moves through the subsurface. We need to be able to predict the consequences of aquifer reduction or depletion at the local and regional scale, and how quickly aquifers recharge—if at all. We need to better understand fluid pathways to protect water supplies from waste contamination, and how surface water infiltrates the subsurface to plan the locations of roads and communities. In the past, drillholes have been the primary means of obtaining information on subsurface fluid flow. The significantly larger surface area of tunnels, combined with the three-dimensional lay out of the EarthLab's tunnels and the available detailed maps of subsurface geology, will permit the needed controlled experiments to be designed and conducted.

Geomechanics, Rock Fracture, and Fluid Flow. The transport of fluids and mobile compounds through fractured rock is fundamental to activities such as recovering oil, gas, or water, protecting the environment, and understanding the formation of ore deposits. The stress and fluid pressure fields control rock deformation and fracture. Many aspects of rock deformation are influenced directly, or even controlled, by fluid flow. Compaction of rock porosity drives fluid flow and fractures. Faults may be conduits or flow barriers. The mathematical theory describing coupling between fluid flow and rock deformation is well developed, but direct observations are limited primarily to tests performed with surface laboratory machines. EarthLab offers the opportunity to observe and investigate coupled fluid flow and rock deformation in situ, within the rocks through which fluids are flowing.

Rock-Water Chemistry. Chemical reactions between rocks and water alter the composition of both. The consequences are of great importance to society. Chemical reactions control the quality of drinking water, the rate of weathering that forms soil and acid-mine drainage, the processes that form mineral deposits, and the development of stable rocks for foundations and other construction. Rates and types of these chemical reactions depend directly on changes in temperature, pressure, and water composition, all of which vary greatly in the subsurface environment. Although studies on outcropping rocks have provided many important insights into these processes, studies in EarthLab will provide better information on small-scale variations related to changes in mineralogy, permeability, and other characteristics of the rocks that host the water. EarthLab offers the opportunity for improving our ability to predict how rock and fluid chemistry evolve through direct experiments.

Deep Seismic Observatory. The many disturbances that are encountered near Earth's surface, both natural and manmade, make this location inhospitable for operating seismographic stations.

An alternative is to locate the stations below ground. In recent years the siting of seismographic stations underground, typically in boreholes at depths of 100 to 200 m, has led to important improvements in signal quality. The possibilities with a underground site like NUSEL, where a 3D array can be built to provide unique directional sensitivity, go beyond anything currently available.

Geophysical Imaging. A common way to develop a subsurface cross section of a region is to conduct a seismic survey. While the cross sections are actually a measure of the travel time of seismic waves bouncing off layers within Earth, we assign geology to these layers based on our general knowledge of regional geology or specific knowledge from local boreholes. EarthLab would permit a significantly superior analysis of geophysical images, such as seismic cross sections, because we would have detailed knowledge of rock types, fractures, and fluids throughout a large, deep three-dimensional volume of rock. This "ground-truth" analysis of geophysical images could be applied to studies of the deep geology of other regions.

These research themes are described in more detail below:

A. Microbial Life at Depth. A major obstacle to understanding the subsurface biosphere has been our limited ability to access the deep terrestrial environment, to acquire uncompromised samples, and to observe in situ the relationships between subsurface microbial ecosystems and the geochemical and hydrogeological processes that control their growth, function, and mobility. Recently, samples collected by the Ocean Drilling Program have permitted scientists to make enormous strides in understanding the microbiology of marine sediments. Studies of biogeochemical and microbial transport in well-characterized, continental aquifers, however, have been limited to brief experiments in two-dimensional well arrays in shallow, geographically dispersed locations, most of which are contaminated by toxic organic or metallic complexes. This has hampered the development of accurate, large-scale models for these complex, interrelated transport phenomena, which are critical to protecting drinking water resources, to subsurface sequestration of CO_2 and to storage of radioactive waste. A recent AAM report on geobiology (Nealson and Ghiorse, 2001) emphasized the need for establishing field laboratories for geomicrobiological research that are available for long-term studies, a need that EarthLab will fulfill.

EarthLab will focus on three major research thrusts: (1) subsurface microbial ecology, the study of crustal environment influences on subsurface microbial communities; (2) subsurface biogeochemical processes, in which subsurface microbial communities alter the crustal environment; and (3) subsurface abiological processes, the geochemical processes that occur within and beyond the subsurface biosphere. One of EarthLab's first achievements will be a complete vertical profile of the subsurface biosphere from the base of the rhizosphere (soil zone), through the deeper mesophilic, thermophilic, and hyperthermophilic zones and into the hydrothermal zone. EarthLab will also initiate a new technological discipline, subsurface biological resource exploration and development. This research and training program will combine science and engineering approaches to explore biotechnological applications of novel subsurface microorganisms and their enzymes and to identify those subsurface environments with the greatest potential for extremozymes (see Scientific and Engineering Innovations).

A.1 Subsurface Microbial Ecology: This research area explores the limits, evolution, and adaptation of life in the subsurface; microbial community changes in response to alterations in their nutrients and energy sources; subsurface chemical, geological and hydrodynamic properties that contribute to the migration and genetic adaptation of life in the deep subsurface; the processes by which microorganisms repair their DNA, cell walls, and membranes under very slow, in situ growth rates; and the stability of subsurface microbial enzymes to temperature changes. Delineating and integrating paleohydrology and thermal history with microbial ecology is essential in constraining evolutionary hypotheses, particularly the long-term and large-scale

microbial migration in the crust and the impact of geological thermal episodes. These studies will also provide guidance to investigations of subsurface life on satellites and other planets in our solar system. Some of the more significant scientific questions are:

- What is the upper temperature limit of life? This temperature controls the depth boundary between the biological hyperthermophile zone and the abiotic hydrothermal zone in the crust. Is it 120°C, the highest survival temperature known for a microorganism in the lab, or can it reach higher levels under favorable circumstances?
- Is large-scale vertical transport of shallow subsurface or soil microorganisms to the deep subsurface occurring with fluid flow? If not, what limits their mobility? That is, is there a connection between the rhizosphere (soil zone) and the deeper mesophile, thermophile, and hyperthermophile zones or have these zones been isolated over geological epochs?
- Do deep subsurface microorganisms possess metabolic plasticity that enables them to use several electron acceptors and donors, or do they develop syntrophic microbial relationships where one microorganism facilitates the metabolism of another by using its waste products?
- Is the average life span for microbial cells in these deep environments on the order of thousands of years?
- Do the rates and/or the variability of fluid flux through subsurface fracture networks dictate the quantity, diversity, and activity of microorganisms present? Or, is fracture formation and nutrient flux from the rock matrix into fluid-filled fractures more important factors for sustaining subsurface ecosystems?
- Are the microbial communities colonizing fracture surfaces significantly different in diversity and abundance compared to freely floating (planktonic) communities?

A.2 Subsurface Biogeochemical Processes: Over geological time, microorganisms have completely altered Earth's atmosphere, ocean, and land surfaces. With increasing depth and temperature and diminishing pore space, the impact of microbial communities on their environment must decline to the point where high-temperature diagenetic and hydrothermal reaction rates dominate. EarthLab will delineate this transition both in space, using in situ experiments, and over geological time, using a combination of geochronology, geochemistry, and petrology.

Subsurface biogeochemical processes emphasize the role of microorganisms in the dissolution, nucleation, and precipitation of mineral phases, the transport and transformation of aqueous chemical and gaseous species, and the alteration of hydrological properties (i.e., storage capacity and permeability) of aquifers. How microbial colonization of various mineral surfaces affects the water/mineral and dissolved gas/mineral interactions can only be validated by in situ observations. Important questions include:

- Will subsurface, chemoautotrophic, and heterotrophic microbial communities contribute to CO_2 sequestration in deep subsurface environments by carbonate precipitation, increasing the pH, or convert to CH_4 and organic acids?
- In deep subsurface environments where gas and water occur as separate phases, e.g., in vadose zones (zones above the water table), natural gas reservoirs, or CO2 injection sites, will planktonic microbial communities concentrate at the phase interface and enhance the flux of dissolved gases into the water?
- Do the microbial communities colonizing fracture surfaces dissolve mineral surfaces and enhance the flux of energy substrates and nutrients from the rock pores to sustain growth?
- How well do theoretical free energy calculations based upon aqueous chemistry predict the type of microbial communities?
- What is the subsurface nitrogen cycle and do microorganisms control it as they do in the oceans?

A.3 Subsurface Abiological Geochemical Processes: Because of uplift and erosion, the rock strata housing EarthLab will contain a geological record that documents the transition from the ~300°C hydrothermal zone, where abiological, rock-water interactions dominate, to a lower

temperature (<120°C) zone where biologically catalyzed rock-water interactions take place. The hydrothermal zone will be preserved in low-permeability zones or gas-tight rock, whereas the lower-temperature zone will be associated with fractures and permeable rock strata that permit meteoric fluid penetration from the surface. EarthLab will offer an unprecedented opportunity to document the depth and rate of the crustal weathering process that moves rock volumes from the hydrothermal zone to the lower temperature zone. This will be studied by obtaining pristine rock cores at specific distances from mapped fractures. The fluids inside these cores will be dated by noble-gas isotopic analyses. If the pore-throat diameters of these rock strata are too small to permit colonization by bacteria, then they provide an abiological control or end member to compare to the subsurface biogeochemical processes studied above. Some of the interesting questions include:

- Are reduced organic species being produced in the crust by interaction of inorganic species with reduced metal oxides and sulfides (i.e., ore deposits)?
- What attributes of mineral precipitates formed by hydrothermal processes distinguish them from those formed at lower temperatures by microbial processes?
- How does the composition of water and gas vary as a function of depth through typical continental crust? In particular, what buffers the oxidation potential and pH?
- Do abiological processes control the C:N:P composition of ground water, or does microbial growth and respiration control it, as in the oceans?

B. Hydrologic Cycle. Water is a precious resource and commodity that is becoming more valuable as our population expands. Surface water and groundwater are used in all aspects of our lives, from drinking water to agriculture to industry. Groundwater has become an increasingly important resource because it has some significant advantages over surface water supplies. It protects us from surface-borne pathogens and decreases susceptibility to contamination of water supplies by bioterrorists. Wastes that should be isolated from the surface can be stored in subsurface areas that lack useful groundwaters. Knowledge of fluid pathways provides assurance that the wastes will not flow into important areas.

To quantify the natural hydrologic cycle, we need direct measurements of subsurface properties and processes that control fluid flow. These will lead to better characterization of the relationship between surface infiltration and subsurface groundwater recharge and flow. Such measurements are most critical for more regional-scale basins and watersheds where deeper data and information are sparse. Oil and mineral exploration provide most point measurements, but even in basins subject to heavy exploration, the best data are biased in favor of oil/gas-producing formations, and not those formations important for water resources. Important scientific issues concerning the hydrological cycle are described below.

B.1 Infiltration of Surface Water to the Subsurface: Infiltration of surface water to the water table—the point at which water from the atmosphere joins groundwater—is a crucial link in the water cycle. Many factors affect the spatial distribution of infiltration and the ratio of infiltration to surface runoff, including surface topography, surface geology (rock/soil types, local terrain variability, local and regional structural geology), vegetation, and climate, all of which are routinely modified by humans.

A better understanding of how surface water reaches subsurface aquifers has many important practical applications, such as evaluating the impact of land development on our water supply. Another critical application is improving our ability to predict the movement of water through radioactive waste repositories located in the deep subsurface, an issue under study in many parts of the country. Water movement through such systems is enhanced by the presence of fractures, but to date, no system has been available in which a large volume of unsaturated fractured rock could be extensively sampled in both vertical and horizontal dimensions. EarthLab provides the opportunity to evaluate direct indicators of infiltration rates and fault/fracture patterns, as measured from the inside, rather than inferred from the surface.

Key questions include:

- What are the pathways that water takes through soil and rock once it infiltrates the subsurface, especially in the critical unsaturated zone closest to the surface?
- What are the interrelationships among the physical, chemical, and biological characteristics of the subsurface, and how do they affect infiltration?

B.2 Groundwater Flow: The permeability of crustal rocks—its capacity for transporting fluid—is probably the most fundamental and critical rock property affecting fluid flow in the subsurface. Detailed knowledge of rock permeability is essential for finding and exploiting water resources in the subsurface. It is also useful in tracking and remediating contaminated groundwater, and in exploring for oil and gas. A rock formation's permeability may have different values depending on the scale at which it is evaluated, making assessments of fluid flow and aquifer or reservoir capacity highly inaccurate at best. Key questions include:

- What is the relationship between permeability and scale? Which scale is appropriate for evaluating and quantifying water resources, calibrating models, or testing hypotheses in general?
- What are the key transport pathways for water, and how can we best measure them?
- Can geochemical tracers be used to accurately predict fluxes of water and solutes through a rock mass?
- Which transport pathways are general to water-saturated environments, and which are unique?

C. Geomechanics, Rock Fracture, and Fluid Flow. A central goal of geomechanics research is to understand the stress and deformation histories of rock masses, and how those histories affect, and are affected by, the flow of groundwater and transport of chemical species. The distributions of stress and deformation impact engineering design of underground facilities, mine safety, location of mineral and hydrocarbon deposits, control of regional groundwater flow systems, and seismic hazard evaluation. Proper characterizations of stress and deformation states, and accurate predictions of the physical and engineering properties of rock masses by geophysical remote sensing, inevitably lead to more efficient exploration for resources and more effective construction design. Because fracture and fluid flow reflect the deformation history and affect the present stress state of a rock mass, fracture processes and coupled thermal-mechanical-hydrologic-chemical-biological (TMHCB) processes at many scales are outstanding issues that cut across geoscience subdisciplines.

Rock deformation deep in the subsurface is not well characterized, except in a few deep mines, particularly in South Africa. Most deformation measurements have been made at the surface, and existing data are disproportionately from areas across or adjacent to active faults. Strainmeters, satellite-generated Interferometric Synthetic Aperture Radar (InSAR), and Global Positioning System (GPS) measurements provide these surface data. Mathematical inversion methods can be used to estimate the displacements at depth associated with fault motions, and these displacements can in turn be used to evaluate the subsurface stress perturbations associated with faulting. Surface measurements by themselves, however, are completely inadequate for determining the baseline (or ambient) stress distribution at depth, and this baseline distribution must be known to predict how faults will slip and how subsurface excavations will deform. Stress measurements in deep boreholes afford a glimpse of the stresses at depth, but are relatively few in number, prone to considerable scatter, and associated with small rock volumes. Consequently they are often inadequate to define the state of stress. Direct, repeatable, in situ measurements throughout a large rock volume at depth in a tectonically quiet environment are the only way to define an accurate stress baseline.

EarthLab priorities for geomechanics include: 1) elucidating the state of stress and stress history of a large rock mass; 2) investigating the origins of a three-dimensional fracture system; and 3) performing active experiments underground to study TMHCB coupling.

C.1 State of Stress: Fundamental to progress in both geomechanics and tectonics is better knowledge of the distribution of stresses in space and through time. Considerable research is needed to provide a more realistic assessment of the state of deformation and stress in rock, on scales ranging from engineering excavations to the earth's tectonic plates. Such studies could assist in verifying the predictions of analytical and numerical models, allowing more confident application of the models to still larger-scale problems. Implicit in this discussion is the need to develop improved experimental procedures for the in situ observations.

Techniques are available to determine the state of stress in situ and to measure deformation induced by the redistribution of stress, but these are costly procedures and often limited in scope. It is not uncommon to see stress measurements at essentially a point extrapolated far beyond their range of validity. In some cases, isolated point measurements are used to infer stress conditions throughout almost an entire tectonic plate many thousands of square kilometers in extent.

Access to the large rock volume in EarthLab will also permit testing of the hypothesis that Earth's crust is "critically stressed," that is, some portion of the rock is always close to failure by fracture. Repeated shearing of critically stressed fractures can keep flow paths open that minerals precipitated from flowing fluids might otherwise seal. The greatest rock permeability at depth, therefore, is predicted to occur along "critically stressed" fractures. Characterizing the fractures, stress, and fluid flow within the subsurface will permit a rigorous test (and perhaps an extension) of this critical stress theory.

Key questions EarthLab will address about state of stress in the crust include:

- Is crust at EarthLab critically stressed as at sites in other stable, intraplate areas?
- How do point measurements relate to regional and global stress values?
- How does stress state vary in scale from borehole to tunnel to mine to regional geology?
- How are stress state and strength related to geologic heterogeneity, the presence of fluids, and rock anisotropy?
- How does the stress state affect the stability of tunnels, shafts, wellbores, and large, room-sized excavations?

C.2 Fracture Processes: Pervasive fracturing of a rock mass is common and can occur over a broad range of scales in both space and time. Detailed knowledge of fracture systems is important for assessing the mechanical properties and strength of rock masses. Fractures serve as conduits and/or barriers to subsurface fluid flow, so they are important to the flow of groundwater, hydrocarbons, ore-forming fluids, geothermal fluids, and fluids that sustain life deep within the biosphere. Fracture distributions, and how we think of them, also influence strongly how we design exploration strategies for the subsurface. Nonetheless, we still have much to learn about the geometry of fracture systems, the processes that create them, and how they conduct fluids and heat.

To date our most sophisticated characterizations of fracture networks in the subsurface typically involve extrapolating information gained from surface exposures, borehole observations, and inferences drawn from geophysical data. These methods, however, have some distinct limitations, especially when applied separately. Soil, vegetation, and water commonly obscure surface exposures, and in many cases fractures formed near the surface are superposed on those that formed at depth. Boreholes sample small volumes of rock, making characterization of large fracture networks problematic. Existing borehole and surface geophysical techniques are unable to detect fractures below certain size thresholds, and they commonly cannot detect details that illuminate how fracture systems develop.

Accurate and detailed information on fracture locations, sizes, orientations, and physical characteristics would be invaluable for testing, improving, and developing new hydrologic methods and new non-invasive geophysical methods for subsurface characterization. In general, a tradeoff exists between geophysical resolution and spatial scale. Innovations developed and tested at EarthLab would provide for more effective and more efficient characterization of subsurface fracture networks in aquifers, in economically viable hydrocarbon reservoirs, and in ore bodies. An important point to note is that the geophysical evaluations would naturally be done in conjunction with direct observations rather than separately. This would have a very positive synergistic effect, not just on technique development, but also in fostering interdisciplinary collaboration among geologists, geophysicists, specialists in rock mechanics, and hydrologists.

Subsurface access to a well-exposed, extensive, three-dimensional rock mass will make a tremendous contribution to our understanding of fractures in rock. Key questions that can be addressed include:

- How are the three-dimensional geometry and its evolution related to the state of stress, temperature, and chemical transport?
- How do fracture networks and faults form and grow?
- Can we improve geophysical imaging of fractures?
- Can we relate geomechanical and hydrogeological properties of faults?
- How do the fractures in a rock volume of about one cubic kilometer relate to regional tectonic patterns?
- How are fracture networks affected by mining and construction activities?

C.3 THMCB Coupling: Fluid circulation within the crust is strongly influenced by the pathways the fluid itself etches or seals, and the new fractures that may result from changes in stress, temperature, or fluid pressure. These complex coupled-process interactions of thermal, hydraulic, mechanical, chemical, and biological effects (TMHCB), control the flow and transport of fluids, and of energy and nutrient fluxes in the fractured subsurface. The processes are strongly stress, temperature, and scale dependent, exhibit strong feedbacks, and as a result remain poorly understood, particularly in complex fractured rock, and at large scales. The opportunity for the multidisciplinary investigation of the important parameters controlling these processes is an important benefit of an underground science laboratory. A better understanding of the feedbacks between key processes will aid in the development of innovative techniques for resource recovery, waste disposal, site restoration and remediation, and underground construction.
The observed distribution of geochemical and biological markers may be used to indicate the large-scale upflow or downflow of fluids and nutrients that have occurred over geologic time. These records yield insights of past process interactions, for example, defining how flow pathways may have evolved over time, and providing clues in finding zones of mineral wealth or enhanced groundwater yield. Similar surveys will quantify the switch between the stresses and other agents that enhance the development of fracture porosity, and those that result in the loss of porosity by mineral precipitation and dissolution. These observations will improve our understanding and expectations of long-term isolation of wastes in deep repositories.

In addition, active coupled-process experiments will provide a unique opportunity to observe process interactions relevant to understanding the response of the engineered or natural environment. Opportunities to confirm predictions of anticipated behavior with measured behavior are rare. This is especially true for the strong and uncertain feedbacks that couple THMCB processes in fractured rock, over unusually large scales. Surprising outcomes are the norm, rather than the exception. These experiments may examine, for example, microbial growth and colonization in newly developed fractures, inclusive of bio-stimulation for aquifer remediation, and the converse effects of bio-clogging and bio-mineralization.

Key questions related to coupled THMCB processes that may be addressed in EarthLab include:

- Under what thermal and chemical conditions do fluid-conducting fractures gape or seal with net dissolution? Are rates accelerated or retarded in the presence of microbial colonization?
- How well constrained are predictions of transport rates and breakthrough behavior with changes in test scale?
- Are drill-bit to rock interactions recorded at the end of a full drill-string, similar to those observed in the drill simulator?
- Are hydraulically or gas-driven fractures influenced by pre-existing fractures at all scales?
- At what limiting conditions does the healing of micro-cracks outstrip their rate of generation, and therefore influence their persistence in time and space?

D. Rock-Water Chemistry. Rock-water interaction involves the many dissolution and precipitation reactions that control the mobility of elements and compounds at Earth's surface. Earth's surface varies greatly in composition from place to place, in part because groundwater dissolves minerals and rocks and transports their constituents to new locations. This combination of dissolution and precipitation reactions, which is known as rock-water interaction, controls the mobility of elements and compounds and the quality of both water and rock in the surface environment. Rock-water interaction affects our environment in many ways, determining, for example, the abundance of arsenic in well water, the amount of clay in the soil, and the amount of acid drainage from abandoned mines.

EarthLab will allow study of active water-rock interaction at a multitude of scales in both space and time. Most active geochemical processes can be studied in nature only at the surface and after they have evolved for extended periods. The opportunity to observe them in an underground setting, at earlier stages in their evolution and over shorter time scales, will provide better understanding of the processes and will permit extrapolation of results from the laboratory to larger, natural scales. This, in turn, will enhance our ability to use laboratory results to benefit society with, for instance, methods to limit acid mine drainage or dispersal of radioactive waste from disposal sites.

D.1 Acid Mine Drainage: One of the most important focuses of research on active water-rock interaction in an underground science laboratory is acid-mine drainage (AMD). AMD results from active rock-water interactions around working and abandoned sulfide-bearing mines and mine wastes, and it is a multi-billion dollar environmental problem. Over 200,000 active and abandoned mining sites in the United States alone release large amounts of acidic, metal-bearing water into the environment, creating trails of contaminated soil and sediment that extend up to hundreds of kilometers away from their source, usually along rivers and streams. Most of these sites were created before society recognized this as a large-scale problem, and their remediation is a major environmental challenge that we face today. Although AMD has been studied extensively, many important issues must be resolved before remediation can be carried out efficiently and effectively in a wide range of natural settings.

Chemical reactions that take place between water and sulfide minerals, especially pyrite (FeS_2), are among the most complex and dynamic of all near-surface rock-water systems. When these reactions take place in the presence of oxygen, they can generate AMD solutions with pH values as low as -3.6, which are the most acid natural waters observed so far at Earth's surface. Where AMD effluent mixes with air and oxygenated surface water, it precipitates iron oxides, oxyhydroxides, and/or hydroxysulfates that contain very high concentrations of toxic heavy metals and that can be dispersed as sediment into surrounding streams, rivers and groundwaters.

Effective remediation of AMD requires that we understand the forms in which metals and other elements are dissolved and the forms that they take in the solid phase. We also need information on rates of dissolution and precipitation reactions, and the role of biological activity in them.

Key questions to be addressed at EarthLab include:

- What dissolved forms are most important in AMD and what controls their activity in natural settings?
- What role do submicron particles such as colloids and microbes play in metal mobility during AMD?
- Do existing surface reactivity models and thermodynamic databases accurately predict their chemical reactivity and behavior of minerals and rocks?

D.2 Underground Waste Storage: Rock-water interaction is also important to problems of underground waste disposal. Underground facilities are widely regarded as the most secure sites for disposal of nuclear and other highly contaminated wastes because they can be isolated from the surface environment. Nuclear wastes will be placed in containers in most underground disposal sites, and the rock will serve as a secondary barrier. Most other types of wastes are not placed in containers, however, with the rock serving as the primary barrier to waste migration.

There is a strong interest in learning how rock-water interaction will impede the movement of waste. Adsorbtion is the most important process that allows rocks to serve as barriers. During adsorbtion, waste elements and compounds that are dissolved in migrating water become chemically attached to the surface of minerals in the rock, thus becoming immobile. The capacity of rocks and minerals to adsorb elements and compounds in the natural environment is affected by the composition of the water that passes through it, as well as temperature, pressure, and other variables. Temperature is important because radioactive waste and even some chemical wastes are hot enough to cause changes in the rocks and minerals, thus affecting their adsorbing capacity. Although great progress has been made in the study of these problems, the ability to perform in situ experiments in an EarthLab facility will be an important addition to our research capability.

D.3 Origin of Mineral Deposits: Studies of mineral deposits can clarify the processes that formed the deposits and determine the distribution of elements and compounds in and around the deposits. Mineral deposits are formed by circulating hot waters, or hydrothermal solutions, that change the composition of the rocks through which they migrate. Evidence of this rock-water interaction is found in the rock in the form of fluid inclusions and new minerals. Fluid inclusions are small amounts of the hydrothermal solutions that were trapped in new minerals precipitated. These fluid inclusions provide information on the composition of ancient fluids. New minerals that form during rock-water interaction provide useful guides to the location of mineral deposits.

We have learned a great deal during the last decades about the processes that form mineral deposits, but important questions remain. Answers to these questions are critical to improving exploration for the new resources necessary for continued economic development. EarthLab would permit much more detailed research on ore formation than is possible in most currently available settings, addressing the following key questions:

- What are the sources of hydrothermal solutions that form deposits? Are they from rainwater (meteoric water) that circulates downward through the crust, where it is heated and rises again, or are they from magmas, rocks undergoing metamorphism, or other sources, such as heated sea water?
- Were elements found in mineral deposits leached from surrounding rocks or introduced by special hydrothermal solutions, possibly from a crystallizing magma?
- What controlled the circulation of fluids in the deposit and what mechanism caused minerals to deposit?
- What other elements of possible environmental interest (e.g., As, Se, or Hg) were deposited at the same time as the desired element or compound, and why and how will this affect mining and processing of the ores?
- How large were the fluid circulation systems that formed the deposits and what types of evidence did they leave in rocks far outside the deposits? Far-field effects such as this are

critically important to exploration for mineral deposits and to understanding the environmental effects that deposits have on surrounding crust.

E. Deep Seismic Observatory. Earth's surface is an inhospitable place to operate a seismographic station. Cultural noise, noise caused by wind and barometric changes, scattering from topography, and scattering from the high degree of heterogeneity in physical properties that exists near the surface greatly increases the difficulty of data interpretation. Lack of access to subsurface sites has made it necessary to operate most seismographic stations either at the surface or in shallow vaults a few meters below the surface. In recent years more instruments have been placed in shallow boreholes, typically at depths of 100 to 200 m, often greatly improving signal quality. However, the cost and restrictions of working in small boreholes has significantly limited this type of installation. Thus, with seismometers at a depth of over 2 km below the surface, EarthLab would be a unique seismological laboratory, with unmatched potential for recording seismic signals with a fidelity that has not been achieved in the past.

The types of problems that could be addressed by an EarthLab seismological laboratory depend on its location, but a site like Homestake, near the center of the continent in a stable geologic setting, would offer several advantages. Although other areas would yield opportunities as well, a position far from the most important sources of natural noise, such as oceans, and far from the most important sources of cultural noise, such as large metropolitan areas, would be preferable. Furthermore older continental shields are capable of propagating seismic waves with much less attenuation than younger, more tectonically active regions such as the western United States. These factors, together with the siting of seismometers at depth to avoid the highly attenuating materials near Earth's surface, may allow observation of otherwise difficult to detect high-frequency components of seismic waves emerging from Earth's mantle. This additional high-frequency content translates into improved precision for a broad range of seismological studies, such as detection of weak signals, localization of seismic events, determination of source processes, deciphering triplications in travel time curves, and measuring polarization anomalies of S waves.

An EarthLab with a large complex of drifts – Homestake provides a 3D array consisting of 600 km of drifts spanning nine cubic kilometers of rock – would permit installation of an underground array that would have much enhanced capabilities, when compared to an isolated seismographic station. Whereas a single station samples the ground motion in time, an array of stations can sample ground motion in both time and space. This means that it is possible to determine both the time that a signal arrives and the direction that it is traveling. This is extremely useful because signals frequently arrive from several different directions at the same time. The array can be aimed, much like a telescope, to look in a particular direction. Furthermore, the availability of data from an array makes possible a wide variety of signal processing and enhancement methods that are not options with data from a single station. Depending upon the spatial coherence of signal and noise, these array-processing methods can greatly increase the signal-to-noise ratio of the seismic data. The presence of both a vertical array, which is never possible with a surface installation, and a horizontal array, further expands the variety of processing methods that can be used. Such a seismological observatory could be based on three main elements, a single very broad band three-component station, a broad band vertical array of three-component stations, and a broad band horizontal array of three-component stations. Adding accelerometers at some or all of the stations could enhance the facility's sensitivity to high-frequency ground motion. The preferred arrangement would provide a horizontal array with about six elements and an aperture of about six kilometers. Dynamic spatial and temporal filtering will provide unprecedented sensitivity to different wavefield components. This offers the possibility, for example, of better discrimination of small events buried within the waveforms of larger events. This underground array consisting of 10 three-component seismometer packages has the potential to be one of the most sensitive and versatile instruments in the world.

Although the goals of EarthLab's Deep Seismic Observatory and EarthScope's USArray are quite different, the facilities will be complementary. The Deep Seismic Observatory will provide high quality seismic data that can be correlated with that derived from USArray when the EarthScope stations move through the Observatory area. USArray, in turn, will provide valuable information about the local velocity structure in the vicinity of the Observatory area. Depending on the instrumentation selected, the Observatory may also provide an important monitoring function in recording seismic signals from small events within EarthLab itself, such as rock bursts or collapses. As many of the physics instruments operating underground are sensitive to very small disturbances as background events, there are opportunities for interesting synergism. The Observatory instruments will be able to detect ground motions that would affect instrumentation throughout NUSEL.

F. Geophysical Imaging. The ability to image fractures and to characterize their length, width, and apertures cuts across many different fields of research and societal concerns. Knowledge of fractures and fracture networks is important to studies of groundwater flow, recovery of gas and oil, hazardous waste containment, carbon sequestration, and as a habitat for subsurface biota. Fractures and fracture networks are critical elements in chemical transport, ore formation, heat flow, faults, and earthquakes. EarthLab will offer a variety of opportunities to develop a better understanding of fracture networks at the field-scale level.

Commonly used geophysical imaging techniques for high-resolution applications include electromagnetics, seismics, microgravity, resistivity, induced polarization, and ground penetrating radar (GPR). Fractures present both a mechanical and a electrical conductivity anomaly, especially if they are filled with fluid. As the rock volume of interest becomes larger, other methods involving the determination of electrical resistivity through direct electrical methods or electromagnetic induction methods can probe deeper into the rock to detect and delineate fracture systems.

In the case of EarthLab, the fractures will control the mechanical as well as the hydrological response of the entire system. It is critical to know not only the initial state of the fractures (geometry, density, spacing, filling, length and connectivity) but also how perturbing the system changes the interaction of the fractures with the rock matrix. Recent developments in fracture imaging from the oil and gas as well as the geothermal industries can be used to characterize the fracture system. For example, effects of the fracturing on the transmission and reflection of seismic energy can be used effectively to map out the extent and, in some cases, the aperture of the fracturing. Seismic attenuation can be used to locate very small features (on the order of a few millimeters) that have very large effects on the hydrologic response of extensive volumes of rock.

To gain a more complete understanding of the implications of geophysical data, one must correlate with great accuracy geophysical results with the geology, including fracture geometry, and with the corresponding hydrologic and microbial properties. EarthLab is one of the few places where one would be able connect geophysical data with actual fracture mapping at a variety of scales. Scaling is one of the most important unresolved issues in geoscience: What scale must be measured to understand the dominant processes and properties controlling important phenomena? For example, in the case of microbial ecology, at what scale must one characterize the chemical and physical environment to understand the microbial behavior? At EarthLab it will be possible to make very detailed measurements using drilling results and borehole measurements, as well as broad volumetric geophysical and hydrological measurements.

The EarthLab Experimental Program: Five Major Experiments

EarthLab's primary goal is to provide experimental testbeds for investigating the origin and bounds of life, for probing the coupling of hydrological, deformational, thermal, biological, and chemical processes in fractured rock, and for developing practical applications for the mining, bioremediation, biotechnology and pharmaceutical industries. EarthLab will be the only facility in the world where long-term, in situ geomicrobiology and biogeochemistry experiments will test the evolution, adaptation, and limits of microbial life, in the deep subsurface. The research goals of EarthLab will be achieved by closely integrating hydrogeological, rock mechanical, geomicrobiological, geochemical, geological, and geophysical activities and will rely upon geological, geochemical and geophysical characterization of the underground environment. EarthLab can provide a field platform for developing the technologies that NASA will need to search for subterranean life on other solar system planets, especially Mars.

EarthLab experiments will require state-of-the-art instrumentation for assessing and monitoring subsurface processes. All of the experiments will make use of web-based data acquisition to permit scientists from across the country to monitor experimental results in real time. Data bases will be open to the public, and thus available to any scientist seeking to test a theory or calibrate a model.

During the initial two to three years, the primary focus of scientific efforts at EarthLab will be on fundamental issues, for example, examining the microbiological diversity, characterizing comprehensive geological properties throughout the site, and monitoring geophysical, mechanical and hydrologic processes. Underground mapping and geophysical surveys will be used to identify the locations of appropriate subsurface sites for EarthLab experiments. A surface laboratory facility for EarthLab will be established to coordinate the multidisciplinary research program with educational objectives.

Essential to the science program is **the initial characterization of the EarthLab site**. Accordingly, an organized, comprehensive characterization effort must precede new construction. Compiling existing data on the geology, hydrology, fluid chemistry, and construction history of the mine is the first step. The physical properties of rock throughout the mine should be subjected to a combination of both in situ and laboratory tests. These studies will provide a data base important to NUSEL physicists, as well. Homestake's existing library of maps and geotechnical data is already extensive, and is supported by knowledgeable mine geologists and by important numerical tools, such as a complete 3D mine model.

Characterizing the three-dimensional fracture network and the distribution of rock types requires mapping of the tunnel walls and, locally, exploration using new boreholes. This information, together with existing mine maps, historical records of fluid flow rates, rock and water temperatures, relative humidity, water chemistry, and in situ stresses will be used to develop a quantitative geo-hydrological model of the geologic system. Hydraulic, tracer, and geophysical tests will be used to characterize rock structure, fracture connectivity, and transport properties, and their variability with scale, with depth, and with distance across the envelope of rock disturbed during cavern excavation. These results will be correlated with stress, rock deformation, and physical property data.

Long-term instrumentation for monitoring rock deformation will be installed in selected tunnels. Rock samples recovered from boreholes will help characterize the rock structure, groundwater history, and the physical, chemical, and biological properties of the rock and fluids. By instrumenting the boreholes, a host of processes can be monitored in situ (e.g., excavation-induced displacements, microseismic activity, temperatures, and fluid pressures). The boreholes also allow recovery of aqueous and particulate samples. These measurements will provide a baseline documenting ambient conditions prior to new excavation.

Hydraulic, tracer, and geophysical characterizations of transport parameters, concurrent with cavern-enlargement will help define the form of the coupling between mechanical and thermal effects, and hydraulic transport parameters. After excavation, the instrumentation arrays will be used to monitor the long-term passive response in the stable zone surrounding the detectors.

Following this initial characterization of the EarthLab site, **five major, long-term, multidisciplinary experiments** will be carried out at, including

- An Ultradeep Underground Observatory for Biological and Biogeochemical Education and Research
- The Paleohydrology Experiment
- The Coupled Processes Experiment
- The Induced Fracturing Experiment
- The Deep Percolation and Groundwater Flow Experiment

These experiments and other proposed studies are described below.

A. An Ultradeep Underground Observatory for Biological and Biogeochemical Education and Research. The science goals of the experiment include:

- Determine the upper temperature limit of life in the crust and what factors control it.
- Identify the mineralogical and geochemical signatures marking the transition between the hyperthermophile and hydrothermal zones, and distinguish biological from abiological processes.

The experimental design elements include:

- Drill three 2-km holes from the bottom level of EarthLab to depths that will reach rocks with temperatures of 120°C, the highest temperature limit for known life forms. The three boreholes will form a triangular array, 10-20 m on each side. Geophysical logging of the first borehole will be used to identify fracture zones and coring intervals for the second and third boreholes.
- Collect 30 2-m cores for biological, geochemical, and petrophysical analyses. Tracers will be used during coring to monitor and quantify contamination.
- Place samples from each core within evacuated canisters on site for pore gas analyses and dating. Process other samples from each core in an anaerobic glove bag for microbial enrichment and activity experiments. Freeze remainder of each core in dry ice on site, transfer to -70°C archives, and preserve for molecular, isotopic, petrographic, geochemical, petrophysical, and geochronological analyses.
- Upon completion of all three boreholes, characterize the rock strata using geophysical logging and tomography between the boreholes. These data will provide a complete 3-D image of a crustal slice down to 4.5-5 km. Conduct pump tests of fracture zones isolated by downhole packers to determine the hydraulic conductivity of the fractures.
- Select two of the boreholes for *in situ* experiments where retrievable packers isolate sections of hole that contain fluid-filled fractures at 100-120°C and ambient pressures. Incubate microorganisms and solid substrates surrounded by filters in the ambient environment and measure their metabolic products and activity in real time. These in situ experiments will determine the factors that limit life at those high temperatures. Static, *in situ* experiments will employ radio-labeled or isotopically enriched compounds. Upon retrieval, biofilms will be analyzed by fluorescent *in situ* hybridization combined with either microautoradiography or secondary ion mass spectrometry. The two boreholes can also be used for microbial or chemical transport experiments along specific fracture zones or for push-pull, in situ microbial activity experiments.
- Fit the third borehole with a multi-level packer system that draws fluids from all the fracture zones intersected in the borehole. Plumb the fluids and gases from each zone into an anaerobic glove bag on site for microbial experiments. For each fracture fluid, determine its viral, microbial, and eukaryotic composition; its dissolved and colloidal inorganic and

organic composition; its isotopic composition; and the stable, cosmogenic, and radiogenic composition of the dissolved organic, inorganic, and gas species.

- Fit the third borehole with strainmeters to provide stress data to determine if the crust at EarthLab is critically stressed.
- Perform fluid inclusion analyses on fracture-filling minerals to compare the temperature and pressure, organic, inorganic, and isotopic composition of the ancient water and gas with that of present-day fracture fluid.

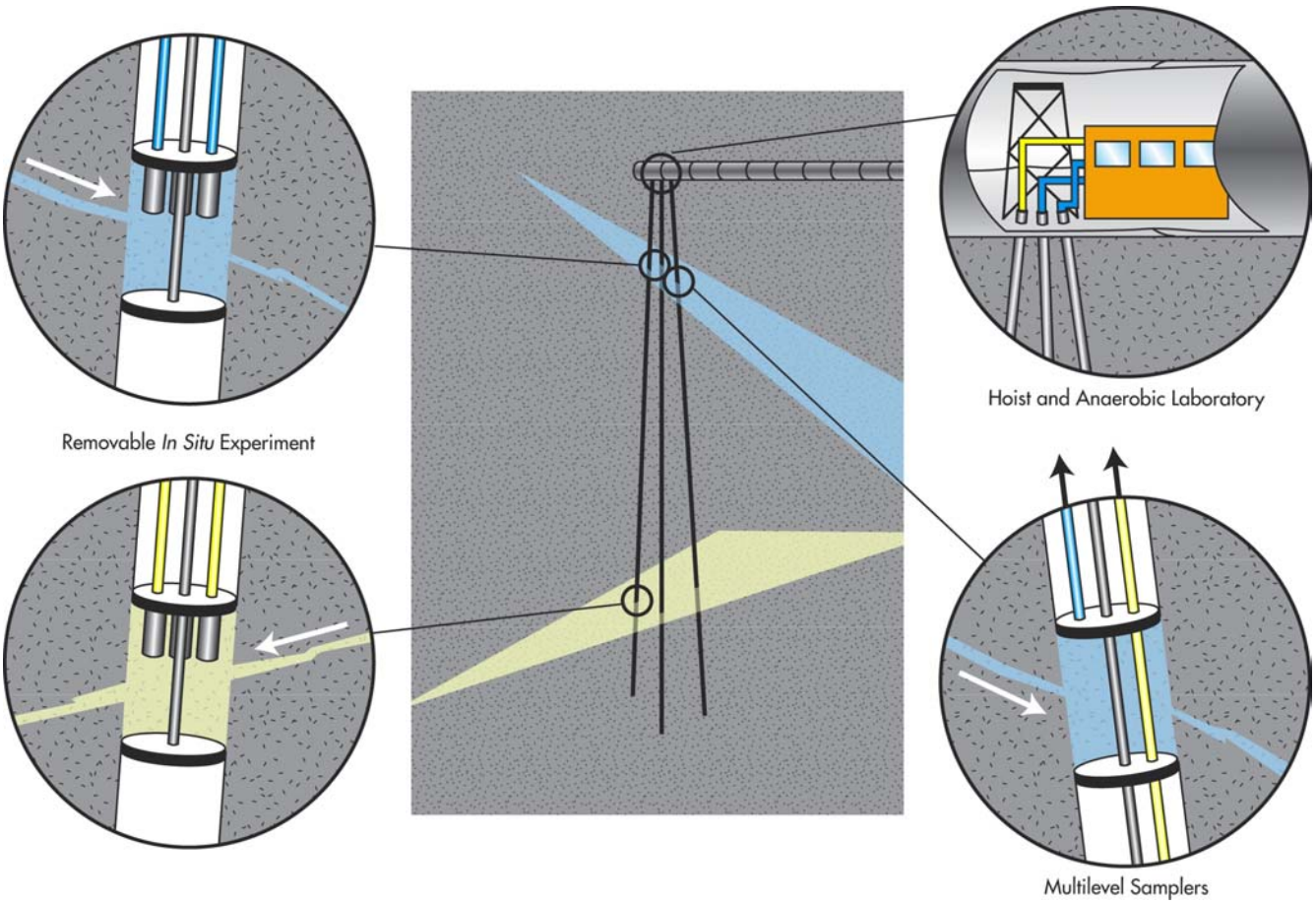


Figure C.15: The Ultradeep Underground Observatory for Biological and Biogeochemical Education and Research. A) Three boreholes penetrate two kilometers intersecting several fluid-filled fractures, attaining temperatures at the bottom of ~ 110-120 C. After holes are drilled, cored, and logged, and the interborehole rock volume tomographically imaged, fluid-filled fractures are isolated with multilevel samplers B) or *in situ* experiment samplers C) and D), equipped with compression packers. Fluids from both sampler types travel through the tubing to well head and pass through SS double gate high-pressure valves and into a laboratory equipped with an anaerobic glove bag E). A winch is used to insert and remove the samplers and geophysical probes from the borehole.

- Perform fission track and U-He apatite and $^{40}Ar/^{39}Ar$ K feldspar and illite dating of the cores. This will provide a record of the temperature versus time history of the rock unit as it cooled from the hydrothermal zone through the hyperthermophile zone, determining the age at which changes in the fluid composition occurred. Use ion microprobe chemical and stable isotope analyses of fracture-filling minerals to determine the composition of the fluid flowing through the fracture zones as the strata were uplifted and eroded. These analyses can also distinguish thermodynamic equilibrium isotopic fractionation from biologically produced kinetic fractionation as the rock strata cooled from the hydrothermal zone to the hyperthermophile zone.
- Chemical and isotopic analyses of pore water and gases trapped in the low-permeability matrix of the rock core may still record the ancient pristine hydrothermal fluid that has yet to mix with younger water passing through fractures. Noble gas analyses of rock cores can constrain the age of the fluid. The ^{13}C and δD of methane and light hydrocarbons can distinguish a microbial versus thermogenic versus abiogenic origin for these gases. These analyses will also delineate the chemical energy fluxes from the rock to the fracture fluid that is available for life. Cosmogenic and nucleogenic isotopic analyses, for example, ^{14}C, ^{36}Cl, and ^{22}Ne, of the fracture fluids will constrain their age and the ambient radiation flux when combined with detailed geochemical analyses of the rock composition. The main caveat is that in the very deepest part of such systems, where residence times are longest and flow rates slowest, the different components (water, solutes, nuclides produced *in situ*) may have quite different behaviors and histories, and "dating" in the conventional sense may be very difficult. Valuable history information can still be obtained from these measurements, however.

B. The Paleohydrology Experiment. The science goals of the experiment include:

- Microbial ecology for the mesozone and thermozone: To examine variations in planktonic and sessile (rock colonizing) viral, microbial and eukaryotic communities as a function of groundwater age, depth, and chemical energy flux from the surrounding rock. EarthLab will be the first facility to permit scientists to compare planktonic to sessile subsurface microbial communities.
- Fluid, reactive chemical and microbial transport: To examine the extent of deep infiltration from the rhizozone (soil zone), and to test the hypothesis that changes in infiltration and flow paths, resulting from changes in topography and/or climate, are recorded in the isotopic and chemical signatures of groundwater and fracture-filling minerals, in the colloidal composition, and in the planktonic microbial community structure.
- Paleoclimate: To delineate Pleistocene climate changes for the continental interior and compare this history with marine records, and to compare and calibrate methods for measuring the groundwater age and recharge temperature.
- THMCB scaling with depth: To examine the effects of tidal forcing and confining stress on transport properties in a vertical fracture zone.

A tenet in geology is that "the present is the key to the past." This holds true for groundwater flow in deep rocks. EarthLab will use several approaches to study past groundwater flow. The experimental design elements of the paleohydrology experiment include:

- Identify a subvertical fracture that is hydraulically connected to the surface aquifer and is accessible at 1-2 km depth using a combination of subsurface structural mapping, preliminary groundwater dating from existing boreholes in candidate fractures, and surface geophysical surveys.
- Core the fracture zone at several depths ranging from ~100 m down to 2.4 km. Coring will use the positive pressure of the fracture water to eject the cores from their barrel, hence preserving any biofilms that exist on the fracture surfaces and avoiding contamination from drilling fluids.

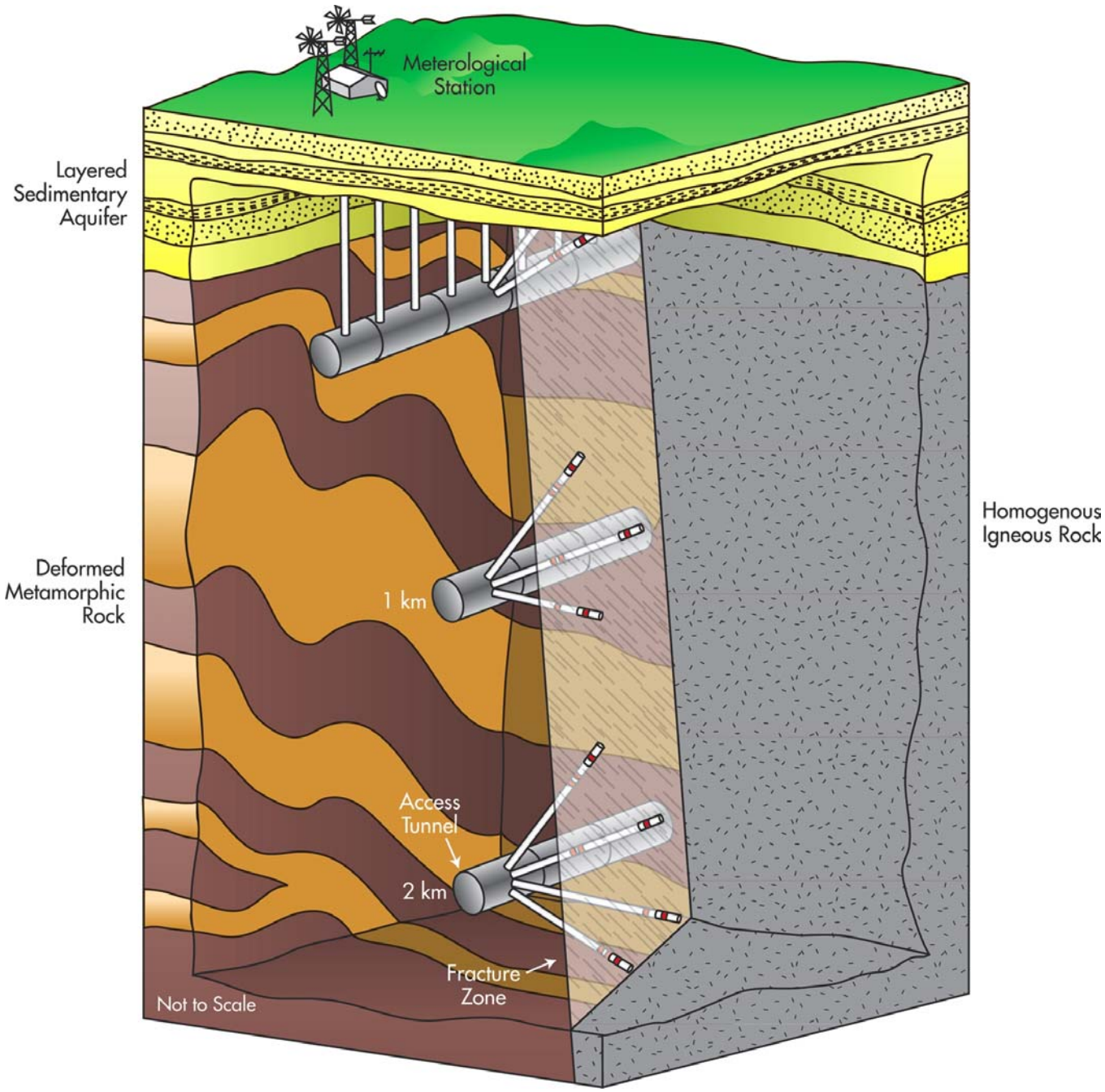


Figure C.16: The Deep Flow and Paleoclimate Laboratory and Observatory. Deeply penetrating crustal fractures are located typically along reactivated fault zones or steeply dipping contacts between two different rock types. Using surface geophysical surveys and subsurface mapping a deeply penetrating fracture zone will be identified. Surface and subsurface drilling will intersect the fracture zone at depths up to 2.4 km; cores of the fracture zone will be collected, cross borehole tomography will be used to image the fracture zone, and the fracture zone will be isolated using a compression packer equipped with gas/fluid samplers.

- Instrument the boreholes with transducers or tensiometers to quantify the pressure changes as a function of depth that may be related to tidal forces.
- Install permanent sampling ports for long-term water sample collection and analyses and for delineating any temporal variations.
- Determine if viral, microbial, eukaryotic community structure, and composition of dissolved and colloidal species correlate with ground water age, and whether they originated from the rhizosphere and have been transported to great depths.
- Measure noble gas concentrations and distributions of isotopes such as $\delta^{18}O$ and δD of formation fluids to provide quantitative details of flow paths, ages, and paleoclimate changes.

- Perform U-Th disequilibrium dating on any carbonate fracture-filling minerals that may provide a record of Pleistocene climate changes.
- Perform transition metal and isotopic analyses on carbonate minerals to document any changes in the groundwater redox state during these climate changes.
- Analyze the microbial community structure of the fracture surface biofilms compared to groundwater to determine if the sessile community represents adsorbed planktonic species or a community of species distinct from the planktonic species that have grown *in situ*.
- Perform noble gas, pore gas, and aqueous geochemical analyses of the rock adjacent to the fracture to determine when the fracture formed and the flux of formation fluid constituents from the rock matrix to the fracture fluid. This will yield estimates of crustal-scale gas flux into the rhizosphere and atmosphere, which can constrain CO_2 storage times in the crust.
- Perform U-He and fission track apatite analyses of fracture material and compare results to those determined for host formation. These data will be used to calibrate coupled thermal and fluid advection models.

C. The Coupled Processes Experiment. The science goals of the experiment include:
- THMCB coupling: Develop a fully coupled model of fluid flow, solute transport, microbial transport, activity and growth in fractured rock environments, referred to here as THMCB coupling. An ultimate scientific goal of EarthLab is to develop a high-resolution calibrated model capable of simulating subsurface, coupled biological, hydrologic, mechanical, thermal, and chemical processes.
- Gas/fluid interactions: Examine the effects of mixed gas/fluid migration along fractures on the transport of metals, organic compounds, and microbes.
- CO_2 sequestration: Determine the impact of microbial processes, fracture permeability, rock porosity, and water-mineral interactions on liquid CO_2 injection.
- Microbial remediation: Determine the effects of microbial oxidation or reduction on the chemical form and mobility of toxic metal and radionuclide analogs.
- Scaling with depth: Determine the effect of overburden pressure on fracture conductivity and microbial and chemical transport.
- Chemical heterogeneity effects on transport: Determine the effects of mineral and geochemical rock composition, ground water salinity, pH, inorganic composition, dissolved and colloidal organic composition and Eh on colloidal, dissolved organic and inorganic, viral, microbial, and eukaryotic transport.
- Microbial heterogeneity effects on transport: Determine the effects of eukaryotic predation of microbial communities on microbial transport and biogeochemical cycling. Using microorganisms of selected size or adhesive properties, examine microbial transport rates relative to conservative tracers.

The experimental design elements include:
- Install borehole arrays that intersect undisturbed fracture zones and span ~50 m vertical transport distance. These borehole arrays will be situated at depths of ~100-200, ~500, ~1500 and ~2400 m.

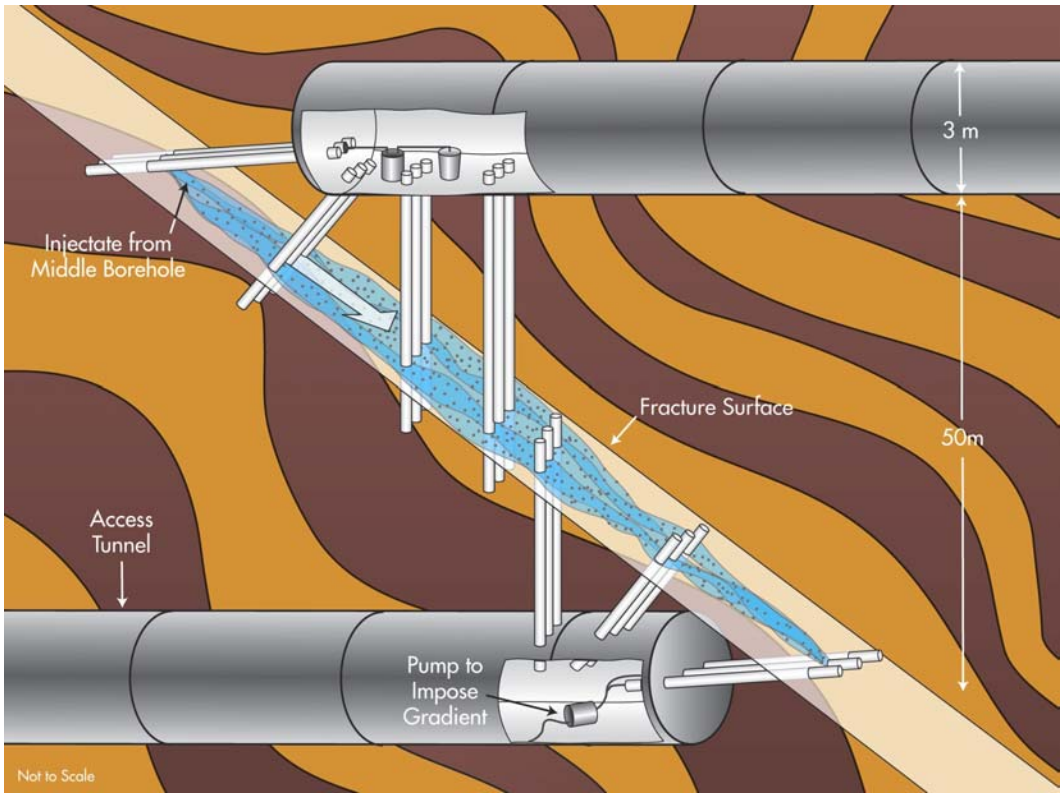


Figure C.17: The Deep Coupled Processes Laboratory. Four experimental arrays will be established at different depths and within the same rock formation. The rock formation will be of heterogeneous chemical and mineral composition. Subhorizontal fractures will be intersected by an array of approximately 20 boreholes. Cross-borehole geophysical tomography and multiple tracer tests will be used to characterize the hydrological structure of the fracture zone. Based on this analysis, injection and heating experiments will be modeled, and designs optimized. Liquid or particulate injections may occur at the top of the array, whereas gas injection (for example, CO_2) could occur at the bottom of the array to monitor leakage. Hydraulic gradients can be imposed on the fracture, as can various degrees of water saturation.

- Acquire cores of the fracture zones for characterization of the sessile microbial communities, surface mineralogy, and surface charge.
- Use pump tests, petrophysical analyses of the cores, geophysical tomography, and tracer tests to characterize the 3-D hydraulic structure of the fracture zones.
- Install multi-level samplers in the boreholes and run controlled experiments simultaneously with heating, nutrient stimulation, gas injection, or geochemical alteration experiments in forced or natural hydraulic gradient modes.
- Use static and dynamic self-potential measurements to monitor changes in ionic strength and fracture surface charge during the course of each experiment.
- Use geophysical tomography to image changes in the water/gas values during the course of experiments.
- Install removable multi-level samplers in some of the boreholes of each array to be used for insertion of solid substrates or model microbial communities. Alter the aqueous and gas chemistry of the fracture system by injection of isotopically tagged electron donors, acceptors, shuttles, and gas phases. Determine *in situ* transformation rates for these

substances from stable isotope analyses and microbial cells using compound-specific isotope approaches (CSIA), ion probe mass spectrometry (SIMS), radioisotopes (^{3}H, ^{14}C, and ^{35}S) and fluorescent in situ hybridization of the ^{16}S rRNA (FISH). Relate geochemical reactions to microbial community structure and growth rates.

- Insert isotopically spiked, artificial mineral substrate coupons into the fracture system, remove at specific time intervals, and analyze the microbial colonies by a combination of FISH, microautoradiography, and SIMS.
- Inject a variety of geophysical and geochemical detectors, such as micro-electromechanical systems (MEMS), into the borehole arrays in these experiments and connect them to data loggers to provide real-time analyses of chemical and microbial transport and conversion rates.

D. The Fracture Propagation Experiment. The science goals of the experiment include:

- Microbial life: To examine the microbial colonization of induced fracture surfaces, determine how these fresh minerals surfaces age, and evaluate how microbial community structure is affected by exposure of freshly fractured rock
- Rock deformation: To evaluate numerical models of fracture creation induced by excavation, hydraulic pressurization, or heating.
- Fluid flow and transport: To evaluate changes in the fluid transport network related to fracture creation.
- Geophysical imaging: To evaluate seismic imaging and microseismicity associated with fracture propagation.
- THMCB coupling: To integrate results from temperature, stress, and fluid pressure fields with geochemical and microbial changes.

Fractures are the keystone to many interacting geologic and life processes in rock masses. Three experiments are planned to create a process laboratory where the several scientific themes are all stakeholders. The experimental design elements include:

- Mine-by: This controlled, *in situ* fracture propagation experiment will be designed as part of EarthLab construction: borehole instrumentation and geophysical imaging of ancient fractures will follow initial drilling during tunnel advancement.
- Hydraulic fracturing: Boreholes at different orientations will be pressured to evaluate the influence of existing fractures and stress field on induced fracture propagation. Fracture propagation will be monitored by microseismicity followed by borehole logging and entire excavation of the study volume to correlate the geophysical results directly to changes in the rock mass. Geochemical, gas, and microbial samples will be collected from boreholes intersecting the induced fractures, which will be mined later and their surfaces analyzed.
- Thermal heating: Heaters will be placed in boreholes and sensors will be placed in the surround rock mass to monitor temperature, fluids, and fluid chemistry. As with hydraulic fracturing, geophysical imaging and geochemical and microbial sampling of the rock mass will be conducted.

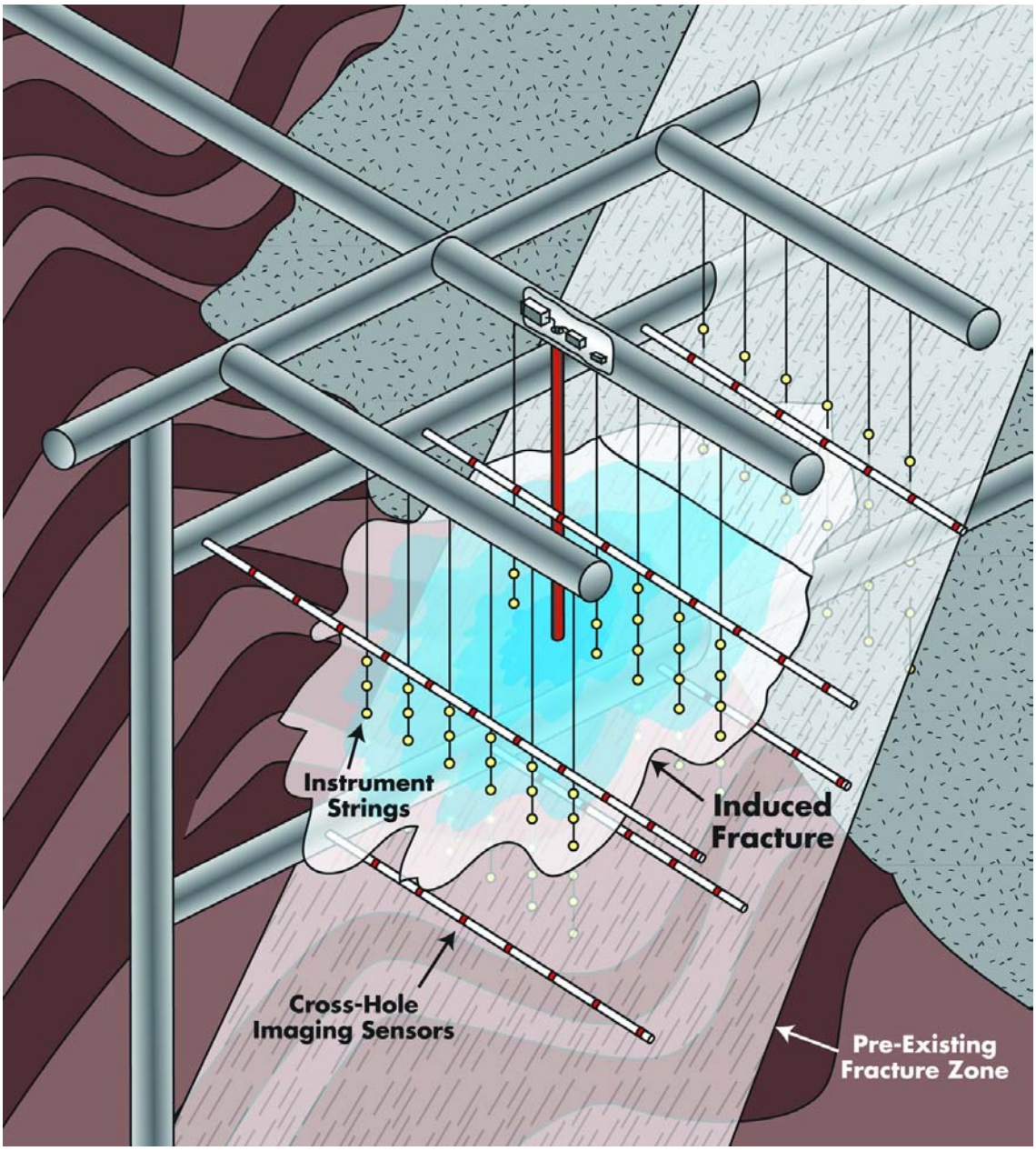


Figure C.18 The Induced Fracture Processes Laboratory. Facilities developed for this experiment will be located at three levels to take advantage of the different states of stress in EarthLab. Induced fractures are expected to be horizontal at shallow depths. A network of boreholes will contain pressure and displacement transducers, temperature sensors, flow meters, and fluid sampling ports for monitoring fracture propagation. Additional sets of boreholes will be created perpendicular to the first set and used for cross-borehole geophysical imaging. The instruments would be placed in the holes and then sealed with cement. Vertical sensor strings will intersect the induced fracture at points above and below, and will be connected by wires and tubing, and embedded in cement. An array of seismometers will also be used to monitor microsiesmicity accompanying fracture growth.

E. The Deep Recharge Experiment. The goal of this experiment is:

- To constrain hydrological models for deep recharge for fractured media by measuring biological aspects in tandem with direct hydrologic measurements (capillarity, seepage, etc.).

The experiment will use a horizontal tunnel approximately 100 m beneath the surface to:

- Record a dense, three-dimensional subsurface distribution of fluid pressures/flow rates, fluid chemistry (e.g., dissolved constituents, isotopic measurements, etc.), and temperature, among other variables.
- Map, in detail, three-dimensional subsurface geology including structure, mineralogy/lithology, facies/depositional environments, thermal conductivity, and permeability.
- Monitor migration of soil microorganisms and soil constituents in fractures for seasonal fluctuations.
- Monitor migration, diversity, and metabolic activity of microbial communities over extended time periods.
- Take low-level ^{14}C measurements to help discern organic carbon and bacterial cells that originated in the soil zone
- Use surface observatories (or mini-observatories, consisting of precipitation collectors, tensiometers, meteorological stations, etc.), assembled throughout the recharge areas, to monitor infiltration and climate.
- Compare isotopic "fingerprints" between potential recharge areas and fluids flowing into different parts of the mine to help delineate the recharge area distribution and associated different flow paths.
- Quantify surface water run off versus infiltration to elucidate the relative geologic controls on groundwater recharge. By controlling surface water (human-made and controlled precipitation) and measuring the recharge reaching subsurface monitoring sensors, the effects of rock types, topography, and other features can be isolated. Different tracers spatially distributed in the "controlled precipitation" at the surface can be used to further delineate specific effects, such as where precipitation is likely to percolate into the ground versus where it is likely to run off. Even in the dewatered portion of EarthLab, active infiltration experiments such as this may be used to evaluate with higher resolution the preferential flow effects in a fractured, unsaturated medium.

Other EarthLab Experiments

In addition to these five major experimental programs, many others opportunities exist at EarthLab:

F. Fundamental Experiments in Hydrology:
Groundwater Storage: A dense network of pressure transducers (saturated fluid pressure) and tensiometers (capillarity) will be installed throughout the 3-D expanse of EarthLab. The pumping regime used to dewater the mine will be deliberately modified and monitored and the response examined using the network of pressure transducers (saturated extents outside of EarthLab's tunnels and workrooms) and tensiometers (within the unsaturated portions of EarthLab). Storage properties throughout will be characterized. Three-dimensional characterization at this scale has never been possible before, and properties have been measured at local scales only. Wetting fronts and their behavior will also be characterized as a function of storage and other properties.

Well Test Verification Studies: The general approach to verifying the performance of well testing techniques will be to first describe in detail several regions in the vicinity of EarthLab tunnels and proposed borehole extensions. This effort will be initiated by identifying candidate regions using data obtained during tunnel and workroom development. Potential sites will be characterized by drilling arrays of borings, obtaining core samples from the borings, and conducting geophysical tests, hydraulic well tests, and tracer tests within the closely spaced array. Wells will be drilled from tunnel or room floors, or existing borings will be used. Tests will be conducted in those wells and investigators will be required to make initial interpretations without knowledge of the control data. The results of the well tests will be compared to the control data set, and we expect that the well testing techniques will then be refined and evaluated with additional work at EarthLab.

Rock Permeability and Scale-of-Evaluation: To develop a quantitative relationship between permeability and scale, high-resolution measurements of permeability, densely distributed in three dimensions and at different scales, is required. To quantify the factors controlling the scale-effects, an effective three-dimensional subsurface geological characterization including structure, mineralogy/lithology, facies/depositional environments, and porosity, among other properties, is needed. Thousands of core-scale measurements may be accomplished using mini-permeameters. Incrementally larger-scale measurements could be undertaken stepwise by designing and completing conventional flow and/or tracer tests between different parts of the mine, including between shafts, and including pump tests induced in surface wells and monitored within different parts of the mine at depth.

Contaminant Transport: Detailed studies of storage properties, leaching, and contaminant transport may be accomplished more effectively from in situ. Whatever site is chosen for EarthLab, new tunnels and rooms will be excavated at depth. One possible approach for basic studies of contaminated groundwater is to excavate tunnels on the outskirts of the lab that are currently saturated. The site would be backfilled with material of known hydrologic properties, permeated with controlled amounts of tracers in the form of benign dyes and solutes, and instrumented throughout with sensors. Re-flooding of the backfilled area can be done in such a way as to provide a controlled hydrodynamic regime. Such an experiment would require the sampling sensors to be placed at discrete intervals to monitor evolving concentrations of solutes and tracers. This type of experiment would permit detailed characterization of transport and storage similar to previous studies at contaminated sites, but this time with controlled, high-resolution calibration data. We do not know whether the time scale of such studies (years to decades) will be sufficient. Computer simulation models will be used to address this issue.

Heat Flow: To verify the coupling between groundwater and heat flow, temperature and pressure sensors will be installed throughout the vast three-dimensional volume of EarthLab. Long- term

monitoring of carefully designed flow experiments will lead to more effective exploration for water and resources, brought on by a better basic understanding of processes that control fluid flow.

G. Fundamental Experiments in Geophysics: EarthLab will be important in calibrating and verifying geophysical parameters and in testing geophysical techniques. Critical issues include improving the ability to image fracture formation and growth, fracture network formation, effect of geologic heterogeneity, effect of rock anisotropy, scale, and three-dimensional geometry. The potential to collect data from different techniques on the same mass of rock followed by excavation to reveal the actual geology is an exciting possibility.

On a larger scale, EarthLab will provide a platform for collecting geophysical data on a regional, or even global, scale through the acquisition of high-quality seismic and electrical data. The will be helpful in the interpretation of other regional data, such as those provided by seismic arrays and regional magnetic and gravity measurements.

Geophysics, however, ultimately is a tool to assist in the investigation of Earth processes, history, and geometry. Therefore, many of the advances will be made in concert with other experiments in EarthLab. Studies to find and delineate fractures for the geomicrobiologists and hydrologists will be facilitated by geophysics. Regional geologic investigations will be assisted by the geophysical instrumentation that takes advantage of subsurface access of EarthLab. In this regard, geophysics and geology are a system and efforts that take advantage of the synergism between these disciplines and EarthLab will benefit greatly.

H. Fundamental Experiments in Rock Mechanics and Deformation: EarthLab provides a special opportunity to conduct coordinated examinations of the chemistry, biology, hydraulics, and mechanics of a fractured geologic system, at spatial scales of meters to hundreds of meters, and at temporal scales of days to years. The facility offers important synergistic opportunities to (a) develop and validate new mechanical, hydraulic, tracer, and engineering geophysical methods aimed at characterizing mechanical and transport properties, and (b) develop and test new sensors and improved mathematical models to be applied to fractured rock masses, aquifers, and reservoirs.

Construction of a cavity with a clear span of 60 m at a depth of 1500-2100 m in jointed rock is unprecedented. The responses of the surrounding rock system will be both pronounced and highly interdependent. The opportunity to observe the coupling between transport parameters, mechanical stresses, and thermal stresses will truly be unique. Measurements and analyses of the responses are necessary for the safe construction and operation of the facility, and, given the anticipated scale of the responses, they inevitably will yield valuable fundamental insights to advance the state of the art of rock mechanics.

Active Experiments for TMCHB Processes: TMCHB experiments are designed specifically to investigate processes of transport, fluid-environment interaction, and methods of characterizing material properties and modeling process interactions. These experiments fall into two categories: (1) those that seek pristine conditions, remote from the main excavations, to examine transport and fluid-environment interaction processes and (2) those that examine the influence of an engineered structure on the hydraulic response.

Large block tests involve the hydraulic and mechanical (and TMCB) characterization of a relatively pristine block using mechanical, hydraulic, tracer, and geophysical methods. Sequential studies may involve the validation of hydraulic, tracer, or geophysical characterization methods themselves, and may involve short- or long-term environmental changes to the block itself (such as heater-tests, hydraulic fracturing, or forced fluid injection and heat recovery tests). Tests may terminate in a variety of ways, all of which would be instructive:

(a) post-test exhumations to confirm recovered structure; (b) mine-by and drift-structure tests to define the evolving hydraulic characteristics of the excavation-disturbed zone; or (c) as an extended experiment to observe the very-long-term evolution of transport parameters. The tests may be conducted at a variety of scales, involve characterization for single and multiphase flow, aqueous, particulate, thermal, and reactive transport. They also could be correlated with seismic, electrical, and electromagnetic methods of determining structure and correlating transport parameters.

Drift-structure tests examine the response of the rock mass to engineered structures, specifically the role of the drift in focusing or diffusing flow, as transport parameters are modified throughout the excavation-disturbed zone. Excavation of the drift (mine-by) within a pre-instrumented block allows changes in transport parameters to be monitored concurrently with mechanical deformations, giving key information regarding the evolution of the excavation-disturbed zone, and illuminating how hydro-mechanical processes are coupled. Following excavation associated with laboratory construction, instrumentation arrays installed within and adjacent to the laboratory excavation will be used to monitor the long-term passive response in the stable zone surrounding the detectors. The broad range of *in situ* stresses and temperatures present at EarthLab, together with the extended period of access, make it a unique location for extended-duration tests examining complex THMCB processes.

EarthLab and NUSEL-Homestake: Summary. One of the most remarkable aspects of the NUSEL-Homestake proposal is the quality of this site for both physics and earth science. Physics benefits greatly from Homestake's great depth, the integrity of its rock, the remarkable infrastructure, the existing access to the desired rock formations, the multiple access to important drifts, and the suitability of the site for megaexperiments and for experiments that are best conducted in isolation. The congruence between Homestake and EarthLab needs is just as remarkable. The site provides 3D access to a very large volume of complex, highly folded rock. The existing geologic data base is extensive, including not only all of the mining data bases, but an extensive academic literature due to years of study of this site. The rock is old, with a unique geothermal history that is responsible for the gold found there. Interesting extremophiles have been identified on the 8000 ft level. The prospect of probing extremophiles in pockets of water within the ancient rock below is exciting. The site meets all of the criteria for the Deep Seismic Observatory. The site is ideal for the proposed Hard Rock Mine Training and Research Center (discussed below). The interesting ecology arising from 125 years of human habitation of Homestake presents another class of possible studies.

Other benefits may come from the juxtaposition of earth science and physics: new ideas coming from the interactions of these communities. Physics has recently developed several precision instruments – new torsion balances, improved gravitometers, laser interferometers – that could potential impact earth science. Earth science experience with large cavern stability and other aspects of rock mechanics will be crucial to physics as experimenters tackle unprecedented underground construction projects. The daily interactions of these communities in NUSEL-Homestake/EarthLab could easily lead to important and unexpected new ideas.

III. Science Book: Applied Science and Engineering

This section deals with some of the applied science and engineering opportunities that NUSEL will provide. The discussion is representative rather than inclusive, as the collaboration has had several inquiries from industry that have not yet been followed up, given that the main focus of recent community workshops has been on basic science. A key contribution that NUSEL will make is in advancing the technology of very-low-level counting. This involves both the isolation of certain atoms or molecules from very large volumes and the subsequent counting (at nearly single-atom levels). This technology is crucial to many of the basic science goals of the previous two chapters. A second related issue is materials purity. A third is the development of ultrasensitive detector technologies, including those that can be deployed on large scales economically. All of these technologies have important applications in industry and to homeland security, including global monitoring efforts important to nonproliferation. In earth science the subsurface biology program has remarkable potential for the discovery and recovery of life forms that may have pharmaceutical or other applications. Because of its mining history, Homestake is an interesting site for studies of environmental monitoring and remediation. The underground construction that will be undertaken for NUSEL, including very large cavities that must remain stable for many decades, has relevance to the broader issue of the engineering and architectural challenges in designing underground living spaces. Finally, there is a specific proposal to use NUSEL as a national research center for innovations in deep mining.

NUSEL's low-level counting facility is envisioned as a centerpiece of basic and applied low-level counting efforts. In the original Bahcall Committee study of the need for NUSEL, such a facility was requested by more than 30 of the underground science collaborations that responded to the Committee's call for input. The proposed NUSEL-Homestake facility is described in this chapter.

Low Level Counting for Basic and Applied Science. In recent community workshops on searches for rare processes deep underground, it is apparent that radiopure materials and extremely low background rates are universal concerns. For example, some current experiments require bulk materials to be free of U and Th at levels of 10^{-16} g/g. This presents both a materials purity challenge and an assay problem, as even the measurement of a contaminant at such a low level is exceedingly difficult. In typical experiments extreme purity is imperative not only for the bulk target material, but also for the active detection media, the containment and segmentation materials, the detection and readout hardware, the structural support, and the shielding.

Current experiments that required extensive radioassay campaigns include SNO, Borexino, and KamLAND. In each experiment hundreds of samples had to be tested. The assay techniques included direct γ-ray counting with high-purity Ge detectors, specialized counting with neutron activation analysis (NAA) and advanced radiochemistry, radon emanation chambers and radon counters, and single-atom manipulation techniques in large volumes of water, scintillator, and gas. The purity criteria ranged from the 10^{-16} g/g requirement for U and Th mentioned above (for the central target volumes), to the ppt and ppb levels for the outer support, containment, and readout hardware. The respective experiments each developed many of their own specialized assay techniques.

These pioneering experiments, however, have established the need for common, multi-user systems. Such facilities have been introduced at Frejus and Gran Sasso: the Frejus laboratory has 15 dedicated Ge counting stations.

This trend is responding to the demands that next-generation experiments will make. The R&D efforts for solar neutrino experiments like CLEAN, HERON, and TPC and for large-mass double

beta and dark matter experiments like Majorana, EXO, XMASS, DRIFT, and MOON will require assays for hundreds of components. High-purity Ge counters are important in establishing tolerances for γ emission from outer containment materials and readout hardware. Given the extremely high radiopurity standards, whole-body counting capability is important: the capacity to count whole crystals, scintillator panels, and other assemblies will be essential for future experiments. For many materials (e.g., plastics in TPC, scintillators) NAA techniques must be used. Radon emanation limits are important in noncryogenic experiments. Many experiments employ large volumes of gas, cryogenic fluids, and water for shielding, introducing the need for advanced radiopurification and monitoring technologies. As experiments are often susceptible to surface contamination, the capability to measure αs and βs from surfaces of area ~ few m^2 at rates of ~ few/m^2/d must be developed. Clean-room facilities with dust and radon suppression will be critical in any next-generation underground laboratory.

Applied-science needs are also severely challenging existing technologies and facilities:

- The European underground laboratory HADES (located in Mol, Belgium at a depth of 225 m) is assaying a large number of human lung-tissue samples by means of low background counting. These were collected in uranium mining areas of Germany with the goal of correlating the activity content with cancer mortality. The same laboratory is involved in a second epidemiological study, assessing the exposure of the public to fast neutrons around the accident site at the Japanese Tokai-mura nuclear fuel processing plant. This was done by assaying neutron activation products in metal spoons collected from locations near the accident site. The assays were done with low background Ge detectors. Typical counting sensitivities required for these applications are of the order of mBq/kg or ppb for U/Th.
- Los Alamos National Laboratory has worked together with the semiconductor manufacturers to understand how radioactivity can influence the soft error probability in highly integrated circuits, an issue essential to both national defense and industry applications. The performance of microelectronic devices can be seriously impaired by ionizing radiation. A charged particle intruding near a p-n junction may cause a "single-event effect" (SEE) by generating excess electrons and holes, which are then separated by the electric field of the junction and swept to a nearby device contact. If the collected charge exceeds a critical threshold value, the memory state of the device is changed unintentionally. Malfunctions due to SEEs become an increasing concern as the packing density of computer chips grows. Thus understanding SEEs is essential for the design of microcomputer chips. It has recently been determined that one of the limiting factors in chip manufacture is the radiopurity of the substrate and other materials used in the fabrication. Very low levels of radioimpurities can cause spontaneous SEEs that render the circuits unreliable. It is clear that future progress in microelectronics requires the ability to radioassay materials at unprecedented levels of sensitivity. There is also interest in underground sites providing access to a range of depths, so that the cosmic ray contribution to the microelectronics error rates can be assessed. (IBM scientists have contacted the collaboration about doing such studies at Homestake.)
- There is an important example from national security, the need to determine whether a rogue nation is attempting to develop clandestinely nuclear weapons by testing low-yield nuclear devices deep underground. The global atmospheric monitoring program designed to deter such activity requires a deep underground laboratory and sophisticated low-level counting capabilities. This example is discussed in some detail in the national security section below.

These examples – both basic science needs and a range of important applications – illustrate why an ultra-low-level counting facility must be a centerpiece of NUSEL, to be built very early in the NUSEL program. For this reason this facility is included explicitly in the facilities development plan and in the budget. It is also important to recognize the intimate ties between NUSEL basic science and applied programs important to security and to the economy. A large fraction of the national security community currently involved in low-level counting work within, or were trained within, the rare-event (solar neutrino, double beta decay, dark matter) community. Such a facility will also impact many applied programs not discussed above. Examples include

ultrapure materials for commercial purposes, monitoring trace radioactive elements in the environment, and radioactive dating.

Limits of Current with Ge Detectors: Traditionally, low background gamma ray spectroscopy using Ge detectors has served as the primary tool for materials selection. Sensitivities down to a few hundred ppt of U and Th are routinely achieved using commercially available detectors. Such detection limits will suffice for the bulk of the technical construction components, even for the most demanding applications. (Ge detectors were employed in materials selection for SNO and Borexino.) High sample through-put requires multiple counting stations. More sophisticated Ge detectors can probe even the few ppt level. Ge detectors also serve as counters for neutron activation analysis, which has played an important role in many low background experiments.

Ge detector technology is quite mature and readily available commercially. The outstanding energy resolution gives these detectors high diagnostic power. This makes Ge an excellent choice for counting applications where radioisotope identification is important. The main limitation of these detectors is the comparatively poor detection efficiency (a few percent, depending on the gamma ray energy).

Even after careful material selection Ge detector background is typically a mixture of primordial and cosmic-ray-induced activation products in the metal parts of the device. It is quite probable that background levels could be reduced substantial by careful materials selection to minimize the primordial activity level, by designs that minimize metal content, by storing and machining cryostat parts underground to prevent the build-up of cosmogenic activities in the materials used, and by growing crystals underground. These developments would benefit from an underground machine shop, cleaning area, and materials storage area. Counting sensitivities somewhat below the ppt level for U/Th might result from such a Ge detector development program. Many of these ideas are being pursued by the Majorana collaboration, illustrating the importance of this basic science project to future applications of Ge detector technology.

Despite the maturity of the technology, there is no general US user facility for Ge detector counting. Lawrence Berkeley National Laboratory operates an underground counting lab inside the Oroville dam. This facility, now more than 15 years old, would be difficult to modernize and upgrade. Pacific Northwest National Laboratory has operated Ge detectors in various underground locations. Various university and national laboratory groups perform low background counting either above ground or at very shallow sites. In several of the surface facilities automatic sample changers are in use, allowing efficient assaying of a large number of samples. No dedicated counting site exists in the US that is accessible to the broader scientific community. There is no coordinated program among the smaller facilities that do operate.

The new generation of experiments will require material testing that is a factor of 100-1000 beyond the limits of existing Ge detectors. Candidates for a "next generation" counting facility include 1) a large liquid scintillation detector modeled on the Borexino collaboration's Counting Test Facility at Gran Sasso and 2) a large plastic scintillator detector shielded by a water tank. Such a facility would expedite R&D efforts on many next-generation experiments and serve a variety of applied needs.

The NUSEL Ultra-low-level Counting Facility: The low-level counting facility must offer a variety of state-of-the-art technologies in addition to developing new, ultrasensitive techniques. Basic facilities must include:

- low background Ge counters
- NAA and advanced radiochemistry
- large area surface counters
- radon air monitors and emanation systems

- single atom manipulation and extraction techniques
- dust and particle counters
- U and Th leach testing systems
- whole-body counting

The facility must have the capacity to accept on the order of hundreds of samples per year, judging from the response to the Bahcall Committee on low-level counting. Additional infrastructure requirements include clean rooms, chemistry labs, sample storage areas, Rn suppression systems, a clean nitrogen supply, and water and scintillator purification systems.

The facility should serve as a national center for trace analysis, available to a broad community of physical and biological scientists. The facility's staff scientists should be of excellent quality, with time to pursue individual research and development, and with ties to experimental programs hosted by NUSEL. The facility would maintain a database of measurements performed on different materials, simplifying materials selection by experiments and helping them avoid duplicate measurements. NUSEL-Homestake will have a materials storage area that could be used for frequently needed pure materials, especially those needing to be "cooled" before use.

Here we describe in more detail a few of the facilities listed above. The envisioned low-level counting would contain a range of different counters, allowing experiments to the right balance between sensitivity and speed and ease of measurement:

- *An array of four Ge detectors* could be set up rather quickly as a *"first stage" counting laboratory*. A counting system with sufficient sensitivity to detect activities ~ 1 mBq/kg (the equivalent of 80 ppt of ^{238}U or 250 ppt of ^{232}Th, assuming secular equilibrium) requires a large Ge detector equipped with a low activity cryostat, an inner sample box made of high purity Cu (about half a ton), and an outer shield made of low activity lead bricks (5-10 tons). The sample chamber would allow the assay of large samples, important to increase sensitivity. Environmental radon is typically displaced with boil-off nitrogen from the detector dewar. Once a high purity nitrogen gas supply is available at NUSEL, one could exploit its lower Rn content to further reduce backgrounds. Typical counting times for a 10-kg sample are ~ 2 weeks/sample. At the overburden planned for the facility (it will be located at 7400 ft) a cosmic ray veto system will not be needed. Read-out electronics are comparatively simple and commercially available. A high-voltage power supply, high quality amplifier, and a resident data acquisition card would suffice for most applications.

  Automatic sampler changers similar to those in existing surface facilities (see above) could be modified and deployed in such a low-background facility, helping to improve throughput. Low-background materials could be used in the sample changers and holders, and large separations maintained between samples. Another improvement would be the development of multiple Ge detector arrays, offering higher counting efficiency. This would be an uncomplicated step that would increase counting sensitivity.

- The laboratory would also serve as a center for *trace element analysis*. NAA offers (in its most sophisticated form) sensitivities of 10^{-16} g/g for U/Th in selected materials. As this technique also requires low-level counting, it would be a logical addition to the low-level counting facility. Samples irradiated at US research reactors could be shipped to NUSEL in ~ two days. NUSEL's low-background environment and high-resolution detector facilities would be helpful in the assay.

  To take full advantage of its counting facilities, NUSEL should provide a surface chemical processing laboratory where radiochemical separation can be performed to suppress source-related backgrounds. Even after post-irradiation processing, samples usually contain a mix of different radioisotopes. The Ge detectors used for NAA must have excellent energy resolution and peak-to-Compton ratio to suppress interfering side activities. These detectors should be distinct from those used in low-level counting, as the NAA samples present

contamination risks. In fact, it would be best to isolate these counters within a separate room in the low-level counting facility. As the NAA analysis is generally not count-rate limited, extreme counting sensitivity is unnecessary.

- *Advanced counting methods:* The next-generation experiments in solar neutrinos, dark matter, and double beta decay will need to reach radiopurity levels that are far below the screening capabilities of even the most sophisticated Ge counters. The requisite sensitivities for certain activities can be reached by "chemical" methods such as mass spectrometry and NAA. But these techniques do not check the total activity of a sample, including short-lived isotopes for which chemical methods are impractical. An advanced direct-counting screening technique with a counting sensitivity orders of magnitude beyond Ge detectors would thus be extremely useful – perhaps essential to several next-generation R&D efforts.

  Two ideas for an advanced screening facility have been discussed at recent meetings. Both are "full body" counting facilities using liquid scintillator. The first idea involves a large water tank, 12 m in diameter and 9 m deep, containing six counting modules. Each module is an acrylic sample box, with the box walls containing liquid scintillator. The box is submerged deep in the water shield, with a minimum thickness of 4m to the cavern walls. Light guides, which also serve as the structural support for the sample box, carry light to external PMTs. The sample volume is 0.5 m^2. This facility should provide a sensitivity of 1 pp t for U and Th within a plastic. This scheme is low cost, offers one to two orders of magnitude increase in sensitivity over current Ge counters, and offers a large volume for samples. The information provided is limited to the total count rate. The water tank could also serve a second purpose, a ready-made shield for up to three prototype experiments with 1 m^3 volume.

  A second possibility is a small-scale version of the Borexino experiment, quite similar to Borexino's Counting Test Facility (CTF). The sample is immersed in liquid scintillator (protected from the scintillator by a thin plastic layer, if necessary). The shielding material is quenched scintillator, separated from the active counting scintillator by a thin, nonstructural nylon vessel. An array of PMTs attached to a stainless steel sphere records any signals, and the entire structure (5-7.5 m in diameter) is surrounded by a water shield. Several cylindrical samples with a mass of several hundred kilograms could be measured for a month with negligible background, resulting in a sensitivity of 10^{-15} g/g for U and Th. This would improve the current state-of-the-art by three to four orders of magnitude. Advantages of this scheme are very high sensitivity, modest spectral information, ability to distinguish surface from bulk contamination, and discrimination between γs, βs, and αs. The drawback is higher cost.

Ultra-low-level counting: facility requirements: Some of the general facility requirements of a low-level counting facility include:

- The physical extent of the facility must be sufficient to house the suggested complement of detectors, allow for future expansion, and accommodate several user-operated experiments.
- The lab would be within a clean area. A class 1000 clean room would be a reasonable compromise between cleanliness and cost. The lab should provide a mobile "mini-clean room" (e.g., a tent on wheels equipped with HEPA filtration) which can be used to isolate the Ge detector stations when they are opened for sample changes. As its entrance the lab has to provide a changing area for the users and a cleaning station for samples.
- Room temperature and humidity should be well controlled (e.g., ± 1° C). Regulated stable power should be maintained through uninterruptable power supplies, and line filtering and shielding from radio frequency interference provided.
- A sample staging area of at least class 100 quality is needed to prepare samples for counting. The chemical laboratory will require fume hoods and other equipment necessary for safe use and disposal of acids and organic solvents. A high-purity water supply will be needed for

sample cleaning.

- A supply of pressurized Rn-free nitrogen gas is important for drying samples after cleaning. Initially boil-off N_2 from a large liquid nitrogen tank would suffice, but later this should be replaced by extremely pure Rn-free N_2. Other industrial cleaning technologies and liquid cleanliness measurement techniques would be employed.
- Laboratory ventilation must replenish the air at least every hour, assuring low ambient Rn levels and removing boil-off N_2. A Rn-scrubbing system might be helpful in relaxing requirements on the gas tightness of individual detectors and on the plating out of Rn daughters on samples during installation. The Rn levels in N_2 and air must be monitored with systems exploiting the preconcentration techniques developed for Borexino and SNO.
- An overhead crane must serve the detector stations, especially the large-volume "full-body" station.
- Underground machining and electroplating capabilities will help in minimizing materials exposures to cosmic rays and ambient radioactivities.
- Sensitive fire and smoke detectors and a fire distinguishing system will be needed, particularly if large quantities of flammables like liquid scintillator are used.

A consortium of scientists and institutions formed at the Lead conference to develop plans for a low background NUSEL-Homestake facility. Collectively the participants have the experience and breadth to design a world-leading facility. The collaboration has developed a rather specific plan for a ultra-low-level counting facility located on the 7400 ft level of Homestake:

- Hall A is focused on ultra-low-level gamma counting, with a CTF-like scintillator assay system, six liquid scintillator assay modules, and three ports providing shields for prototypes. These facilities would be able to process ~ 100 samples/y at the 10^{-12} g/g level, ~ 30 samples/y at the 10^{-13}–10^{-14} g/g level, and ~ 10 samples/y at the 10^{-15} g/g level.
- Hall B is focused on low-level α, β, and γ counting, with 10 high-purity Ge detectors, 10 α and β surface counting detectors, 10 radon counting systems, and a room with two 2m × 5m shields for prototypes. The goal is the capability to handle 300–400 samples per year.
- Hall C is dedicated to leaching, emanation, and sample preparation. It contains two leaching/emanation systems, a surface contamination laboratory, a general-purpose chemistry laboratory, a sample preparation laboratory serving Hall A, and a sample storage area. NUSEL's surface laboratory would house a NAA sample preparation area and a mass spectrometry laboratory.

The floor plan for this facility is shown in the figure. The required rooms have been included in the facility development plan and in the budget.

The low-level counting facility will be important to virtually every science activity described in this Science Book: the range spans basic physics research, national security issues, industrial applications, and the counting needs of earth science. The envisioned facility would be open, run as a user facility. Its professional staff would actively develop new low-level counting techniques and would catalog results and procedures. The facility and its staff would promote the dissemination of counting techniques developed for basic science into applied fields.

Detector Development and Homeland Security. A recent report issued by the Office of Science, Department of Energy, stressed that issues facing the underground basic science community – detecting very low levels of a contaminant, often in a large volume of material – are strikingly similar to problems facing the national security community. This has resulted in particularly strong connections between these two communities, which share people and R&D goals. Many of the detector advances being made underground are almost immediately applied to homeland security problems. Some of the counting problems facing national security scientists (Xe counting for nonproliferation is an excellent example) require deep underground counting laboratories – again promoting the mixing of these communities. Some of the examples below are taken from the DOE report, "The Role of the Nuclear Research Community in Combating Terrorism."

One key problem is the imaging of cargo. The magnitude of this problem is staggering. A large ship may unload at port many hundreds of cargo containers at a rate of roughly one/minute, making any inspection process involving opening and physically inspecting the cargo impossible. A similar problem is the monitoring of cars and trucks in a high traffic public venue. The key to distinguishing explosives or highly enriched uranium hidden in a large volume is sensitive elemental analysis. The most promising techniques for providing elemental analysis involve neutron or gamma probes. For example, pulsed fast neutron analysis uses a nanosecond-wide pulsed and collimated beam of monoenergetic neutrons. The neutrons interact with nuclei to produce γ-ray spectra that are highly characteristic of the elements in the target. By scanning the beam over a cargo container, rastering while the object is moving horizontally, a time-dependent γ-ray spectrum is produced that can be unfolded to create a three-dimensional map of the container. The spectrum can be referenced against a library of similar spectra, allowing quick identification of materials. Similarly, a broad-band photon source can be used as a probe. The resulting resonant absorption spectrum is characteristic of the bound-state spectrum of the nucleus being probed. Thus the elemental composition of the object can be deduced.

Each of these imaging technologies requires efficient, large volume detectors to record the γ-ray signal. Segmented Ge detectors – a technology now being developed for both nuclear spectroscopy and underground experiments like Majorana – combined with digital signal processing electronics and fast algorithms provides γ-ray tracking, which greatly improves the efficiency and resolving power of Ge detectors. This counting technology will have immediate impact on homeland defense problems.

One of the technologies being explored for large-volume imaging – the cargo container problem – is a direct outgrowth of neutrino physics experiments like KamLAND, LSND, and SNO. Both water Cerenkov detectors and liquid scintillator tanks viewed by large-diameter PMTs offer the possibility of imaging large areas quickly and with high sensitivity. The sensitivity is crucial because one of the materials of greatest concern, highly enriched uranium, has a low specific activity. One detector under development for large-area neutron detection is a virtual copy of LSND, modules filled with mineral oil and instrumented with PMTs to provide large solid-angle coverage. This would allow sensitive detection of neutron-emitting nuclear materials or devices hidden in vehicles attempting to cross a border, for example. This technology is special because very large area detectors can be fabricated relatively cheaply – the neutrino physics community has deployed kiloton-scale scintillation detectors. The PMTs developed for such experiments cost less than $1000 and can operated unattended for more than a decade.

A second crucial homeland security problem is the identification of trace contaminants in a very large volume – a signal that a threat may be present in the general area. Underground searches for rare processes such as double beta decay, dark matter interaction, and solar neutrino events have led to the development of the technologies important to solving this problem:

- few atom, high purity chemical separations,
- ultra-low-level gas counting systems constructed of materials nearly free of natural radioactive contaminants,
- almost zero-background Ge and scintillator detectors, and
- deep underground laboratory facilities where cosmic-ray backgrounds are reduced by orders of magnitude, allowing few-atom counting.

One example of the security applications of these techniques involves the challenge of **nonproliferation**. All nuclear explosions produce large quantities of fission products and their daughters. Important among these isotopes are ^{133}Xe and ^{135}Xe. The monitoring of radioactive noble gases is one of the techniques enumerated in the Comprehensive Test Ban Treaty (CTBT) for verifying appliance with the accord. The amount of radioactive xenon reaching the surface after an underground detonation is a function of the permeability of the rock, the depth of burial,

and the fission yield of the device, often complicating radiochemical monitoring efforts. On reaching the surface the Xe mixes in the atmosphere, diluting the concentration greatly, and continues to decay.

In principle the detection of ^{133}Xe ($\tau_{1/2}$ ~ 5.3 d) would suffice to confirm that a nuclear explosion has occurred. However, small but fluctuating amounts of ^{133}Xe are present in the air as a result of emissions from nuclear reactors. Consequently it is important to detect the ratio of ^{135}Xe ($\tau_{1/2}$ ~ 9.2 h) to ^{133}Xe in order to confirm that a nuclear detonation is the source of the signal.

The short half lives, the severe atmospheric dilution, and the comparatively long time that may be required to get an air sample make few-atom counting essential. Also, attempts to evade the CTBT, which bans all tests regardless of yields, may employ small devices, where the yield is tons rather than kilotons. These considerations led to the establishment of a very-low-background counting facility by the PIsCES (Precision Isotope Counting Experimental Setup) group of the US Naval Research Laboratory. The PIsCES group employs a technology that came directly from the solar neutrino program, miniaturized gas proportional counters of the type Davis perfected to measure the noble gas ^{37}Ar (and subsequently further developed by the SAGE and GALLEX groups). As PIsCES also requires a very low background environment in which to do counting, the equipment will be installed in an underground site in the US.

The PIsCES program combines R&D efforts to improve Xe counting with better sampling techniques, with the goal of lowering the yield threshold for the radiochemical detection of nuclear explosions by one to three orders of magnitude. Such an improvement over the current state-of-the-art would impose threshold limits for clandestine explosions that are so low that little useful information would be gained for improving a nuclear stockpile.

Sensitive radiochemical detection of nuclear explosions is particularly important when possible cheating scenarios are considered. The most commonly cited method of evasive testing is to detonate the device in a very large underground cavity. In theory, at least, the shock wave and seismic signal from the explosion can be reduced by a factor approaching 100. This would make a 1-kiloton explosion seem to seismographers to be only 10 tons, making identification very much more difficult. However the Xe yield is not reduced by the seismic decoupling. On the contrary, cavity decoupling acts to release additional radioactive gases in two ways. A fully coupled blast causes a collapse "chimney" to form, sealing in much of the radioactive debris, while a decoupled test is not self-sealing. In addition, the large surface area of the decoupling cavity produces more channels through which radioactive gases can reach the surface.

The concern that another country could improve its nuclear weapons by evasive testing, while the US adhered to treaty restrictions, played a role in the October, 1999, rejection of the CTBT by the Senate. An underground laboratory with much improved low-level counting capabilities would address this concern. This facility would help the US monitor testing programs in other nations. Location within the US is important politically, guaranteeing the laboratory's availability.

While Xe observations indicate nuclear testing, other signature radioisotopes obtained from air sampling may indicate nuclear terrorism or an incipient nuclear weapons effort. Present techniques rely on gamma counting of filters that have been used to process large air samples. The gamma counting is typically done using high efficiency hyperpure Ge detectors located in surface laboratories. The cosmic ray backgrounds at such surface facilities limit the sensitivity of the counting, so that large air samples must be processed, requiring large collection times. While this is satisfactory for many routine applications, there are specific needs for greater sensitivity. For example, in suspect countries where clandestine nuclear activities are suspected, pilots are placed at risk from hostile fire by long sampling times. An alternative is a low-level unmanned Predator aircraft that can quickly collect an air sample and return to base, with a high

probability of survival. If a small air sample suffices, this extends possibilities for monitoring clandestine nuclear activities to remote locations.

Small samples require ultra-low-level counting capabilities, extremely low backgrounds, and very long counting times to achieve the necessary sensitivity to few-atom samples. This is driving national security interest in the development of improved detectors and in the availability of deep, dedicated laboratories for measuring the levels, spatial dependence, and temporal variability of key isotopes. New technologies are being developed for the identification of a range of radioisotopes with extremely high sensitivity by observing the cascade of gammas emitted in their decay. One example is the MEGA 18-crystal high-purity Ge array being constructed by the NNSA at Pacific Northwest National Laboratory. Other efforts include the development of segmented high-purity Ge detectors and ultra-low-level α and β surface detectors with position sensitivity. Position is important in many applications, enhancing the ability to identify, collect, and further analyze chemically extremely small particles important in identifying the origin of suspected nuclear activities. Position information also allows one to distinguish bulk radiopurities from isolated surface contamination.

All of these examples underscore the importance of ultra-low-level counting and deep laboratory locations to national security, as well as the debt owed to basic science for many of the innovations that are advancing applied capabilities.

Technology and Applications from EarthLab Research. The earth science program at NUSEL also has great potential for developing new technologies and applications as a result of deep subsurface scientific and engineering studies. Outstanding opportunities include genetic materials, novel microorganisms, and biotechnology applications; analytic techniques for geomicrobiology and exobiology; natural resource recovery; drilling and excavation technology; novel uses of underground space; mine safety; subsurface imaging; and environmental remediation.

Subsurface biological resource exploration and development: Subsurface biological resources include new microorganisms with novel biological capabilities and microbial products with potential applications in pharmaceuticals (e.g., antimicrobial agents), feedstock chemicals (e.g., chiral synthesis), bioremediation of industrial waste, industrial processing, and nanotechnology. The exploration and development of this resource will provide opportunities for comparative genomics/proteomics and lead to new insights into the mechanisms of prokaryotic and eukaryotic development and new technologies designed to detect and quantify these processes. Some subsurface environments may offer greater biological potential than others do, but unlike oil exploration, subsurface biological exploration currently has no guiding scientific principles. EarthLab will lay the groundwork for subsurface biological resource exploration using the following approaches: (1) a high-throughput, micro-gel enrichment procedure for growing hard-to-grow subsurface isolates, (2) in situ enrichment and enzymatic assays, (3) analyses of the environment for enzyme-specific genes, and (4) screening of samples for proteins or extremozymes of potential value.

As EarthLab builds relationships between subterranean environments and the enzymes expressed by its microbial inhabitants, borehole geophysical tools normally used for hydrocarbon exploration will be modified to identify those environments with greatest biological resource yield.

CO_2 Sequestration: Modern society's energy needs produce a vast array of wastes, including tremendous amounts of CO_2, NO_x, SO_2, and Hg from coal- and/or gas-fired power plants, and long-lived fission products from nuclear power plants. Increasing levels of CO_2 in the atmosphere are often cited as the most likely cause of global warming. For many of these energy

waste products, deep geologic isolation is a potentially effective method of disposal, although many questions remain regarding specific methods and their relative effectiveness. Similarly, deep CO_2 sequestration is one suggested method for offsetting the release of this and other greenhouse gases to the atmosphere. EarthLab will be an ideal location for field testing such a strategy. One field experiment would seal and charge a tunnel with air tagged with a tracer to sufficient pressure to test the seals. Monitoring devices could then be placed in other areas within the same tunnel as well as nearby tunnels to detect the tracer. Pressure and temperature measurement within the sealed portion of the lab would mimic a field application. Inventory cycles could then be run and simulated to verify models.

Injection of CO_2 into deep saline reservoirs is another means of CO_2 sequestration. When an injection well is completed to depth, the CO_2 is pumped as a low-density liquid that will float on top of a brine. Disposal is relatively inexpensive and secure if subsurface properties of the area are well understood. But the rates of CO_2 leakage and conversion to bicarbonate and carbonate, and the impact on subsurface microbial ecosystems and the physical properties of the rock are unknown. Methods for measuring these processes in situ must be developed at a facility such as EarthLab, which permits the type of closely spaced, real-time observations that are needed.

Instrumentation for Monitoring and Mapping in Extreme Environments: Geochemical research in an underground laboratory would encourage development of field-deployable, long-term, remote-monitoring instruments using micro-electromechanical systems (MEMS). Instruments of this type are badly needed to provide information on geochemical processes at spatial and temporal scales that will permit us to understand active rock-water interaction from both and equilibrium and kinetic perspective. The greatest challenge for instrumentation of this type is to find ways to make measurements on a continuing basis without disturbing the chemical environment.

A second instrumentation frontier for research relates to underground mine mapping. As our exploitation of natural resources continues, we will find it necessary to mine deposits at greater depths, usually by underground methods. Data collection in these environments will require laser-based systems using data capture software, which need to be tested in the underground science laboratory. These systems must function under extreme physical conditions over a broad spectrum of geological environments, including above ground, underground, and airborne platforms. Relatively few universities currently provide training in mining geology and the on-site training once routinely provided by corporations for their technical staff is becoming a rarity. Justification for this approach lies in improving and expanding the technical workforce productivity through advancing the quality, efficiency, and uniformity in scientific and technical standards of mine mapping and related activities.

Some of the experimental work at EarthLab will focus the development and application of inexpensive and miniaturized sensors capable of widespread deployment and distribution, and capable of reporting reliably at high sampling rates and for long durations. What do these sensors measure? These signals will provide a wealth of data applicable to bioremediation, exploration and geologic engineering, and other applications. Thus, EarthLab can serve as a testbed for new sensor technologies in extreme environments.

Rock Engineering: Access to extreme depths in rock for long times provides an opportunity to improve rock engineering practice, such as the long-term (~ 100 y) support of rock masses. The long-term effectiveness of rock bolts, durable linings, and shotcrete currently are poorly defined. As a result, even though rockbolts and shotcrete are commonly used as initial support for underground excavations in rock, their potential contributions to the long-term strength of reinforced concrete linings are commonly neglected in design. It is important to understand the mechanisms that contribute to loss of support over time, such as corrosion of rock bolts and steel fibers in fiber-reinforced concrete, the loss of keying in a blast-damaged zone, and the potential

buildup of fluid overpressures as drainage conduits degrade over time. By testing a variety of support methods (e.g., bolts, anchors, cables, mesh and shotcrete) in a range of configurations in new tunnels and caverns adjacent to an underground facility, both their short-term and long-term effectiveness can be monitored. This research is another area of overlap with the physics community, which currently aspires to build deep underground cavities of unprecedented scale to house megadetectors capable of operating for decades. Thus the mechanical stability of caverns for periods ~ 50 years is of great importance.

The evaluation of subsurface coupled processes under long-term stress change, moisture removal, chemical/mineral redistribution, and thermal transfer can lead to more effective design and reliable assessment of long-term stability of underground structures. All experiments will be preceded by predictions using numerical models of coupled processes in fractured, lithogically heterogeneous rock at a range of spatial scales. Comparison between model predictions and outcomes of experiments will provide insight into our understanding of process-feedbacks of varying complexity, and the scale-dependence of behavior at scales not possible in the laboratory.

The Hard Rock Mining Training and Research Center. There is a specific proposal connected with NUSEL/EarthLab to create a Hard Rock Mining Training and Research Center. HRMTRC research activities include experiments in stoping and rock breaking, with the goal of enhancing safety and productivity; in mining geology, with the goal of maximizing ore recovery through improved digital mine mapping techniques; and in mine engineering, with the goal of optimizing production by improving stoping methods, robotics, and other mining technologies.

The motivation for the HRMTRC proposal is the recognition that open surface mining is reaching its economic limits with depth and increased stripping ratio. In response more open-pit mines are planning deep underground mines to extend mine life. The domestic hard rock mining work force is insufficient to meet this demand, as fewer schools are training geologists and engineers. Some of the universities that maintain programs no longer have the student counts to justify local training facilities. Thus the HRMTRC is envisioned as a national training and research center that would support the existing university programs, while serving as a national institute for practical research and development work.

The HRMTRC proposal specified the following facility requirements:

- locally available expertise and support facilities (provide through NUSEL and the SDSM&T)
- dedicated space priority, separated from physics experiments
- access to upper level (North) 7 and 9 ledges (1400-2300 ft levels)
- good accessibility: access by existing rail with locomotive and man cars
- 9 ft × 9 ft and 11ft × 11ft tunnel cross sections
- access from the Ross shaft
- good exposure of walls without much ground support
- power and ventilation

It appears that these requirements are fully compatible with other planned NUSEL activities. Some of the engineering problems of large-scale NUSEL excavations for physics will likely be of interest to the staff and students of HRMTRC.

IV. NUSEL Education and Outreach

A number of factors, already enumerated in the Overview, suggest that the NUSEL education and outreach program should have exceptional impact:

- South Dakota is an EPSCoR (Experimental Program to Stimulate Competitive Research) state, as are most of the states neighboring the Homestake site (North Dakota, Montana, Idaho, Wyoming, and Nebraska). The Lead, South Dakota, site of the Homestake Mine is a reasonable approximation to the geographic center of these six contiguous states. NUSEL will be able to work with the region's colleges and universities to grow and broaden their research programs.
- The area is a very popular tourist destination: each year approximately three million visitors are drawn to Mt. Rushmore and the lakes, parks, and historical sites of the Black Hills. Thus a science center could prove enormously popular, providing NUSEL with an opportunity to introduce visitors to themes ranging from the big bang to deep subsurface microbiology.
- NUSEL's science story is linked to the history and people of the area. The unique geology of the Black Hills – the hydrothermal activity, the retreat of the inland oceans, and the erosional scouring that followed domal uplift, exposing ancient rock – produced the usual topography that made this region sacred to the indigenous peoples of South Dakota. That same geology produced the Homestake gold deposit, the discovery of which shaped the history of this region and spurred the technological development of the American west. The mine South Dakotoans developed became the birthplace for neutrino astrophysics and, now, a laboratory that will probe both the origins of our cosmos and the limits of life in the deep subsurface. That is, there is a story to tell that naturally links the history and people of the region to the science of NUSEL. If properly told, it can help make science more accessible.
- The region has responded to geographical challenges and declining school-age populations by emphasizing distance learning and technology. This opens important opportunities for NUSEL to serve as a science magnet for the region, reaching out to K-12 teachers and students electronically and otherwise.
- Arguably Native American K-12 and tribal college students are the most scientifically underserved community in the US. Through programs like NAMSEL (Native American Mathematics and Science Educational Leadership) the NSF is working to address school culture and teacher leadership issues with the goal of promoting science education. Strong institutional networks, such as the South Dakota Space Grant Consortium, coupling research universities, industry, and the tribal colleges already function well. There is an opportunity for NUSEL to become an important partner in these efforts, one that can offer additional choices to the students of the region.
- NUSEL can enhance research opportunities for undergraduate and graduate students (and their faculty advisors) throughout the region. The possibilities include Research Experiences for Undergraduates programs, graduate student internships, summer schools, research collaborations anchored in regional universities, and joint NUSEL/university programs to recruit researchers/educators to the region. The potential is illustrated by the NUSEL-Homestake collaboration, where 16 South Dakota scientists have been active in developing this proposal, with several in leadership positions.

These ideas are developed more fully below.

NUSEL as a major-science focus for the Northern Great Plans states. The nation's economy and security are increasingly dependent on science and technology, and thus on the availability of technologically sophisticated employees. Mathematics, engineering, and science are among the more taxing disciplines in schools and colleges. Thus it is important to provide stimulating learning and research environments that will attract students to these difficult but important fields. One way to do this is by exposing students early to the aspects of these fields that raise the passions of professional scientists – the excitement and sense of discovery that accompanies research. To this end it is important to have cutting-edge research broadly represented in the nation's colleges and universities.

The National Science Foundation's EPSCoR program is one effort to promote strong research programs throughout the nation's colleges and universities. The EPSCoR states tend to be clustered, with the greatest geographic concentration being the contiguous states of the northern and middle Great Plains and the northern Rockies. In counterclockwise order, these are Oklahoma, Kansas, Nebraska, South Dakota, North Dakota, Montana, Wyoming, Idaho, and Nevada. In the middle of this region is the Homestake Gold Mine. Five of these states, North and South Dakota, Montana, Wyoming, and Nebraska – are within 120 miles of the mine. Several others (Idaho, Nevada, Kansas) are within approximately 500 miles. Noticeably absent from the Northern Great Plains is any major basic science research center. NUSEL could fill this vacuum, working with regional institutions to grow new research programs and to provide new learning opportunities for students of all ages.

The short history of the NUSEL-Homestake project illustrates the potential impact the Laboratory could have on South Dakota and neighboring states. We suspect it is no longer possible to find any student in the Lead area over the age of eight who is unaware of solar neutrinos. Similarly, our collaboration has had great success in engaging South Dakota scientists in NUSEL. The tone was set by Ken Lande, who initiated the NUSEL-Homestake proposal as Homestake began its downsizing in 1999. Lande gave lectures in all of the state's research universities, acquainting the faculty with underground science. Several South Dakota scientists have played major roles authoring this proposal, leading working groups, and advising NUSEL engineers on rock mechanics issues at Homestake. Many more participated in the Lead workshops, including faculty from teaching and tribal colleges.

This proposal makes a major commitment to education and outreach, focusing about 10% of the funding toward this purpose. In the proposed management plan Education and Outreach is an office at the Associate Director level. The efforts of that office will be collaborative: we would like to see state and regional colleges and universities take the lead in managing many of the outreach and education efforts, with the support and collaboration of NUSEL and its scientists. These responsibilities could be assigned, at the time the Management Plan is negotiated, through Memoranda of Understanding. Some South Dakota institutions already in place could shoulder these responsibilities, or could provide a model for new organizations willing to do so:

- The South Dakota Space Grant Consortium is led by the South Dakota School of Mines and Technology, South Dakota State University, Augustana College, and the US Geological Survey EROS Data Center. It includes among its educational affiliates South Dakota's research, teaching, and tribal colleges and universities, as well as several community Science Centers. It also includes affiliates from industry and government. This kind of broad, inclusive organization might be a model partner for NUSEL in developing and implementing many of the education and outreach programs discussed below.
- A broader regional body is needed to coordinate NUSEL research collaborations with colleges and universities in the Northern Great Plains. We envision an organization with the goals of Oak Ridge Associated Universities, for example – advancing more effectively science and education within regional institutions by partnering with the Laboratory. NUSEL science ranges over many scales and several disciplines, making broad involvement of regional universities natural. Much of the current R&D work on dark matter, solar neutrinos, and double beta decay is being carried out in university laboratories, often at a "tabletop" scale. SDSM&T is an example of a university with specific expertise crucial to NUSEL – mine engineering and rock mechanics. Thus we see ways that NUSEL and regional universities could both benefit by distributing research projects, building the underground science community at the same time states strengthen and enlarge their research efforts. The elements of an ORAU organization already exist because of the EPSCoR interactions among regional institutions. The Homestake Collaboration has contacted universities throughout the region about NUSEL-Homestake plans. We have asked several South Dakota collaborators – leading educators – to suggest how an ORAU-like organization

could be formed and operated.

An EPSCoR-associated ORAU-like organization could be effective in identifying large-scale efforts like new Centers that could be developed cooperatively with NUSEL. This organization could also promote participation in NUSEL activities by regional scientists.

Public outreach: the NUSEL Visitor Experience Center and museum/archive*:* Three million visitors come to the Black Hills annually, attracted by the outdoor recreation opportunities and the region's colorful gold mining and Native American history. This opens wonderful opportunities for interesting these visitors in science, particularly if the science is presented well and connected to the region's history and geology. As noted in the Overview, professionals believe that an attractive NUSEL visitor center would draw 400,000 visitors each year, making the NUSEL visitor center program far larger than that of any other pure-science research site.

The importance of the region's unique geology to South Dakota's cultural history, to the creation of the Homestake Gold Mine, and to the science that NUSEL will place there makes an excellent unifying theme. The Black Hills are a peep hole through the sedimentary rock that covers most of the rest of the Great Plains, into the ancient geologic past. The domal uplifts that exposed this island of Precambrian rock, 1.9-2.5 billion years old, occurred 530 and 65 million years ago, the last after the great inland sea retreated. The accompanying erosion scoured off 5000 feet of soft rock, exposing the dome. The extraordinary mineralization that formed the Homestake gold deposit occurred beneath the ancient seas because of submarine hot springs activity.

The five-year vision for the NUSEL Visitor Experience Center provides for the initial development of on-site and off-site activities that include science, mining, history, and cultural education. The Center will be part of the distance education efforts of the NUSEL Education and Outreach Office, with Internet-based activities an early priority. On-site experiences will include an underground tour (but at very shallow depths); a series of science exhibits beginning with ancient geology and ending with NUSEL explorations of neutrino physics, cosmology, and deep life forms; a gallery; a 3D "cave" on large scale structure formation and supernovae explosions, exploiting scientific simulation tools now under development at Los Alamos using LANL's Q machine; a planetarium that will also serve as an auditorium and theater; and visitor amenities (restaurant, gift shop, services).

The proposed research at NUSEL spans many disciplines (e.g., physics, astronomy, geology, biology, microbiology, chemistry). The Experience Center will stress the connections between these fields, as well as the connections between the Homestake site and the cultural and geologic history of the region.

To insure a best-in-class facility and on-line experiences, a thorough review of respected government and non-profit science visitor centers will be done prior to undertaking a detailed development plan. Outside experts will be enlisted to help formulate and critique Experience Center plans. A start was made at the Lead workshop (and will be continued at the TAUP2003 outreach workshop), resulting in the following recommendations:

- The visitor center must be welcoming, attractive, safe, and secure. Security and safety procedures should be integrated into the visitor experience, and not perceived as a burden. Transportation and parking must be efficient and convenient, and access must be designed in accordance with the latest ADA standards.
- There must be extensive community involvement in planning the site and its program because of the substantial impact on Lead and neighboring towns. Issues include access, traffic, and services. The partners in this enterprise include nearby Black Hills cities (e.g., Spearfish, Rapid City), the Lakota (Native Americans indigenous to the Black Hills and surrounding areas), and state tourism officials. The management must work with local, state, and regional citizens, representatives from the tourism industry, and government agencies to

ensure that the visitor experience is properly engineered.

- Scientists and other NUSEL staff should be involved with the visitor program and with the online sites. This includes program design (e.g., speaker bureau, classroom visits, chat rooms, dignitary tours) and facilities (e.g., common cafeteria).
- The facility must reflect the internationalism of the site and the researchers. Displays should touch on underground science in other international laboratories, and online and other exhibits should include translation options.
- A modern digital planetarium and large-format film projection technology increases both the attendance and revenue to sites. The planetarium provides a visually powerful introduction to NUSEL themes like cosmology, dark matter, and nucleosynthesis, and can relate these themes to Native American star knowledge and other culture important to the Black Hills. The theater will attract visitors who may not otherwise stop at a science center. Suitable large-format films already exist (e.g., Cosmic Voyage, Solar Max, and Journey into Amazing Caves). The planetarium and theater will provide a respite from traveling and walking and will increase time visitors spend at the Experience Center.
- Cutting-edge visualization tools coupled with the power of massively parallel computers have been used very recently to construct 3D "caves," allowing visitors to walk through large-scale-structure maps of our universe and to experience a core-collapse supernova. (The Los Alamos displays required 4.3 million processor hours!) This technology should soon be available in the open: the collaboration's Los Alamos members hope to bring it to NUSEL. The effects are spectacular. Such an exhibit will provide an entree into discussions of massively parallel computing and visualization, in addition to the science.
- Visual and performing arts provide opportunities for communicating to a larger audience the excitement of science and its connections to culture and nature. The visitor center should include a gallery for permanent (e.g., a large sculpture or mural) or temporary art exhibits. This would be of importance to NUSEL staff, as well.
- The facility design should reflect the regional environment and history, particularly the mining history and the cultural and artistic history of the indigenous Lakota people, which reaches back centuries before European settlement.
- Expanding the outreach program to include mobile displays (NUSEL-on-wheels) will extend the number of students and citizens served directly. This could be an important part of the K-12 education efforts discussed below, allowing important follow-up. Many science centers double their reach in this way. The portable displays could be set up in a school gym or community center, for use with in-class instruction or in teacher workshops.
- There should be a closed-loop communication process with visitors to both the on-site and Internet-based parts of the experience center, to solicit suggestions, measure satisfaction, and identify needed improvements. Actions taken in response should be communicated back to visitors in a public way.

NUSEL Visitor Experience Center and technology: An important goal of the Experience Center is the thoughtful integration of Internet-based technology into the exhibits, and the virtual extension of the Center by using Internet tools to reach off-site visitors. This extension of the Experience Center should be engineered as an essential component of K-12 and other educational outreach, as well. The virtual parts of the Experience Center should include standard offerings, such as science discussions appropriate to various ages and virtual tours. But in addition, science links and archives, lab research results, and online readouts for operating experiments should be included, to enable some of the K-graduate research opportunities discussed below.

The Experience Center will take advantage of the Dakota Digital Network, a high-speed data and videoconferencing network that interconnects all South Dakota public schools. Access to fiber-optic cable exists in many nearby towns, so that interested citizens can connect to hear popular or technical science presentations. These networks are an important link to state and regional colleges and universities.

NUSEL Visitor Experience Center and exhibits: Exhibits that optimize the educational and entertainment opportunities associated with NUSEL science, geology and mining, history, and regional culture will be central to the Experience Center. Their design, creation, and subsequent evolution will require cooperation between experts in design and display, in crowd management, in education, and in science. There will be a focus on reaching students and others that may visit as a group. Facilities like the Lawrence Hall of Science and the Adler Planetarium provide interesting examples.

The interdisciplinary nature of NUSEL science argues for displays that tell a broad, connected story, e.g., the ancient geology of the Black Hills, how that geology influenced the Native American and mining history of the region, and how that mining opened a window on new sciences such as neutrinos and deep subsurface life. The ongoing research program should be illustrated through discussion of the universe's macrophenomena (the big bang, large-scale structure, and supernovae) and microphenomena (neutrinos, dark matter particles, proton decay).

A significant number of displays will be interactive and layered, so that visitors captured by a given topic can look deeper into the science. The 3D "cave" and other visually impressive displays will provide variety and visual stimulation.

The online virtual Experience Center will mirror the physical site to the extent possible, while also providing an archive of past displays and announcements of coming attractions. Associated links will allow students to do research much more deeply into NUSEL research.

NUSEL Visitor Experience Center and site tours: In addition to the Experience Center offerings, we intend to offer a shallow underground walking tour that would illustrate the unique geology of the site, the techniques of mine engineering, and the advantages and challenges of doing science underground. Possibly the tour could be arranged so that the terminus is the open cut, an imposing open-pit mine, excavated at the point where the gold veins reached the surface.

Deeper tours to the underground laboratory will most likely have to be restricted, due to insurance and other considerations. These will require a dedicated guide, appropriate dress, and an orientation.

NUSEL Visitor Experience Center and the museum/archive: There have been discussions between the past and present mine owners (Homestake Corporation and Barrick Gold) and the collaboration about establishing a museum/archive, the operations of which might be supported through revenue provided by the mine's hydroelectric facility. Homestake for many decades was the most sophisticated mine in the US. It is steeped in history and invention. In addition there are libraries of geologic maps that will be of value to the NUSEL earth science community, and should be preserved and archived. There are employment records dating back 125 years that are a significant genealogical resource: many miners immigrated to the US to work at Homestake.

The mine's foundry building is architecturally interesting and could be converted into a museum/archive. We envision half of this building as a geology and mine engineering museum, featuring many of the inventions that came from this mine. It will also tell the history of Homestake Mine, beginning with Custer and the gold rush and continuing to NUSEL. This would be open to the public. The archive would contain the maps and records deemed to be important historically. It would also be open, but access would be controlled – much like the reserve section of a library.

The museum/archive will be funded outside of this grant request.

NUSEL Visitor Experience Center and partnerships: The Experience Center will cooperate with

Lead and other nearby communities. Its activities will be integrated with those of the K-graduate education and outreach efforts described below, with regional parks (such as Mt. Rushmore) and museums (e.g., nearby mining museums), with National Laboratories, and with international underground laboratories (Gran Sasso, Super-Kamiokande).

The workshop on underground science and outreach being planned for TAUP2003 was suggested by Gran Sasso, which wanted an international forum for discussing outreach plans of underground laboratories.

NUSEL Visitor Experience Center and the visitor profile: It is expected that the majority of visitors to the Experience Center will be tourists already visiting Mt. Rushmore or other Black Hills destinations. At least half of them will be families with children. Only a small percentage (~ 5%) are likely to make NUSEL their main destination.

Most visitors will arrive during the 100-day summer season and have limited time for visiting the Experience Center. As vacation itineraries are often crowded, the Experience Center should be advertised, so that vacationers will plan a stop as part of their general vacation preparations. This means coordination with the South Dakota tourism industry will be helpful. Because more than half of all vacationers now use the Internet to make plans, the Experience Center will need to have an effective on-line presence that is well integrated with the websites already serving South Dakota tourists.

The Experience Center will also work to attract nontraditional visitors. These include the year-around flux of gamers through the neighboring town of Deadwood and the ~ 500,000 motorcycle enthusiasts that attend the annual Sturgis Bike Rally. The Homestake Mine connects well with the old-west theme of Deadwood.

Strong emphasis will be placed on K-12 and other student groups, who will visit the Experience Center as part of the outreach programs described below. School group visits dominate many of the nation's leading science centers. Given that the school year and peak tourist season are largely non-overlapping, this provides a mechanism for "load leveling." A special emphasis will be placed on partnering with South Dakota tribal colleges and reservation schools to ensure that their students have an opportunity to visit NUSEL. Additional partnering opportunities include the Space Grant and EPSCoR organizations.

NUSEL Visitor Experience Center and regional tourism: Tourism is South Dakota's second largest industry. More than half of all state tourism dollars are spent in the Black Hills/Badlands/Lake region to which Homestake belongs. Tourism is increasing. Mt. Rushmore is the leading attraction, accounting for 2.5M visitors annually. Twenty-five other major attractions exist within 60 miles of NUSEL. These statistics indicate some of the potential of the Experience Center, if it is designed, operated, and advertised properly.

NUSEL Science Education. The following describes NUSEL efforts, through its Office for Outreach and Education, to enhance the educational experience and level of science interest among students K-graduate, as well as Laboratory obligations to postdocs and young faculty.

NUSEL science education policy and K-12 education: The Lead workshop on outreach and education, held late in 2001, brought national and regional educators together to formulate a strategy for NUSEL efforts at the K-12 level. The advice provided to the collaboration included:

- Target teacher education for greatest impact. Several K-12 outreach programs have succeeded by focusing on teacher motivation and training, rather than direct interactions with students.
- Build on other successful science education programs and resources.
- Maintain a rigorous assessment program involving outside experts.

- Exploit the breadth and interdisciplinary nature of underground science to reach a broader community. Physics, earth science, astronomy, ecology, and microbiology are among the relevant disciplines.
- Focus significant resources on under-represented groups, especially the large regional Native American population. Recruitment and retention of Native American teachers and students should be a priority. NUSEL should work collaboratively with reservation schools and the tribal colleges toward this end. The NUSEL Visitor Center should prominently describe the significance of the Black Hills to the Lakota Sioux and other Native American cultures.

One mechanism for engaging teachers is a Laboratory program of workshops for teachers, focused on strengthening teacher understanding of science (thereby building confidence) and improving curricula in their classrooms. Ideally this would be done in collaboration with the South Dakota Board of Regents so that teachers could earn continuing education credit and certificate renewal from attendance. Motivated teachers should be able to progress through a series of such workshop to master teacher status, at which point they would be encouraged, on returning to their school districts, to help in the training of other teachers. The NUSEL Education and Outreach Office would not only organize the workshops, but also follow up through newsletters, annual meetings, and distance education to keep connections with classroom teachers alive.

There are interesting opportunities to marry such a program with existing South Dakota efforts. For example, the Black Hills State University's Center for the Advancement of Mathematics and Science Education has as one of its main missions the preparation of science curriculum kits, in support of K-12 science teachers. (CAMSE is a South Dakota Board of Regents center of excellence.) Their distribution currently reaches about 300 teachers in western South Dakota. This program could be adapted to the workshops so that the teachers, on returning to the classroom, would have both new training and new materials.

The Lead workshop urged that additional opportunities be available to highly motivated teachers with interest and aptitude for research. One suggestion was an 8-week summer internship for teachers wanting to participate in research. The internships would resemble standard REU programs, with each teacher paired with a NUSEL researcher/mentor.

The primary direct interactions with K-12 students would be through the Visitor Experience Center and through distance education. Institutions like the Lawrence Hall of Science conduct day-visit science programs that reach tens of thousands of students annually. Despite the disadvantage of its rural setting, the envisioned Experience Center would provide a spectacular experience for any students within reasonable busing distance of Lead. Such visits could be coupled to the teacher workshops – once a teacher has completed a summer workshop, for example, he/she could be encouraged to return with his/her students. An attractive chronology might be a teacher workshop, followed by student instruction with a CAMSE-assisted curriculum, followed by a classroom trip to the Experience Center. This would build anticipation among the students and focus attention properly on the teacher.

As mentioned in the Overview, South Dakota and other states in this region are facing unusual problems due to declining student population densities. The contraction of school districts makes it more difficult to maintain a critical mass of science teachers, for example. South Dakota has responded to this challenge by creating one of the most "wired" K-12 educational systems in the nation. All South Dakota schools are networked and have PicTel, Vtel, DDL, and other distance learning technologies. The state has made a substantial investment in training K-12 teachers and university faculty in the use of such tools. NUSEL hopes to build on this by creating interactive web sites for science students and by encouraging advanced students to join distance education programs. The content could include NUSEL materials connected with the teacher workshops, interactive science activities, and downloadable classroom materials. One proposal that has been

implemented elsewhere is online access to experimental data, coupled with programs to enable real-time observations, data analysis, and hypothesis testing. Participation in experiments online could be one other form of follow-up to the teacher-focused activities described above.

Finally, to encourage exceptional achievement, the Lead workshop supported the creation of one-week student residential workshops at the NUSEL campus. While this suggestion presents some challenges (such as proper supervision of the students), the benefits may outweigh the organizational difficulties. As we stressed in the version #1 proposal, NUSEL will encourage its scientists and scientific visitors to be active in the community by visiting school rooms, participating in science fairs as mentors and judges, etc. One could envision the student residential workshops as a reward for high placement in a high school science fair or science Olympiad.

NUSEL and undergraduate students: The Visitor Experience Center will be available as a science focus for regional college undergraduates, as well. In addition, NUSEL will sponsor a Research Experiences for Undergraduates program, available to any US undergraduate, but with a special emphasis on Native American and other regional undergraduates. The NSF REU program is widely known and regarded as highly successful, and NUSEL's program would follow national models. It would be a residence summer program of about 10 weeks in length, with national advertising, one or more directors, pairing of the selected students with mentors from NUSEL or long-term visiting faculty, and a weekly program of faculty talks on underground science. The students will do guided research, writing up their results at the end of the summer and presenting a short seminar. Regional participants in the REU program might be able to continue their involvement during the academic year through occasional visits and the Internet, particularly if a second mentor from the student's university were available to provide additional support.

NUSEL may be able to enhance the academic-year experiences of regional undergraduates as well. Colleges from the EPSCoR states near Homestake as well as from regional nonEPSCoR states (Colorado, Iowa, Minnesota) will be invited to participate in Undergraduate Research Opportunity (UROP) semester programs. These could involve classes in NUSEL partner universities, possibly SDSM&T and Black Hills State, as well as research at NUSEL. Several undergraduate institutions in the region already participate in UROP arrangements with Oak Ridge, Los Alamos, and other national laboratories.

NUSEL and faculty and undergraduates from the tribal colleges: NASA has a very successful outreach program that places science in the context of Native American culture, which embraces a view of the individual as a small but important part of a much greater cosmos. South Dakota tribal colleges have also been successful in this endeavor. For example, Sinte Gleska University (with about 1000 students) and Oglala Lakota College are known for their computer science, pre-engineering, and environmental science curricula. Sinte Gleska is a leader in regional efforts to reform science education, a partner with the National Science Foundation and SDSM&T in NAMSEL, the Native American Mathematics and Science Educational Leadership. This program seeks to develop leadership capacity in teachers, addresses the needs of Native American students, and promotes school cultures that support systemic change. Sinte Gleska and Oglala are partners in an NSF Model Institutes for Excellence (MIE) grant, which supports the science curriculum developments mentioned above, as well as distance education efforts involving three other tribal colleges (Si Tanka College on the Cheyenne River Reservation, Sitting Bull College on the Standing Rock Reservation, and Sisseton Wahpeton Community College in northeastern South Dakota). Together these five institutions comprise the Oyate Consortium. Currently 94% of OLC and 85% of SGU graduates are employed or are seeking advanced degrees; in comparison, reservation unemployment rates frequently reach 80-85%. The goal of the MIE initiative is to integrate traditional tribal values into new programs of study for Native American students. It includes new programs in environmental science, information

technology, computer science, pre-engineering, and life science.

As some of these programs are designed to prepare students for more advanced studies at other institutions, NUSEL-based relationships could help advance certain MIE goals. More generally, NUSEL will be located in a center for progressive Native American education. There is interest in the opportunities NUSEL may offer: two tribal college faculty members took part in the Lead workshop on outreach and education. The tribal colleges will be a focus of NUSEL distance education and the NUSEL REU program.

NUSEL and graduate students: Graduate students will be a vital part of NUSEL, with 20-30 expected to be in residence as employees or as visitors associated with a university project. The NUSEL Education and Outreach Office will be concerned with the needs of these students. Simple measures include proper student representation on site: graduate student organizations provide important support, such as student-oriented lectures, mailing lists, representation in laboratory committees, and social and recreational activities. Generally student organizations are self-run and operate with small budgets.

Quality-of-life issues include housing, transportation, education, and social activities. NUSEL and the city of Lead need to address these issues as part of the general planning process. Health care is an important issue for NUSEL, as graduate students often do not have a plan that is adequate for off-campus health care. In some cases off-campus copayments are prohibitive. NUSEL's human resources office ought to plan for these contingencies as it arranges Laboratory health care insurance policies.

NUSEL must plan for graduate student office and computer needs, including those of students from regional universities that may make many short-term visits to NUSEL. If such students lack assigned space, laboratory efforts to build strong collaborations with regional universities may suffer.

In our view NUSEL should assign to the Education and Outreach Office all responsibility for student welfare. This office then can then seek needed help on issues like health care from other appropriate offices.

NUSEL post-graduate and young faculty programs: NUSEL will employ postdocs and young faculty, and will host many young researchers from the user community. These young scientists will need significant laboratory support, including offices, computing support, access to libraries, information on housing, assistance with visas, and orientation services. Nonemployees should have a formal Visiting Scientist status that guarantees that all such needs will be efficiently and routinely addressed.

Several laboratory-regional university partnerships involve young faculty plans in which tenure-track university positions are created for promising researchers, partially funded by the laboratory. The faculty member, in return, receives release time that allows him/her to support laboratory research programs. Existing programs, such as those at Jefferson Laboratory and RHIC, are not universally regarded as successes. NUSEL has an opportunity to improve on such programs. Two NUSEL responsibilities – growing the US underground science community and partnering with regional universities to strengthen research in the Northern Great Plains – seem compatible with a wisely structured junior faculty program of this type.

NUSEL and Rock Mining Training. The Hard Rock Mining Training and Research Center was described earlier in connection with research. It will also have an important educational mission. The motivation for the HRMTRC is the need for a centralized national training and research center for geologists and engineers interested in deep underground mines. Many US schools of mining have contracted to the point that local training mines are no longer

economically feasible. HRMTRC is envisioned as a national center run cooperatively by the nation's mining schools. It would exploit Homestake as a training center and the SDSM&T as a local, supporting school of mining. Students of mining would spend periods of residence at the Center, learning modern mining techniques and attending classes, for which the students would receive credit at their home institutions. The research component of the Center will help guarantee that the students are exposed to the most modern equipment and ideas in mining. Geologists from Berkeley, the Colorado School of Mines, New Mexico Institute of Technology, and the South Dakota School of Mining and Technology are collaborating on the HRMTRC proposal.

D. SCIENCE TIMELINE

The NUSEL proposal under discussion here is tied in detail to the science projects that the broad science community will approve through existing mechanisms, such as SAGENAP. While one cannot predict precisely either the R&D progress of developing experiments or future funding decisions, the Science Book nevertheless provides a useful guide to the number and variety of experiments NUSEL may be asked to accommodate. We summarize this information in the timeline given below. The Reference Design, in consideration of this timeline, then answers the following engineering questions:

- Given the science needs, what are the appropriate parameters and design goals for NUSEL-Homestake?
- How does one meet those goals while minimizing costs and construction risks?
- How does one ensure safety?
- What can be done to preserve future options for mounting next-generation experiments, especially as future project needs – such as size and safety requirements – cannot be fully anticipated now?
- What are the major uncertainties or options in the reference design, and what is the plan for reaching decisions on the way to the baseline definition?

Science Timeline: Physics. Here we summarize the conclusions we have drawn from the Science Book:

Experiments mounted at the start of construction: There are several physics experiments and R&D efforts that would like space, even on a temporary basis, at the earliest possible time. Examples include the development of Ge detectors for national security (MEGA/SEGA), the early-stage efforts on Majorana (the Majorana proposal, which is being submitted approximately now, proposes a staged development of detector arrays), and nonproliferation projects similar to the PIsCES effort. These experiments have modest footprints and utility requirements and could be set up in existing space, using prefabricated cleanrooms of low cost.

Several groups involved in R&D have materials that should be "cooled," stored underground to allow cosmogenic activities to decay away. Storage space at modest depth is needed.

EarthLab scientists desire access to as much of the 600 km of drifts as possible, to install sensors that will continue to monitor humidity, stresses, and rock movement after the drifts are closed. The closing of unused drifts will be one of the first construction activities. Thus EarthLab scientists need to be integrated into initial construction activites.

For definiteness we will take FY06 as the start of construction. (This follows agency advise. We believe the Baseline Definition Project Book could be completed in time to allow FY05 consideration, however.)

The program development plan calls for the first new-construction finished rooms to be available on the 7400-ft level at the beginning of FY07, with all rooms completed four months into FY08. Therefore to meet the early needs described above, suitable existing space must be provided for approximately two years. That space must be accessible during construction, and must have adequate utilities. This presumes that maintenance continues on the Homestake site, from now until construction, so that at least moderately deep drifts can be reached safely in FY06.

Initial experiments and R&D efforts: There are a number of efforts that are clearly either ready to go now, or should be with an additional four years of R&D and preparation. First among these is the low-level counting facility, crucial not only to the first experiments to be constructed at NUSEL, but also to most R&D efforts that will want space there. The low-level counting facility will be central to many of the detector development efforts undertaken because of

national security concerns. It will also serve as a national user facility. The importance of this facility became clear at the Lead and NESS workshops, leading to the world-class proposal incorporated into this Reference Design document. The low-level counting facility is under active development by physicists from Los Alamos, Princeton, NIST, Alabama, and other institutions.

Majorana and likely one additional one-ton-scale double beta decay experiment will ready by FY07. Majorana requires a deep site, at least 4500 mwe, though the experimenters feel additional depth is important to provide a safety margin.

The geomicrobiology program and many other components of the earth science program would be underway by FY07. It is likely that boreholes for the geomicrobiology program could be done in FY06. Required supporting facilities include a small room at the 8000 ft level, a clean laboratory in the complex at 7400 ft, and eventual access to chemistry and other surface laboratory facilities.

There are several dark matter experiments that will be seeking deep locations at about FY07. In particular, CDMS II, currently being deployed in Gran Sasso, will run through 2006. Its one-ton successor CryoArray shares much of the same technology, though some materials and background R&D remains to be done. CryoArray is likely to be ready by FY07. The depth requirements are similar to those for double beta decay.

The Science Book describes many R&D projects – solar neutrino detectors, new technologies for supernova detectors, applied science detector developments, etc. – that will require space at depth as soon as it is available.

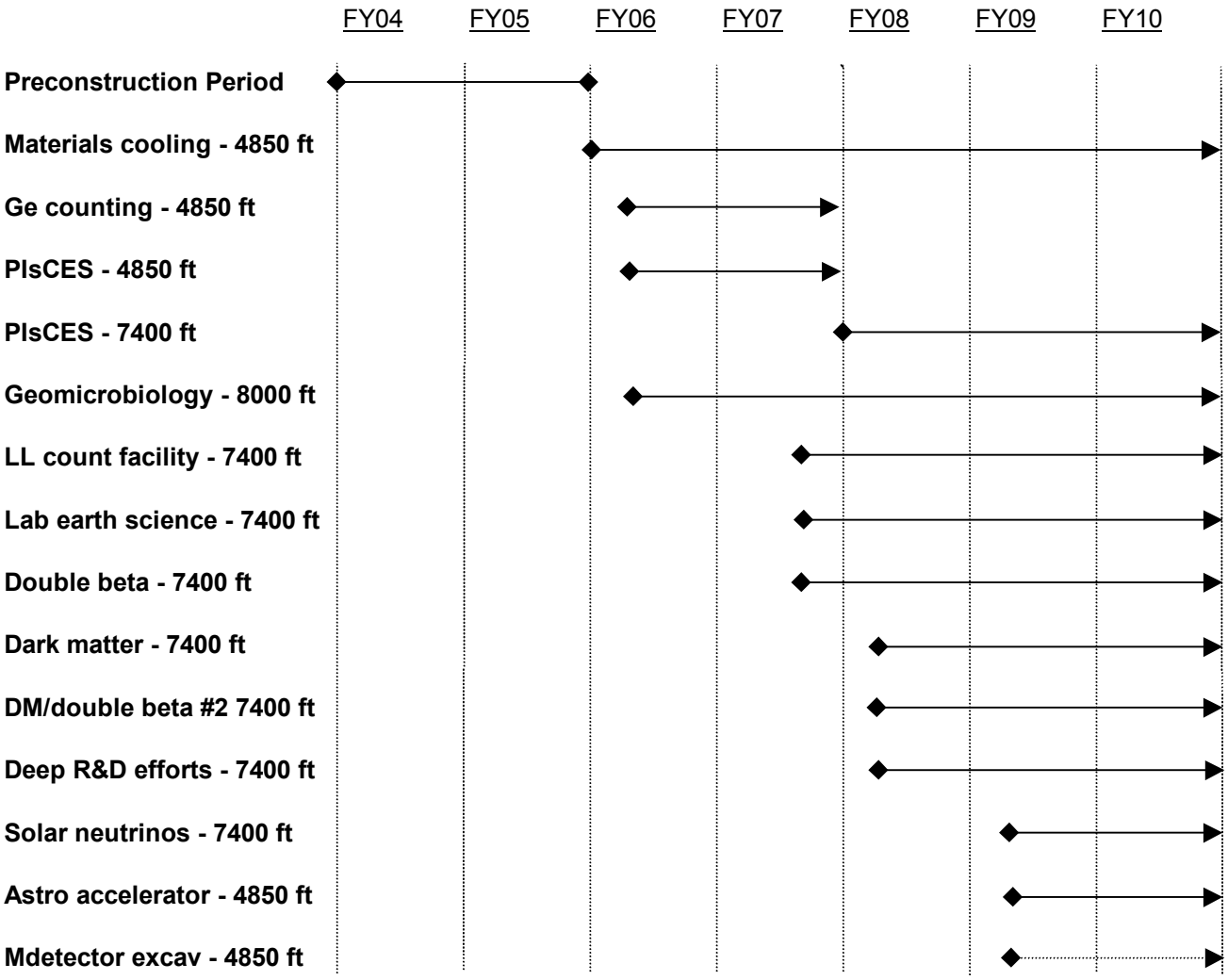
Next experiments: Although some of the solar neutrino experiments have more ambitious R&D schedules, we have placed the mounting of a full-scale experiment no earlier than FY08. Most of the proposed experiments require construction of a specialized cavity. As selection of a pp solar neutrino experiment is unlikely to occur before initial construction on the 7400-ft level, this requires NUSEL to build such a cavity after the deep level is already an operating scientific laboratory. Thus a scheme is needed to facilitate this and future construction while maintaining the cleanliness of existing, operating experiments.

A second facility that will be installed in FY08 is the low-energy accelerator for nuclear astrophysics. This is a staged facility for which the planning has already commenced (a national coordinating committee has been meeting regularly). This group's schedule calls for submission of a proposal by FY06. The facility requires moderate depth, does not require exceptional cleanliness, and could be conveniently located on the 4850-ft level, away from most other experiments. This would minimize concerns about electric interference with other experiments.

The megadetector: The excavation requirements of the megadetector dwarf those of other experiments discussed here. This excavation is not part of the NUSEL proposal – yet it is crucial for NUSEL to be able to accommodate this detector, given the intense interest in next-generation proton decay searches and very long baseline experiments to measure CP violation and other new neutrino properties. HEPAP, in its recent response to the DOE Office of Science call for comments on future megaprojects, called for a depth of at least 4000 mwe. It also stressed that a rigorous professional civil and mechanical engineering design for the detector depends on the NUSEL site choice. NUSEL-Homestake's first option would be to place this detector near the base of theYates hoist (4400 mwe), dedicating the hoist to the excavation. The needed conveyor for rock disposal in the open cut could be built in FY08 (or earlier, if there is need), so that megadetector construction could begin in FY09.

This **proposed initial NUSEL physics program** is displayed in the **Timeline**.

TIMELINE: NUSEL-Homestake Initial Science



Assumptions:

1) No. 6 Winze renovations completed by fourth quarter, FY07
2) Some 7400-ft rooms finished by first quarter, FY07, remainder by second quarter, FY08

Science Timeline: Earth Science. The EarthLab community also proposed a plan for its activities over the first five years of NUSEL:

First year: The earth scientists will undertake two surveys, the mining of existing Homestake data bases and direct reconnaissance of all accessible mine areas in order to compile relevant geochemical, hydrologic, and rock mechanics data. This will help the community identify optimal candidate sites for subsurface experiments. As many unneeded drifts will be closed in the first year, the positioning of various sensor arrays must be connected with this work: fluid pressure transducer arrays, tensiometer arrays, and temperature probes will be installed in areas where future access may be impossible. Initial installation of the Deep Seismic Observatory will begin. The data obtained in the initial surveys will be used to plan a fracture characterization, geophysical imaging, hydrologic measurement, and stress measurement program. The EarthLab steering group will begin development of a web-based system for data distribution, and of a preliminary mechanical, thermal, and hydrological model based on drilling and excavation history.

Second year: The plan includes completion of hydraulic fracturing measurements for the stress field in key areas of the mine and the performance of tracer tests on candidate sites for coupled experiments, with the goal of picking shallow, intermediate, and deep candidate sites. Borehole drilling and coring from 8000 to 14000 ft will be done for the ultradeep biology experiment and associated experiments, and stress and permeability measurements will be made. The Deep Seismic Observatory installation will be completed. Boreholes will be excavated for the deep heater experiment and temperature sensors installed for the coupled thermal-hydrologic-chemical-biological experiment. Sites will be selected for hydrology stations, deep percolation, and paleohydrology boreholes.

Third year: By the end of the second year the anaerobic room for geomicrobiology will have been excavated and early in the third year the geolab will be available in the 7400-ft complex. Data collection will begin for the deep flow and paleoclimate experiment, after coring and borehole installation, and the ultradeep biology facility will be readied for experiments. The heater experiment will be initiated, obtaining temperature, geophysical, geochemical, microbial, and hydrologic data. The fracture propagation experiment will be conducted, with monitoring of gas fluctuations, microseismic data, and tracer transport. The borehole arrays for the deep-coupled-processes facility sites will be completed, and cross borehole tomography and tracer tests performed for each coupled-processes site.

Fourth year: Goals include completion of the microseismic analysis of the induced fracture experiment, of the analysis on changes in fluid chemistry and microbial populations to temperature changes, and of the 3D fracture transport models for coupled experiment sites. The preliminary thermal, hydrologic, and mechanical model will be revised to take into account new data from the heater experiment in progress. An analysis of first results from the deep flow and paleoclimate experiment will be completed, including a preliminary hydrology model, readying the facility for more detailed analyses and in situ experiments.

Fifth year: The first heater experiment will be completed and the facility readied for further experiments. It is expected that the first set of funded experiments at EarthLab facilities will be initiated.

The earth science community has recently focused on developing the EarthLab science case, and thus has not played a very active role in the detailed NUSEL facilities planning that is described in this project book. (Efforts have been made to address the needs this community has identified, such as the rooms on the 8000- and 7400-ft level and the scheduled excavation for the earth science drilling rig). **One main goal in the next Baseline stage of the project book will be to better integrate the earth-science timeline into the NUSEL facilities development plan.**

E. REFERENCE DESIGN AND PROJECT PLAN

In the following we consider the elements of the Reference Design for the Homestake National Underground Science and Engineering Laboratory:

- The Facilities Development Plan: This describes the plan for subsurface access; development for the 4850-, 7400-, and 8000-ft levels of NUSEL; subsurface infrastructure; the surface campus, land acquisition, and related permitting issues; and preconstruction maintenance and operations issues.
- The Facilities Operation Plan: This describes the facility and site operations plan.
- The Outreach/Education Plan: This describes the visitor center and museum/archive plans, as well as associated operations.
- The Program and Management Plans: This describes our plan for carrying out the NUSEL-Homestake project, including roles, responsibilities, and methods for accomplishing our goals. Pending guidance from the NSF, we present a possible management scheme.

I. The Facilities Development Plan: Subsurface. The current facilities development plan differs from that of our June 2001 conceptual proposal, reflecting important advances in our understanding of the Homestake site and of its potential for science. We propose a laboratory with two main levels, 4850 ft and 7400 ft. This furthers several of our goals:

- Various science reviews have concluded that a new multipurpose laboratory must provide at least 4500 mwe of overburden and should strive for 6000 mwe, to accommodate future experiments. The 7400-ft level (6600 mwe) of Homestake has a well maintained (and relatively recently constructed) 9 ft by 9 ft drift. It is the deepest level reached by the No. 4 Winze, which will serve as the mining shaft for future expansion of 7400-ft laboratory facilities as well as a secondary escape route. This level is also reached by the No. 6 Winze, which will serve as primary access. The No. 6 end of the main drift at 7400 ft reaches the Yates formation, generally regarded as the most competent rock within the site. The combination of excellent rock, dual hoists, and convenient access argues for locating the deep NUSEL rooms on this level, in the vicinity of the No. 6 Winze.

- The two main shafts from the surface, the Ross and Yates, terminate at the 4850-ft level (4300 mwe). They are connected by a one-kilometer major drift, in excellent condition, with a 13 ft × 13 ft cross section, off of which several serviceable rooms with good utilities exist. There are important reasons for developing a second laboratory level on this level. First, several proposed experiments that were discussed in the Science Book require 4000 mwe of overburden or less, and thus could be located at the 4850 ft level, providing more convenient direct access from the surface (avoiding transfer to the No. 6 Winze) -- science access would be through the Ross. Second, an additional laboratory level allows us to separate experiments that might interfere. (The nuclear astrophysics accelerator will be placed on the 4850-ft level because of electrical interference and machine-associated background concerns.) Third, a split-level laboratory helps to distribute the ventilation load. Fourth, the existing rooms on this level can be used for materials storage ("cooling" activated materials) and for mounting certain experiments at the beginning of construction.

  But by far the most important consideration is reserving an ideal site for the megadetector. The base of the Yates shaft is in the middle of the Yates formation, the optimal rock for large excavations. According to a recent HEPAP report, a depth of 4000 mwe is desirable. By placing the megadetector near the base of the Yates, this hoist could be dedicated to this experiment during both the excavation and construction stages. Mined rock can be removed from the Yates hoist at the 600-ft level and transported by conveyor to the open cut, solving the megadetector's substantial waste rock disposal problem.

- In addition, some development will be done on the 8000-ft level in support of the geomicrobiology program. This includes a small room and excavations to allow headroom for the drilling rig to be used in boring to 16,500 ft.

The earlier conceptual proposal advocated an extension of the Yates shaft to the 7400-ft level, connecting the new base to the No. 6 Winze by constructing a one-kilometer major drift. The Yates extension was the most technically risky aspect of the original proposal, as a single shaft to 7400 ft would be near the limit of what has been accomplished in mining. Both the Yates extension and the new drift are expensive: the hoisting goals of the original proposal would have required replacing the Yates head frame. Most important, the base of the Yates would then be in the Poorman formation, generally considered to be the weakest rock in the site.

The current proposal is far less risky, more cost effective, and places all major construction in the most competent rock. It leads to a somewhat smaller hoist "footprint" for science access: the Ross and No. 6 can support a cage footprint of slightly more than 12 ft × 11 ft. However, given the existing hoist engines, this tradeoff allows larger loads, which virtually all of the experimental groups we consulted preferred. In contrast, a single hoist reaching 7400 ft would pull so much tonnage in rope that the load limit would be reduced substantially.

I.1 General Subsurface: Rock and Site Characterization: This section briefly summarizes general characteristics of the underground site relevant to underground construction.

Earthquake potential: South Dakota is rated as a 5 on the 1 to 5 scale of the National Fire code, with 1 being "maximum potential for earthquake damage" and 5 denoting the least potential.

Regional geologic setting: The Precambrian core of the Black Hills uplift in South Dakota is exposed in an elongated dome approximately 85 km long and 35 km wide. Archean igneous and early proterozoic sedimentary and volcanic rocks were deformed in a regional metamorphic event. These rocks were then intruded by Harney Peak granite approximately 1.7 Ga ago. The Precambrian core of the Black Hills was uplifted and eroded. Paleozoic and Mesozoic sediments were uncomformably deposited on this uncomformity surface.

Mine geology: Early Proterozoic statigraphic units within the Homestake Mine are the Poorman (oldest), Homestake, Yates, and Ellison (youngest) formations. The Poorman is characterized by a gray to black, banded to laminated micaceous phyllite, and contains minor amounts of slate and schist. The Homestake is a carbonate facies banded iron formation. The Ellison consists of phyllite, quartz, and mica schist, with a considerable amount of dark quartzites. The Yates formation is hornblende-plagioclase schist. All of the proterozoic rocks have been subjected to multiple deformation events leaving complex isoclinal folds. Generally the rocks strike northwest and dip northeast. The isoclinally folded synclinorium/anticlinorium couplet plunges at various attitudes to the southeast. Tertiary intrusive rocks, mainly rhyolite-phonolite dikes, are fairly abundant in the district.

There are differences in the ability of these rocks to support large excavations. The most competent rock is that of the Yates formation, and the least competent is Poorman rock. One parameter that illustrates the variation of rock strength in Homestake is the uniaxial compressive strength Co. The rock is characterized by Co(1), Co(2), and Co(3), defined as the strengths parallel to the strike of the schistosity, perpendicular to the schistosity, and parallel to the dip of schistosity, respectively. The results (Co(1), Co(2), Co(3)) for Homestake, Poorman, and Ellison were measured by Hladysz: (20.15, 11.15, 13.27), (13.63, 10.00, 12.27), and (11.34, 11.41, 8.15), respectively, in units of 1000 psi. Thus there are factors of two differences that can be gained by picking the rock judiciously. Hladysz states that the Yates Formation values will be much higher than those for Homestake Formation, the best of the three above. **Measurements in the regions planned for development, of course, will be part of the baseline definition effort**.

We have placed all major construction – the large halls planned for the 7400-ft level and the megadetector on the 4850-ft level -- in Yates rock. The figures below show a cross section of Homestake, where the Yates Formation is identified, as well as the views from above on the 7400-ft and 4850-ft levels. Note that Yates rock is immediately accessible on the 7400-ft level from the No. 6 Winze. Also, the base of the Yates is in Yates rock, as is 60% of the vent drift connecting the Yates and Ross shafts.

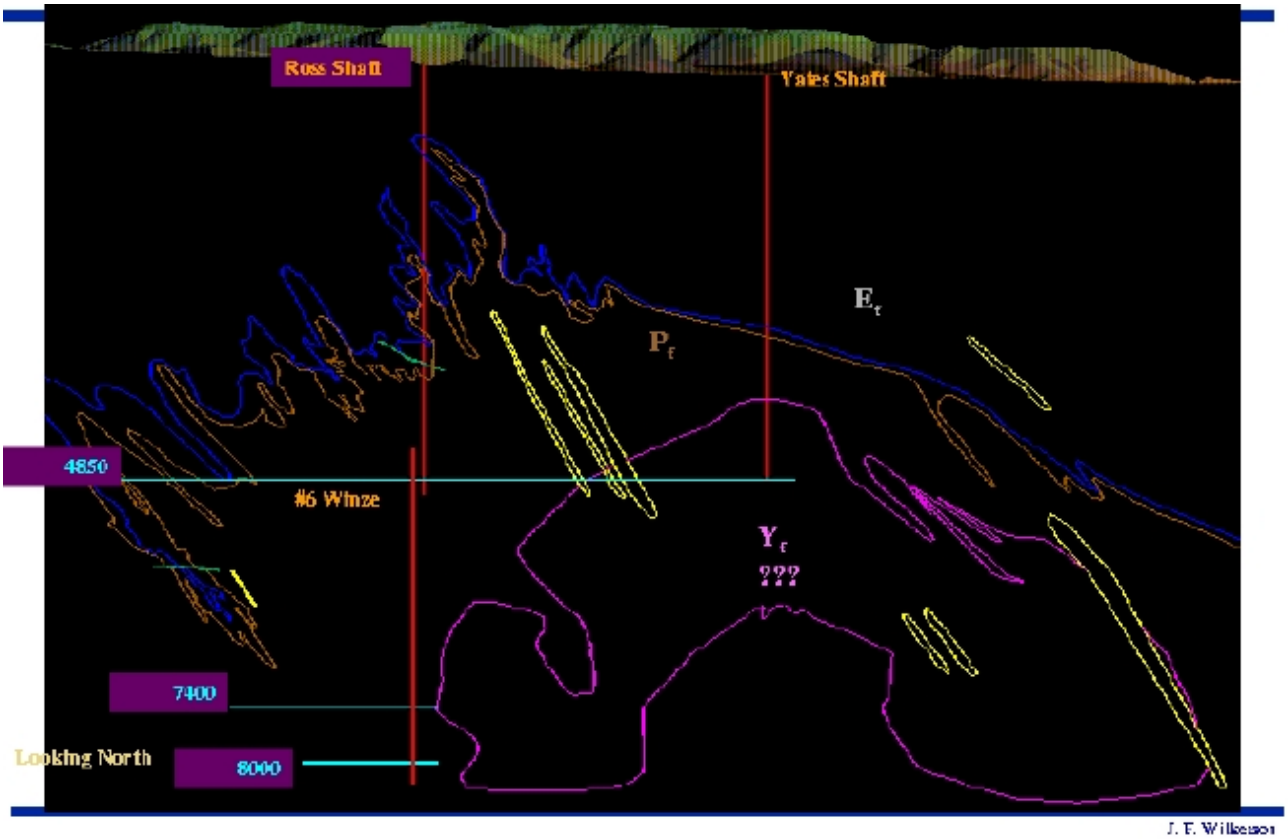


Figure E.1: Cross sectional view of Homestake showing the Yates formation, denoted Y_f. (Note that this view is 180° from the cross sections shown early in the Project Book, where the Yates shaft was on the right.) The base of the Yates – the optimal position for the megadetector in terms of depth ease of mining and construction, is in the middle of the Yates formation. Similarly, the drift at the 7400-ft level near the No. 6 Winze extends to the Yates formation, allowing one to develop into that area. The strongest direction is perpendicular to the rock face. Thus one should orient large halls with their longest dimension in this direction.

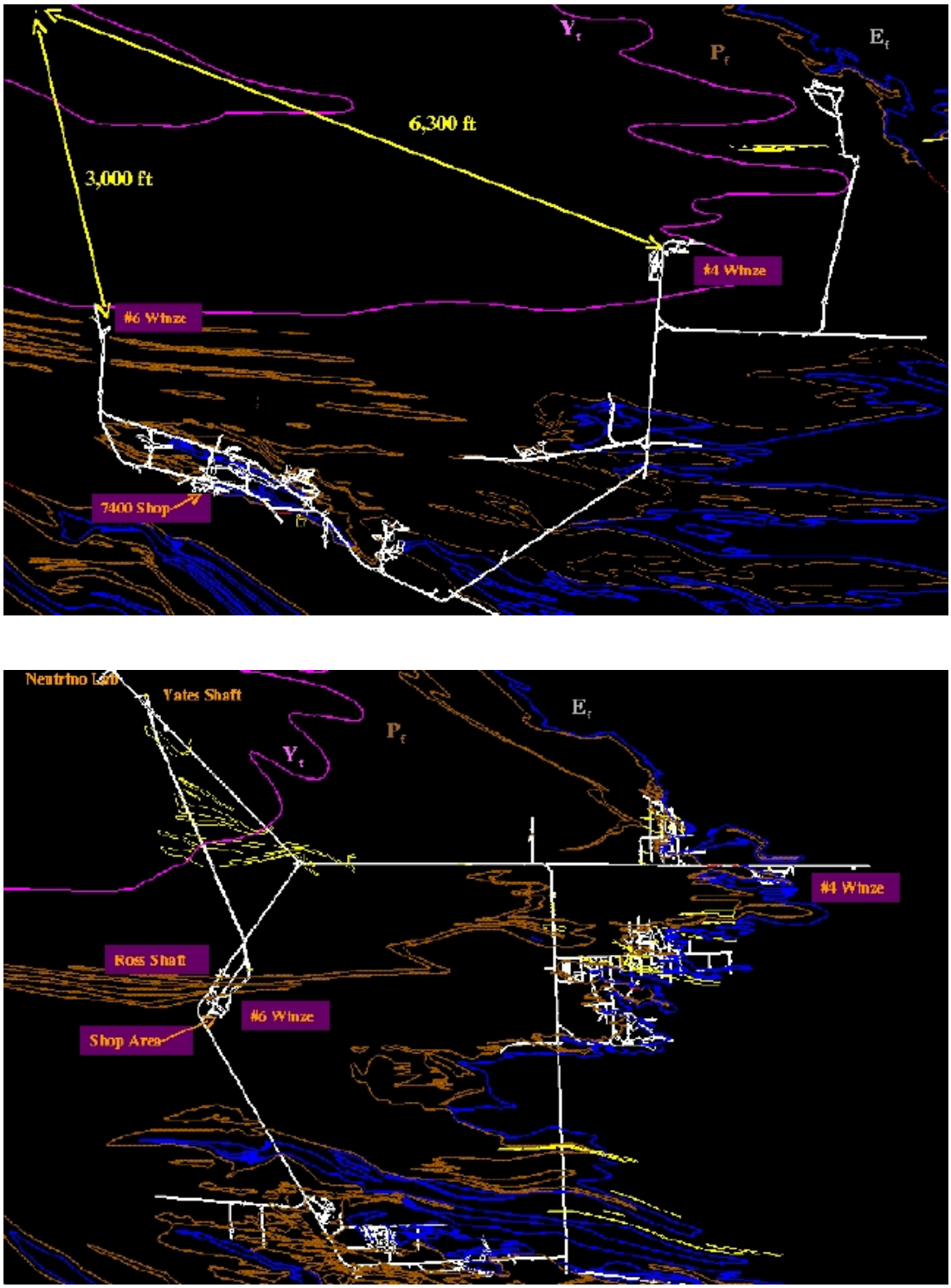


Figure E.2: Top views showing formation boundaries on the 7400-ft (top) and 4850-ft (bottom) levels. The Yates formation is outlined in purple.

Ground support: The rock formations described above are stable. Regional stress fields are minimal and regional seismic events are rare. In instances when stress has exceeded compressive strength, as has occurred in some stope pillars, the rocks generally deform in an elastic rather than brittle manner. However underground openings require ground support to assure safety. The different rock bolts used at Homestake are friction stabilizers (splitset and swellex), point anchor bolts (pattin), grouted or resin bolts (rebar or fiberglass), and cable bolts. Mats, screens, and shotcrete are also used. Spans up to 40 ft are routinely excavated using the standard ground supports mentioned above. Larger openings are entirely possible (and have been excavated, as described in the Overview), given appropriate rock mechanics assessments to determine support requirements.

Typical drift sizes: Most tracked drifts above the 4100-ft level are 7 ft by 7 ft. Tracked drifts between 4100 and 6800 ft are typically 8 ft by 8 ft. The 4850-ft level vent drift from the Yates shaft to the Ross/No. 6 shaft is about 13-15 ft wide and arched to 12 ft. Rail access drifts between the 6800-ft and 8000-ft levels are typically 9 ft wide and arched to 9 ft. Trackless drifts throughout the mine are typically 10 ft in width and arched to 10 ft.

I.2 ***Subsurface access (WBS category 3.1):*** Guiding principles for the proposed underground access include:

- For safety, all levels should have dual access.
- The scientific access should be clean – not necessarily a cleanroom environment, but far cleaner than typical mine access.
- The scientific access should be designed around a standardized module, the dimensions and size of which will determine how most equipment is transported underground.
- Some provision to transport oversized materials is helpful.
- As 24/7 access is important, a single-person automated man-hoist is important.
- As specialized excavations will be necessary for many future experiments, NUSEL must retain the capacity to excavate new rooms on the 7400- and 4850-ft levels, as needs arise in future years. This must be done without disrupting existing experiments or compromising the cleanliness of the scientific access.
- Megadetector construction should be optimized, and interference of this project with the ongoing science minimized.

Figure E.3 shows a two-dimensional projection of Homestake's main drifts and hoists. The relevant hoists are the Yates and Ross (from surface to 4850 ft), No. 6 Winze (from very near the base of the Ross to the mine bottom, at 8000 ft), and the No. 4 Winze (from 4850 ft and 7400 ft). These hoists form a triangle, viewed from above: the Yates – Ross/No. 6 separation is ~ 1 km, the Ross/No. 6 – No. 4 separation is ~ 1.6 km, and the No. 4 – Yates separation is ~1.9 km.

The proposed chronology for optimizing the access for NUSEL is as follows (assuming a FY06 start of construction):

- For the 2.3 years of the preconstruction period, the site must be maintained (pumping, ventilation, etc.), which requires safe access to depth. Because the mine owner, Barrick Gold, has deferred maintenance in anticipation of abandoning the site in 2003, substantial shaft and hoist maintenance will have to be funded by the science community during preconstruction, in order to guarantee safe access. This is an unresolved issue for the proposers and NSF.
- With the start of construction in FY06, the Ross and No. 6 Winze will be used to mine the 7400-ft laboratory level and to clear any areas on 8000-ft needed for the borehole program. This should take about one year. Following this the No. 6 Winze and Ross will be upgraded and modernized, and a major rebuild of the Ross shaft undertaken. When the No. 6 Winze worked is completed, estimated to be 8 months into FY07, some early science can move into the 7400-ft level. The planned work on the Ross shaft and hoist is more extensive, and will

not be completed until the start of FY08. At that point the Ross/No. 6 system is fully converted to clean science access, surface to 8000 ft. All future excavation must be done through other shafts.

- The Yates and No. 4 will be retained as mining hoists. Important maintenance and modernization of these hoists will have been done in parallel with the work on the Ross/No. 6. Initial development on the 4850-ft level will proceed from the Ross side of the Yates-Ross drift. Future development can be done by moving rock toward the Yates. Such excavations can be done cleanly, without affecting operating experiments, by arranging ventilation circuits properly, as will be described later.
- Future expansion of the 7400-ft level can be done similarly, routing the waste rock to the No. 4 Winze, along the separate 4850-level drift connecting the top of the No. 4 to the base of the Yates, then up the Yates. Again, the hauling never protrudes into areas being used for science.
- Access for geomicrobiology and earth science to 8000 ft is provided by the Ross/No. 6 and by a ramp that connects the 8000- and 7400-ft levels (thereby reaching the No. 4).
- The most likely site for future excavation of the megadetector is in the Yates formation, near the base of the Yates shaft. As noted before, the rock would be transported to the open cut on a conveyor system built on the 600-ft level.
- It is quite possible that the megadetector experimentalists would chose, on completing excavation, to reconfigure the Yates hoist and cage to more efficiently lower scientific loads. A cage footprint of at least 18 ft × 13 ft could be achieved. A dedicated clean hoist could make construction more efficient. If this option were pursued, then it would be important, during megadetector excavation, to complete any anticipated excavation on the 7400-ft level in parallel. (That is, the Yates would be available for mining during megadetector excavation, but not during later construction.) Parallel excavation on the 4850- and 7400-ft levels is feasible because megadetector excavation requires only 50% of the Yates mining capacity, assuming a five-year excavation period. (Yates hoist upgrades for the megadetector are not included in this proposal.)

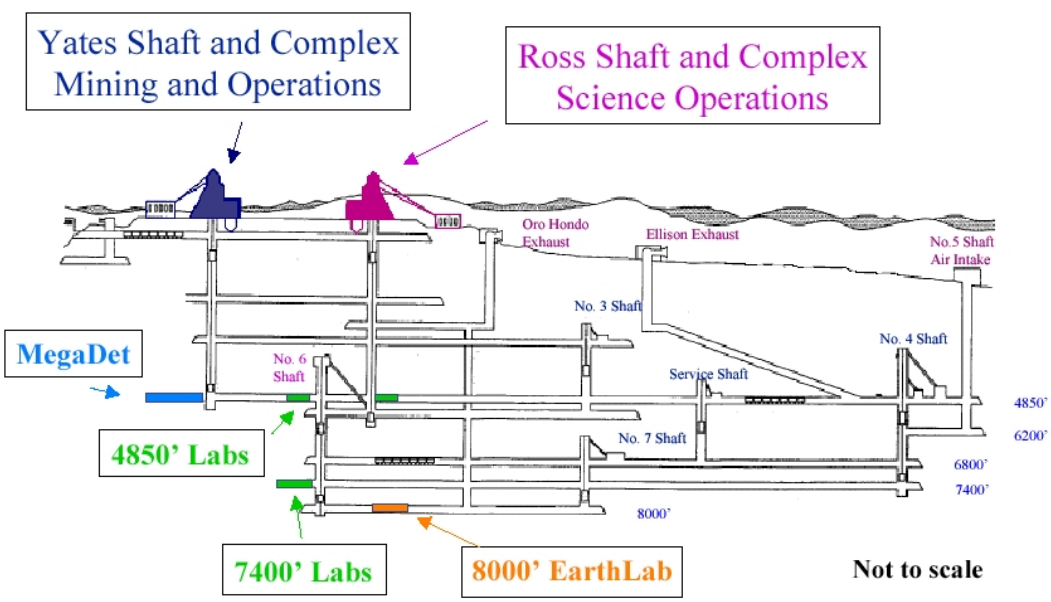


Figure E.3: The cross section of the mine, inserted here to show the shafts relevant to access. This is a 2D projection: see Figures E.2 for a top view showing relative positions.

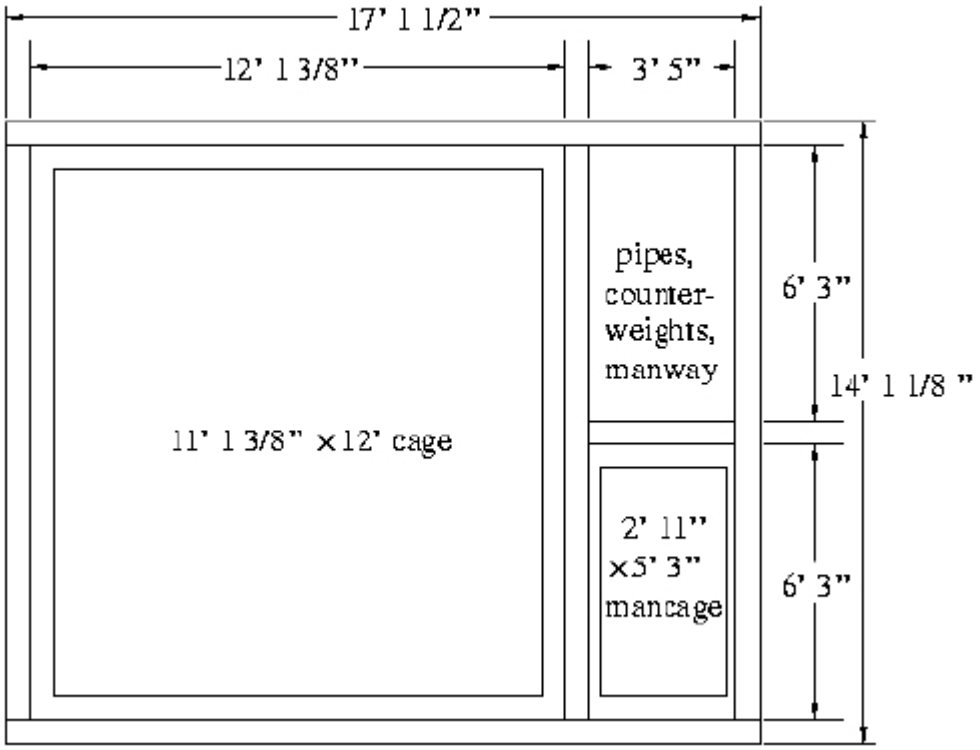


Figure E.4: Schematic showing the planned No. 6 Winze cage reconfiguration and 24/7 mancage.

The envisioned Ross and No. 6 shaft/hoist upgrades represent a substantial investment, but the return is decades of enhanced efficiency in mounting experiments. The improvements on the Yates and No. 4 are focused on maintenance and automation, with the goal of reducing NUSEL operating costs. Shaft improvements include:

- Realign and replace steel and timber as needed
- Realign and replace guides
- Repair and replace utilities, pump column as needed
- Convert the Ross and No. 6 Winze ore hoisting compartments to dedicated personnel lifts and counterweights
- Clean and dewater the Ross and No. 6 Winze
- Rebuild the Ross and No. 6 Winze level station areas at 4850, 7400, and 8000 ft

The plant and equipment improvements include:

- Conduct all deferred maintenance and repairs
- Replace the Yates and Ross MG sets
- Automate the Yates, Ross, No. 4 Winze, and No. 6 Winze hoists
- Convert the Ross and No. 6 Winze ore-hoists to second man-hoists
- Replace the No. 4 Winze ore-hoist and skip pocket
- Investigate high strength ropes and new drum liners to upgrade the hoisting capacity of the Ross and No. 6 Winze

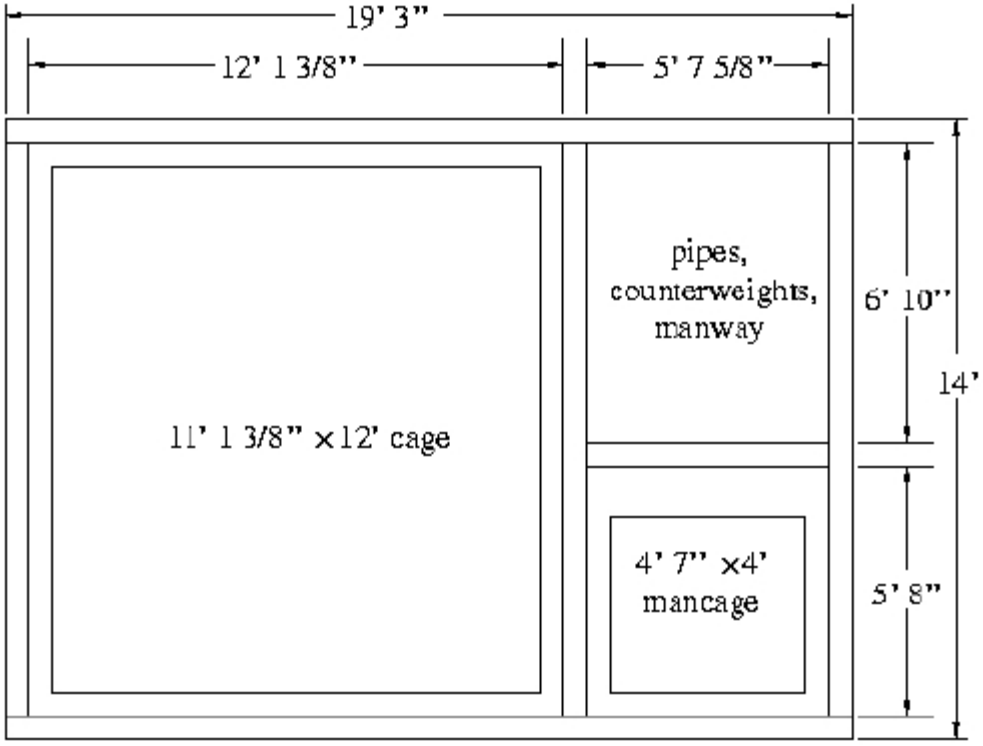


Figure E.5: As in Figure E.4, but for the Ross hoist.

The engineering schedule and costing for these upgrades is presented in Appendix A.

The Ross and No. 6 shafts have cross sections of 19.25 ft × 14.0 ft and 17.13 ft × 14.1 ft. This permits a cage footprint of 12 ft × 11.1 ft. The envisioned cage is light in weight and enclosed, resembling a standard elevator compartment. The vertical dimension is not yet fixed. The load capacity of the hoist is at least 8 tons. In the engineering studies that will be done to fix the final design, one option that will be explored is the use of light-weight ropes and new drum liners, which could substantially increase the hoist capacity.

Both the Ross and No. 6 Winze will include small man hoists, approximately 3 ft × 5 ft, to provide 24/7 access to depth. The after-hours use of these small cages would be via card keys: a system could be put in place where the nightwatchperson could serve as backup operator.

All of the hoist and shaft work is detailed in the appropriate section of the appendix, where the spreadsheets for the proposed work are presented.

I.3 ***Laboratory developments on the 7400-ft level (WBS category 3.2)****:* The design of space on the 7400-ft level was based on the following conclusions, drawn from the science book and from discussions at Lead, NESS02, and elsewhere:

- The laboratory should be a class 10,000 clean room, with provision for achieving higher levels of cleanliness in selected rooms.
- There is a preference for small, individualized rooms for many experiments (in contrast to the large-hall format of Gran Sasso).

- The low-level counting facility should be state-of-the-art, capable of serving the broader community in addition to NUSEL's experiments and R&D efforts.
- There is need for some high-bay general-purpose space that can accommodate a large experiment or several R&D efforts.
- A hallmark of NUSEL-Homestake should be the excavation of special-purpose cavities to enable specific experiments. The site should be engineered to allow such excavations without unduly interfering with ongoing experiments.
- The Homestake site presents unique opportunities for guaranteeing safe venting of experiments, e.g., by routing exhausts to higher drifts. These opportunities should be exploited.
- While the Gran Sasso model of a surface laboratory is used, there should be significant facilities underground (cafeteria, clean and outside machine shops, some office space, a meeting room) to eliminate unnecessary use of the hoist.

These considerations – folded with the requirements specified in the Science Book – leads to the following set of rooms on the 7400-ft level. All are initial construction apart for the solar neutrino facility, which we discuss below as a special-purpose excavation coming perhaps two years after initial construction (when a decision is made among pp neutrino detectors now under development). Thus the solar neutrino cavity poses the interesting issue of excavating an additional room while maintaining the cleanliness of the operating laboratory.

	Dimensions* W x L x H (m)	Volume (m^3) #	Floor Area (m^2)	Wall Surface (m^2) #
7400' Level				
Car wash/change	10 x 8 x 8+ 10 x 8 x 5	675 400	80 80	400 260
Lunch/refuge	15 x 20 x 5	1500	300	700
Utilities	10 x 50 x 8	4400	500	1700
Geo Lab	15 x 28.5 x 5	2140	430	860
LLCF	29 x 14 x 18 + 21 x 14 x 9	10,000	1000	3000
LLCF Utilities	20 x 14 x 6	2000	280	900
Secure Counting Lab	10 x 15 x 5	750	150	475
General Purpose Lab	20 x 80 x 20	35,000	1600	7200
Dark Matter #1	20 x 15 x 8	2700	300	1100
Double Beta decay	30 x 15 x 8	4000	450	1300
Dark Matter #2	20 x 15 x 8	2700	300	1100
Future Solar Nu Lab	12 dia x 24 + 8 x 40 x 4	4500	430	2200
Central Hall, Entrance	5 x 265 x 5	7950	1590	5930
Connecting Halls	5 x 80 x 5	2400	480	1800
Exhaust/utility drift	3.5 x 400 x 3.5	4900	1400	4200
Seminar room/offices	20 x 25 x 4	2000	500	860
Interior machine shop	10 x 30 x 5	1000	200	500
Ext. machine shop	10 x 20 x 5	1000	200	500
Subtotal		*90,015*	*10,270*	*34,985*

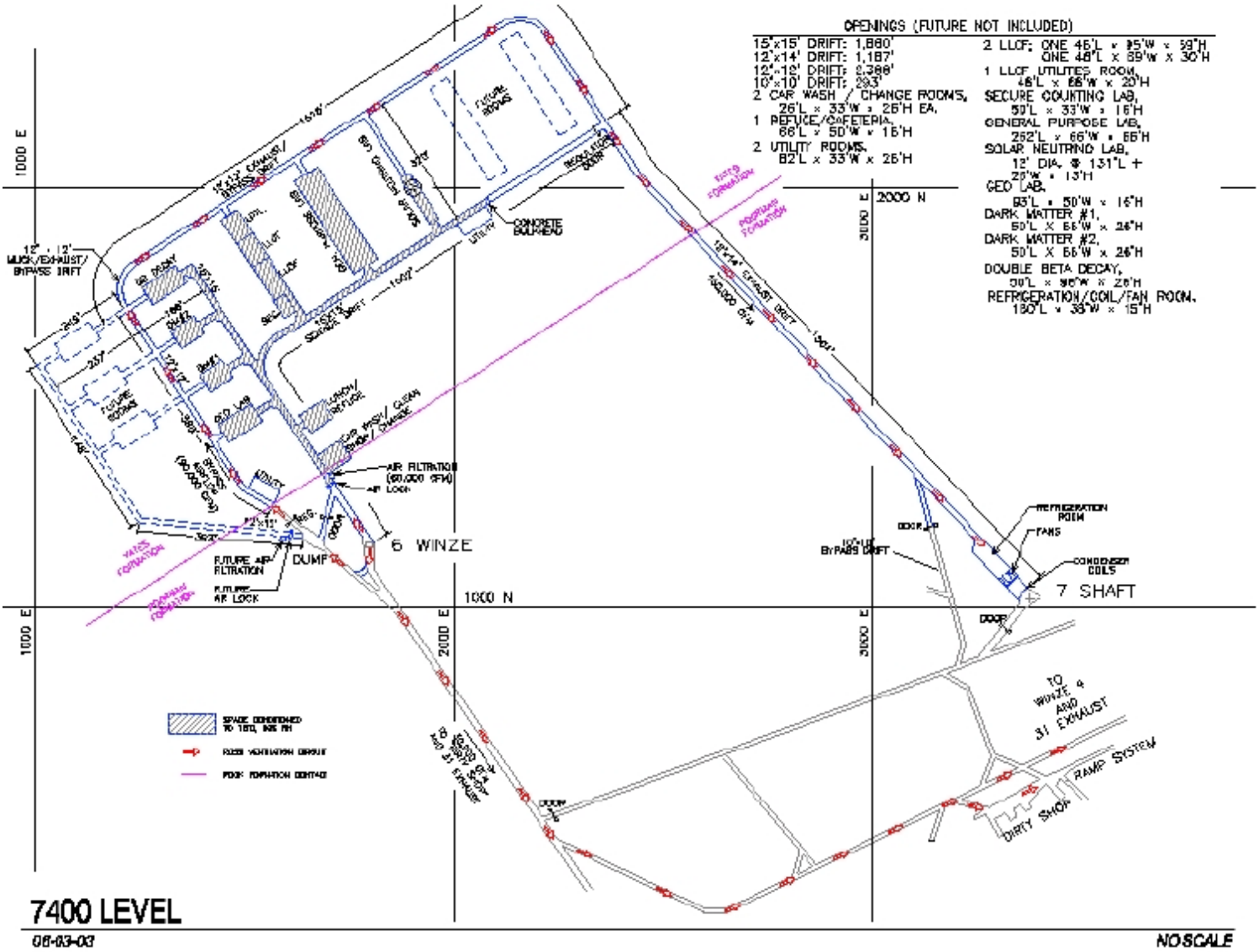


Figure E.6: The proposed layout of the main laboratory level at 7400 ft. The design allows additional rooms to be excavated on the right, through the exhaust drift. Similarly, a major laboratory expansion could be done on the left, again through exhaust drifts so that the existing laboratory remains isolated from the work. Service spaces (offices and the clean machine shop) are not shown. Note that all major construction is well within the Yates Formation (boundary indicated in red).

The main drift on the 7400-ft level extends somewhat beyond the No. 6 Winze station area, ending at the Yates formation, the rock best suited for large excavations. An entrance drift, 5.5m × 5.5m, will be driven into this formation, perpendicular to the edge of the formation. Rooms are oriented in that perpendicular direction, the direction of maximum stability.

Figure E.6 shows the laboratory layout. The design was based on the following considerations:

- Positioning of rooms in the Yates formation.
- Alignment of the longest dimension of the major excavations perpendicular to the edge of the formation (and thus to the rock structure), the most stable direction.
- Spacing of major excavations by two times the width of the excavation. It is generally accepted that two parallel excavations should be separated by twice their width. However multiple parallel excavations may require additional spacing, as discussed below.
- The development should have space for future excavations, in that specialized cavities are required for several experiments now in the R&D phase. Expansion should not unduly affect the cleanliness or seismic quietness of operating experiments.

The entrance to the clean area includes a changing room and a car wash, an arrangement that has worked well at SNO. Four smaller rooms for dark matter, double beta decay, and laboratory earth science are arranged along the left side of the main entrance corridor. (The dimensions of these rooms were increased over those specified in the Science Book to allow for unanticipated needs, such as a water shield.) Each has a 5m portal area where a higher-level clean room barrier or addition radon filtration could be installed. Two machine-shop areas (one clean, one intended for equipment not compatible with the clean area and thus accessible only from the outside) are provided. The latter will be located in existing space in the 7400-level shop area. A cafeteria/refuge and a utilities room are positioned immediately to the right of the entrance corridor. Further to the right is the low-level counting facility (described separately below) and a Gran-Sasso-style high bay area, an arched hall with floor dimensions of 20m × 80m and with a minimum ceiling height of 20m.

The third major development, farthest to the right, illustrates how the layout allows future expansion. This is designated as the solar neutrino area, representing a special-purpose excavation that would likely be undertaken one or two years after the science program commences on the 7400-ft level. Approximately 900 feet of expansion space has been left for this and other future excavations. Development will proceed to the right, with

Common areas include the cafeteria/refuge, a modest office area (10 offices and a 30’ by 40’ seminar/discussion room), a machine shop within the clean area, and a second machining area outside the clean area.

Accepted practice calls for the rooms to be separated by about two times their width at this depth. However, one of the issues that must be studied carefully is whether such separation is sufficient when there are a series of parallel excavations, which can increase the net stress on each. This question requires coring of the area, numerical modeling of the rock mechanics, verification of the model by further tests, and, of course, conservative ground support once the answers are known. If the spacing is increased to 3 time the widths, a possible outcome of such a study, this would require us to extend the length of 5m × 5m science drifts (for accessing the rooms) and 3.5m × 3.5m exhaust drifts, a modest alteration. A second point requiring further study is radon. While the entire clean area will use scrubbed air, **additional radon remediation will be studied during the baseline definition process**, as we want to understand better the consequences of ventilating along long drifts providing substantial rock surface area.

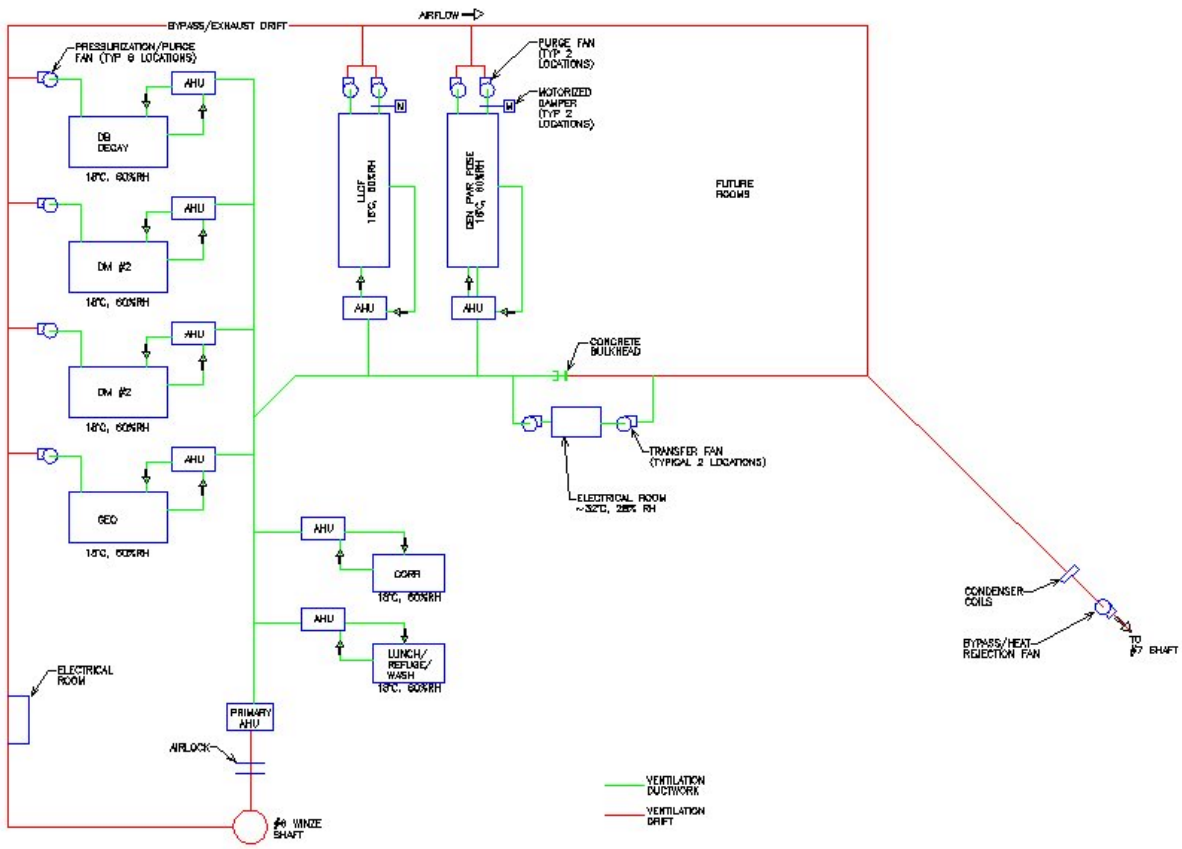
The floor space and volume occupied by the experimental halls is 4660 m^2 and 66,190 m^3, respectively, while the common areas (car wash/change, lunch/refuge, seminar room, offices, machine shops) account for 1360 m^2 and 6575 m^3. The utility areas (general and within the

low-level counting facility) require 780 m^2 and 6400 m^3.

The laboratory ventilation and cooling system is shown in Figure E.7. As will be shown later, the gross ventilation pattern is down the Ross and No. 6 shafts, into the laboratory complex, and exhausted through a vent drift to the No. 7 shaft.

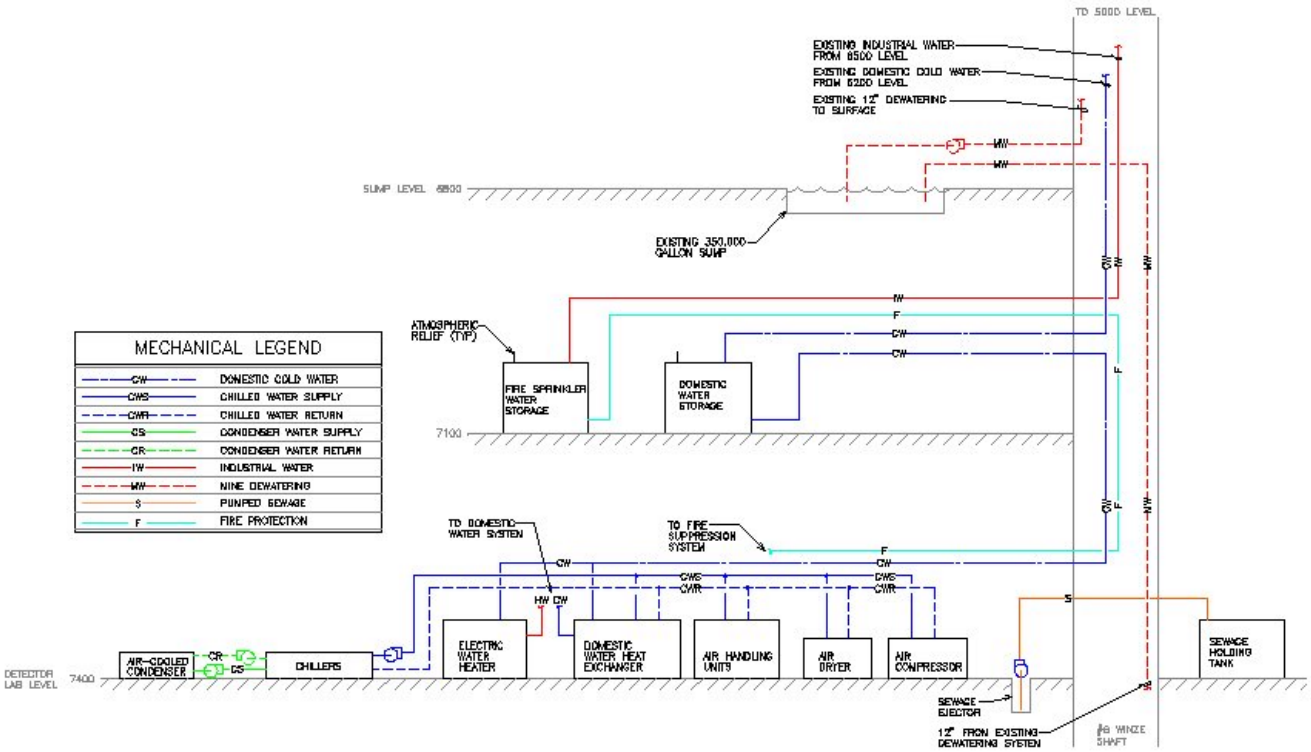
Similarly, the process diagram – industrial, domestic, and chilled water, the mine dewatering system, sewage, and fire protection – is diagrammed in Figure E.8.

Figure E.7: The 7400-ft main laboratory level ventilation and cooling scheme.



7400 LEVEL VENTILATION AND AIR CONDITIONING

05-29-03 NO SCALE



7400 CHILLER AND PROCESS PIPING SCHEMATIC

05-29-03 NO SCALE

Figure E.8: The 7400-ft main laboratory level process diagram.

I.4 Laboratory development on the 4850 and 8000 ft levels (WBS categories 3.3, 3.4). Additional developments are planned for the 4850-ft level and for the 8000-ft level. The former, of course, will likely at some point host the megadetector near the base of the Yates. The excavation costs of that major experiment is not part of this proposal. (However, in the spreadsheets presented in the appendix, we include the conveyor that would be needed to transport rock from the megadetector excavation to the Open Cut. This is a major item, approaching $5M. However, if implemented early in the NUSEL-Homestake development plan, this facility would substantially reduce haulage costs. Thus we have included it in our costs and schedules to leave open this option.) Apart from the megadetector, an ideal facility for the 4850 level is the accelerator for nuclear astrophysics. This experiment should be isolated electrically from some of the sensitive experiments that will be done on the 7400-ft level. The 4300 mwe provided by the 4850-ft level is also more than adequate. In addition, storage areas for materials cooling will be placed on the 4850-ft level. This level will be accessible continuously, starting approximately six months after the start of construction. There is excellent excavated space on this level (as Figure E.7 shows), which would allow us to mount moderate scale experiments there very early, using prefabricated clean rooms. Two groups have made inquiries about this possibility.

Also shown in the table below is a room on the 8000-ft level for geomicrobiology and an estimate of the excavation needed to provide space for the drilling rig this group will use (depending on the location they choose). The 8000-ft room is the laboratory for the geomicrobiology anaerobic glove box. There is a larger earth science laboratory in the 7400-ft complex.

	Dimensions* W x L x H (m)	Volume (m^3) #	Floor Area (m^2)	Wall Surface (m^2) #
4850' Level				
Accelerator	20 x 35 x 10 + 5 x 10 x 4	8000	750	2700
Clean Room	8 x 12 x 6	*600*	*96*	*220*
Materials Storage	10 x 20 x 4	*800*	*200*	*300*
Lunch/refuge room	10 x 6 x 4	*300*	*60*	*120*
Subtotal		9700	1106	3340
8000' Level				
Anaerobic Room	10 x 3.5 x 10	350	35	305
Drilling Area	7 x 16 x 10	1120		
Subtotal		*1470*	*35*	*305*
Total		*101,185*	*11,411*	*38,630*

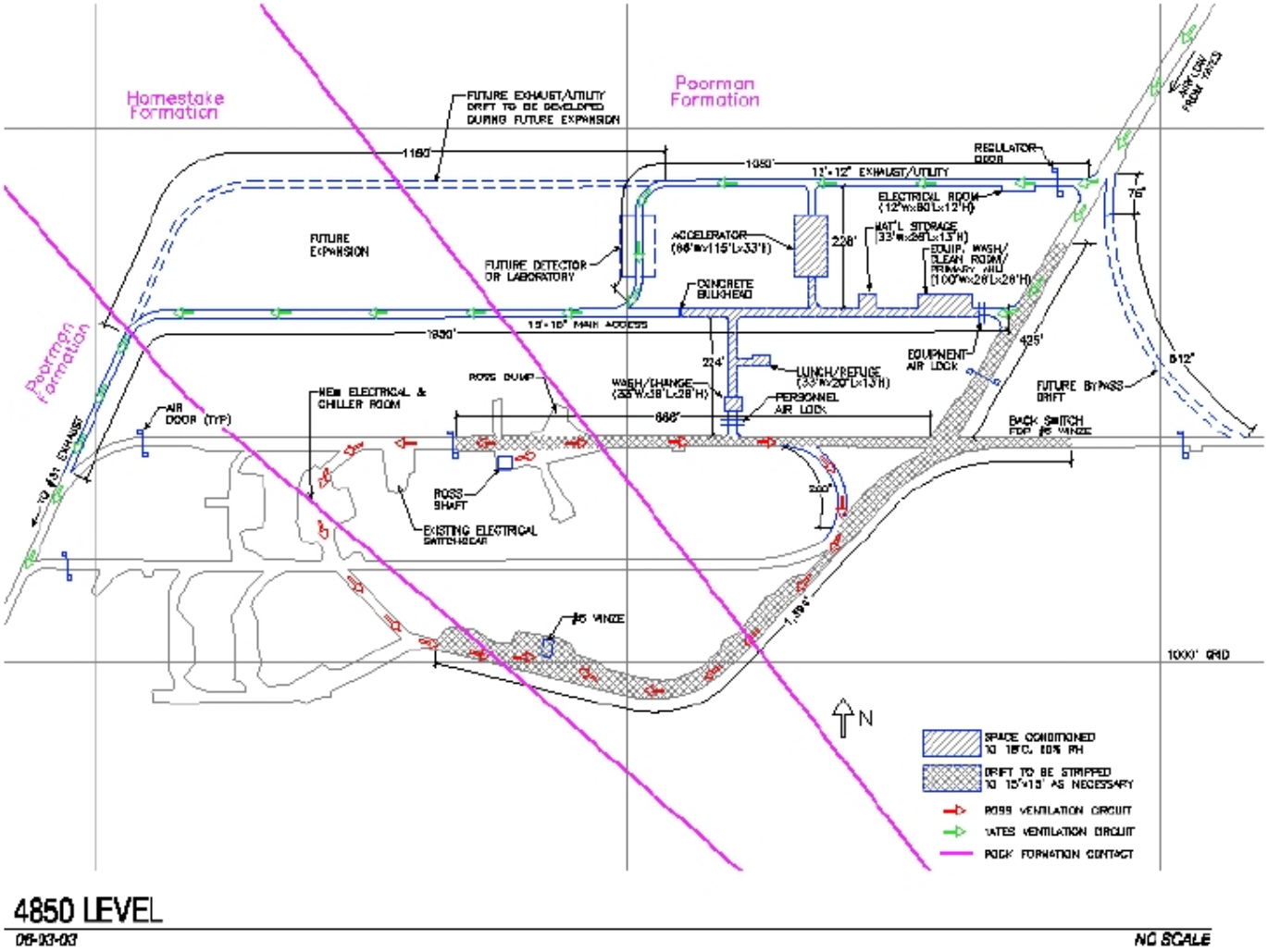
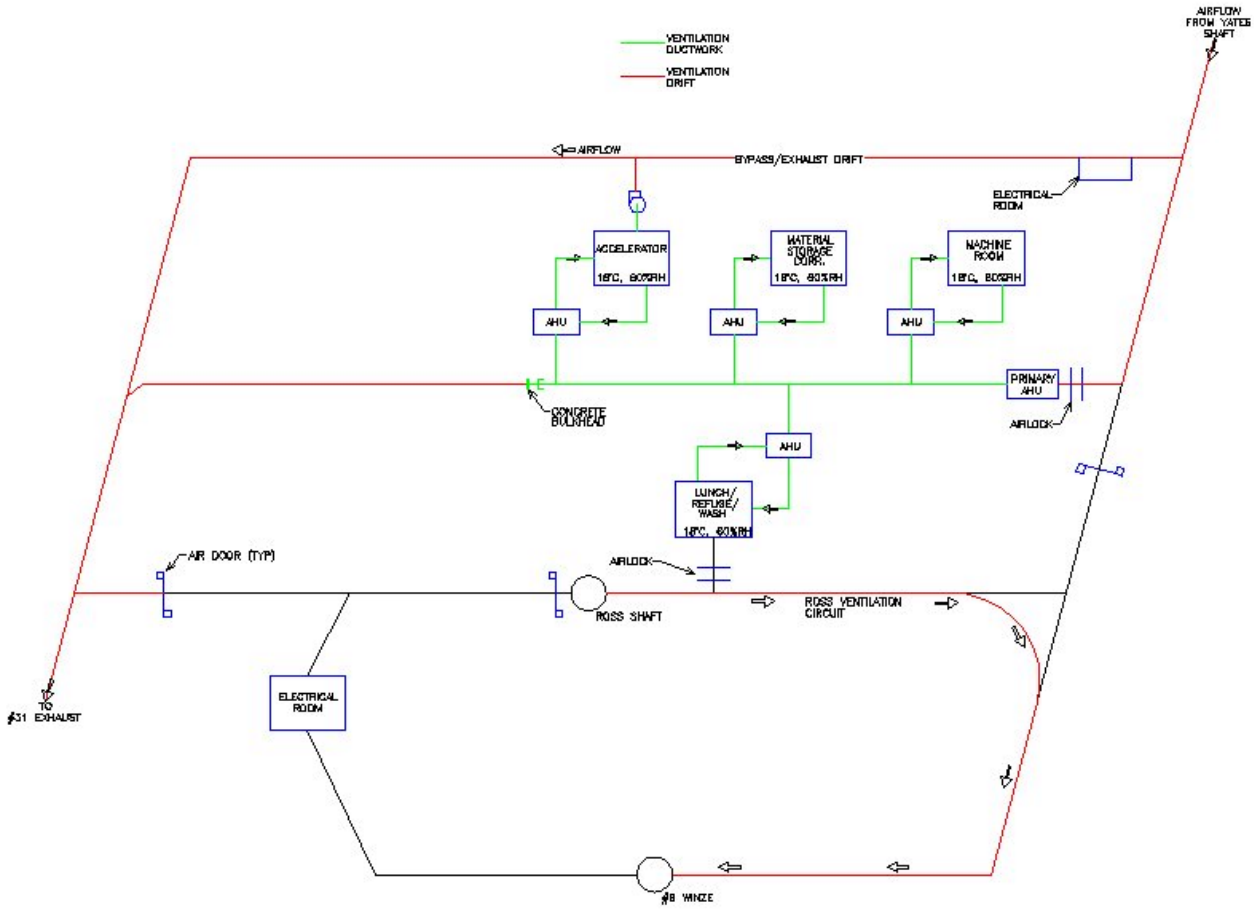


Figure E.9: The proposed layout of the 4850-ft intermediate laboratory level.

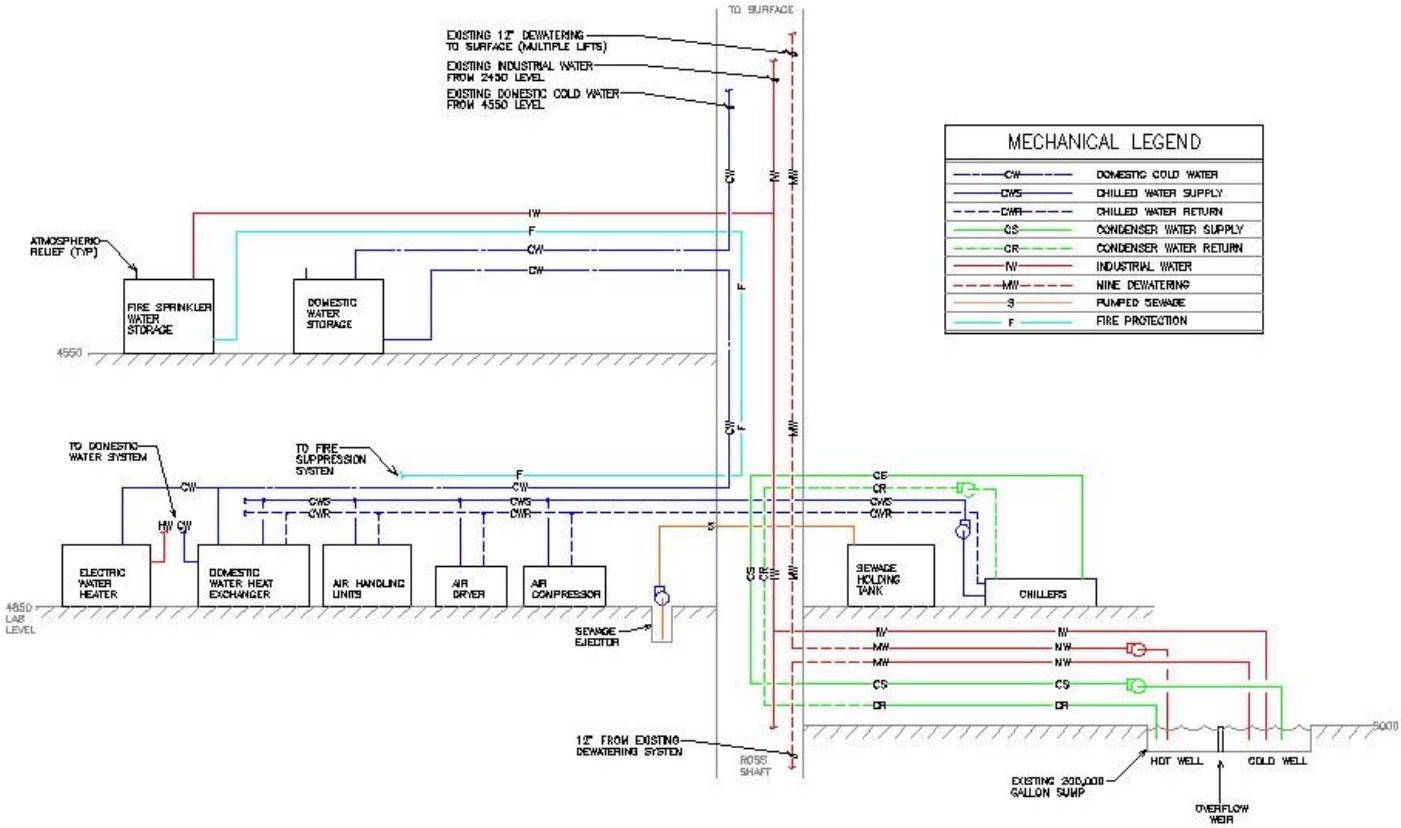
Note that the 4850-ft development is outside the Yates formation, in the weaker Poorman formation. It is likely that the area chosen is quite suitable for excavations of the modest size proposed for this level. In this immediate vicinity, as one can see from the Figure E.7, there are a number of shops and other excavations that have been in existence for a long time. There are two reasons for wanting this development very near the base of the Ross shaft. The first is the obvious convenience of reaching this area quickly. The second is good ventilation schemes off either the Yates or Ross circuits (see below). However, safety is paramount. Thus this area will be cored and carefully studied, to verify its suitability. If the decision is negative (highly unlikely), then this development could be moved approximately 450m along the main vent drift, toward the Yates shaft, where the Yates formation begins.



4850 LEVEL VENTILATION AND AIR CONDITIONING

05-29-03 NO SCALE

Figure E.10: The 4850-ft level ventilation and cooling scheme.



4850 CHILLER AND PROCESS PIPING SCHEMATIC

05-29-03 NO SCALE

Figure E.11: The 4850-ft level process diagram.

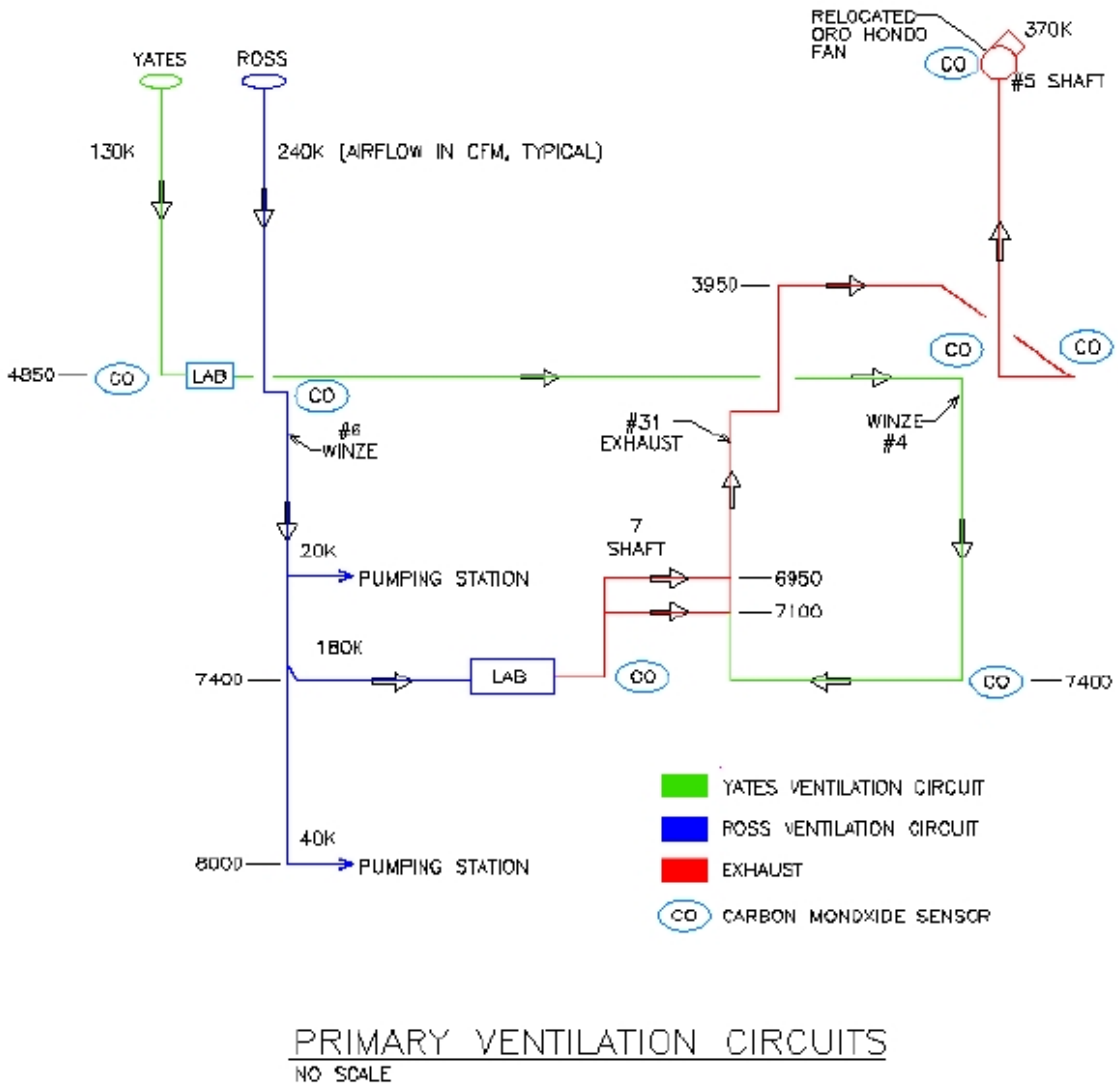


Figure E.12: The primary ventilation diagram for the laboratory, showing the Yates and Ross circuits and the repositioned gas monitors and Oro Hondo fan.

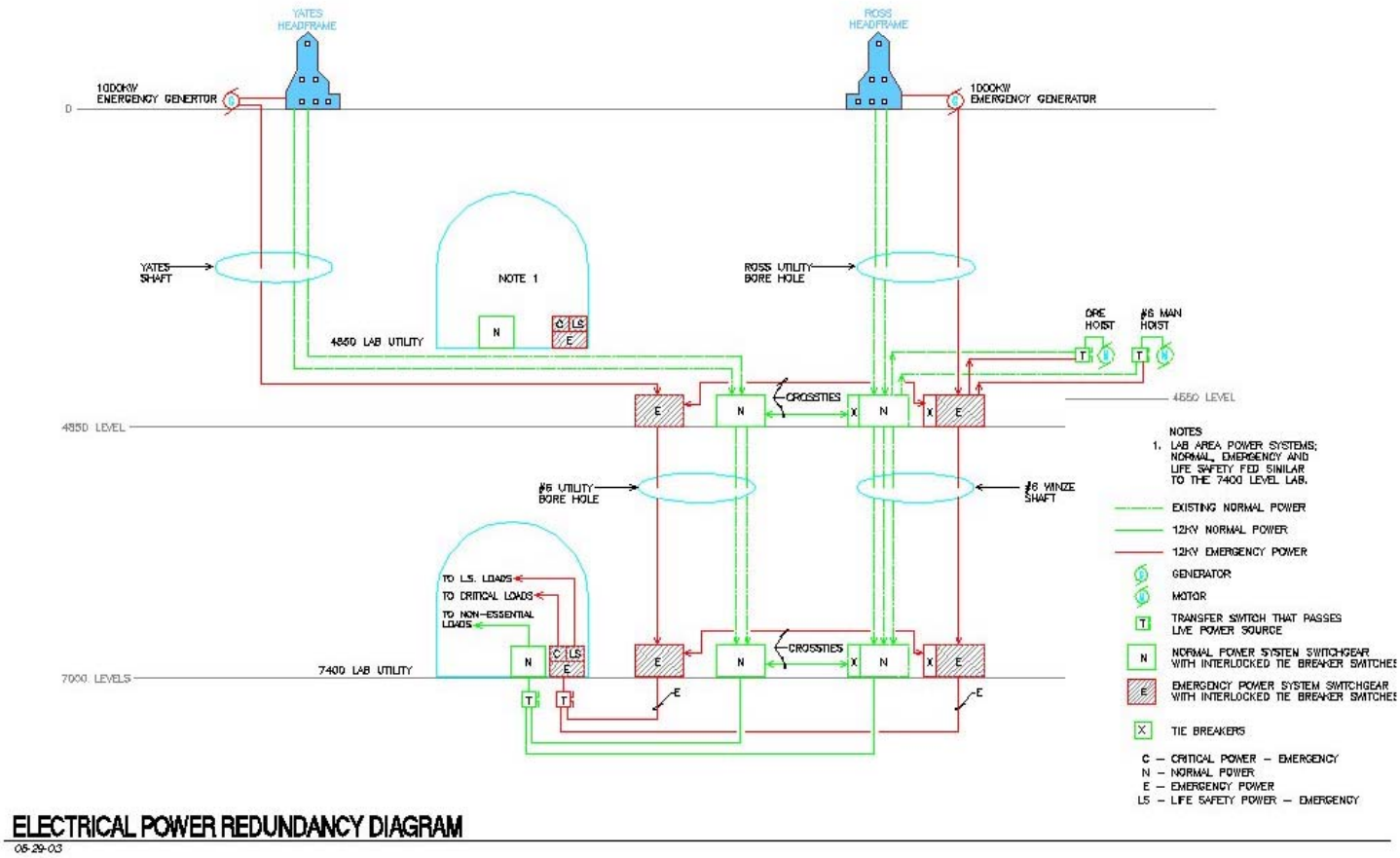


Figure E.13: The overall power redundancy scheme planned for NUSEL-Homestake. See discussion in section 3.9 of the WBS.

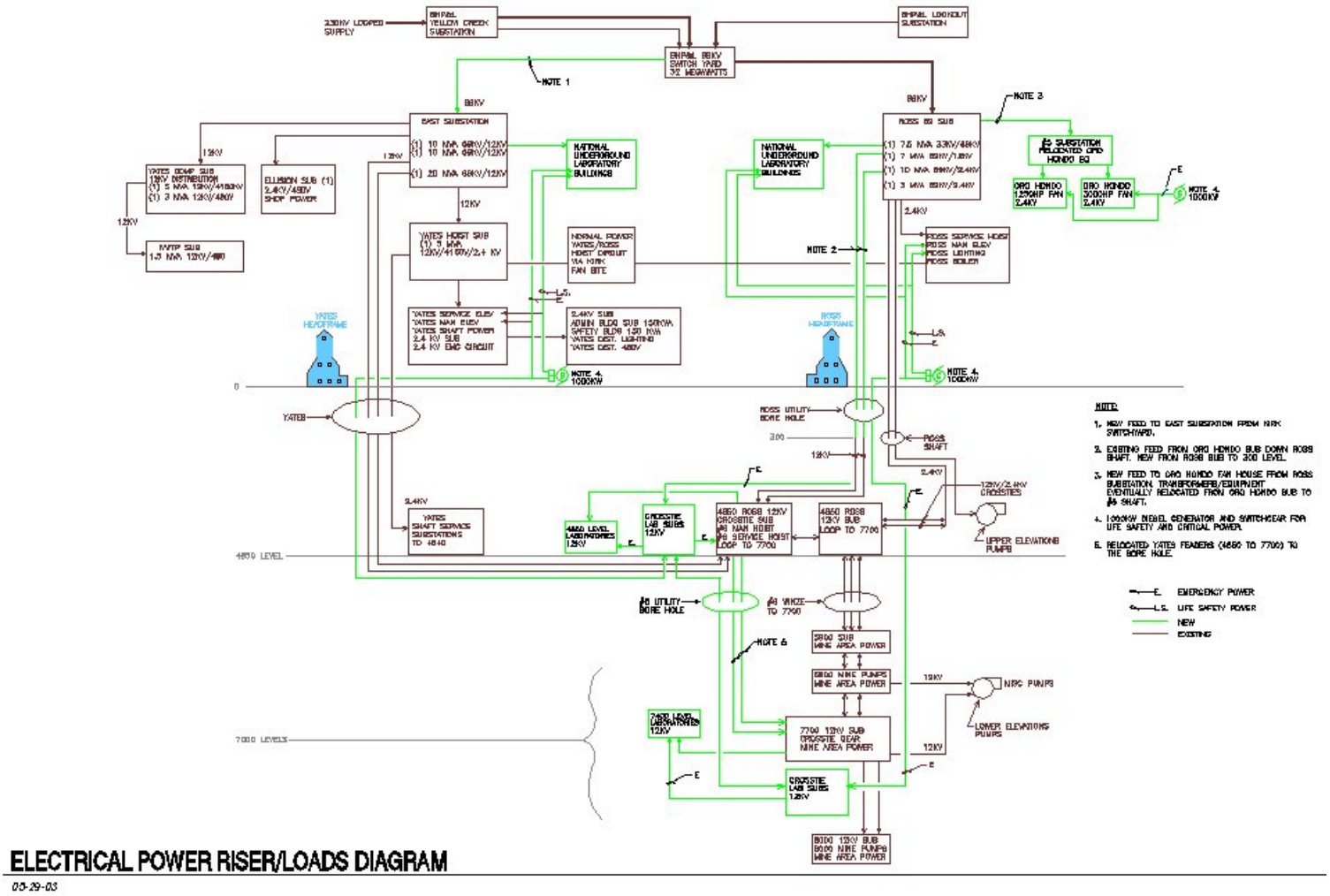


Figure E.14: The power riser-loads diagram proposed for NUSEL-Homestake showing the distribution system including new electrical boreholes. Much of this is detailed in section 3.9 of the WBS, and the associated excavation schedule and costs appear in the appendices.

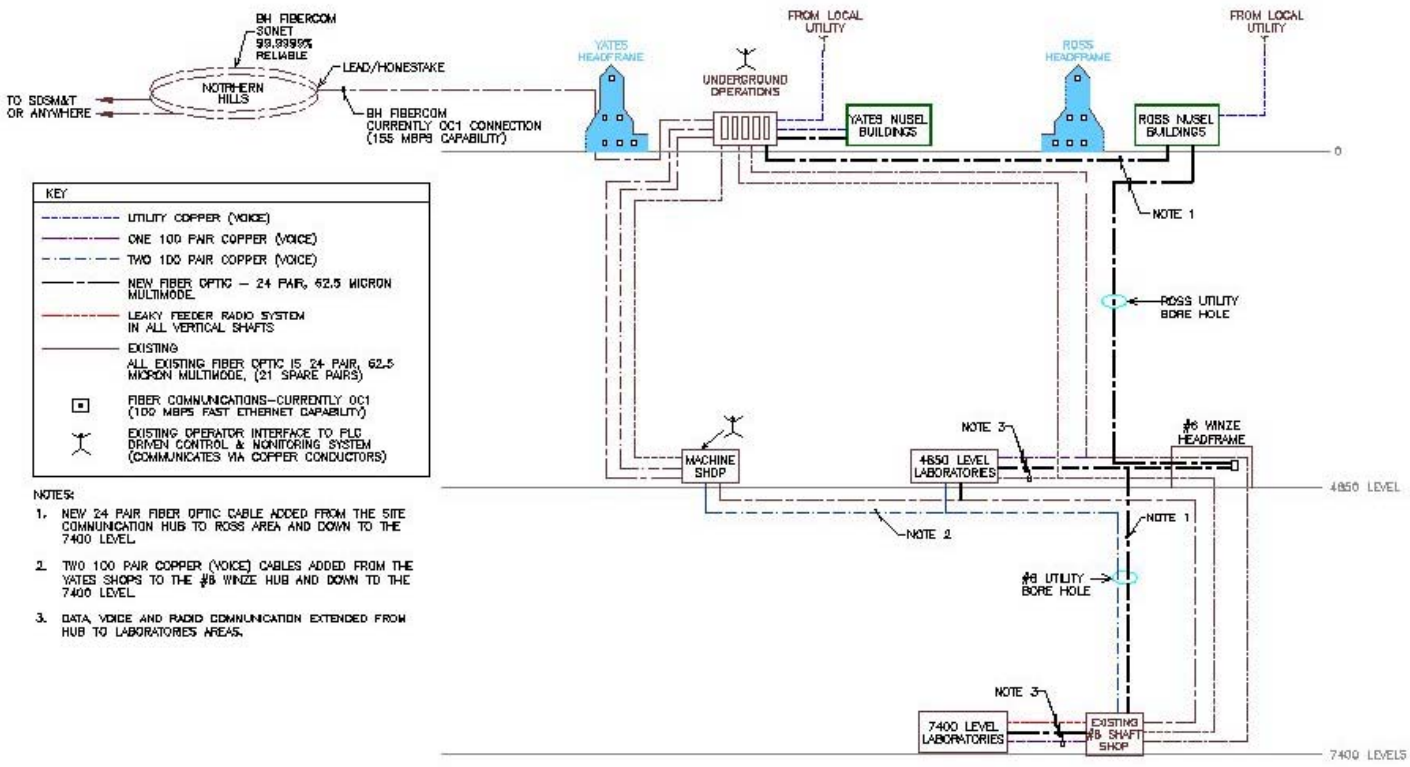


Figure E.15: Proposed NUSEL-Homestake communications plan, adapting current Homestake facilities. See the discussion in Section 3.9 of the WBS.

I.5 Ventilation circuits. An important attribute of the Homestake mine is its sophisticated and flexible ventilation scheme. NUSEL will use two ventilation circuits, corresponding to air flowing down the Yates and the Ross/No. 6. Note that the flow is downward on all access shafts (the Ross, Yates, No. 6, and No. 4). Also note that the main laboratory level, which is on the Ross circuit, is vented through the No 7 shaft to drifts on the 7100 and 6950 levels, up the #31 exhaust, and out the #5 shaft. Thus if an accident produced a large quantity of suffocating gas, for example, it would be vented away from the occupied laboratory level. Workers would be able to exit via either the No. 6/Ross or the No. 4.

The 4850-ft laboratory area is on the Yates circuit. The intake is located near the equipment wash at the eastern end of the main corridor (see Figures E.7 and E.8). This circuit and bypass exhaust to the #31 exhaust vent at the lower right on these figures. The overall scheme is shown in Figure E.10. The red arrows in Figure E.7 show the Ross circuit airflow on the 4850-ft level between the Ross and No. 6 Winze. This crossover is sequestered from the Yates circuit (and thus the laboratory areas) by various air doors. Thus access to the laboratory is achieved by coming down the Ross, walking a short distance in the Ross ventilation circuit, and entering an airlock.

However it is clear that the 4850-ft level ventilation scheme could be reconfigured easily to run off the Ross circuit. This flexibility could be important when megadetector excavation begins "upstream" on the Yates ventilation circuit. By switching to the Ross circuit, the laboratory areas illustrated in Figure E.7 could be kept clean.

I.6 Utilities and finishing of the underground halls (WBS category 3.9): An extensive discussion of utilities – power, communications, HVAC, sensors – appears in the WBS. That narrative walks one through the ventilation, power, and communications diagrams presented in this section (E.12 through E.15). We are concerned that Homestake flooding (see Section G) could alter these plans, which are largely based on cost-effective adaptations of current Homestake utilities.

A second category included in "underground systems" is the finishing of the underground halls, e.g., the transforming of the rough halls (excavated, shotcreted, concrete floors, mineguard) into finished labs. This includes bringing basic utilities into each hall. It also includes the detailed technical design specific to experiments: the clean room requirements, radon mitigation, the quantities and purities of experimental "utilities" such as liquid nitrogen, nitrogen gas, ultrapure water, accommodations for specialized electronics or chemistry needs, mechanical capabilities such as Cu electroforming, etc. In a process that began almost 20 months ago, during the Lead meeting, our collaboration has helped to organize the community into "interest groups" focused around science areas, such as dark matter or double beta decay, in order to move toward a consensus on the needs of each area. (This was a "deliverable" for the Lead convenors: their responses have been incorporated into the Science Book.) This information was essential in locating rooms and in defining their dimensions. It stimulated the further development of the low level counting facility and the specialized utilities it will provide. **We believe strongly that this kind of iterative process must continue and must be augmented: our engineers and the interest groups must check and cross-check each other in the Baseline Definition process.** We do not believe the NSF should be a spectator to this process: it must provide adequate funding to us so that we can continue this process. **The absence of agency support during the Reference Design has already limited this iterative process, which we believe is central to any successful large project**. During the Baseline Definition science-engineering teams will again review the configuration of each hall, to make sure that all utility needs have been adequately met. We have already "flagged" certain issues, such as radon control, that must be examined because of Reference Design changes within the last three months. The use of extended ventilation drifts (necessary in placing the 7400-ft development in Yates rock while utilizing the No. 7 shaft for ventilation) could increase radon levels. Certain rooms may require

additional air scrubbing.

Because of these issues – the uncertainties of flooding and our desire to present cost breakdowns only after adequate interation between the science groups and the engineers have taken place – we have taken the following approach:

- We present a reasonably detailed plan in the WBS describing how we will use the existing Homestake utilities (some of which are virtually new) in our engineering.
- But in the WBS budget, costs are not derived in detail (as for underground construction), but by comparing to SNOLab, which kindly provided a detailed breakdown of underground systems costs and which is located at a depth comparable to Homestake's 7400-ft level. We have made adjustments of the SNOLab numbers for use on 4850- and 8000-ft levels.
- We assign a contingency of 40% to account for any uncertainties.

I.7 The low-level counting facility (WBS category 6.1): This proposal contains funding for one science facility, the Low-Level Counting Facility (LLCF). It is viewed in this proposal as a general facility for users, important to most of the basic and applied science projects that NUSEL will host. The LLCF integrates many functions into three primary areas: ultra-low-level counting and sample preparation, low-level counting and analysis, and utilities.

The ultra-low-level counting chamber consists of two large ultra-pure water pools and associated sample preparation and data acquisition/analysis areas. The water pools are separated by a low-activity steel and sulfurcrete retaining wall and are lined with urylon, a water- and radon-impermeable plastic coating. Each pool is a 12m cube filled with ultrapure water (~10^{-14} g/g U and Th), covered by a hermetic deck, with a 4m high chamber above for handling and insertion of counters and samples into the water. The chamber is supplied with radon-free air, while the air between the water surface and the deck is purged with radon-free nitrogen.

In the first pool several reentrant ports extend into the water. Six of the ports house large acrylic thimbles, each containing an annulus of liquid scintillator surrounding a central sample chamber 0.5m in diameter and 0.5m in length. The light from the scintillator is channeled through light pipes to an array of photomultipliers on the deck above the water. It will be possible to measure U and Th in samples at sensitivities of 10^{-13} – 10^{-14} g/g. The samples to be counted must be first enclosed in a water- and Rn-impermeable plastic bag that is also highly reflective on the outer surface. VM2000 (manufactured by 3M Corporation) appears quite suitable. LLCF plans provide a sample preparation laboratory and data acquisition (DAQ) room for the pool. Three other reentrant ports are provided for prototyping, important for experiments requiring extremely low levels of external background.

Bulk assay of large amounts of materials for U and Th at the 10^{-13} – 10^{-14} g/g will be possible in this pool. As the figure shows, two of the ports are in the central region of the pool, where the highest level of sensitivity can be achieved, while four others are near the periphery, allowing assay at the 10^{-13} g/g level. Although the energy resolution of the modules is relatively poor (~ 20%/√E/MeV), Monte Carlo simulations do indicated some limited ability to distinguish U from Th, based on the measured energy spectrum. The primary justification for the facility is the need to assay large representative samples of materials to be used in shielding, supports, and front-end electronics in the outer regions of dark matter, double beta decay, and solar neutrino detectors. As the measurement time per sample is two (10^{-13} g/g) to four (10^{-14} g/g) weeks, the first pool will be able to process about 100 samples/y at the 10^{-13} g/g level and about 24/y at the 10^{-14} g/g level. This should be adequate for NUSEL and national needs, according to our surveys.

Three reentrant ports for prototyping detectors are installed in the first pool. All can accommodate detectors up to 1m in diameter and 1m in length. One of the ports is located in the pool's central region, minimizing external backgrounds, while the other two are closer to the

periphery. Separate DAQ rooms are provided for each test port.

As the deck of the first pool is modular, it is possible to reconfigure the area to handle larger samples or a larger number of samples.

The second pool is reserved for future developments, possibly a "mini-CTF" similar to the Counting Test Facility (CTF) built by the Borexino collaboration at Gran Sasso. This would extend sensitivities to U and Th by approximately two orders of magnitude beyond that possible with the modular system pool. Such a facility could also be filled with Gd-loaded liquid scintillator to provide unparalleled sensitivity to neutrons. While the second pool awaits development, experimentalists will use the facility to prototype detectors in a very low background environment.

The ultra-low level hall also houses a leaching/emanation laboratory. It will allow experimentalists to measure U and Th (and other radioisotopes) leaching out of samples placed in ultra-pure water. SNO and other experimentalists have developed the extraction and counting techniques (vacuum degassing and counting in Lucas cells) required for 10^{-12} g/g sensitivity to U and Th. The leaching/emanation laboratory contains three large (1m × 3m × 1m high) leaching tanks filled with ultrapure water, associated pumping and degassing systems, and counting and DAQ systems.

The ultra-low-level counting hall contains three staff offices to allow on-site analysis and reporting of measurements made in the ultra-low- and low-level counting halls.

The LLCF will house a full array of alpha, beta, and gamma counting systems. An array of eight well-shielded single, segmented, and multiple hyper-pure Ge detectors will be available. Eight novel ultra-low background tracking detectors sensitive to surface alpha and beta contaminants will be deployed. Small proportional counters (similar to those originally developed for the chlorine solar neutrino experiment) will be placed inside shields to allow single-atom counting of gas samples containing argon, krypton, xenon, radon, and various molecular gases. Sample handle and preparation laboratories will be in close proximity to the counting rooms. As each sample requires one to four weeks for counting (depending on sample size and sensitivity desired), several hundred samples can be processed per year per array. This corresponds to projected needs, based on our survey of groups planning ultra-low-level experiments.

Sensitivities of 10^{-9} g/g U and Th can be achieved with the hyper-pure Ge detectors. This can be extended to 10^{-12} using neutron activation analysis (NAA). As SNO has demonstrated in background measurements on neutral current detectors, surface activities of 1/day/m^2 can be counted. Single-atom counting of Rn and other radio-isotopic gases has also been demonstrated. These capabilities complement those of the ultra-low-level hall: the hall provides unprecedented sensitivity at the cost of lower throughput.

An important aspect of the LLCF is the separate area provided for national security samples. The secure counting laboratory will provide strict access control, and will include electrical, mechanical, and personnel isolation consistent with classified operations. The counting capabilities will be similar to those of the open facility, including high-purity Ge counters; alpha, beta, and Rn counters; and shields. The area is designed for approximately half the throughput of the open area. We expect the MEGA detector (18 high-purity Ge detectors currently being built at the Pacific Northwest National Laboratory, with NNSA support) to be sited in the secure counting area. Sample preparation and DAQ/analysis rooms are included, so that the secure area is selfcontained. When not in full use, unclassified samples could be counted in the secure area.

The LLCF will also provide two passive shields (2-3 m^3 inner volume) for measuring internal backgrounds in prototype detectors. Measurements with a similar shield at Gran Sasso have

demonstrated remarkably low backgrounds, ~ 1 mHz/liter in scintillator with a threshold of 50 keV. In our survey many experimentalists wanted access to a well-shielded environment for detector development. The two LLCF shields complement the three reentrant ports in the ultra-low-level counting hall, which provide a smaller, better-shielded environment for long-term determinations of backgrounds in detectors that do not require frequent access (access would be disruptive to other detectors operating in the pool). The LLCF shields will provide good shielding of gammas and neutrons while providing experimentalists with access: they can be opened and closed on demand. Separate DAQ rooms are provided for the electronics associated with detectors placed in the shields.

These activities require specialized utilities and/or process support, including radon-free nitrogen gas and liquid nitrogen, radon-free air, ultra-pure water, and ultra-pure liquid scintillator. Due to SNO and Borexino, the required techniques are well developed. The capacity will be sufficient to meet the needs not only of the LLCF, but other 7400-ft level experiments needing ultra-pure gases and liquids. Specifically, 400 m^3/h of Rn-free air will be produced, which is sufficient (at one room change per hour of air) to provide Rn-free air to the deck rooms of the ultra-low-level counting laboratory, the leaching/emanation laboratory, the shields of the low-level counting laboratory, the sample preparation rooms of the LLCF, and the electroforming room. The capacity is sufficient to encapsulate four dark-matter experiments, for example, with a shell of Rn-free air while personnel work on the detectors (assuming experimental volumes of 500 m^3). Ultrapure liquid scintillator could be provided (and repurified) at a rate of about 2 m^3/d. This is sufficient to meet the needs of the ultra-low-level counting hall, including repurification about once a week. Excess capacity of about 1 m^3/d would be available to the experimental halls. Rn-free liquid nitrogen and nitrogen gas will be produced in sufficient quantities to meet the needs of the LLCF and several detectors in the 7400-ft halls. (It would not be sufficient for large-volume cryogenic detectors like HERON or Icarus, however.) Finally, ultra-pure water is used in the water shields and in the pools of the ultra-low-level counting facility. The LLCF will have a capacity of about 65 tons/d and a purity of 10^{-14}—10^{-15} g/g U and Th. This production rate corresponds to three weeks for filling one of the pools in the ultra-low-level counting hall. As water repurification will consume about 20% of the system's operating time, there is sufficient excess capacity to produce and repurify 5-10 ktons/y of ultra-pure water for use in the experimental halls.

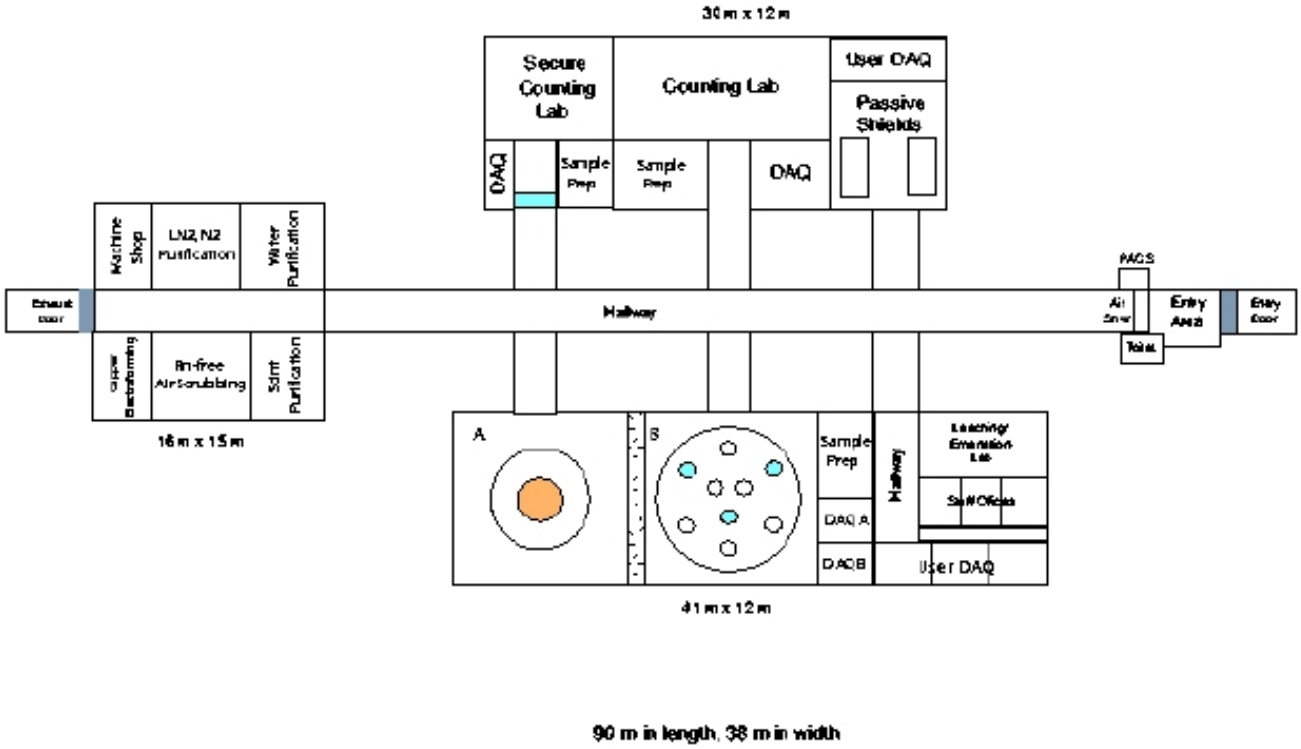


Figure E.16: One of two configurations now under consideration for the low-level counting facility.

Other capabilities offered in the utility area of the LLCF are electroforming of Cu (and possibly other metals), machining of the electroformed Cu, and a detector construction area. The electroforming area is isolated and exhausts directly into the ventilation drift, for safety reasons. The electroforming systems would be provided with Rn-free air to ensure that Rn daughters are not incorporated into materials. The procedures have been worked out with the Majorana collaboration. Production capacity is expected to be several kg/week. The machining area will include a clean lathe, mill, and small tools, and will be dedicated to electroformed materials, with specially selected tool bits, etc., to ensure cleanliness and radiopurity. An assembly area (4m × 8m × 4m high) is provided on the second floor of the utilities room.

Supporting surface facilities include a chemistry laboratory to handle Neutron Activation Analysis (NAA) samples, as irradiated samples will not be allowed directly into the LLCF because of contamination worries. Additional needed surface chemistry capabilities include optical emission spectroscopy, chromatography, inductively coupled plasma mass spectrometry (ICPMS), and standard chemical analysis. Clean rooms will be provided for high-sensitivity measurements, such as those with ICPMS. A surface contamination laboratory is needed for optical and x-ray fluorescence measurements of surfaceswipes from underground experiments. None of these facilities requires an underground location. The surface chemistry laboratory is an essential complement to the LLCF.

Space for detector development – important to many NUSEL activities – is also crucial to the LLCF, providing a dedicated area for developing new counting techniques that will later be incorporated into the LLCF. This is an essential part of the proposed facility: we envision the LLCF as an evolving, dynamic facility that not only serves the community, but also makes innovative advances in experimental technologies. In this way the diagnostic capabilities of NUSEL will progress as new experiments make increased demands.

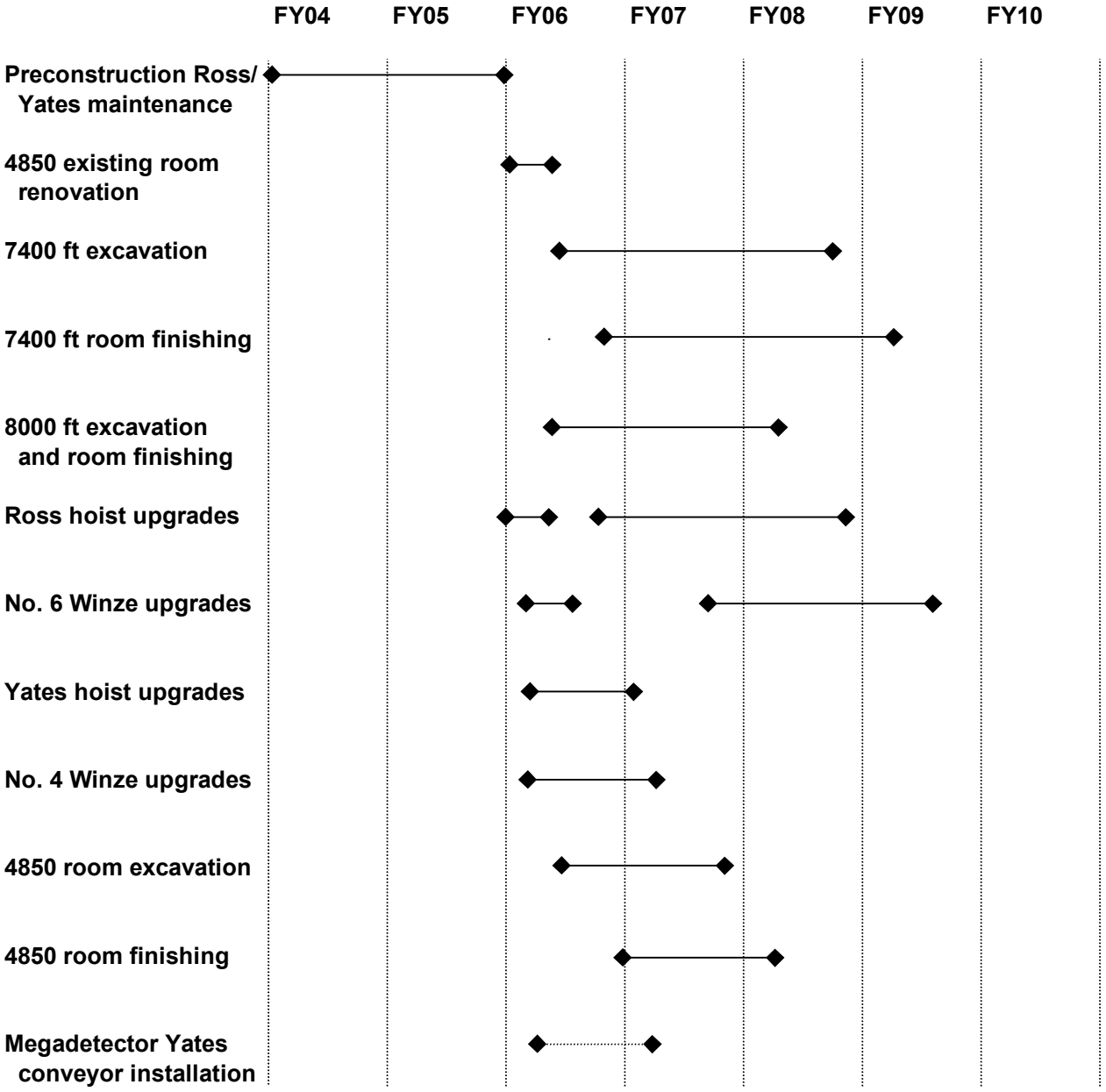
We have budgeted two full-time staff members for the LLCF. We anticipate that the staff will in fact be larger because the counting specialists will share their time between the LLCF and experiments needing counting expertise. This would be helpful in keeping the LLCF responsive to the needs of the experimental community.

I.8 Costs and schedules for underground development: The detailed costing for this Reference Design Project Book have been completed for underground developments, not yet including costs for finishing the experimental halls or for instrumenting the low-leveling counting facility, as noted above. Thus the spreadsheets given in the appendices will be updated when these engineering studies are completed.

The master schedule spreadsheets and summary of costs are the synthesis of the engineering plans given in the various appendices. These cover the specifics of the upgrades on the Ross shaft/hoist, the No. 6 shaft/Winze, and No. 4 shaft/Winze, and the Yates shaft/hoist; pump column and ventilation conversion; and the various underground excavations, including rough excavation, shotcreting, concrete floors, and rock bolting.

The next figure summarizes the schedule implicit in the master sheets. The schedule assumes an FY06 start.

ANTICIPATED UNDERGROUND CONSTRUCTION SCHEDULE



II.Facilities Development Plan: Surface Campus.

II.1 General issues: As discussed above, NUSEL underground activities will be centered on the Ross and Yates shafts. Early excavation will be done through the Ross, then terminated. Future excavations (including the megadetector) will be done through the Yates. Mine maintenance activities will be carried out through the excavation shafts. This proposal advocates a Gran Sasso-caliber surface laboratory building, so that NUSEL-Homestake can host major experimental activities and collaborations on site. (This departs from our conceptual proposal where we advocated a five-story underground office building approximately equal in square footage to the surface science campus. We no longer believe this is a cost effective strategy.) Ideally that building would be placed near the scientific shaft (the Ross shaft). It is anticipated that the site will include a Visitor Experience Center as well as a museum/archive. These efforts require coordination and partnership with the city of Lead and the state. Several office building and other usable structures occupy parts of the site – preserved at our request.

Discussions with Homestake/Barrick on proposed site boundaries have occurred, though no resolution is possible before an agreement for transferring the site is obtained. We would ask for only a fraction of the available surface land (though all of the subsurface workings). Some of the important surface site boundary issues include:

- NUSEL would like to control all shaft accesses to the subsurface. This includes the Yates, Ross, Oro Hondo, B&M, and No. 5 shafts, and the portal entrances for the Kirk Power Tunnel, the Kirk Powder Tunnel, and the Ellison Fan Tunnel.
- It is quite likely that some future experiments, e.g., ones using cryogenic detectors, will require additional ventilation shafts with surface access. Thus it would be desirable for NUSEL to own all surface areas immediately above the usable underground workings.
- NUSEL underground excavations will be for civil purposes, not mining. It is not yet clear to us what this implies about the surface rights required about these excavations. While the simplest solution would be to contain all such excavation within the site boundary (e.g., the point made above), if this is not possible, some transfer of rights might be needed.
- Experiences of existing national laboratories demonstrate, over laboratory lifetimes, that surface space often becomes confining. Thus a surface footprint larger than that needed for the initial program would be prudent.

The conclusion is that the surface footprint should include all land directly about the underground workings, with the southern boundary extending south to the No. 5 shaft. Two isolated areas that would be desirable to acquire are the Ross parking lot and an area around the B&M shaft. The proposed boundary is shown in the Figure. Note that the northern boundary is constrained by the town and by the area that formerly housed the mill, while the western boundary is constrained by the town. Thus these boundaries, apart from possible minor adjustments, are fixed. The southern boundary extends beyond Whitewood Creek in order to include are surface areas above the underground drifts. Within this site, steep slopes and other topographic challenges render much of the requested land of limited use.

This proposal excludes the Open Cut, the proposed dump for waste rock from the megadetector excavation. Thus the agreement with Barrick must provide permission for this use. Other items we have marked for future discussions with Barrick include the inclusion/exclusion of the Yates rock dump, waste facility, and Mill reservoir within/from the NUSEL boundary; the inclusion of private or leased buildings within the property boundary; and possible steps to enhance public access to the site. These issues will require detailed discussions between Barrick, the new landlord (the state of South Dakota), and the collaboration at the time a site agreement is reached.

II.2 NUSEL boundary and development possibilities: Below we present a series of maps of the Homestake complex, with notes on building sites and other issues. These are referenced several

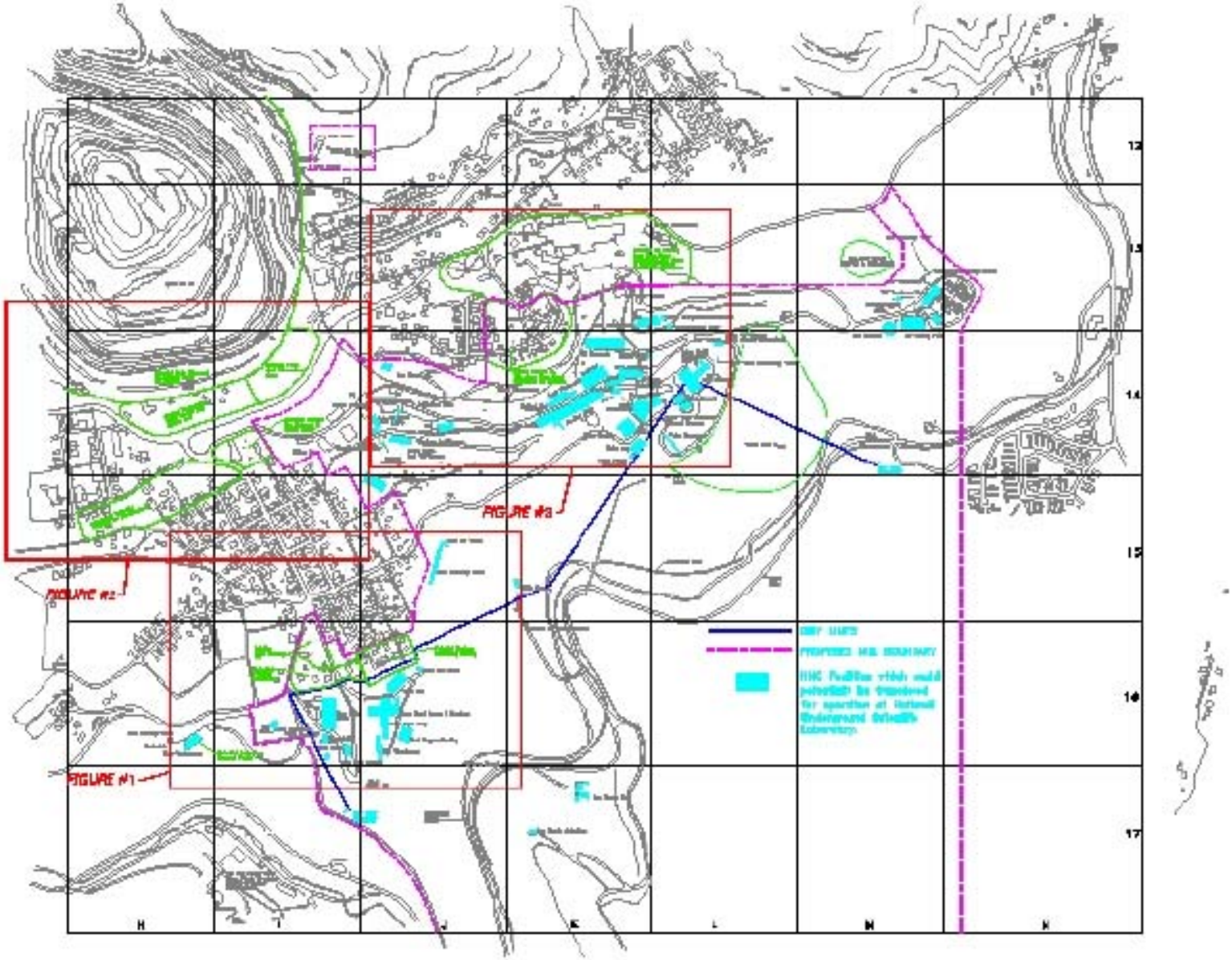
times in the WBS narrative.

Figure E.17: This large-scale map of the Homestake site and surrounding areas gives the proposed NUSEL boundary that was under discussion with the Homestake Corporation at the time it merged with Barrick Gold Corporation. Since that time, site discussions have been on hold while site transfer issues are being negotiated. In the first figure three areas are outlined in red, corresponding to the larger-scale Figures E.14-16.

Figure E.18: (Marked NUSEL Figure #1) This figure shows the area around the Ross head frame that would be the first choice site for developing the main surface science laboratory. A parcel covering approximately two acres is available at the top of Mill Street near the Ross head frame. This site could be prepared for building by relocating or demolishing some homes, and by cutting and grading this hill site to create a level building site. The rock and soil from the excavation could be used to fill a nearby depression, creating an additional level building site for other facilities or parking. The existing Ross parking lot is shown along with the extension that could be created by regrading. Several of the buildings in the Ross development will be retained for NUSEL. For example, the Ross dry facility has underground access to the Ross head frame and could easily be converted to additional laboratory or office space.

Figure E.19: (Marked NUSEL Figure #2) This figure shows an area between the Ross and Yates head frames and very near the open cut – the site of the original Homestake claim. Immediately next to the open cut is the site of the Homestake visitor center, which runs surface tours much of the year, and its parking lot. There is a substantial area outlined in green, outside the NUSEL property boundary, that could be used for the NUSEL Outreach Center. This location, a 1.5 acre site adjacent to Highway 85 and Mill Street, has good exposure along the highway, ample parking, and is located near the road that will serve the main Ross facility. The site is currently vacant. Placing the NUSEL Visitor Experience Center near the Homestake visitor center would likely be viewed very favorably by the Lead development officials. Also outlined in green is an additional six acres across from Mill Street that is available for new facilities (NUSEL or commercial) and for parking. Before such use demolition of some existing structures and grading would be required.

Figure E.20: (Marked NUSEL Figure #3) This figure shows the area around the Yates complex, which will serve as the main mining hoist for NUSEL. The large area outlined in green was the former Homestake mill area, which we propose leaving outside the NUSEL boundary. All buildings in this area have been demolished during the Barrick reclamation. There is a second area in green, located within the NUSEL boundary, occupied by homes that have been purchased by Barrick. Very near the Yates head frame is the mine office and the Yates dry facility. The mine office building is very serviceable. It will likely be used initially as temporary office space, and it and the Yates dry facility might prove valuable as an assembly area during megadetector assembly, particularly if the Yates is the hoist used by the experiments during construction. (We discussed elsewhere the possibility that the Yates would be adapted to this use, giving this experiment a dedicated hoist.) The foundry building is in good shape and is interesting architecturally. The renovation of this building for the museum/archive has been discussed.



NATIONAL UNDERGROUND SCIENCE AND ENGINEERING LABORATORY SITE PLAN

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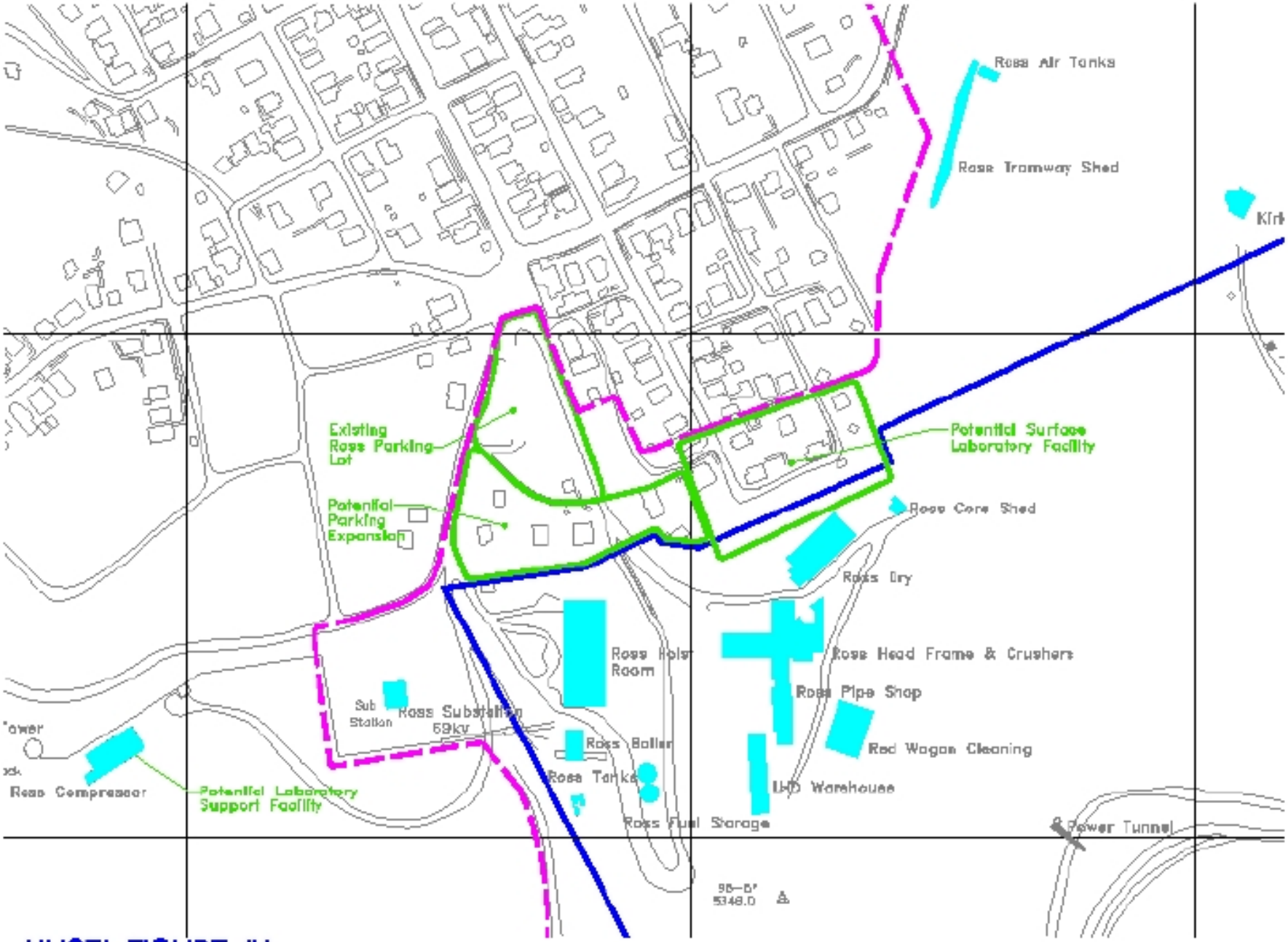

NUSEL FIGURE #1

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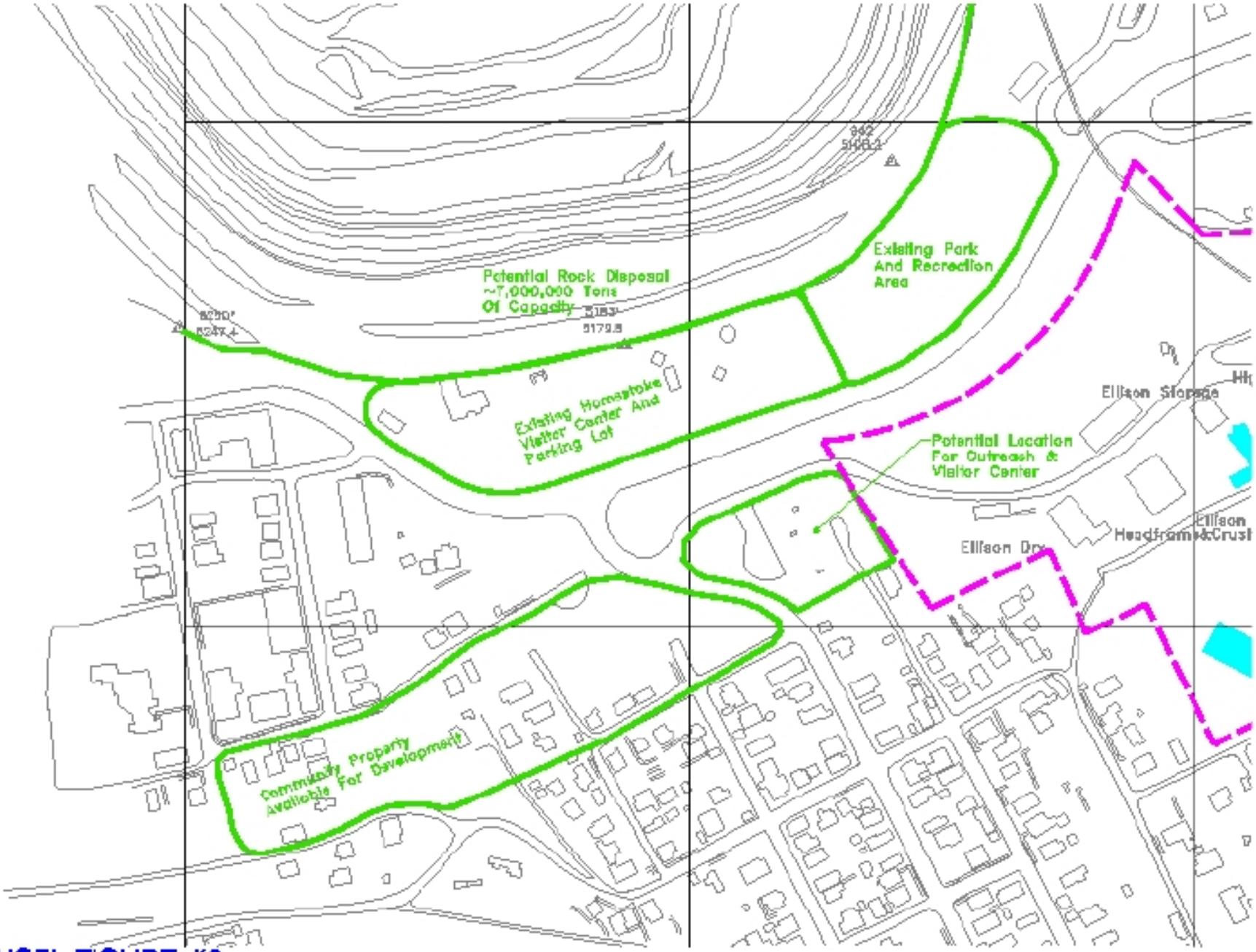

NUSEL FIGURE #2

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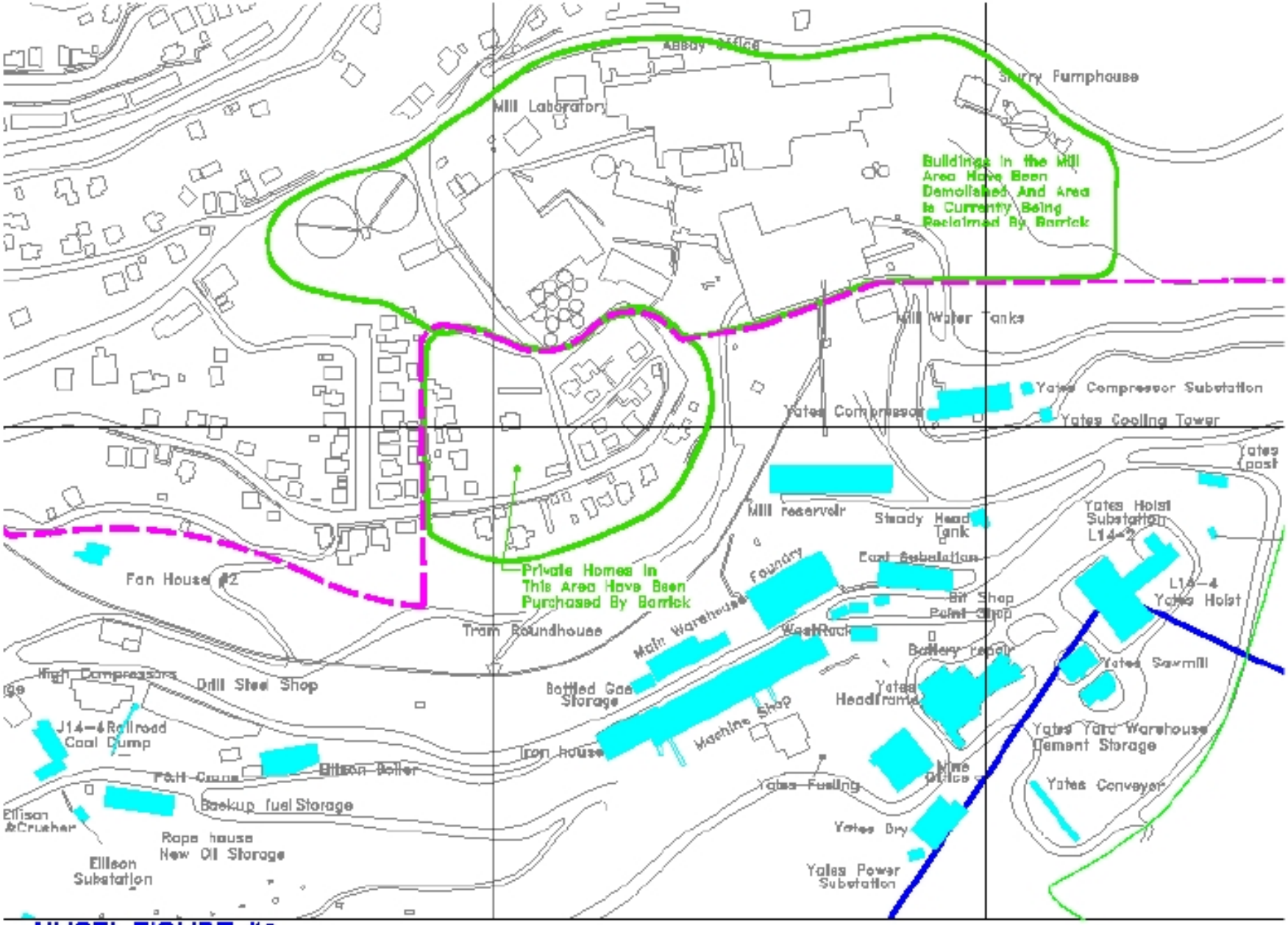

NUSEL FIGURE #3

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II.3 NUSEL surface facilities: renovations. Discussions were conducted with the Homestake Corporation about the extent to which existing buildings might be preserved and adapted to NUSEL needs. However, the surface campus is the least well developed part of the current Reference Design because, in the absence of a site agreement, we were unable to proceed to the next step, an inspection by a civil engineer. That is, we do not have a professional assessment of the state of repair and potential renovation costs of existing buildings. **Thus the Baseline Definition must include a reassessment of this section based on such an engineering inspection: this reassessment could in turn impact the new space we will build.**

NUSEL activities will be concentrated in two areas, around the Ross and Yates complexes depicted in Figs. E.18 and E.20, respectively. Most science operations will be carried out in the Ross complex and most excavation activities will focus on the Yates. The Ross complex will likely undergo major renovations, including the addition of a new surface laboratory. The changes in the Yates complex will be less extensive, as its use will continue to be mining. As we have noted in connection with Figure E.19, additional areas will be used for public outreach, and we anticipate that the operations of the outreach areas will involve state and local partnerships.

There are many potentially serviceable buildings that Barrick intends to make available to NUSEL. As noted above, none of these has been fully evaluated, nor have anticipated maintenance costs been estimated (often a key factor is deciding between renovation and new construction). Renovation would include new HVAC systems for all needed buildings along with structural reconfiguration, as needed. Depending on the future cost analyses, it is possible that existing buildings could meet many (and perhaps most) NUSEL needs. A partial list of existing structures potentially important to NUSEL includes:

- Ross headframe and crushers: required for underground operations and rock handling during initial excavations; after the Ross becomes the scientific access, the crushers will be removed.
- Ross hoist room: required for underground operations.
- Ross dry facility: potentially convertible to additional laboratory or office space – has underground access to the Ross head frame.
- Ross LHD warehouse: usable as a facility maintenance warehouse.
- Ross core shed: candidate site for a NUSEL operations office.
- Ross boiler: used to heat all buildings at the Ross complex.
- Ross electrical substation.
- Ross compressor: most of the underground civil excavation will utilize skid-mounted compressors. A dedicated compressor for science activities will be installed at the subsurface facility. Thus the Ross compressor facility can be utilized for other purposes. As it has an overhead crane, a warehouse is one potential use.
- Yates head frame and crushers: required for underground operations.
- Yates hoist room: required for underground operations
- Yates dry facility: potentially convertible to additional laboratory or office space – has underground access to the Yates head frame.
- Yates east electrical substation.
- Mine office (Yates): usable as initial office space; could be used as assembly or office space during megadetector construction.
- Foundry: candidate building for museum/archive. Brick construction requiring major renovations.
- Yates machine shop: candidate building for museum/archive or other outreach. Wooden building requiring major renovations.
- Oro Hondo fan: will be adapted to NUSEL ventilation needs.
- Oro Hondo electrical substation.

The Ross pipe shop is also very convenient to the Ross head frame. We expect to demolish this building and replace it with a new receiving and assembly facility. This new facility would

incorporate clean assembly space, convenient to the Ross, the science access to the underground campus.

II.4 NUSEL surface facilities for science. The discussion above establishes the existence of convenient, buildable sites on the proposed campus and of a variety of existing structures that could prove useful to NUSEL. This section deals with the surface campus needs of NUSEL, which we have based on Gran Sasso and similar laboratories. Gran Sasso is an excellent model for NUSEL-Homestake because this laboratory was built in a region of Italy without strong research universities. Because of this, and because the INFN wanted Gran Sasso to serve as an international center for underground science, the laboratory included from the outset significant infrastructure to support visiting scientists. Generally Gran Sasso gets very high marks from its user community for the support it provides. The present proposers feel that the Gran Sasso model is the correct one to follow in the US, particularly as the Homestake site is in a region of the country where the existing scientific infrastructure is somewhat underdeveloped.

Below we describe the procedure by which we estimated the facilities and space the upper campus should provide. The needs are better defined than the cost, we believe. The lack of site access is a general source of uncertainty in defining costs for the surface campus (and is the reason we have employed a 40% contingency for this development in the WBS). Until we can access the site to inspect existing buildings and construction sites, costs will remain somewhat uncertain.

While our group used Gran Sasso, the Sudbury Neutrino Observatory, and KamLAND as benchmarks for infrastructure, space, and manpower needs, there are obvious assumptions that must be made about the size of the NUSEL-Homestake facility to scale to these other projects. Key factors are the number of simultaneous experiments and the average number of scientists on campus – we will return to these assumptions at the end of this section, when our projections for Homestake are made.

Our information on Gran Sasso came from the Bahcall Committee Technical Subcommittee site visit, presentations at NESS02, and several public presentations by Gran Sasso Director Sandro Bettini. Gran Sasso maintains a web site that provides considerable detail on space and buildings.

Information on SNO and KamLAND comes directly from the collaborations, as several of the scientists belong to the NUSEL-Homestake Executive Committee.

Using Gran Sasso as a model, but taking into account certain infrastructure needs of SNO and KamLAND, we conclude that the following functions would be highly desirable and perhaps essential for a national facility:

- Surface and underground machine shops. (Note our underground laboratory plans include both a clean machine shop and an outside machine shop, with the latter located in the existing shop area on the 7400-ft level.) The underground facilities will help scientists avoid unnecessary trips to the surface for machining. But the surface shop will be the main facility, critical to detector module assembly and other preparatory activities.
- Surface electronics laboratory.
- Surface and underground assembly facilities, including clean room facilities.
- Plating, glass, and high vacuum technology shop.
- Stores and receiving.
- Chemistry facilities.
- Surface support for the low-background counting facility, as described elsewhere in this document.
- Cryogenics support.
- Computing and data acquisition support facility.

While Gran Sasso is generally praised for its support and organization, the most frequent complaint we heard was inadequate underground support, which then costs time by requiring travel back to the surface laboratory**.** (The Gran Sasso surface laboratory is about a 10 km drive from the underground halls.) This complaint is common to most of underground laboratories. For example, a simple mechanical adjustment to a steel member typically involves a three-day delay at SNO: 1) discovery of the problem and shipment to the surface; 2) locating machine facilities and alteration of the component; and 3) cleaning, shipment underground, and installation. **An issue flagged for the Baseline Definition is the adequacy of the underground support we have provided in this proposal.** Note that chemistry and copper electroforming facilities are included in the Low Level Counting Facility (to be discussed below). We want to reexamine the need for improved underground electronics capabilities.

In addition to the specific facilities mentioned above, NUSEL administration would provide the usual functions of safety, security, library services, shipping and receiving, and visiting scientist liaison and support functions. Some of these activities are discussed in the project management section (in connection with the NUSEL offices that will shoulder these responsibilities).

What is the size of the community NUSEL will serve? Gran Sasso supports between 450 and 600 scientists each year: the lower number is the visitor count, while the higher corresponds to all of the collaborators listed on experiments that are underway. On a typical day there are approximately 200 individuals on site, including contractors. (This number is consistent with the number of lunches the cafeteria serves each day.) There are on the order of 10,000 visitors/year to Gran Sasso, with associated tours and public outreach being a significant focus for the local administration. We expect the NUSEL outreach program to be at least a factor of ten larger.

Figure E.17: Aerial view of the Gran Sasso facilities.

The Gran Sasso surface facilities total approximately 110,000 gross square feet (gsf). The laboratory has had plans to expand by about 60%, as current facilities are oversubscribed, but these plans are on hold due to recent environmental issues that have affected laboratory operations.

The space estimates we have made are summarized in the table below. The gsf/asf is the approximate gross/assigned square feet ratio appropriate for the designated types of construction. The Gran Sasso numbers are gsf.

Use	Assumptions	gsf/asf	gsf	Gran Sasso (est)
Visiting scientist office space	100 asf/visitor; 100 visitor spaces	2.0	20,000	12,000 (building 3 story addition, too)
Scientist and postdoc office space	30 scientists; 160 asf/scientist	2.0	9,600	8,500
Administrative and support staff space	60 personnel; 130 asf/staff member	2.0	15,600	22,200
Auditorium, meeting rooms, library, cafeteria	14,500 asf	1.6	23,200	21,700
Labs; stores; chem/glass/electronics labs; computing	18,000 asf	2.0	36,000	28,500
Assembly, receiving, staging, materials storage	45,000 asf	1.25	56,250	17,000 (GS says their existing space much too small)
Subtotal science			160,650	109,900
Visitor Experience Center	40,000 asf	2.0	80,000	
Museum/archive	10,000 asf	2.0	(20,000)	
Subtotal outreach			80,000 + (20,000)	
Total			240,650+ (20,000)	

Table: Projected space needs for NUSEL-Homestake and estimated Gran Sasso usage.

NUSEL-Homestake would provide 40 shared visitor offices, assigned flexibly to collaborations doing work on sight, and 30 offices for the permanent scientific staff and postdocs. We have planned for 15 scientists and 10 postdocs, estimating that perhaps two-thirds of these will be in physics and the remainder in earth science/engineering. The estimated auditorium, meeting rooms, library, and cafeteria space matches closely that of Gran Sasso. Gran Sasso's large auditorium accommodates approximately 200, allowing the laboratory to host mid-sized conferences like TAUP (the IUPAP meeting in underground science). (The city of Lead is currently rebuilding its historic opera house, an off-campus venue that could be used by the laboratory for larger conferences.) Gran Sasso has a few small seminar and conference rooms, and about 10,000 gsf of cafeteria space. The NUSEL-Homestake estimate of special laboratory space, electrical/chemical/glass laboratories, stores, and computing/data acquisition labs is somewhat larger than Gran Sasso's, but reflects the earth science needs and the special chemistry facilities that will be needed to support the advanced NUSEL low-level counting effort. NUSEL detector assembly, staging, and receiving space is much greater than that provided by Gran Sasso. However, we anticipate, given the scale of some of the experiments NUSEL will tackle and the distances collaborations will travel, that a great deal of assembly will be done on site. Gran Sasso's modest assembly space is also partially attributable to the horizontal access, which

makes assembly at a remote location and transportation by truck to the laboratory more convenient. We consider the 56,000 gsf estimate to be a realistic estimate for a facility like Homestake. There is a good possibility that much of the detector assembly space will come from renovated Homestake buildings. But our inability at the present time to assess the quality of the available space makes it difficult to guarantee that this is the case. **In the WBS we assume all space is new, to guard against underestimating costs.**

II.5 NUSEL surface facilities for outreach. The Table also provides an estimate of 40,000 asf (80,000 gsf) for the space needed for the Visitor Experience Center described in the Science Book. This space includes exhibit space, flexible "classroom-type" space, workspace for the staff, auditorium space for multimedia, and the center's store. The space estimate is based on a projected visitor load that we anticipate could grow to 400,000/year, with the summer peak tourist season accounting for more than half of the total. Space/visitor ratios for existing centers vary somewhat. For example, the Museum of Science and Technology in Tampa provides 210,000 gsf for 645,000 visitors/year; the new addition of the McDonald Science Center of just 12,000 gsf is planned to allow visitor growth from the current 130,000/year to 250,000/year. A science center with a size and focus similar to that planned for Homestake (a mix of tourists and school groups) is the Lawrence Hall of Science in Berkeley, which handles 250,000 visitors/year in a facility that one administrator estimates to be 60,000 gsf. The 80,000 gsf used in this proposal is typical of centers with capacities up to 400,000 visitors/year.

The table also shows 20,000 gsf provided for the museum/archive. This construction is not currently funded in this proposal (which is why this item is set off by parentheses in the Table). Early discussion between the Homestake Corporation and us focused on private arrangements that might finance renovation of space for this facility and subsequent operations. The foundry building is one possible building of the requisite size. The archive function of the museum/archive is important to NUSEL earth science because Homestake maps and mining records will be valuable in site characterization: the archive has an important science function.

III.Operations. This section deals primarily with the personnel required for NUSEL operations. Most nonpersonnel operations costs are addressed in the Work Breakdown Structure, not here.

III.1 Site operations and maintenance. Facility operations costs at Homestake are very well known because of the long history of successful mining operations.

The facility operating costs divide into personnel and other costs. The needed personnel are:

Operations personnel	***Year-five FTEs required***
Operations/maintenance manager	1
Safety/environment manager	1
Administrative manager	1
Mine engineer/geologist	2
Environmental engineer	1
Safety technician	2
Surveyor/engineering technician	1
Operations/shaft supervisors	2
Secretary/clerical	2
Accounting/purchasing	2
Shaft maintenance staff	12
Hoist operators	6
Yard/warehouse staff	2
Mine construction staff	2
Total	***37***

The first 15 staff positions are technical, supervisorial, or administrative. The remaining workers are the operators for the hoists, shafts, crusher, yard/warehouse, and construction. The effect of the hoist modernization described in I will be to reduce operator needs by more than a factor of two, from 48 to 22 FTEs, by year five. The needs in year five are six hoist operators, 12 shaft maintenance workers, two yard/warehouse workers, and two mine construction workers. The resulting year-five FTEs and associated personnel costs for operations are 37 FTEs and $2.34M (fully loaded). The detailed spreadsheets giving the costs over the five-year grant period are presented in the appendix. **These personnel are under the Associate Director for Construction, Facilities, and Operations,** as described in the Management Plan.

The other operating costs are based on very recent operating experience at Homestake. In general these costs may somewhat overestimate future operating costs because the NUSEL footprint will be reduced. The table shows these costs total $2.479M/y, yielding a total year-five operations cost of $4.82M. The personnel site operations and administration spreadsheets included in the appendix show how the personnel portion of these costs evolves as the hoist modernization is implemented.

Operations activity	***Overhead and fixed (annual)***
Haulage	$150,000
Other mine operating	$147,000
Mine general	$279,000
Ventilation/cooling	$691,000
Hoists/shafts	$507,000
Waste water	$88,000
Administration/general	$617,000
Total	***$2,479,000***

Table: Non-personnel Homestake fixed operations costs.

In year five, site maintenance requires 21 FTEs, as listed in the table below. The year-five loaded costs are $1.34M/y. The detailed spreadsheets are presented in the appendix**. These personnel will also be the under the Associate Director for Construction, Facilities, and Operations**.

Site maintenance activity	***Required FTEs***
Mechanical plant engineer	1
Electrical planner/supervisor	2
Field maintenance supervisor	1
Maintenance planner	1
Surface electrician	1
Underground electrician	3
Maintenance technician	4
Field maintenance	4
Mine maintenance (ground control/track)	4
Total	***21***

As was done in Homestake operations, mine safety will be handled by a crew selected from the workers listed above, and especially trained. Homestake's crew has won many national awards.

III.2 Science operations. Science operations needs were evaluated by examining what has been needed at Gran Sasso, KamLAND, and SNO, with adjustments to reflect the special requirements or goals of NUSEL-Homestake. The basic information is summarized in the table:

Category	***NUSEL FTE needs***	***Baseline FTEs***	***Comments***
Director (0.7), Assoc. Directors (2)	2.7		
Senior, associate, and assistant scientists	12	10 (Gran Sasso)	Homestake includes EarthLab effort
Postdocs	10	30 (Gran Sasso)	
Graduate students	10	?	
Undergraduates	5	?	
Subtotal: scientists	***40***		
Librarian/publication	2	2 (Gran Sasso)	
Machine shop	3	3 (Gran Sasso)	
Undergrd. machinist	1		New to NUSEL
Draftsman	1	1 (Gran Sasso)	
Electronics	3	1 (SNO)	
Glass	1		
Low-level counting	2	1 (SNO)	
Chemistry	5	5 (SNO)	
Computing	5	5 (SNO)	
Receiving	2	1 (SNO)	
Administration	4	30 (Gran Sasso)	Gran Sasso number is total lab administration
Subtotal: support	***29***		

These personnel are under the Associate Director for Research.

III.3 Detector operations. The following personnel are required for detector operations:

Category	***NUSEL FTE needs***	***Baseline FTEs***	***Comments***
Assistant manager	1		
Large assembly/staging	3	1 (Gran Sasso warehouse)	Vertical access → additional needs
Underground assembly/staging	3	3 (SNO carwash cleaners)	
Transportation	1	0.5 (SNO)	
Maintenance machinist	2	0.5 (SNO)	
Professional operators	3	2 (SNO)	
Mechanical engineer	1	1 (SNO)	
Process engineer	1		
Secretary/clerical	1		
Total	***16***		

These personnel are under the Associate Director for Research.

III.4 Administrative operations. Administrative operations describe those administrative activities within the **Administrative Office** (see the project management organizational chart) within the Director's office.

Category	***NUSEL FTE needs***
Administrative Office director	1
Personnel/benefits officer	1
Financial officer	1
Visitor liaison officer	1
Public information officer	1
Secretary/clerical	4
Security guards	8
Total	***17***

This office will also oversee various activities that are handled by outside contracts, including the cafeteria, custodial services, underground (MSHA) and other safety training, and possibly administering Lead housing for visitors. This office would also support the Associate Director for Construction, Facilities, and Operations in outside contract activities, including contracts for mining and for facilities construction.

III.5 Outreach/education operations. Outreach and education are also positioned as a **separate office within the NUSEL directorship**, which will allow the Director to take a personal role in supporting this office and its director. This could be helpful in the formation of collaborative outreach and education agreements with South Dakota, regional, and national organizations.

Category	***NUSEL FTE needs***
Laboratory Director	0.2
Director, Education/Outreach Office	1
Manager, K-12 Education	1
Manager, Visitor Experience Center	1
Manager, Computing and Networking	1
Display design staff	3
K-12 education staff	3
Visitor experience center staff	6
Web and interactive display staff	4
Secretarial/administrative	2
Total	***22.2***

III.6 Management operations. Our working assumption is that a nationally recognized nonprofit university management group, such as URA, UCAR, or SURA, will manage NUSEL-Homestake. (AUI is another possibility.) This group will maintain an office on site to work with the laboratory Director's office and with the NUSEL landlord (the state of South Dakota). It will be responsible for organizing periodic construction and operations reviews, for guaranteeing that all agency reporting requirements are satisfactorily addressed, and for addressing state reporting requirements (particularly those associated with land stewardship). The personnel requirements

are summarized below:

Category	***Management FTE needs***
Laboratory director	0.1
Site Office director	1
Site office adm. assistant	1
Off-site administration	0.5
Total	***2.5***

IV. Site Development: A small staff for site development – science and education/outreach – will reside within the Director's office. This group will also work closely with Lead and other regional officials on issues such as site access, traffic impacts, etc., that affect NUSEL science or outreach.

Category	***NUSEL Science FTEs***	***NUSEL Outreach FTEs***
Manager	0.8	0.2
Assistants	1.6	0.4
Secretarial/clerical	0.8	0.2
Total	***3.2***	***0.8***

V. Proposed Management Plan*:* The collaboration looks forward to working with the National Science Foundation in formulating a management plan for NUSEL-Homestake. To start this process, the scientists in our collaboration offer a plan we believe has considerable merit.

General structure and overall principles: We believe that a recognized, stable, nationally representative management body is important to the success of this project:

- The underground science community has not previously united behind a national initiative of this sort. The current competition for NUSEL has produced four proposals. We believe a nationally prominent, inclusive management body could help unite the community behind the winning proposal. The current proposers would be comfortable stepping aside, in favor of such an organization.
- NUSEL will be a challenging project to manage successfully. While submitted as an MRE, the laboratory probably will operate for decades. As the NRC Quarks and the Cosmos report stressed, the NSF and DOE will each support major NUSEL projects. NUSEL will also host international projects, important national security work, and industry scientists. A management group with experience in dealing with a spectrum of funding sources is needed. The project is unique in combining two rather distinct disciplines, physics and earth science.
- An agreement with the site owners, Barrick Gold, is essential. Barrick has agreed to donate the site, but has placed conditions on the transfer, some connected with potential liabilities. The state of South Dakota has made a major commitment by agreeing to accept ownership of the needed portions of the mine (the underground workings and certain surface areas and buildings). Despite these steps, a final agreement is not yet in hand. We believe an experienced management group could help the state and the NSF put into place the insurance and trust fund guarantees that would address Barrick's concerns about government use of its property, while also assuring South Dakota that science uses of the mine will not adversely affect its new property. An established management group would address a key concern in the current negotiations, how to guarantee the longevity of any agreement.

A cooperative agreement between the NSF and an experienced nonprofit management group would provide the stability and experience necessary for NUSEL's success. There are several

groups that might satisfy the requirements, including AUI, AURA, and URA. We concluded that each of these organizations is capable of providing high-level management for NUSEL, but found that URA offers special advantages:

- URA has a 38-year record of successful management. Its broad charter to "…acquire, plan, construct, and operate machines, laboratories, and other facilities, under contract with the Government of the United States or otherwise, for research, development, and education in the physical and biological sciences… and to educate and train technical, research, and student personnel in said sciences" encompasses NUSEL's activities. Recently URA has become increasingly involved with particle astrophysics and astronomical sciences relevant to NUSEL, through participation in the Sloan Digital Sky Survey, the Pierre Auger Cosmic Ray Observatory Project, and the dark matter experiment CDMS II at the Soudan Underground Laboratory.
- Almost all of the institutions prominent in NUSEL physics, including those interested in other NUSEL proposals (e.g., UC Irvine, the University of Minnesota, and New Mexico State University), can be found among URA's 90 US member universities. Thus URA is naturally positioned to unify the community behind the proposal NSF selects.
- URA includes member universities from three other nations, Canada, Italy, and Japan. These nations are host to the three most prominent underground laboratories, SNO, Gran Sasso, and Kamioka. (Also, the NUSEL-Homestake collaboration includes researchers from Japan (Osaka University) and Canada (University of Toronto). The University of Toronto, a URA member, has close ties to Barrick Gold.) Thus URA addresses the collaboration's concerns for strong relations with laboratories and scientists outside the US.
- URA will create a separate governing board to oversee NUSEL.
- A major goal of our proposal is the stimulation of new research and education endeavors in South Dakota and neighboring Northern Great Plains states. URA has expressed its desire to help in these efforts. URA will welcome regional research universities as new URA associate members. The management plan calls for South Dakota and regional universities to have a significant presence on URA's NUSEL Board of Overseers. The Board of Overseers' Environment, Safety, and Health Committee would meet regularly with the cognizant state officials, so that the state can verify that all aspects of the site's use agreement are respected. The management plan calls for state and regional organizations to play the leading roles in education and outreach, proposing Memoranda of Understanding to delegate these responsibilities. Finally, URA will be supportive of NUSEL plans to partner with regional universities, through NUSEL's university associates, in efforts to enhance research and education.

The Organizational Chart below shows a possible management structure. Below we describe its basic elements:

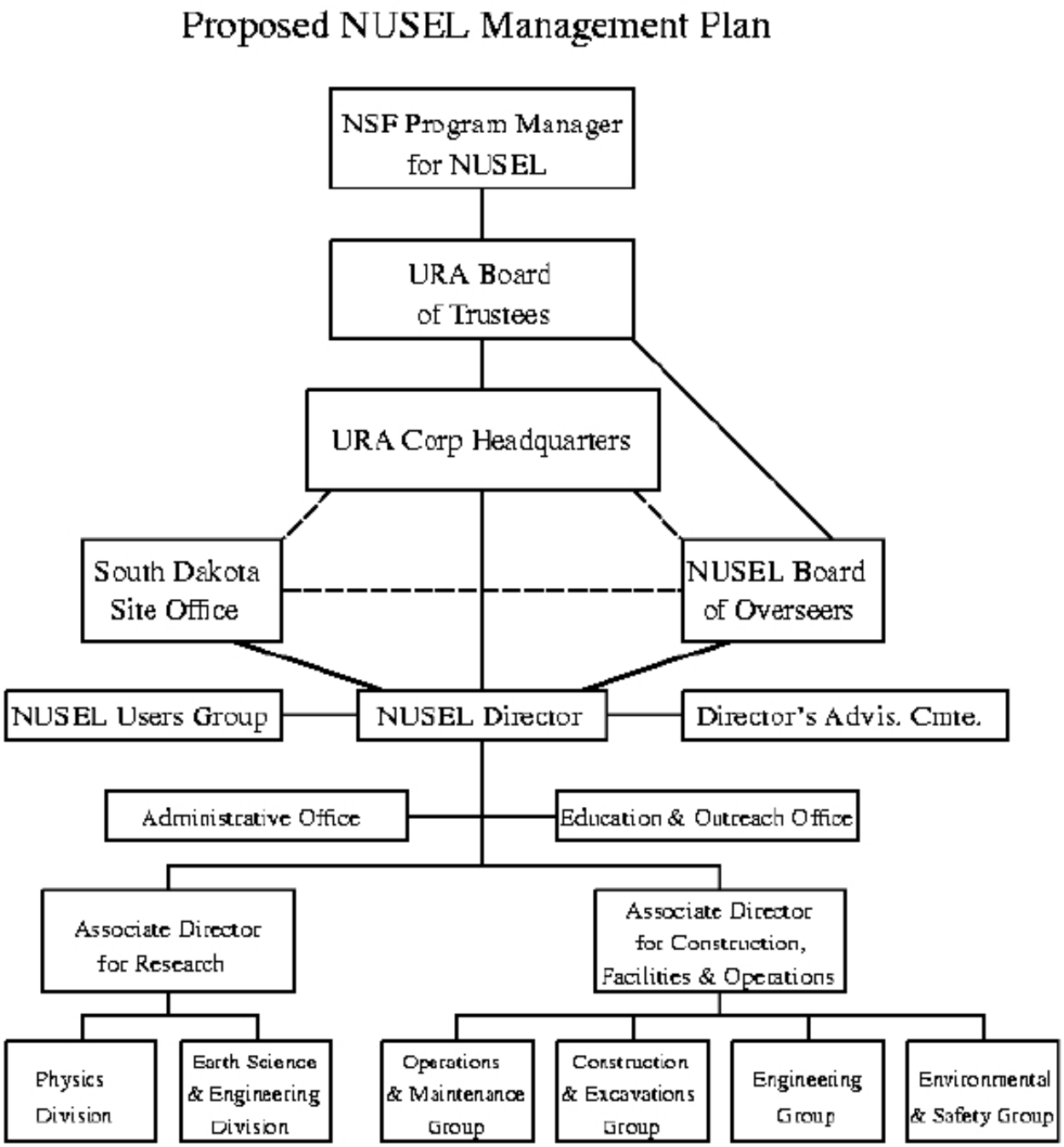

Figure E.21: A possible management plan for NUSEL-Homestake.

- NSF would administer NUSEL through a cooperative agreement with URA. URA has suggested an internal management scheme similar to that for FermiLab with an independent Board of Overseers. The Board structure would include Science; Administrative and Audit; and Environment, Safety, and Health Committees, as well as external and visiting committees for program review. The Board will appoint the NUSEL Director, with NSF concurrence, after conducting an international search. The Board would also schedule periodic project management ("Lehman"-style) reviews of NUSEL during and after construction, to ensure that the project remains on schedule and on budget. If a management agreement were put in place soon after site selection, URA would like to be active in helping the current collaboration join with others in the underground science community in completing the final proposal update.

  Given the breadth of NUSEL science and the need for both science and large-project advice, an appropriate size for the Board of Overseers would be about 15. Of these, URA would reserve four places for regional scientists, two from South Dakota and two from the neighboring EPSCoR states. The remaining appointments would also take into account geographic balance and any need for international representation. In addition, URA would welcome research universities from the Northern Great Plains into the Association. (Among South Dakota and its EPSCoR neighbors, the University of Nebraska is currently the one URA member institution.)

  The University of Washington submitted the NUSEL-Homestake proposal. In this update the UW has designated URA as the performing institution. If URA were designated by the NSF as the managing entity for NUSEL, the UW intends to turn over all responsibilities to URA. It would cease to have any role other than as one of the member universities of URA.

  URA will create a local office in South Dakota. It will provide any needed assistance to the Director during NUSEL's first year, when Laboratory budget and personnel procedures are being formulated.

- We assume South Dakota will act as custodian of the Homestake site, designated the Site Office in the organizational chart. URA and the State of South Dakota, in full consultation with the NSF, will negotiate a mutually satisfactory site use agreement. It will work with the NSF and other agencies supporting NUSEL science projects to put into place use and decommissioning agreements addressing all state concerns connected with the scientific use of the site. The state Site Office and/or Department of Environment and Natural Resources will consult closely with the URA Board's Environment, Safety, and Health Committee. URA and the State of South Dakota would agree on the level of funding needed to support the State's Site Office, and that funding would be provided to to the State through the site agreement.

- URA, after an international search and with the concurrence of the NSF, will appoint the NUSEL Director. The Director will be responsible for all day-to-day decisions affecting NUSEL operations. TheDirector will appoint an outside, independent Advisory Committee, representing the broad community that NUSEL serves (including university, national laboratory, and international scientists). As with the URA Board of Overseers, four members of the Advisory Committee will be chosen from South Dakota and regional EPSCoR institutions. The NSF, URA, and Director, by mutual agreement, will choose the initial group of Committee members. Members will serve three-year staggered terms. The Committee is intended as an independent community body that provides advice to and otherwise assists the Director.

A NUSEL's Users Group will be formed to provide advice to the Director on user needs. As in other national laboratories, the Users Group will have its own governance and select its representatives. The chair of the Users Group will be an ex officio member of the Director's Advisory Committee.

- Two Offices and two Associate Directorships are positioned under the Director. The Administrative Office will be responsible for all personnel functions, purchasing and procurement, accounting, legal review, and public relations. Purchasing functions include competitive bid preparation, contract agreements, legal review, the documentation and accounting interface, inventory and supply management, and warehouse and yard supervision. This office will coordinate NUSEL shipping/receiving and visitor and user services. The office will assist the Director's Office with funding reporting requirements for the NSF and other agencies and for URA.

  The Education and Outreach Office will operate the Visitor Experience Center and the Museum/Archive, and will direct all on-site programs connected with education and outreach, such as the REU and UROP efforts. As noted in the Science Book Education and Outreach chapter, our South Dakota and regional partners would like to play the lead role in education and outreach activities involving South Dakota and its EPSCoR neighbors. We envision these responsibilities being transferred to appropriate state and regional organizations through Memoranda of Understanding incorporated into the Cooperative Agreement. For example, we noted previously that the South Dakota Space Grant Consortium includes most of the partners we have identified as important to outreach and education in South Dakota: its research and teaching universities, the tribal colleges, affiliates in industry and government, and community Science Centers. The NUSEL Education and Outreach Office would then be responsible for coordinating on-site activities with those of the South Dakota Space Grant Consortium (or whatever organization shoulders these responsibilities). Similarly, it could coordinate regional outreach with the organization holding those responsibilities. The Education and Outreach Office would also work closely with the city of Lead and with state tourism officials, so that traffic, services, and other visitor requirements are adequately addressed.

  The Administrative Office and the Education and Outreach Office are both viewed as extensions of the Director's Office, and thus directly accountable to him/her.

  The Associate Director for Research will oversee all research activities of the laboratory, and thus will be accountable for the wise use of laboratory resources in support of the science program. He/she will be responsible for building NUSEL's permanent scientific staff and for attracting a strong user community to the laboratory. We envision the Directorate being divided into two Divisions, Physics and Earth Science/Engineering, with separate program advisory committees. All technical services and personnel that primarily support science – the chemistry, glass, and machine shops, the low-level counting facility, the NUSEL library, computing service, etc. – will be under the Associate Director for Research. This office also handles visitor and scientific staff office and laboratory space needs in the surface campus.

  The Associate Director for Construction, Facilities, and Operations is the individual immediately under the Director that is accountable for on-time and on-budget execution of the construction plan, as well as the operations of the resulting facilities. The structure of the Directorate follows that used successfully at Homestake for many years. As many of the Directorate's employees will be former Homestake engineers, operators, and geologists, this will allow NUSEL to begin with a well-tested operations structure. The tasks assigned to the four operations groups (Operations/Maintenance, Underground Excavations/Construction, Engineering, Safety/Environmental) are described in detail in the Overview section of this Project Book. The employees will be very experienced in underground operations, but will

need to shoulder additional, unfamiliar tasks associated with science operations, and thus will undergo additional training. For example, the Operations/Maintenance Group would help with transport of experimental equipment between the surface laboratory and the underground halls; the Engineering Group would be responsible for scheduling of facilities used in transport of experimental equipment and in oversight of transport and underground installation; and the Safety/Environmental Group would be responsible for the safe handling of scientific materials like cryogens, compressed gases, and hazardous liquids.

Other project management issues: There are several points relevant to project management during the current interim period:

- The Homestake Collaboration has an interim structure that includes a PI (Haxton, Washington) and eleven other members of the Executive Committee (Balantekin, Wisconsin; Bowles, Los Alamos; Conrad, Columbia; Farwell, South Dakota School of Mines & Technology; Lande, Pennsylvania; Lesko, Lawrence Berkeley; Marciano, Brookhaven; Marshak, Minnesota; Onstott, Princeton; Shaevitz, Columbia; Wilkerson, Washington.) The Collaboration has a set of bylaws and is open, with a posted procedure for including new members. It is divided into interest groups, which have shouldered responsibilities for preparing Science Book materials, for recommending hall sizes, utility and cleanliness requirements, etc. The recent NRC Barish panel report noted the strong leadership behind the NUSEL effort.
- The Executive Committee has frequent conference calls and meets several times a year. On several occasions meetings have been scheduled in Lead, to encourage local supporters of NUSEL. The full collaboration meets during major conferences. The next such meeting is schedule for September (TAUP 2003). The PI recently began monthly newsletters to the collaboration with the goal of improving information flow. The newsletter and all other NUSEL-Homestake information is kept on the collaboration's web site, http://int.phys.washington.edy/nusl/.
- We envision this organization giving way to a Director and Users Group some time during the next phase of the project, in which the Baseline Design Project Book is created. The Director will be the new PI. The process would be expedited by early decisions by NSF on site selection and project approval.

F. WORK BREAKDOWN STRUCTURE: BUDGET AND EXPLANATION

The Work Breakdown Structure presented here describes the costs and contingencies associated with laboratory construction and operations. It is divided into three sections:

WBS-1: Laboratory Science Construction and Operations
- Property
- Insurance
- Underground Development for Science
- Surface Development for Science
- Site Operations and Maintenance
- Science Operations
- Detector Operations
- Director's Operations

WBS-2: Laboratory Education and Outreach Construction and Operations
- Property
- Insurance
- Underground (near-surface) Facility
- Surface Development for Education and Outreach
- Education and Outreach Operations
- Director's Operations

WBS-3: Laboratory Management
- Management Site Office
- Landlord (South Dakota) Site Office

These WBS spreadsheets are supported by two other sets of documents:
- The WBS explanations, which set the stage for going beyond the Reference Design to the Baseline Definition by explaining the costing procedures here, and the factors that limit the current Reference Design. These limitations are almost exclusive connected with the absence of a site agreement and property transfer, and the resulting lack of access necessary for some of the detailed planning.
- The appendices, which present far more detailed spreadsheets for all of the planned underground work (the most important cost item), for site operations and maintenance, and for science, outreach, detector, and administrative operations.

An effort has been made to assign reasonable contingencies. The scheme adopted is:
- 50% contingencies have assigned to items like property issues (acquisition, environmental, permitting, insurance) where substantial uncertainties will exist until a site agreement is finalized and a site boundary defined.
- 50% contingency was used for sealing unused areas: we lack an adequate survey of the sealing needs.
- 40% contingencies have been used for surface construction and for underground systems. We have good benchmarks for these costs from other laboratory developments, but a 40% contingency is prudent until we have a design specific to Homestake.
- 40% contingency has been used for underground shaft and hoist upgrades. Here we have detailed engineering estimates that justify a smaller contingency, but the flooding now occurring (see Section G) will affect at least one shaft/hoist system needed by NUSEL, the No. 6 Winze. Thus a 40% contingency was considered prudent.
- 40% contingency was used for surface demolition
- 40% contingency was used for certain non-personnel operating costs and for contract services (e.g., custodial and cafeteria) for which estimates specific to Homestake cannot be made at this time.

- 40% contingency was used for South Dakota site office costs, while 25% contingency was used for the management group.
- 25% contingency has been used for underground rough construction (excavation, rock bolting, shotcreting). Detailed engineering estimates of these costs have been made and are presented in the appendices.
- 25% contingency has been used for administrative personnel costs, as there is some uncertainty in the adequacy of staffing proposed.
- 10% contingency was used for personnel areas where we felt it was feasible to assign a definite manpower level. As discussed in the previous section, we made such assignments by using existing laboratories as models, generally choosing as our baseline the laboratory providing the best level of service (as we believe service needs of future experiments will be greater, not lesser).

Note that our conceptual proposal, submitted in June 2001, used a contingency of 25%.

The total cost of the project at the Reference Design stage is $331M, an increase over the conceptual proposal of approximately $50M. This results from the following combination of factors:

- Inclusion of a much-enhanced low-level-counting facility, adding about $16M.
- Inclusion of a waste conveyor for disposing of rock into the open cut. We feel it is important to establish this facility at the outset, as it is essential to future megadetector construction. Early installation will, in the end, lower rock disposal costs, including those associated with the developments of this proposal. The cost is about $7.3M.
- More cautious use of contingencies.

During the Reference Design effort we found several items that had been overlooked earlier, when we had a less complete understanding of the site. But our increased site knowledge also led to a far more efficient design, one that avoided the costly Yates shaft extension and major drift construction. There was a net savings in this process.

Because sites are often compared, we wanted to characterize Homestake costs, distinguishing costs that are site-dependent (and thus form a basis for selecting a site) from those that are less site dependent (and thus would be comparable, if each site provides the same level of service):

Category of expenditure	*Homestake cost*	*Dependent on site?*
Access (cost of going deep)	$44.3M	Very
Site operations/maintenance	$44.0M (5 years)	Very
Property	$1.8M	Very
Underground systems	$45.8M	Somewhat
Waste rock/coring/sealing	$11.6M	Somewhat
Underground room excavation	$37.6M	Somewhat-weakly
Surface development	$55.4M	Weakly
Science operations+LLCF	$35.2M (5-years)	Weakly
Director's operations	$11.8M (5 years)	Weakly
Detector operations	$4.3M (5 years)	Weakly
Total Science	*$291.7M*	
Total outreach/education	*$30.5M*	Weakly
Total management	*$8.9M*	Somewhat

The year-five site operations/maintenance costs for Homestake are $8.2M/y.

WBS-1: LABORATORY SCIENCE CONSTRUCTION AND OPERATIONS								
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Years 1-5**		**Salary basis ($/FTE/y)**
1 Property								
1.1 Property acquisition	$500,000	$0	$0	$0	$0	$500,000		
1.2 Environmental	$200,000	$0	$0	$0	$0	$200,000		
1.3 Easements	$200,000	$0	$0	$0	$0	$200,000		
1.4 Permits	$300,000	$0	$0	$0	$0	$300,000		
Subtotals	$1,200,000	$0	$0	$0	$0	$1,200,000		
Contingency (50%)	$600,000	$0	$0	$0	$0	$600,000		
Totals Property	$1,800,000	$0	$0	$0	$0	$1,800,000		
2 Insurance/Gen. Conditions								
2.1 Insurance/trust fund	$0	$0	$0	$0	$0	$0		
2.2 General conditions	$0	$0	$0	$0	$0	$0		
Contingency (50%)	$0	$0	$0	$0	$0	$0		
Totals Insurance/Gen. Cond.	$0	$0	$0	$0	$0	$0		
3 Underground development								
3.1 Shaft/hoist upgrades								
3.1.1 Yates shaft upgrade	$3,586,000	$0	$0	$0	$0	$3,586,000		
3.1.2 #4 Winze upgrade	$1,652,000	$300,000	$0	$0	$0	$1,952,000		
3.1.3 Ross shaft reconfiguration	$3,849,000	$4,888,000	$2,987,000	$0	$0	$11,724,000		
3.1.4 #6 Winze reconfiguration	$91,000	$811,000	$5,306,000	$2,579,000	$0	$8,787,000		
Subtotals access	$9,178,000	$5,999,000	$8,293,000	$2,579,000	$0	$26,049,000		
Contractor markup (15%)	$1,376,700	$899,850	$1,243,950	$386,850	$0	$3,907,350		
Excise tax (2%)	$211,094	$137,977	$190,739	$59,317	$0	$599,127		
Contingency (40%)	$3,671,200	$2,399,600	$3,317,200	$1,031,600	$0	$10,419,600		
Totals access	$14,436,994	$9,436,427	$13,044,889	$4,056,767	$0	$40,975,077		
3.2 7400 facilities								
3.2.2 Central hall/entrance	$598,000	$1,195,000	$598,000	$0	$0	$2,391,000		

3.2.3 Exhaust/utility drift	$473,000	$946,000	$473,000	$0	$0	$1,892,000		
3.2.4 Main exhaust drift	$466,000	$466,000	$0	$0	$0	$932,000		
3.2.5 Car wash/change	$154,000	$0	$0	$0	$0	$154,000		
3.2.6 Utilities room	$544,000	$0	$0	$0	$0	$544,000		
3.2.7 GeoLab	$285,000	$0	$0	$0	$0	$285,000		
3.2.8 LLC Hall	$0	$915,000	$915,000	$0	$0	$1,830,000		
3.2.9 Hall B (large hall)	$0	$2,026,000	$1,959,000	$0	$0	$3,985,000		
3.2.10 Dark matter #1	$298,000	$99,000	$0	$0	$0	$397,000		
3.2.11 Double beta decay	$271,000	$271,000	$0	$0	$0	$542,000		
3.2.12 Dark matter #2	$0	$398,000	$0	$0	$0	$398,000		
3.2.13 Solar neutrinos	$0	$173,000	$518,000	$0	$0	$691,000		
3.2.14 Offices/seminar room	$0	$300,000	$0	$0	$0	$300,000		
3.2.15 Interior machine shop	$0	$170,000	$0	$0	$0	$170,000		
3.2.16 Exterior machine shop	$0	$0	$0	$0	$0	$0		
3.2.17 Refrig/fan/coil room	$340,000	$0	$0	$0	$0	$340,000		
3.2.18 Lunch/refuge	$202,000	$0	$0	$0	$0	$202,000		
Subtotals 7400 facilities	$3,631,000	$6,959,000	$4,463,000	$0	$0	$15,053,000		
Contractor markup (15%)	$544,650	$1,043,850	$669,450	$0	$0	$2,257,950		
Excise tax (2%)	$83,513	$160,057	$102,649	$0	$0	$346,219		
Contingency (25%)	$907,750	$1,739,750	$1,115,750	$0	$0	$3,763,250		
Totals 7400 facilities	$5,166,913	$9,902,657	$6,350,849	$0	$0	$21,420,419		
3.3 8000 facilities								
3.3.1 Anaerobic glove room	$0	$58,000	$0	$0	$0	$58,000		
3.3.2 Drilling platform	$0	$114,000	$0	$0	$0	$114,000		
Subtotals 8000 facilities	$0	$172,000	$0	$0	$0	$172,000		
Contractor markup (15%)	$0	$25,800	$0	$0	$0	$25,800		
Excise tax (2%)	$0	$3,956	$0	$0	$0	$3,956		
Contingency (25%)	$0	$43,000	$0	$0	$0	$43,000		
Totals 8000 facilities	$0	$244,756	$0	$0	$0	$244,756		
3.4 4850 facilities								
3.4.1 4850 lab access	$277,000	$555,000	$1,110,000	$277,000	$0	$2,219,000		
3.4.2 4850 materials storage	$92,000	$0	$0	$0	$0	$92,000		
3.4.3 Lunch/refuge	$34,000	$0	$0	$0	$0	$34,000		
3.4.4 Accelerator room	$147,000	$587,000	$245,000	$0	$0	$979,000		
3.4.5 Clean room	$0	$74,000	$0	$0	$0	$74,000		

3.4.6 Lab vent/utility	$184,000	$184,000	$367,000	$0	$0	$735,000		
Subtotals 4850 facilities	$734,000	$1,400,000	$1,722,000	$277,000	$0	$4,133,000		
Contractor markup (15%)	$110,100	$210,000	$258,300	$41,550	$0	$619,950		
Excise tax (2%)	$16,882	$32,200	$39,606	$6,371	$0	$95,059		
Contingency (25%)	$183,500	$350,000	$430,500	$69,250	$0	$1,033,250		
Totals 4850 facilities	$1,044,482	$1,992,200	$2,450,406	$394,171	$0	$5,881,259		
3.5 Other excavation								
3.5.1 4850 Yates station	$0	$107,000	$0	$0	$0	$107,000		
3.5.2 4850 Ross/#6 connection	$815,000	$815,000	$0	$0	$0	$1,630,000		
3.5.3 4850 Vent drift to #5 shaft	$0	$0	$94,000	$94,000	$0	$188,000		
3.5.4 #4-#6 Winze connection	$334,000	$0	$0	$0	$0	$334,000		
3.5.5 Pump/Electrical Boreholes	$1,908,000	$327,000	$0	$0	$0	$2,235,000		
3.5.6 #5 Shaft vent. Conversion	$0	$0	$0	$374,000	$0	$374,000		
3.5.7 Mine doors and walls	$84,000	$168,000	$0	$0	$0	$252,000		
Subtotals other excavation	$3,141,000	$1,417,000	$94,000	$468,000	$0	$5,120,000		
Contractor markup (15%)	$471,150	$212,550	$14,100	$70,200	$0	$768,000		
Excise tax (2%)	$72,243	$32,591	$2,162	$10,764	$0	$117,760		
Contingency (25%)	$785,250	$354,250	$23,500	$117,000	$0	$1,280,000		
Totals other excavation	$4,469,643	$2,016,391	$133,762	$665,964	$0	$7,285,760		
3.6 Waste rock handling								
3.6.1 Yates waste conveyor	$2,547,000	$2,260,000	$0	$0	$0	$4,807,000		
Subtotals waste rock handling	$2,547,000	$2,260,000	$0	$0	$0	$4,807,000		
Contractor markup (15%)	$382,050	$339,000	$0	$0	$0	$721,050		
Excise tax (2%)	$58,581	$51,980	$0	$0	$0	$110,561		
Contingency (25%)	$636,750	$565,000	$0	$0	$0	$1,201,750		
Totals waste rock handling	$3,624,381	$3,215,980	$0	$0	$0	$6,840,361		
3.7 Core drilling								
3.7.1 4850 coring	$72,000	$0	$0	$0	$0	$72,000		
3.7.2 7400 coring	$216,000	$0	$0	$0	$0	$216,000		
Subtotals core drilling	$288,000	$0	$0	$0	$0	$288,000		
Contractor markup (15%)	$43,200	$0	$0	$0	$0	$43,200		
Excise tax (2%)	$6,624	$0	$0	$0	$0	$6,624		
Contingency (25%)	$72,000	$0	$0	$0	$0	$72,000		
Totals core drilling	$409,824	$0	$0	$0	$0	$409,824		

3.8 Other								
3.8.1 Mobilization	$556,000	$0	$0	$0	$0	$556,000		
3.8.2 Demobilization	$0	$0	$0	$0	$111,000	$111,000		
3.8.3 Engineering	$834,000	$0	$0	$0	$0	$834,000		
Subtotals other	$1,390,000	$0	$0	$0	$111,000	$1,501,000		
Contractor markup (15%)	$208,500	$0	$0	$0	$16,650	$225,150		
Excise tax (2%)	$31,970	$0	$0	$0	$2,553	$34,523		
Contingency (25%)	$347,500	$0	$0	$0	$27,750	$375,250		
Totals other	$1,977,970	$0	$0	$0	$157,953	$2,135,923		
3.9 Lower campus systems								
3.9.1 4850: 9700m^3@$250/m^3	$0	$0	$970,000	$1,455,000	$0	$2,425,000		
3.9.2 7400:74765m^3@$325/m^3	$0	$1,869,000	$11,215,000	$9,346,000	$1,869,000	$24,299,000		
3.9.3 8000: 350m^3@$600/m^3	$0	$210,000	$0	$0	$0	$210,000		
Subtotals low campus systems	$0	$2,079,000	$12,185,000	$10,801,000	$1,869,000	$26,934,000		
Contractor markup (15%)	$0	$311,850	$1,827,750	$1,620,150	$280,350	$4,040,100		
Excise tax (2%)	$0	$47,817	$280,255	$248,423	$42,987	$619,482		
Contingency (40%)	$0	$831,600	$4,874,000	$4,320,400	$747,600	$10,773,600		
Totals low campus systems	$0	$3,270,267	$19,167,005	$16,989,973	$2,939,937	$42,367,182		
3.10 Sealing unused areas								
3.10.1 Sealing	$400,000	$160,000	$165,000	$85,000	$0	$810,000		
Subtotals sealing	$400,000	$160,000	$165,000	$85,000	$0	$810,000		
Contractor markup (15%)	$60,000	$24,000	$24,750	$12,750	$0	$121,500		
Excise tax (2%)	$9,200	$3,680	$3,795	$1,955	$0	$18,630		
Contingency (50%)	$200,000	$80,000	$82,500	$42,500	$0	$405,000		
Totals sealing	$669,200	$267,680	$276,045	$142,205	$0	$1,355,130		
Totals 1:10	$31,799,407	$30,346,358	$41,422,956	$22,249,080	$3,097,890	$128,915,691		
EDIA (8%)	$2,543,953	$2,427,709	$3,313,836	$1,779,926	$247,831	$10,313,255		
Totals Undergrd Development	$34,343,360	$32,774,067	$44,736,792	$24,029,006	$3,345,721	$139,228,946		
4 Surface Develop. Science								
4.1 Demolishing Ext. Structures	$1,000,000	$1,030,000	$1,591,000	$1,639,000	$0	$5,260,000		

4.2 Roads, parking	$0	$309,000	$318,000	$492,000	$506,000	$1,625,000		
4.3 Science/Admin building								
4.3.1 68.4K gsf office @ $150	$0	$2,052,000	$3,078,000	$3,078,000	$2,052,000	$10,260,000		
4.3.2 36.0K gsf lab @ $250	$0	$1,800,000	$2,700,000	$2,700,000	$1,800,000	$9,000,000		
4.3.3 56.25K gsf assem @ $120	$0	$1,350,000	$2,025,000	$2,025,000	$1,350,000	$6,750,000		
4.4 Upper campus systems	$300,000	$309,000	$955,000	$983,000	$675,000	$3,222,000		
Subtotal surface sci. develop.	$1,300,000	$6,850,000	$10,667,000	$10,917,000	$6,383,000	$36,117,000		
Excise tax (2%)	$26,000	$137,000	$213,340	$218,340	$127,660	$722,340		
Contingency (40%)	$520,000	$2,740,000	$4,266,800	$4,366,800	$2,553,200	$14,446,800		
Totals	$1,846,000	$9,727,000	$15,147,140	$15,502,140	$9,063,860	$51,286,140		
EDIA (8%)	$147,680	$778,160	$1,211,771	$1,240,171	$725,109	$4,102,891		
Totals Surf. Develop. Science	$1,993,680	$10,505,160	$16,358,911	$16,742,311	$9,788,969	$55,389,031		
5 Site Operations/Maintenance								
5.1 Capital equipment	$500,000	$500,000	$0	$0	$0	$1,000,000		
Contingency (40%)	$200,000	$200,000	$0	$0	$0	$400,000		
Subtotals	$700,000	$700,000	$0	$0	$0	$1,400,000		
5.2 Operations								
5.2.1 Haulage	$150,000	$150,000	$150,000	$150,000	$150,000	$750,000		
5.2.2 Other mine operating	$147,000	$147,000	$147,000	$147,000	$147,000	$735,000		
5.2.3 Mine general	$279,000	$279,000	$279,000	$279,000	$279,000	$1,395,000		
5.2.4 Ventilation/cooling	$691,000	$691,000	$691,000	$691,000	$691,000	$3,455,000		
5.2.5 Hoists/shafts	$507,000	$507,000	$507,000	$507,000	$507,000	$2,535,000		
5.2.6 Waste water	$88,000	$88,000	$88,000	$88,000	$88,000	$440,000		
5.2.7 Administration/general	$617,000	$617,000	$617,000	$617,000	$617,000	$3,085,000		
Subtotals	$2,479,000	$2,479,000	$2,479,000	$2,479,000	$2,479,000	$12,395,000		
Contingency (25%)	$619,750	$619,750	$619,750	$619,750	$619,750	$3,098,750		
Subtotals	$3,098,750	$3,098,750	$3,098,750	$3,098,750	$3,098,750	$15,493,750		
5.3 Operations personnel								
5.3.1 Operations manager	$100,000	$100,000	$100,000	$100,000	$100,000	$500,000		$100.00
5.3.2 Other managers (2)	$150,000	$150,000	$150,000	$150,000	$150,000	$750,000		$75,000
5.3.3 Engineers (2.25-3)	$146,250	$195,000	$195,000	$195,000	$195,000	$926,250		$65,000
5.3.4 Technicians (1.75-3)	$78,750	$135,000	$135,000	$135,000	$135,000	$618,750		$45,000

5.3.5 Supervisors (1.75-2)	$96,250	$110,000	$110,000	$110,000	$110,000	$536,250		$55,000
5.3.6 Secretarial/clerical (1)	$25,000	$25,000	$25,000	$25,000	$25,000	$125,000		$25,000
5.3.7 Accounting (1.5-2)	$67,500	$90,000	$90,000	$90,000	$90,000	$427,500		$45,000
5.3.8 Operators (42.75-22)	$1,496,250	$1,443,750	$1,190,000	$822,500	$770,000	$5,722,500		$35,000
Subtotals	$2,160,000	$2,248,750	$1,995,000	$1,627,500	$1,575,000	$9,606,250		
Inflation (+3%)	$2,160,000	$2,316,213	$2,116,496	$1,778,413	$1,772,676	$10,143,798		
Subtotals (+ 30% benefits)	$2,808,000	$3,011,076	$2,751,444	$2,311,937	$2,304,479	$13,186,937		
Contingency (10%)	$280,800	$301,108	$275,144	$231,194	$230,448	$1,318,694		
Subtotals	$3,088,800	$3,312,184	$3,026,589	$2,543,131	$2,534,927	$14,505,631		
5.4 Maintenance personnel								
5.4.1 Mech. Plant Engineer	$65,000	$65,000	$65,000	$65,000	$65,000	$325,000		$65,000
5.4.2 Supervisors (2-3)	$137,500	$165,000	$165,000	$165,000	$165,000	$797,500		$55,000
5.4.3 Maintenance planner	$45,000	$45,000	$45,000	$45,000	$45,000	$225,000		$45,000
5.4.4 Electricians/Techs(14.5-16)	$580,000	$640,000	$640,000	$640,000	$640,000	$3,140,000		$40,000
Subtotals	$827,500	$915,000	$915,000	$915,000	$915,000	$4,487,500		
Inflation (+3%)	$827,500	$942,450	$970,724	$999,845	$1,029,841	$4,770,359		
Subtotals (+ 30% benefits)	$1,075,750	$1,225,185	$1,261,941	$1,299,799	$1,338,793	$6,201,467		
Contingency (10%)	$107,575	$122,519	$126,194	$129,980	$133,879	$620,147		
Subtotals	$1,183,325	$1,347,704	$1,388,135	$1,429,779	$1,472,672	$6,821,614		
Total direct costs	$8,070,875	$8,458,637	$7,513,473	$7,071,660	$7,106,349	$38,220,994		
Indirect costs (15%)	$1,210,631	$1,268,796	$1,127,021	$1,060,749	$1,065,952	$5,733,149		
Total, direct+indirect	$9,281,506	$9,727,433	$8,640,494	$8,132,408	$8,172,302	$43,954,143		
6 Science Operations								
6.1 Capital equipment								
6.1.1 LLCF equipment	$100,000	$680,000	$2,950,000	$3,040,000	$3,045,000	$9,815,000		
Contingency (40%)	$40,000	$272,000	$1,180,000	$1,216,000	$1,218,000	$3,926,000		
Subtotals	$140,000	$952,000	$4,130,000	$4,256,000	$4,263,000	$13,741,000		
6.2 Science Op. Personnel								
6.2.1 Director (0.7)	$126,000	$126,000	$126,000	$126,000	$126,000	$630,000		$180,000
6.2.1 Assoc. Directors (1-2)	$150,000	$300,000	$300,000	$300,000	$300,000	$1,350,000		$150,000
6.2.2 Senior scientists (0-4)	$0	$0	$250,000	$500,000	$500,000	$1,250,000		$125,000

6.2.3 Associate scientists (0-4)	$0	$0	$200,000	$400,000	$400,000	$1,000,000		$100,000
6.2.4 Assistant scientists (0-4)	$0	$0	$150,000	$300,000	$300,000	$750,000		$75,000
6.2.5 Postdocs (0-10)	$0	$0	$180,000	$360,000	$450,000	$990,000		$45,000
6.2.6 Graduate students (0-10)	$0	$0	$80,000	$160,000	$200,000	$440,000		$20,000
6.2.7 Undergraduates (0-5)	$0	$0	$30,000	$60,000	$75,000	$165,000		$15,000
6.2.8 Librarians (0-2)	$0	$40,000	$80,000	$80,000	$80,000	$280,000		$40,000
6.2.9 Machinists (0-4)	$0	$40,000	$80,000	$160,000	$160,000	$440,000		$40,000
6.2.10 Draftsman (0-1)	$0	$35,000	$35,000	$35,000	$35,000	$140,000		$35,000
6.2.11 Electronics (0-3)	$0	$40,000	$80,000	$120,000	$120,000	$360,000		$40,000
6.2.12 Glass (0-1)	$0	$40,000	$40,000	$40,000	$40,000	$160,000		$40,000
6.2.13 LLC (0-2)	$0	$60,000	$120,000	$120,000	$120,000	$420,000		$60,000
6.2.14 Chemistry (0-5)	$0	$50,000	$100,000	$150,000	$250,000	$550,000		$50,000
6.2.15 Computing (0-5)	$0	$80,000	$200,000	$200,000	$200,000	$680,000		$40,000
6.2.16 Receiving (0-2)	$25,000	$50,000	$50,000	$50,000	$50,000	$225,000		$25,000
6.2.17 Secretarial (0-4)	$25,000	$50,000	$100,000	$100,000	$100,000	$375,000		$25,000
Subtotals	$326,000	$911,000	$2,201,000	$3,261,000	$3,506,000	$10,205,000		
Inflation (+3%)	$326,000	$938,330	$2,335,041	$3,563,383	$3,946,034	$11,108,788		
Subtotals (+ 30% benefits)	$423,800	$1,219,829	$3,035,553	$4,632,398	$5,129,844	$14,441,424		
Contingency (10%)	$42,380	$121,983	$303,555	$463,240	$512,984	$1,444,142		
Subtotals	$466,180	$1,341,812	$3,339,108	$5,095,637	$5,642,828	$15,885,566		
6.3 Other Science Operations								
6.3.1 Domestic travel	$14,000	$16,000	$36,000	$56,000	$60,000	$182,000		
6.3.2 Foreign travel	$4,000	$6,000	$18,000	$30,000	$30,000	$88,000		
6.3.3 Supplies	$10,000	$15,000	$20,000	$25,000	$30,000	$100,000		
6.3.5 Publications	$10,000	$15,000	$20,000	$25,000	$30,000	$100,000		
6.3.6 Consultants (PACs)	$10,000	$20,000	$20,000	$20,000	$20,000	$90,000		
6.3.5 Computer services	$10,000	$30,000	$30,000	$30,000	$30,000	$130,000		
Subtotals	$58,000	$102,000	$144,000	$186,000	$200,000	$690,000		
Contingency (40%)	$23,200	$40,800	$57,600	$74,400	$80,000	$276,000		
Subtotals	$81,200	$142,800	$201,600	$260,400	$280,000	$966,000		
Total direct costs	$687,380	$2,436,612	$7,670,708	$9,612,037	$10,185,828	$30,592,566		
Indirect costs (15%)	$103,107	$365,492	$1,150,606	$1,441,806	$1,527,874	$4,588,885		
Total, direct+indirect	$790,487	$2,802,104	$8,821,315	$11,053,843	$11,713,703	$35,181,451		

7 Detector Operations								
7.1 Detector opers. personnel								
7.1.1 Assistant manager (0-1)	$0	$0	$75,000	$75,000	$75,000	$225,000		$75,000
7.1.2 Mech/process eng. (0-2)	$0	$65,000	$130,000	$130,000	$130,000	$455,000		$65,000
7.1.3 Maintenance mech. (0-2)	$0	$0	$80,000	$80,000	$80,000	$240,000		$40,000
7.1.4 Profess. operators (0-3)	$0	$40,000	$40,000	$120,000	$120,000	$320,000		$40,000
7.1.5 Undergr. assembly (0-3)	$0	$0	$40,000	$120,000	$120,000	$280,000		$40,000
7.1.6 Large assembly (0-3)	$0	$0	$40,000	$120,000	$120,000	$280,000		$40,000
7.1.7 Transportation (0-1)	$0	$0	$35,000	$35,000	$35,000	$105,000		$35,000
7.1.8 Secretary (0-1)	$0	$25,000	$25,000	$25,000	$25,000	$100,000		$25,000
Subtotals	$0	$130,000	$465,000	$705,000	$705,000	$2,005,000		
Inflation (+3%)	$0	$133,900	$493,319	$770,373	$793,484	$2,191,075		
Subtotals (+ 30% benefits)	$0	$174,070	$641,314	$1,001,484	$1,031,529	$2,848,397		
Contingency (10%)	$0	$17,407	$64,131	$100,148	$103,153	$284,840		
Subtotals	$0	$191,477	$705,445	$1,101,633	$1,134,682	$3,133,237		
7.2 Other detector operations								
7.2.1 Computer services	$0	$30,000	$35,000	$40,000	$45,000	$150,000		
7.2.2 Domestic travel	$0	$0	$4,000	$6,000	$6,000	$16,000		
7.2.3 Foreign travel	$0	$0	$2,000	$3,000	$3,000	$8,000		
7.2.4 Materials and supplies	$0	$25,000	$50,000	$75,000	$100,000	$250,000		
Subtotals	$0	$55,000	$91,000	$124,000	$154,000	$424,000		
Contingency (40%)	$0	$22,000	$36,400	$49,600	$61,600	$169,600		
Subtotals	$0	$77,000	$127,400	$173,600	$215,600	$593,600		
Total direct costs	$0	$268,477	$832,845	$1,275,233	$1,350,282	$3,726,837		
Indirect costs (15%)	$0	$40,272	$124,927	$191,285	$202,542	$559,026		
Total, direct+indirect	$0	$308,749	$957,772	$1,466,518	$1,552,824	$4,285,862		
8 Director's Operations								
8.1 Site development group								
8.1.1 Manager (0.8)	$48,000	$48,000	$48,000	$48,000	$48,000	$240,000		$60,000
8.1.2 Assistants (1.6)	$56,000	$56,000	$56,000	$56,000	$56,000	$280,000		$35,000
8.1.3 Secretarial/clerical(0.8)	$20,000	$20,000	$20,000	$20,000	$20,000	$100,000		$25,000

Subtotals	$124,000	$124,000	$124,000	$124,000	$124,000	$620,000		
Inflation (+3%)	$124,000	$127,720	$131,552	$135,498	$139,563	$658,333		
Subtotals (+30% benefits)	$161,200	$166,036	$171,017	$176,148	$181,432	$855,833		
Contingency (10%)	$16,120	$16,604	$17,102	$17,615	$18,143	$85,583		
Subtotals	$177,320	$182,640	$188,119	$193,762	$199,575	$941,416		
8.2 Administrative office								
8.2.1 Admin. Office director (1)	$70,000	$70,000	$70,000	$70,000	$70,000	$350,000		$70,000
8.2.2 Personnel officer (1)	$60,000	$60,000	$60,000	$60,000	$60,000	$300,000		$60,000
8.2.3 Financial officer (1)	$60,000	$60,000	$60,000	$60,000	$60,000	$300,000		$60,000
8.2.4 Visitor liaison officer (1)	$0	$60,000	$60,000	$60,000	$60,000	$240,000		$60,000
8.2.5 Public inform. officer (1)	$0	$60,000	$60,000	$60,000	$60,000	$240,000		$60,000
8.2.6 Office assistants (4)	$60,000	$120,000	$120,000	$120,000	$120,000	$540,000		$30,000
8.2.7 Security guards (8)	$120,000	$240,000	$240,000	$240,000	$240,000	$1,080,000		$30,000
Subtotals	$370,000	$670,000	$670,000	$670,000	$670,000	$3,110,000		
Inflation (+3%)	$370,000	$690,100	$710,803	$732,127	$754,091	$3,257,121		
Subtotals (+30% benefits)	$481,000	$897,130	$924,044	$951,765	$980,318	$4,234,257		
Contingency (25%)	$120,250	$224,283	$231,011	$237,941	$245,080	$1,058,564		
Subtotals	$601,250	$1,121,413	$1,155,055	$1,189,707	$1,225,398	$5,292,822		
8.3 Contract services								
8.3.1 Cafeteria	$100,000	$200,000	$200,000	$200,000	$200,000	$900,000		
8.3.2 Custodial	$50,000	$50,000	$100,000	$150,000	$150,000	$500,000		
8.3.3 MSHA training	$35,000	$35,000	$35,000	$35,000	$35,000	$175,000		
Subtotals	$185,000	$285,000	$335,000	$385,000	$385,000	$1,575,000		
Inflation (+3%)	$185,000	$293,550	$355,401.50	$420,700	$433,321	$1,687,972		
Subtotals (+30% benefits)	$240,500	$381,615	$462,021.95	$546,910	$563,317	$2,194,364		
Contractor's markup (15%)	$36,075	$57,242	$69,303	$82,036	$84,498	$329,155		
Subtotals	$276,575	$438,857	$531,325	$628,946	$647,815	$2,523,519		
Contingency (40%)	$110,630	$175,543	$212,530	$251,579	$259,126	$1,009,407		
Subtotals	$387,205	$614,400	$743,855	$880,525	$906,941	$3,532,926		
8.4 Other operations								
8.4.1 Domestic travel	$22,000	$26,000	$26,000	$26,000	$26,000	$126,000		
8.4.2 Foreign travel	$12,000	$16,000	$16,000	$16,000	$16,000	$76,000		
8.4.3 Supplies	$15,000	$25,000	$25,000	$25,000	$25,000	$115,000		
8.4.4 Publications	$40,000	$50,000	$50,000	$50,000	$50,000	$240,000		

8.4.5 Consultants	$20,000	$20,000	$20,000	$20,000	$20,000	$100,000		
8.4.6 Computer services	$7,000	$10,000	$10,000	$10,000	$10,000	$47,000		
Subtotals	$116,000	$147,000	$147,000	$147,000	$147,000	$704,000		
Contingency (40%)	$46,400	$58,800	$58,800	$58,800	$58,800	$281,600		
Subtotals	$162,400	$205,800	$205,800	$205,800	$205,800	$985,600		
Total direct costs	$1,328,175	$2,124,252	$2,292,829	$2,469,794	$2,537,714	$10,752,764		
Indirect (15% - no contract)	$141,146	$226,478	$232,346	$238,390	$244,616	$1,082,976		
Total, direct+indirect	$1,469,321	$2,350,730	$2,525,175	$2,708,184	$2,782,330	$11,835,739		
LABORATORY COST SUMMARY: SCIENCE CONSTRUCTION AND OPERATIONS								
Property	$1,800,000	$0	$0	$0	$0	$1,800,000		
Insurance/Gen. Conditions	$0	$0	$0	$0	$0	$0		
Underground Development	$34,343,360	$32,774,067	$44,736,792	$24,029,006	$3,345,721	$139,228,946		
Surface Develop. Science	$1,993,680	$10,505,160	$16,358,911	$16,742,311	$9,788,969	$55,389,031		
Site Operations/Maintenance	$9,281,506	$9,727,433	$8,640,494	$8,132,408	$8,172,302	$43,954,143		
Science Operations	$790,487	$2,802,104	$8,821,315	$11,053,843	$11,713,703	$35,181,451		
Detector Operations	$0	$308,749	$957,772	$1,466,518	$1,552,824	$4,285,862		
Director's Operations	$1,469,321	$2,350,730	$2,525,175	$2,708,184	$2,782,330	$11,835,739		
TOTALS	**$49,678,353**	**$58,468,242**	**$82,040,460**	**$64,132,271**	**$37,355,848**	**$291,675,174**		

WBS-1: BUDGET SUMMARY

	FY06	FY07	FY08	FY09	FY10	FY06-10
Total senior faculty	$303,600	$482,658	$1,197,332	$1,954,452	$2,013,085	$5,951,126
Postdoctoral associates	$0	$0	$210,058	$432,720	$557,127	$1,199,905
Graduate students	$0	$0	$93,359	$192,320	$247,612	$533,291
Undergraduates	$0	$0	$35,010	$72,120	$92,854	$199,984
Senior professional staff	$565,300	$736,759	$846,386	$871,778	$897,931	$3,918,154
Technical staff	$625,625	$1,319,945	$1,843,844	$2,103,499	$2,290,410	$8,183,324
Secret./receiv,/adm. asst.	$315,350	$512,528	$586,253	$603,841	$621,956	$2,639,928
Operators	$2,283,875	$2,406,209	$2,409,834	$2,328,874	$2,333,743	$11,762,535
Total salaries	$4,093,750	$5,458,099	$7,222,077	$8,559,604	$9,054,718	$34,388,248
Fringe benefits	$1,228,125	$1,637,430	$2,166,623	$2,567,881	$2,716,416	$10,316,474
Total salaries+benefits	$5,321,875	$7,095,528	$9,388,700	$11,127,485	$11,771,134	$44,704,722
Equipment	$840,000	$1,652,000	$4,130,000	$4,256,000	$4,263,000	$15,141,000
Domestic travel	$50,400	$58,800	$92,400	$123,200	$128,800	$453,600
Foreign travel	$22,400	$30,800	$50,400	$68,600	$68,600	$240,800
Materials and supplies	$35,000	$91,000	$133,000	$175,000	$217,000	$651,000
Publications	$70,000	$91,000	$98,000	$105,000	$112,000	$476,000
Consulting	$42,000	$56,000	$56,000	$56,000	$56,000	$266,000
Computer services	$23,800	$98,000	$105,000	$112,000	$119,000	$457,800
Security	$195,000	$401,700	$413,751	$426,164	$438,948	$1,875,563
Contract services	$387,205	$614,400	$743,855	$880,525	$906,941	$3,532,926
Utilities/operations costs	$3,098,750	$3,098,750	$3,098,750	$3,098,750	$3,098,750	$15,493,750
Total other direct costs	$4,764,555	$6,192,450	$8,921,156	$9,301,238	$9,409,039	$38,588,439
Total direct costs	$10,086,430	$13,287,979	$18,309,856	$20,428,723	$21,180,173	$83,293,161
Noncont. ind. costs (15%)	$1,454,884	$1,901,037	$2,634,900	$2,932,230	$3,040,985	$11,964,035
Total direct+indir costs	$11,541,314	$15,189,015	$20,944,756	$23,360,953	$24,221,158	$95,257,196
Property/insurance costs	$1,800,000	$0	$0	$0	$0	$1,800,000
Construction contracts	$36,337,040	$43,279,227	$61,095,703	$40,771,317	$13,134,690	$194,617,977
Total costs	$49,678,354	$58,468,242	$82,040,459	$64,132,270	$37,355,848	$291,675,173

WBS-1: LABORATORY SCIENCE CONSTRUCTION AND OPERATIONS

1 Property

1.1 ***Property acquisition***: The "landlord" agreement between Barrick Gold and the state of South Dakota remains under discussion. When resolved, the laboratory must verify that the agreement meets its legal needs; negotiate a use agreement with the state of South Dakota; resolve ownership issues for remaining Barrick buildings and for buildings the Laboratory constructs; address issues associated with private ownership or leases on buildings within the laboratory boundary; negotiate shared use agreements with Barrick for roads, fences, and other facilities that cross site boundary lines; and understand responsibility for and disposition of properties at the time the laboratory ceases to operate. An estimate of $500,000 is given to cover the associated legal fees.

1.2 ***Environmental assessment and mitigation***: The laboratory will conduct an environmental assessment of the property, to make sure that all laboratory and funding agency environmental requirements can be met.

1.3 ***Easements***: Easement issues include access roads and utilities, including civil (e.g., drainage), mechanical (gas, industrial water, potable water), and electrical. For electrical power, Homestake Mine is currently a "primary customer" which means that it owns, operates and controls the existing on-site power distribution required for all mine facilities. All land anticipated to be required for future on-site overland or underground transmission is currently owned by Barrick Gold Corporation. Transference of the land on which the power distribution network exists will effectively transfer any easements that may be required to support a future laboratory. This transference will be negotiated with the owner.

1.4 ***Permits*:** Permit issues include waste rock disposal, water discharge, and underground construction.

2 Insurance and General Conditions

2.1 ***Insurance and trust fund***: The current South Dakota-Barrick Gold negotiations, if concluded successfully, will require the state to shoulder certain insurance obligations to relieve Barrick Gold of potential liabilities associated with the donation of its lands to public use. The amount of that insurance is not yet fixed. We enter no cost, instead electing to discuss this issue in Section G.

2.2 ***General Conditions:*** Often within a WBS General Conditions include typical construction requirements such as scheduling and supervision; performance and payment bonds; and temporary site controls and utilities. Elsewhere in this WBS we have included a contractor's markup of 15% as well as EDIA, costs for engineering, development, inspection, and administration.

Homestake will present special risks to the General Contractor because, beginning June 2003, water has been allowed to infiltrate the mine in an uncontrolled manner and ventilation has been or will be lost to lower portions of the mine. The General Contractor will be responsible for inspecting and certifying the existing infrastructure prior to reuse. The risk involved in the inspections will increase the cost of contractor's risk insurance.

Our philosophy in doing this WBS, however, has been to sequester issues connected with the consequences of flooding in Section G. The reason is that the duration and thus the severity of

the effects are difficult to assess at this time: we do not know when the state will achieve a property agreement with Barrick, and whether that agreement will allow immediate intervention. Thus we have not included General Conditions costs in this WBS, but do discuss the financial consequences (qualitatively) in Section G.

3 Underground development

3.1 ***Shaft and hoist upgrades***: The current proposal assumes that the South Dakota-Barrick Gold agreement will allow the laboratory to use much of the existing underground infrastructure: the hoists, if upgraded and properly maintained, will serve the laboratory well for many decades. A detail plan of upgrades for scientific access through the Ross and No. 6 Winze are presented in the appendices. A similar plan for modernizing and maintaining the Yates and No. 4 Winze as mining access is also detailed in the appendices. Other aspects of the hoist/shaft modernization for the Ross/No. 6 scientific access are discussed below.

3.1.1 ***No. 6 Winze:*** The existing normal power systems for the #6 Winze hoist room and development areas and the shaft stations will be reused.

For redundancy, a cross tie to a new and remote normal power tiebreaker will be added per the redundancy diagram.

A utility borehole will be created parallel to the #6 shaft. The section of the Yates 12KV system twin cables that are routed down the #6 Winze will be relocated to the #6 Winze utility borehole during the #6 shaft reconfiguration. The balance of power cabling down the #6 shaft will be repositioned and re-supported within the #6 shaft during the shaft reconfiguration.

Emergency power will be provided to the #6 hoist room and area/station including the new man hoist via the Ross and the Yates head frames emergency generators and the crosstie switchgear that will be located in the 4850 development. These redundant emergency power systems will be routed down the # 6 shaft and the #6 utility borehole to supply redundant and independently routed emergency power to the 7400 laboratory facilities and elsewhere as required.

Existing normal lighting will remain in place for the stations and adjacent facilities. Life safety lighting consisting of egress fixtures will be provided throughout the reconditioned stations and development areas. The life safety lighting will be powered from normal and emergency circuits.

The existing voice, data, and leaky feeder radio communications system from the surface to the existing #6 Winze hoist room will be utilized. These systems are also currently serving the existing #6 shaft stations and the #6 shop near the 7400 level.

The existing 24 pair fiber-optic cable is routed from the Yates shaft through the #6 Winze hoist room area to the existing 7700 #6 shop. This fiber cable will remain in service.

The #6 Winze borehole will be utilized to install a redundant 24 pair fiber optic cable from the #6 Winze hoist room area to the 7400 level laboratory chambers.

The existing 100 pair copper cable routed down the #6 Winze will remain in service. The Yates 4850 machine shop 200 pair voice cable will be extended across the 4850 drift to the #6 Winze and down the borehole to the 7400 levels laboratory chambers. This extension will make voice communications to 7400 redundant.

The Leaky Feeder radio system extends throughout the #6 shaft, shops, hoist area, and 4850 development areas.

Existing communications cabling in the #6 shaft will be repositioned and re-supported within the shaft during the shaft reconfiguration.

***3.1.2 Ross shaft**:* The existing normal power systems for the Ross head frame and the shaft stations will be reused. Loop redundancy will be accomplished with the tiebreaker that is being added per the No. 6 Winze scope.

A utility borehole will be created parallel to the Ross Shaft. The section of the Ross 12KV system twin cables that are routed down the Ross shaft will be relocated to the utility borehole during shaft reconfiguration. The balance of power cabling down the Ross shaft will be repositioned and re-supported within the shaft during the shaft reconfiguration.

Emergency power will be provided to the Ross headframe and area/station including the new man hoist via the Ross and the Yates surface emergency generators and the subsurface crosstie/switchgear that will be located in the 4850 development facilities.

These on-site and redundant emergency power systems will respectively be routed down the Yates shaft and the Ross utility borehole to supply redundant and independently routed emergency power to the 4850 development facilities. The systems will also be looped through the 4850 tiebreaker switchgear to backfeed each other per the power redundancy diagram.

Existing normal lighting will remain in place for the stations and adjacent facilities. Life safety lighting consisting of egress fixtures will be provided throughout the reconditioned stations and development areas. The life safety lighting will be powered from normal and emergency circuits.

The existing voice and leaky feeder radio communications system from the Yates headend equipment to the existing Ross head frame will be utilized.

A new 24 pair fiber-optic cable for data communications will be routed from the through the Ross utility borehole to the existing 4850 #6 Winze headframe area. In addition, a new 24 pair fiber-optic cable for data communications will be routed from the Yates surface facility to the Ross headframe area.

The existing 100 pair copper cable routed down the Ross shaft will remain in service.

The existing Leaky Feeder radio system extends throughout the Ross shaft, shops, and hoist area.

Existing communications cabling in the Ross shaft will be repositioned and re-supported within the shaft during the shaft reconfiguration.

3.2 ***7400 Facilities**:* The detailed plan, costs, and schedule of the 7400-level excavations described in the Facilities Development section are given in the appendices.

3.3 ***8000 Facilities***: The detailed plan, costs, and schedule of the 8000-level excavations for geomicrobiology (the microbiology room and drilling area) are given in the appendices.

3.4 ***4850 Facilities***: The detailed plan, costs, and schedule of the 4850-level excavations described in the Facilities Development section are given in the appendices.

3.5 ***Other excavations***: The other excavations, described in detail in the appendices, will improve the Ross/No. 6 connection (the transfer station for scientific loads going to the deep laboratory

levels) and the drift connecting the No. 4 and No. 6 Winzes on the 7400-ft level. Other work focuses of the new primary ventilation circuits and excavation of boreholes for the pump column and electrical work

3.5.3, 3.5.6, 3.5.7 Ventilation: The Oro Hondo fan is currently located on top of the Oro Hondo shaft. Although this shaft should be adequate for the foreseeable future, it is not the best location for the fan long-term. (There is excessive sloughing of rock, which must be mucked out of the bottom of the shaft.) The Oro Hondo fan will be relocated to the concrete-lined No. 5 shaft, which should serve the subsurface needs for the expected life of the laboratory.

Two separate and distinct ventilation circuits will be provided. The Ross Ventilation Circuit will be utilized to ventilate and cool the laboratory facilities at the 7400 Level. Likewise, the Yates Ventilation Circuit will be utilized to provide ventilation and cooling to the 4850 Level facilities. Both circuits will merge at the #31 exhaust shaft and continue to the relocated Oro Hondo fan at the top of No. 5 shaft.

Air control doors will be installed in strategic locations to allow the airflow throughout the subsurface areas to be properly directed and controlled. Provisions have been made for the installation of approximately 200 air control doors.

Drifts not utilized for the subsurface facilities will have concrete bulkheads installed to minimize ventilation requirements. The bulkheads will be designed with "trapped" drain lines to minimize hydrostatic pressure buildup behind the bulkheads.

Approximately 240,000 cfm of ventilation air will be brought down the Ross shaft and No. 6 Winze, of which 20,000 cfm will be used to ventilate the pumping facilities at the 6950 level and 40,000 cfm will be used to ventilate the pumping facilities at the 8000 level. The Laboratory facilities at the 7400 level will receive 180,000 cfm, of which 30,000 cfm will be diverted for mining purposes. The balance of air will be utilized for ventilating and cooling of the laboratory facilities. From the 7400 level facility, the air will travel up No. 7 shaft, through drifts on the 6950 and 7100 levels to #31 exhaust where it will merge with the Yates Ventilation Circuit prior to being exhausted to the Oro Hondo fan at the top of No. 5 shaft.

Approximately 130,000 cfm of ventilation air will be brought down the Yates shaft for use in cooling and ventilating the 4850 level facilities. The air will continue from these facilities across the 4850 level, down No. 7 shaft and across the 7400 level to #31 exhaust. There it will merge with the Ross Ventilation Circuit prior to being exhausted to the Oro Hondo fan, at the top of No. 5 shaft.

3.6 ***Waste rock handling***: The appendices include a schedule of work and costs for installation of a conveyor system off the Yates shaft, so that waste rock going up the Yates can be transferred to the conveyor and moved underground to the Open Cut. This system, while costly, is essential to the construction of the megadetector. Building this system at the start of construction will also lead to lower rock disposal costs during construction of the 7400- and 4850-ft levels.

3.7 ***Core drilling****:* The core drilling of the 4850- and 7400-ft levels, coupled with laboratory testing, will provide the data the geotechnical modelers will need to verify the room designs, optimize their stability, etc.

3.8 ***Other****:* The engineering, mobilization, and demobilization costs have been calculated for the underground construction detailed in the appendices.

3.9 ***Lower campus systems***: This is a major cost with important uncertainties. The overall costs have been based on a scaling of the systems costs for SNO and similar recent projects, taking

into account differences between those projects and Homestake. Lower campus systems includes the costs of bringing all utilities, communications, and safety systems to the laboratory areas. It also includes all of the finishing costs of the rooms not already accounted for in 3.2, 3.3, and 3.4. (As detailed in the appendices, the 3.2-4 costs include excavation, shotcreting, mineguard coating, concrete floors, track, and cabling.)

Thus lower campus systems includes all of the steps required to transform rough rooms into scientific laboratories, with the required ventilation and clean room engineering, with all utilities and process engineering, with safety systems, etc. Among similar projects, the one most similar to the Homestake 7400-ft level development is SNO and SNOLab: the collaboration provided its finishing costs. These included ventilation, chillers, overhead crane, emergency generators, radon removal systems, the liquid nitrogen plant, electrical and lighting systems, process piping, ultrapure water, fiber optics, certain chemistry capabilities, and civil engineering connected with painting, establishing clean conditions, and relocating and reconnecting facilities. The net cost for SNO is \$5.6M for 17,200 m^3 of space, or \$325/m^3 (US dollars), the figure we have used for the 7400-ft level.

A reasonable estimate for the cost savings on the 4850-ft level, where the needs are somewhat less severe and the access simpler, is \$250/m^3. In contrast, we use \$600/m^3 for the 8000-ft level because the limit volume being developed will necessarily increase the cost per cubic meter. Also, unfortunately, the electrical and other systems on the 8000-ft level are certain to be damaged by flooding (see Section G). (South Dakota is hopeful that flooding can be reversed before waters reach the 7400-ft level.)

We want to stress that our plans for lower campus systems are relatively mature, as can be seen from the description below. Unfortunately we have concluded that site uncertainties (particularly the possibility that the state agreement with Barrick might rule out our use of serviceable existing systems) make it unreasonable for us to cost these systems at this time. We stress that we are prepared to provide such costing in a very short time, once the conditions of the site transfer are known and scientific access restored.

3.9.0 General Systems Issues: Below we address some of the planned approaches to low-campus systems for Homestake:

3.9.0.1 Power delivery to laboratory areas
3.9.0.1.1 General power: Primary site power is supplied from the 69KV East (Yates) Substation, the 69KV Ross Substation and the 69KV Oro Hondo Substation. These primary-power substations are currently owned and operated by Barrick and are fed from Black Hills Power & Light's (BHP&L) Kirk switchyard located near the old Kirk power plant.

The Yates shaft and surrounding surface facilities are currently supplied from the East substation. The Ross shaft and surrounding surface facilities are currently supplied from the Ross Substation and the Oro Hondo Substation. The Oro Hondo Substation also supplies power to the mine ventilation Oro Hondo fans and surrounding surface facilities.

The Oro Hondo Substation will be removed from service because the Oro Hondo fans will be relocated to the No. 5 shaft mouth. To facilitate this, site modifications will include a new overland 69KV line from the BHP&L Kirk switchyard to the East substation. In addition, the Oro Hondo feeders to the Ross shaft 12 KV system will be removed and new feeders will be installed from the Ross Substation to the 300 level in the Ross Shaft. Some Oro Hondo transformers and gear will be relocated to the No. 5 shaft and some will be relocated to the Ross Substation. Very little 69KV Substation gear will be required because future loads will be very

similar to the existing. The removal of this substation will reduce maintenance costs and provide additional on-site power reliability.

The majority of the existing site electrical infrastructure equipment that will remain in service for Laboratory operations has been upgraded within the last 10 years with state-of-the-art equipment.

3.9.0.1.2 Normal power: Significant subsurface electrical infrastructure will remain in place and be utilized for facility operations such as seepage pumping and miscellaneous services. The majority of the existing site electrical equipment that will remain in service for laboratory operations has been upgraded within the past ten years with state-of-the-art distribution and protection equipment. Most of the distribution system is at 12.4 kV with some existing 2.4 kV for miscellaneous pumping and infrastructure support services. Power cabling routings will be revised as outlined in the shaft reconfiguration sections.

The 4850 and 7400 development facilities will be provided normal power from two cross-tied switchgear lineups. An existing normal power switchgear lineup will be reconfigured to serve as one lineup and a new lineup with a tiebreaker will be installed at the other location. These lineups will be operating at 12KV and will be between 600-800 amperes in capacity.

Normal power for the laboratory chambers will be 480 Volt. The chambers will receive normal power from both of the normal power switchgear lineups. An automatic transfer switch located at the chamber main panel will be used to select the available source. The chamber main normal panel will distribute the normal power to non-essential loads within the chamber.

Infrastructure and utility loads located outside the laboratory chambers like fans and HVAC loads will be sourced from an 800 amp, 480V distribution panelboard located adjacent to each 12KV switchgear lineup.

The laboratories developed areas (mainly 4850 and 7400 levels) normal power will be fully redundant from either the Yates 12KV system or the Ross 12 KV system. The subsurface infrastructure will have more than two times the anticipated initial subsurface laboratory's normal power requirements facilitating relatively low-cost expansion capabilities.

3.9.0.1.3 Emergency power: The 4850 and 7400 development facilities will be provided emergency power from two cross-tied switchgear lineups. One lineup will be equipped with a tiebreaker. These lineups will be operating at 12KV and will be 200 amperes in capacity.

Emergency power for the laboratory chambers will be 480 Volt. The chambers will receive emergency power from both of the emergency power switchgear lineups. An automatic transfer switch located at the chamber main panel will be used to select the available source. The chamber main emergency panel will distribute the emergency power to critical and life safety loads within the chamber.

Infrastructure and utility loads located outside the laboratory chambers that are consider life safety (access lighting) will be sourced from a 400 amp, 480V distribution panelboard located adjacent to each 12KV switchgear lineup.

The laboratories developed areas (mainly 4850 and 7400 levels) emergency power will be fully redundant from either the Yates headframe emergency generator or the Ross headframe emergency generator.

Power reliability to the No. 6 Winze hoists will be increased with the addition of new emergency power feeds and transfer switches.

3.9.0.2 Access lighting
3.9.0.2.1 Normal lighting: Normal lighting in each access way will consist of a wet location wall-mounted fluorescent indirect lighting that will be installed intermittently along the drift as required to provide an minimum of 5 foot-candelas at the floor. Higher traffic areas will be equipped with additional lighting as appropriate for the task and/or traffic patterns. In addition, Low-bay metal halide fixtures will be utilized in developed areas like machine shops and utilities.

3.9.0.2.2 Emergency lighting: Emergency lighting each access way will consist of both egress and exit lighting. The exit lights will consist of battery-powered Lightpanel Technologies ¼ watt LightPanel fixtures (or equal) charged from the space lighting circuit. The egress lighting will be powered from the emergency generator life safety power system. The access emergency lighting shall be accomplished utilizing the normal lighting fixtures and equipping them with emergency ballast. The emergency fixtures shall be designed to provide sufficient lighting to satisfy egress lighting code minimums. Approximately 1/5 of the normal access way fixtures will be powered from the life safety system.

3.9.0.3 Data and communications
3.9.0.3.1 General issues: Homestake currently has state-of-the-art communications and data transmission systems throughout the Yates and Ross shafts.

The current systems consist of a copper cable system for voice communications, fiber optics for data transmission, and a leaky-feeder radio system. The leaky-feeder radio system will be utilized for operations and backup communications. Each communication media will be extended to 7,400 and looped through the 4,850 and 7400 drifts for redundancy.

3.9.0.3.2 Voice: The existing infrastructure provides a minimum of 100 pair of copper conductors throughout the proposed footprint for landline voice communications. As each phase of the project is performed, voice communications will be extended.

3.9.0.3.3 Voice/Radio: The Leaky Feeder radio system is just a few years old and is one of the most flexible and reliable mine-ready radio communication systems on the market. As each phase of the project is completed, the leaky-feeder radio system will be extended to each area of underground occupancy. The system includes a telephone interface, which provides for communications with any telephone on the surface.

3.9.0.3.4 Data: Data communication will consist of two infrastructures, internal and external. Both infrastructures currently have existing equipment and connectivity that will be expanded to help provide more redundancy and speed to the remote locations of the complex. As each internal phase of the project is completed, the fiber optics and copper communications will be extended. At the completion of the developments, complete redundant data communications will be achieved throughout the internal facilities hubs

The internal infrastructure will consist of data communication internal to the complex. Due to the nature of the facility, with distance and quality of environment being primary issues, a fiber backbone will be constructed to each of the participating data locations (chambers, hub shops, etc).

Strategically placing enterprise modular switches in several locations will be the key to handle the redundancy and constraints of length. The current fiber backbone consists of 24 pair 62.5 micron multimode run to existing primary locations. New installation of fiber per the communications diagram will also be required to extend the existing internal infrastructure to the new laboratories.

Primary hub and data exchange locations will be connected to the fiber backbone. These areas will include underground operations, new surface lab facilities, 7,400 level machine shops, detector chambers, the No. 6 Winze/Shop, and support shops as required.

Each location will contain a gigabit switch attached to the fiber backbone. These switches are designed for the enterprise network that will be required. The gigabit switches contain the highest bandwidth available on the market today. Features like 'quality of service' and 'spanning-tree algorithm' will automatically adjust routes due to congestion or failure, VLANs will help segment the network traffic and load balancing will allow for the most redundancy available.

The proposed external infrastructure teamed with the proposed internal infrastructure will ascertain the highest speeds and redundancy available. These features matched with possible future expansion available at the complex will allow the opportunity to obtain the highest quality of service.

3.9.0.3.5 Public address system: Subsurface PA systems shall provide paging coverage on the developed levels in the areas normally occupied including the lab chambers. As development is completed, the system will be extended. Two separate and localized systems will be installed; at the 4850 development and at the 7400 development.

3.9.0.4 Monitoring and controls
3.9.0.4.1 Infrastructure controls: The existing site infrastructure FIXDMACS control and monitoring systems include a tried and tested PLC based control and monitoring system. This system has four nodes and includes operator interfaces in the existing mine office and an underground operator interface.

FIXDMACS is used to monitor the entire mine, control pumps, fans, etc., including a carbon-monoxide sensor system. The system power is backed up with inverters for uninterruptible power and increased reliability. The system has approximately 50 process control screens and additional control interface templates and equipment status screens. The system provides vital process information to the facility operators for optimized control. It demonstrates high quality graphics of the name-brand operator interface software - Intellution.

As the process systems are extended, the controls will be reprogrammed and extended to monitor and control the subsurface equipment.

3.9.0.4.2 Subsurface fire detection: The lab structures will be equipped with a single new addressable fire detection and alarm system that is fiber linked to the main fire alarm panel at the surface. This fiber communication will eventually be accomplished through redundant paths. The main fire alarm panel at the surface will serve as the fire alarm command center for the entire facility.

The subsurface fire detection system will also include a remote fire alarm annunciator, door holder/closers, manual pull stations, smoke detection and audio/visual notification devices throughout the corridors, smoke detection and audio/visual notification in the labs and shops. As each Phase of the project adds facilities, the system will be extended to monitor the new areas.

3.9.0.4.3 Subsurface gas detection: The existing mining infrastructure monitors CO with several detectors located throughout the mine. These detectors will be relocated to the new ventilation paths as required and continue to report to the extended control system.

In addition, a multi-gas multi-channel gas monitoring system will be provided for the detector chambers areas. This system will report to the control system and the fire detection system command center.

3.9.0.4.4 Subsurface security/access system: The subsurface security/access system shall consist of a card reader system with card readers installed at all laboratory entrances and exit doors. In addition, access to the facility will be monitored by video cameras at each primary level hoisting station.

3.91 4850 level chambers systems

3.9.1.1 Electrical
3.9.1.1.1 Normal power: Normal power will be redundantly supplied to each chambers main distribution panel from the utility facilities tiebreaker gear.

The main distribution panel will be located at the entrance to the chamber. A typical choice is a 480/277-volt, three-phase, 200-ampere panel equipped with in-surge suppression. A larger main panel or additional distribution panels (with or without surge suppression) can be installed as required depending on the power requirements and the size/shape of the specific chamber. The chamber main panel will typically be utilized to power all chamber 480/277-volt loads. This will not include any substantial HVAC or facilities infrastructure loads.

The main panel voltage will be stepped down with localized transformers to supply 120 volts power panels (with surge suppression as may be required) to serve computer loads, ancillary 120 loads and convenience receptacles. These transformers will be located as dictated by the experiments and loads that they serve.

3.9.1.1.2 Emergency power: Emergency power will be redundantly supplied to each chambers emergency power panel from the utility facilities tiebreaker gear. Emergency power will be available within 10 seconds of a normal power failure. The generators integral fuel storage will be sized for minimum of 8 hours generation. Where necessary by load type, localized uninterruptible power supplies (UPS) will be utilized to provide continuous power to non-interruptible loads.

The emergency panel will be located adjacent to the main distribution panel at the entrance to the chamber. A typical choice is a 480/277-volt, three-phase, 100-ampere panel equipped with in-surge suppression. A larger emergency panel can be installed as required depending on the power requirements of the specific chamber.

Life safety and critical power circuit separation will originate at the chamber emergency panel. The *life safety* circuits will supply loads (typically fire detection and annunciation and lighting for safe entrance and egress) that are required to assure life safety. This will not typically include any HVAC or facilities infrastructure loads unless they are deemed necessary for preservation of life. The *critical* emergency circuits will supply loads (typically equipment and communications) that are not required to assure life safety, but are desired to maintain equipment, experiments, or information systems. This will not include any substantial HVAC or facilities infrastructure loads. The critical emergency loads will be selectively shed in a case of insufficient emergency power for life safety.

The emergency panel voltage will be stepped down with localized transformers to supply 120 volts power panels (with surge suppression as may be required) to serve critical or life safety loads. These transformers will be located as dictated by the experiments and loads that they serve.

3.9.1.2 4850 level chambers lighting
3.9.1.2.1 Normal lighting: Normal lighting in each chamber will consist of a combination of lighting solutions. Wet location wall-mounted fluorescent indirect lighting will be installed around the perimeter of the chamber, open-type suspended industrial high-bay metal halide will be utilized over the main chamber areas, and fluorescent task lighting over walkways, and desk spaces and in other specified areas. An average of 60 foot-candelas will be provided at 30 inches above the finished floor.

3.9.1.2.2 Emergency lighting: Emergency lighting in each chamber will consist of both egress and exit lighting. The exit lights will consist of battery-powered Lightpanel Technologies ¼ watt LightPanel fixtures (or equal) charged from the space lighting circuit. The egress lighting will be powered from the emergency generator life-safety power system. These fixtures shall be instant-on 40-watt biax (qty of six lamps/fixture) low-bay fixtures or Induction Lamp (Sylvania Icetron or equal) low-bay fixtures. The emergency fixtures shall be designed to provide sufficient lighting to satisfy egress lighting code minimums.

3.9.1.3 4850 level chambers communications
3.9.1.3.1 General: The existing communication systems infrastructure consist of a copper cable system for voice communications, fiber optics for data transmission, and a leaky-feeder radio system. The leaky-feeder radio system will be utilized for operations and backup communications. For redundancy purposes, provisions have been made to extend and loop each of these systems at the 4850 level and the 7400 level.

3.9.1.3.2 Voice: Each chamber will be equipped with copper-connectivity landline voice communications. As each development is created, voice communications will be extended.

3.9.1.3.3 Voice/radio: Each chamber will have the leaky-feeder system extended to it to be primarily used for facility operations radio communications.

3.9.1.3.4 Data: A high-speed fiber switch will be located in each chamber that requires high-speed the service. These high-speed facility switches will attached to the fiber backbone at Hubs located on the developed area level.

3.9.1.3.5 Public address: Subsurface PA systems shall provide paging coverage on the developed levels in the areas normally occupied including the lab chambers.

3.9.1.4 4850 level chambers space monitoring
3.9.1.4.1 Gas monitoring: Each chamber will be equipped with a multi-gas monitor connected to the mine-controls system. These signals will allow for active gas purging control. They will also be monitored in the fire command center located on the surface. Monitoring will facilitate the broadcast of appropriate alarms and warnings.

3.9.1.4.2 Fire detection: Each chamber will be equipped with full area coverage fire detection and occupant notification to satisfy the building codes. The system components for each chamber will consist of addressable photoelectric smoke detectors, pull stations, horn/strobe annunciation devices, heat detectors, and sprinkler monitoring flow and tamper switches. These signals will be communicated to the fire command center located on the surface. Central command will initiate the broadcast of appropriate alarms and warnings as may be required for voice evacuation. Certain signals will also be communicated to the central controls system to allow for active gas purging and/or smoke control.

3.9.1.4.3 Security and access: The subsurface security/access system shall consist of a card reader system with card readers installed at all laboratory entrances and exit doors.

3.9.1.5 4850 level chambers HVAC
3.9.1.5.1 General: Personnel access to the 4850 Level facility will be achieved through a pressurized air lock near the Ross Shaft to help maintain cleanliness of the facility. Materials and equipment access will be achieved through an air lock at the east end of the main corridor and will be large enough to accommodate detector crates as well as equipment needed to transport the container.

Ventilation air for the facility will be provided from an intake structure located near the equipment air lock at the eastern end of the main corridor. The intake structure will be ducted to a Primary AHU, which will filter and precondition the ventilation air prior to delivery to individual AHU's serving the accelerator chamber and ancillary spaces. Adequate ventilation will be provided to dilute radon generated by the excavation as well as meet ASHRAE Standard 62-2001 (*Ventilation for Acceptable Indoor Air Quality*) guidelines for specified size and occupancy of the facility. Excess outdoor air from the Yates shaft will bypass the facility by means of a bypass drift.

3.9.1.5.2 Chilled water system: A new chiller plant will be installed on the 4850 Level off the Ross shaft sized to handle the internal heat gain from the laboratory facility as well as heat gain from the surrounding rock structure and autocompression of the air. The existing dewatering system will be utilized to pump water to an existing 200,000-gallon sump located near the Ross shaft on the 5000 Level. A weir will be installed in the sump to divide it into a "cold well" side and a "hot well" side, allowing overflow from the "cold well" side to the "hot well" side. A portion of the water from the "cold well" side will be pumped to the chiller plant for use as condensing water. Condenser water from the chillers will be pumped down to the "hot well" side of sump and then pumped to the surface utilizing the existing pumping infrastructure. Any makeup water required for this system will be obtained from an existing 6" industrial water line from surface.

The new chiller plant will be utilized to cool a new screw air compressor, cool a new air dryer, provide cooling water for coils in the air handling units and chill domestic water to 13° C through a shell and tube heat exchanger.

3.9.1.5.3 Primary AHU: A preliminary estimate of the initial ventilation requirement for the 4850 Level facilities is 6,500 cfm, with a total future requirement of 12,000 cfm. Therefore the Primary AHU will be sized for 12,000 cfm and fitted with a VFD to allow initial operation at 6,500 cfm. The AHU will be fitted with HEPA filtration and no heating coil will be required.

3.9.1.5.4 Accelerator chamber HVAC: The accelerator chamber will incorporate a dedicated AHU system and will be outfitted with HEPA filtration to maintain the chamber to "white room" standards. Air in the chamber will be recirculated to maintain ambient conditions to a maximum of 18° C, 60% RH. Air from the Primary AHU will provide ventilation air as well as positive pressurization in the chamber to maintain cleanliness from corridors.

The accelerator chamber will have a method of egress at each end. One exit will connect to the main corridor and the other to the ventilation air bypass drift. Pressurization/purge fans for this chamber will be ducted to a point in the bypass drift that is "downwind" from the detector chamber exit. The pressurization/purge fan will be equipped with a VFD. Normal operation of the fan will provide enough exhaust to maintain positive pressurization in the accelerator chamber. In the event evacuation needs to be made to the bypass drift, the personnel will walk "upstream" in the bypass drift to the next chamber, where they can again enter the conditioned environment.

3.9.1.5.5 Ancillary laboratory spaces: Ancillary laboratory spaces will incorporate dedicated AHU systems. Portions of this space will be outfitted with HEPA filtration to maintain the

laboratory spaces to "White Room" standards. Air in the ancillary laboratory spaces will be recirculated to maintain ambient conditions to a maximum of 18° C, 60% RH. Air from the Primary AHU will provide ventilation air and provide positive pressurization in the laboratory spaces to maintain cleanliness separation from corridors.

Refuge areas will be incorporated into the Ancillary support facilities near the Ross Shaft.

3.9.1.5.6 Ductwork and devices: An allowance has been made for fabrication and installation of 50,000 pounds of aluminum ductwork and air control devices.

3.9.1.5.7 Corridors: Corridors will incorporate dedicated AHU systems and will be outfitted with high efficiency filtration to maintain the corridors to "White Room" standards. Air in the corridors will be recirculated to maintain ambient conditions to a maximum of 18° C, 60% RH. Air from the Primary AHU will provide ventilation air.

3.9.1.5.8 Smoke control: Each AHU's operation will be controlled to pressurize all corridors and refuge areas associated with a facility evacuation to contain smoke and move it toward exhaust fans. Smoke will be diverted as much as possible to the exhaust drift, relying on the bypass ventilation system to remove products of combustion, while maintaining clear evacuation paths.

3.9.1.5.9 Emergency purge ventilation: In the event of a hazardous spill or toxic gas release in the accelerator chamber, a motorized damper will open. The pressurization/purge fan in the chamber will switch to purge mode (VFD to 100%) and draw air from the Primary AHU system exhausting the contaminated air into the bypass drift. The contaminated air will be diluted and carried off through the exhaust drift to the #31 exhaust shaft and vented through the Oro Hondo exhaust fan. The purge system will allow the accelerator chamber to be cleared in 15 minutes.

3.9.1.6 4850 level chambers plumbing
3.9.1.6.1 Detector chambers: Each chamber will be provided with toilet facilities, mop service basins, water coolers, eyewash and emergency shower stations. Domestic hot and cold water will be provided at each toilet room location. Each fixture group will discharge into sewage ejector, which will pump sewage to a holding tank near the Ross shaft.

3.9.1.6.2 Ancillary support facilities: Plumbing systems will be designed as necessary to meet building function as well as all federal, state and local codes and regulations. Special plumbing systems such as acid waste, compressed gas delivery systems, centralized water treatment, etc. will be provided within laboratory and assembly areas that support the needs of research activities. Each fixture group will discharge into sewage ejector, which will pump sewage via overhead lines to a common collection facility.

3.9.1.6.3 Common waste collection facility: Waste from each ejector sump will be pumped to a holding tank at a central collection point located on the 4850 level near the Ross shaft. The sewage holding tank will be emptied to a portable tank on an as-needed basis.

3.9.1.6.4 Domestic water systems: A new domestic water storage tank will be installed on the 4550 Level of sufficient size and capacity to provide for the domestic water needs of the facility. Domestic water will flow from the tank via gravity feed to a mechanical room located on the 4550 level.

A shell and tube heat exchanger located in the mechanical room will generate domestic cold water, chilled to 13° C by the chilled water loop. Electric storage water heaters located in the mechanical room will generate domestic hot water. An aquastat-controlled recirculating pump will control flow through domestic hot water recirculating piping. This will maintain the

required service temperature in the domestic hot water distribution piping. Domestic water piping will be type L hard copper with lead-free solder and will run overhead.

3.9.1.7 4850 level chambers fire protection
3.9.1.7.1 General: Fire protection to the 4850 level of the underground laboratory will consist primarily of a sprinkler system served by the industrial water source within the facility. All areas containing combustible materials will be protected by either wet, dry, or gaseous fire-protection systems to satisfy the requirements of use. The requirements of the National Fire Protection Association (NFPA) Standards and Guidelines will be met as they apply to this facility.

Refuge areas will be used within the facility for staging areas to prepare for evacuation in the event of a fire or other emergency. These areas will contain surface communications equipment and self-contained breathing apparatus for use during evacuation. Refuge areas will employ clean agent fire protection systems that will allow occupants to function during emergency events even if the area requires fire suppression.

3.9.1.7.2 Water storage tank: A 100,000-gallon fire protection reservoir located on the 4550 Level and fed by Industrial Water from the surface will serve the underground Laboratory Facility. A gravity feed system will pressurize the sprinkler piping and deliver flow to covered areas from the reservoir. The system will be able to deliver flow for at least 90 minutes, if not indefinitely.

3.9.1.7.3 Distribution and sprinklers: Areas of low hazard such as corridors and support areas will be covered by wet sprinkler systems designed for light hazard occupancy in accordance with NFPA 13. Areas of higher combustible material loading such as storage rooms and laboratories will be covered by wet sprinkler systems designed for ordinary hazard occupancy in accordance with NFPA 13. The water source will be designed to accommodate wet sprinkler systems serving extra hazard occupancies as may arise throughout the life of the facility.

For equipment requiring higher levels of protection from water damage, double interlocked preaction fire suppression systems will be installed. This type of system employs automatic sprinklers attached to a piping system charged with air. A detection system will allow the release of water when two independent detection devices have confirmed fire conditions.

3.9.1.7.4 FM 200: Where highly sensitive or irreplaceable electronic equipment is housed, a gaseous fire suppression system designed for computer rooms will be employed as a first line of defense against fire, supplemented by a double interlocked fire preaction system.

3.9.1.8 4850 level process piping
3.9.1.8.1 General: During the Baseline Definition process further discussions between engineers and physicists (especially those designing the accelerator) will be needed to clarify experimental requirements for process piping.

3.9.1.8.2 Bulk fluid storage: It is assumed that cryogenic liquids used in detector labs will be brought into the labs from the surface in portable dewars and either transferred to experimental equipment or used directly from dewars. It is also assumed that all large volume toxic/flammable liquids or suffocating gasses will be transported to and maintained in double containment containers when in detector lab.

3.9.1.8.3 Bulk fluid drainage and spill containment: Large volume liquid spills could be directed down the bypass tunnel to be contained at a lower level drift until such time that they can be recovered.

3.9.2 7400 level chambers systems

3.9.2.1 Electrical
3.9.2.1.1 Normal power: See 3.9.1.1.1.

3.9.2.1.2 Emergency power: See 3.9.1.1.2.

3.9.2.2 7400 level chambers lighting
3.9.2.2.1 Normal lighting: See 3.9.1.2.1.

3.9.2.2.2 Emergency lighting: See 3.9.1.2.2.

3.9.2.3 7400 level chambers communications
3.9.2.3.1 General: See 3.9.1.3.1.

3.9.2.3.2 Voice: See 3.9.1.3.2.

3.9.2.3.3 Voice/radio: See 3.9.1.3.3.

3.9.2.3.4 Data: See 3.9.1.3.4.

3.9.2.3.5 Public address: See 3.9.1.3.5.

3.9.2.4 7400 level chambers space monitoring
3.9.2.4.1 Gas monitoring: See 3.9.1.4.1.

3.9.2.4.2 Fire detection: See 3.9.1.4.2.

3.9.2.4.3 Security and access: See 3.9.1.4.3.

3.9.2.5 7400 level chambers HVAC
3.9.2.5.1 General: Entrance to the 7400 level facility will be achieved through a pressurized air lock near the No. 6 Winze shaft to help maintain cleanliness of the facility. The air lock will be large enough to accommodate detector crates as well as equipment needed to transport the container.

Ventilation air for the facility will be provided from an intake structure located near the No. 6 Winze. The intake structure will be ducted to a primary Air Handling Unit (AHU), which will filter and precondition the ventilation air prior to delivery to individual AHU's serving the detector chambers and ancillary spaces. Adequate ventilation will be provided to dilute radon generated by the excavation as well as meet ASHRAE Standard 62-2001 (*Ventilation for Acceptable Indoor Air Quality*) guidelines for specified size and occupancy of the facility. Excess outdoor air from the No. 6 Winze shaft will bypass the facility by means of a bypass drift and will provide cooling for two air-cooled chillers located near No. 7 Shaft.

3.9.2.5.2 Chilled water system: A new chilled water plant consisting of two air-cooled 300 ton chillers will be installed on the 7400 level within the new facility. It is sized to handle the internal heat gain from the laboratory facility as well as heat gain from the surrounding rock structure and autocompression of the ventilation air. The air-cooled chillers will be located near the No. 7 shaft rejecting heat to the bypass and exhaust air from the 7400 level facilities.

The new chiller plant will be utilized to chill coils in the air handling units and screw air compressor/dryer system, and will be circulated through a shell and tube heat exchanger to cool the domestic water to 13° C.

3.9.2.5.3 Primary AHU: The preliminary estimate of the initial ventilation requirement for the 7400 level facilities is 31,700 cfm, with a total future requirement of 52,500 cfm. Therefore the Primary AHU will be sized for 52,500 cfm and fitted with a Variable Frequency Drive (VFD) to allow initial operation at 31,700 cfm. The AHU will be fitted with High Efficiency Particulate Air (HEPA) filtration and no heating coil will be required.

3.9.2.5.4 7400 level chambers HVAC: Each detector chamber will incorporate a dedicated AHU system and will be outfitted with HEPA filtration to maintain the chamber to "white room" standards. Air in the chamber will be recirculated to maintain ambient conditions to a maximum of 18° C, 60% RH. Air from the Primary AHU will provide ventilation air as well as positive pressurization in the chamber to maintain cleanliness from corridors.

Each detector laboratory will have a method of egress at each end. One exit will connect to the main corridor and the other to the ventilation air bypass drift. Pressurization/purge fans for each detector chamber will be ducted to a point in the bypass drift that is "downwind" from the detector chamber exit. Each pressurization/purge fan will be equipped with a VFD. Normal operation of the fans will provide enough exhaust to maintain positive pressurization in each detector chamber. In the event evacuation needs to be made to the bypass drift, the personnel will walk "upstream" in the bypass drift to the next chamber, where they can again enter the conditioned environment.

In the event there is a problem associated with the No. 6 Winze shaft, egress can be made to either No. 4 Winze or a series of existing ramps to the 4850 Level. Once at the 4850 Level, personnel can utilize either the Ross or Yates shafts for egress to the surface.

3.9.2.5.5 Ancillary laboratory spaces: Ancillary laboratory spaces will incorporate dedicated AHU systems. Portions of this space will be outfitted with HEPA filtration to maintain the laboratory spaces to "White Room" standards. Air in the ancillary laboratory spaces will be recirculated to maintain ambient conditions to a maximum of 18° C, 60% RH. Air from the Primary AHU will provide ventilation air and provide positive pressurization in the laboratory spaces to maintain cleanliness separation from corridors.

Refuge areas will be incorporated into the Ancillary support facilities near the No. 6 Winze egress shaft.

3.9.2.5.6 Corridors: See 3.9.1.5.7.

3.9.2.5.7 Ductwork and devices: An allowance has been made for fabrication and installation of 140,000 pounds of aluminum ductwork and air control devices.

3.9.2.5.8 Cleanrooms: The underground receiving area, within the ancillary laboratory space, will open to a staging Class 100,000 area for unpacking and repacking of containers. Located near the staging area will be individual Class 10,000 parts cleaning rooms with clean benches for rebag of assemblies. A Class 10,000 gowning room with airlock will be located off the staging clean room with access to a assembly Class 100 clean room for individual detector final assembly and repack for trip to or from the detector bays. Cleanrooms will be prefabricated unless high ceilings or special cranes are required. In such cases cleanrooms will be built in place.

3.9.2.5.9 Smoke control: See 3.9.1.5.8.

3.9.2.5.10 Emergency purge ventilation: In the event of a hazardous spill or toxic gas release in any of the detector laboratories, motorized dampers will open, the pressurization/purge fan in each laboratory chamber (other than the LLCF and General Purpose Hall, which will utilize

dedicated purge fans). The switch to purge mode (VFD to 100%) will draw air from the Primary AHU system exhausting the contaminated air into the bypass drift. The contaminated air will be diluted and carried off through the exhaust drift, up through the No. 7 shaft and vented through the Oro Hondo exhaust fan. This purge system will allow all of the detector chambers to be cleared in 15 minutes, except the General Purpose Hall, which will take approximately 22 minutes to clear.

3.9.2.6 7400 level chambers plumbing
3.9.2.6.1 Detector chamber laboratories: Each detector chamber laboratory will be provided with toilet facilities, mop service basins, water coolers, eyewash and emergency shower stations. Domestic hot and cold water will be provided at each toilet room location. Each fixture group will discharge into sewage ejector, which will pump sewage to a holding tank near the No. 6 shaft.

3.9.2.6.2 Ancillary support facilities: See 3.9.1.6.2.

3.9.2.6.3 Common waste collection facility: Waste from each ejector sump will be pumped to a holding tank at a central collection point located on the 7400 level near the No. 6 Winze shaft. The sewage holding tank will be emptied to a portable tank on an as-needed basis for transport to the surface.

3.9.2.6.4 Domestic water systems: A new domestic water storage tank will be installed on the 7100 level of sufficient size and capacity to provide for the domestic water needs of the facility. Domestic water will flow from the tank via gravity feed to a mechanical room located on the 7400 level.

A shell and tube heat exchanger located in the mechanical room will generate domestic cold water, chilled to 13° C by the chilled water loop. Electric storage water heaters located in the mechanical room will generate domestic hot water. An aquastat controlled recirculating pump will control flow through domestic hot water recirculating piping to maintain required service temperature in the domestic hot water distribution piping. Domestic water piping will be type L hard copper with lead-free solder and will run overhead.

3.9.2.7 7400 chambers fire protection
3.9.2.7.1 General: See 3.9.1.7.1.

3.9.2.7.2 Water storage tank: A 100,000-gallon fire protection reservoir located on the 7100 level and fed by Industrial Water from the surface will serve the underground Laboratory Facility. A gravity feed system will pressurize the sprinkler piping and deliver flow to covered areas from the reservoir. The system will be able to deliver flow for at least 90 minutes, if not indefinitely.

3.9.2.7.3 Distribution and sprinklers: See 3.9.1.7.3.

3.9.2.7.4 FM 200: See 3.9.1.7.4.

3.9.2.8 7200 level process piping
3.9.2.8.1 *General:* This category requires extensive iteration with the planned users of the laboratory chambers, a process that will take place during the Baseline Definition. Topics that will be added to this WBS include a reverse osmosis system, compressed gasses, air compressors, and compressed gas distribution. Coordination with the Low Level Counting Facility, which is being designed with certain excess capacities, will be important.

3.9.2.8.2 Bulk fluid storage: See 3.9.1.8.2.

3.9.2.8.3 Bulk fluid drainage and spill containment: See 3.9.1.8.3.

3.9.2.9 7400 level internal structures
3.9.2.9.1 General: The physics community addressed some of the physical support facilities, such as bridge cranes, in the Lead workshops. (The results were included in our Science Book.) However, as with process piping, further iterations – engineers to physicists and the reverse -- during the Baseline Definition will be essential in defining individual chamber needs.

3.9.2.9.2 Prefabricated cleanrooms: Experimental clean rooms within each detector chamber will be assumed to consist of prefabricated, site-assembled rooms with dedicated air conditioning, filtration and fan systems to meet the individual needs of specific projects. The clean rooms will be positively pressurized with respect to the detector chamber to maintain cleanliness separation from the detector chamber. These lab specific cleanrooms could be designed to standards as low as Class 100,000 or as high as Class 1/10 depending upon the requirements of the investigators. Electrical power, chilled water and outside air would be provided in the detector chamber to service the experimental clean rooms. The experimental clean rooms will be provided as needed and capitalized against the particular experimental installation.

3.9.3 8000 level chambers systems
The earth scientists have provided their room and drilling space needs, but have not yet determined the systems requirements for their geomicrobiology space on the 8000-ft level. As noted earlier, we believe costs will be dominated by the work to bring systems to the 8000-ft level, not by chamber work.

4 Surface Development for Science

4.1 Demolishing existing structures: A total of $5.25M is provided for the demolishing existing structures. The Homestake site includes a number of warehouses and shop structures of little historical or practical value. This item will fund the removal of these structures as well as the landscaping and re-vegetation of the site as a scientific laboratory and as a site of major public interest.

4.2 Roads and parking: A total of $1.625M has been provided for construction of roads and parking. We discussed in the Facilities Development section the specific road and parking improvements that will be need for access to the Ross shaft (where parking is currently quite limited) and to the Visitor Experience Center (which we are placing near the existing city visitor center). We noted earlier the opportunities for providing expanded parking for this facility.

NUSEL will generate two to three times as much traffic as recent operations at the Homestake Mine. Furthermore, visitor traffic will consist primarily of drivers unfamiliar with the area, arriving by car, bus, motorhome, trailers, etc. Significant improvements are required in the roadway layout and in the number and size of parking spaces. While we have suggested sites for the main laboratory building and the Visitor Experience Center in this Reference Design, the Baseline Definition decision on sites cannot be made until after a property agreement, as a survey by experienced civil engineers and architects is essential to building placement. But conceptually, we envision a roadway scheme that will separate staff and visiting scientists, public visitors, and freight traffic, likely leading them to their destinations via routes at different elevation levels along the hillside that separates Homestake from Lead. We hope to provide on-site parking for about 300 vehicles, which should be sufficient for 9 months of the year. NUSEL and Lead will discuss summer parking options. Possibilities include expanded parking on Mill

Street, across from the Open Cut Lead visitor center, and various off-site parking arrangements with Lead and Deadwood coupled to shuttle buses.

The six-acre Mill Street site is shown on site Figure #2 in the Facilities Development section. The site would require the acquisition and demolition of some structures as well as site grading.

4.3 Science and Administration building: The space requirements for NUSEL are based on comparisons made with Gran Sasso, as discussed in the Facilities Development section. We have also taken guidance from Sandro Bettini, who just finished his term as Gran Sasso director. Bettini pointed out that Gran Sasso is about to erect a new three-story office building because space is too limited, given the demands of future long-baseline and other neutrino experiments. Bettini also stressed that Gran Sasso's assembly areas are too limiting. One would anticipate that assembly needs of a vertical access facility would exceed those of a horizontal facility. As there are significant uncertainties in the costing discussed below, we have used a 40% for the building.

Building site possibilities have been discussed previously. Approximately two acres of property at the top of Mill Street near the Ross head frame could be made available by relocating or acquiring and demolishing some residential structures (see the site diagram labeled Figure #1 in the Facilities Development section). Grading would require cutting the top of the hill to create a level building site. Rock and soil from this excavation will be utilized to fill a nearby depression, creating a level building site for additional facilities or parking.

4.3.1 Office space in the Science Building: The office space portion of the Science building, 68.4K gross square feet (gsf), has been costed at $150/sf, which is at the upper end of the range for Rapid City office construction. However this building must be designed to last 50 years, and should have a ``signature'' appearance consistent with the outreach and historical preservation goals of NUSEL.

4.3.2 Laboratory space: 36.0K gsf of laboratory space has been costed at $225/gsf, which is at the low end of a range that can extend, for highly technical laboratory space, to above $1000/gsf. However, this space includes substantial areas for glass, machine, and electronics shops, where a lower number is not inappropriate. Furthermore we include substantial funding for upper campus systems in a separate item, which will be used to address utilities and clean room needs of technical areas within the science building.

4.3.3 Assembly space*:* The 56.2K gsf has been costed at $120/gsf. We are hopeful that several of the Barrick building identified in the Facilities Development section can be renovated to provided the needed assembly and warehouse space. However, given that civil engineering inspections of these buildings have not been allowed to date, we have prudently costed this space as new.

Very likely some a good portion of the assembly space will not be located in the main Science Building, but in an area picked for convenience to the underground. The Ross Pipe Shop could be demolished and replaced with a new Receiving and Assembly facility. This new facility would incorporate clean assembly space and be adjacent to the Ross head frame, allowing easy access to the subsurface facilities.

Most of the underground civil excavation will utilize skid-mounted compressors and a dedicated air compressor for the science activities will be installed at the subsurface facility. Moving the air compressors underground will allow the Ross Compressor facility to be utilized for other purposes. As the facility has an overhead crane, it is another candidate for conversion to a warehouse.

4.4 Upper campus systems

4.4.1 ***Offsite electrical infrastructure****:* All site power is distributed from the utility-owned Kirk switchyard. The Kirk switchyard is fed from High Voltage Lines from the Yellow Creek Substation and the Lookout Substation that are currently configured to supply up to 32 Megawatts to the mine site. The available capacity is many times that which is expected for site development and laboratory operations. The Homestake Mine is a "primary customer" which means that it owns, operates and controls the existing on-site power distribution required for all mine facilities.

The Utility (Black Hill Power and Light) substations are very reliable because they are relatively new and are "redundant loop" powered substations. No system changes are anticipated.

4.4.2 ***Communications***: The external infrastructure will consist of data communication external to the complex. Black Hills FiberCom supports the current connectivity to the complex with a direct fiber connection. The current speed of the connection is an OC-1 (51.84 Mbps) supported by a SONET (Synchronous Optical Network) Hierarchy.

Redundancy comes from several paths should the fiber be severed in any location. Future expansion of the current infrastructure can obtain OC-3 (155Mbps) speed if necessary. This expansion would allow remote users to obtain speeds as if they were connected inside the complex infrastructure. This is not planned at this time.

4.4.3 ***Security and access***: Site perimeter fencing and site lighting shall serve as the first intruder deterrent systems. The surface security/access system shall be a site-wide system that will consist of a card reader systems installed at all new-structure exterior doors, movement and proximity detection, and video monitoring.

Access to the facility shall be limited to dedicated entrance gates. Each site entrance gate shall be equipped with a card reader system and will be monitored and recorded by a digital video system.

4.4.4 ***Site lighting***: Site lighting will be added at selective site perimeter fencing, on new and existing surface facilities, and at new parking locations.

The perimeter fencing lighting shall be accomplished with dusk to dawn utility fixtures on 20 ft high round steel fencing poles. These fixtures will have integral photocells.

The new Parking and Roadway lighting shall be commercial grade metal halide fixtures on 35 ft high square tapered steel poles. These fixtures will be controlled with remote controls including time clocks and photocells.

4.4 5 ***Clean rooms***: Clean rooms will be provided with high-efficiency particulate air (HEPA) or ultralow penetration air (ULPA) filtration, humidity control, temperature control and pressurization control to maintain interior conditions. Clean rooms associated with the laboratory and assembly spaces will be staged with regard to level of cleanliness. For example, from a common Class 10,000 corridor, material and staff will enter the Class 100 to Class 1/10 clean rooms.

The Class 1 to 100 clean rooms will incorporate laminar airflow with low wall returns where possible to allow for heavy floor loads. These rooms will include Class 10,000 rooms for gowning, staging, and cleaning of exterior envelopes of clean assemblies. A white room for welding fabrication and controlled assembly will connect to the clean area as well. Clean benches in the staging areas will be provided to pre-clean assemblies prior to entry into clean

spaces for final assembly. Pressurized airlocks will be incorporated between rooms of differing classification and will be large enough to contain the largest assembly.

High bay clean rooms, over 20-foot clear height, will be provided with overhead cranes and monorails to assist in assembly of large detectors. Special clean room protocols will be followed to ensure that the overhead fixtures and equipment do not contaminate the critical items during assembly.

Low ceiling height clean rooms will be of prefabricated type permitting flexibility of assembly and revision to meet the needs of the researcher. High bay clean rooms will be site fabricated and designed to provide a maximum flexibility of use.

Deionized water and clean compressed air will be provided in the clean lab areas for parts cleaning and laboratory use. Laboratory clean rooms will have pass through openings for parts transfer and utility service for cryogenic gasses or compressed gasses. Lab configurations will strive to keep the cylinders and dewars outside of the lab spaces where possible. Spill containment and special exhaust will be provided in selected clean rooms to ensure safety from hazardous and suffocating materials.

Clean detectors and supplies will be bagged and placed in a transfer container in the surface facility assembly cleanrooms for their trip to the subsurface detector labs. These containers will then be placed on transfer carts and towed to the Yates lift staging room. The containers will be moved to the air-conditioned lift car and the cart brakes set for the trip down to the detector level of the facility.

4.4.6 Central energy plant: To accommodate the large and varying load throughout the surface campus, a central energy plant will be developed to provide chilled water, steam and heating hot water to the complex. Electric water chillers and gas-fired boilers will be the primary equipment housed in the energy plant. Another readily available source of heat is the water pumped from the underground facilities (steady flow rate of 350 – 500 gpm after drift development ceases). However a feasibility study will be required to determine if energy recovered from the Mine Water through the use of heat pumps is an economical solution to heating some of the facilities at the Ross complex.

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4.4.7 Normal power/transformers: Most of the existing surface support facilities will not require any new electrical service transformers or other electrical equipment. A standard oil-filled utility grade service transformer will be installed to serve each new on-site laboratory facility. Each new facility will have a 480-volt main power panel sized per the 2002 NEC and powered from the Ross or East Substations. The local utility will provide a standard oil filled service transformer to serve each new off-site laboratory facility. Each new facility will have a 480 volt main power panel sized per the 2002 NEC and powered from the local utility grid.

4.4.8 Emergency power: A generator will be supplied for the surface facilities that will require substantial emergency power for Life Safety or Critical Equipment loads.

Surface facility generators will be located outdoors in a weatherproof enclosure with an integral fuel tank. The fuel supply shall be sized for 2 hours minimum full load operation. Each generator shall be sized for communication loads, critical experiment loads, elevator loads, fire pump loads, and life safety loads including egress and exit lighting.

4.4.9 Lighting: The new facilities interiors will be equipped with normal energy efficient fluorescent lighting as well as emergency lighting consisting of combination entrance and exit fixtures. Exterior wall fixtures and pole fixtures will be commercial grade 100% cutoff metal halide fixtures.

4.4.10 Security: Facility security will be tied into the site-wide security network. Each new facility will have a card reader access system and some level video monitoring. Each exiting critical "maintenance" facility will be equipped with video monitoring and recording.

4.4.11 Fire detection: The new facilities will be equipped with addressable Fire detection systems.

4.4.12 External communications: Each of the new surface facilities will be connected to the Black Hills FiberCom Network through the existing direct fiber connection currently located in the machine shop.

4.4.13 Internal communications: The new surface facilities will be wired to EIA Category 6 (cat 6) standards unless faster connectivity (fiber) is required to certain jack locations. Dual cat 6 data jacks will be located throughout the facility rooms and will be wired to an intermediate communications patch panel (IDF) on each level. Each IDF will be connected by fiber back to a main distribution patch panel (MDF). The MDF will serve as the connection point to the Black Hill FiberCom Network via the fiber backbone.

Facility paging will be accomplished through the Building Phone system.

4.4.14 HVAC: Heating, ventilation and air conditioning will be accomplished throughout the surface facilities with individual AHUs and terminal devices with hydronic heating and cooling coils (or heat pumps if Mine Water is used as a heating source). These AHUs will be utilized to condition and distribute the appropriate amounts of outside air to ventilate the space. Air within each space will be filtered to meet the operating standards of cleanliness dictated by facility function.

Clean rooms within the space will be served by dedicated clean room air handling systems. Air will be filtered by high efficiency filtration systems and distributed at an air change rate appropriate for the room class served.

Special ventilation systems will be provided to serve scavenger and hood exhaust systems. Exhaust systems and hoods will be designed to contain and remove contaminants from the space and discharge with dilution and/or filtration in a safe location. Shielding of hoods and special rooms to filter nuclear or electromagnetic radiation will also be available on an as-needed basis.

The complex will utilize state of the art direct digital control systems to control all building functions associated with heating, air conditioning and ventilation. This will also allow building function to be monitored from remote locations to increase maintenance efficiency and trouble shooting ability. This system will allow a high level of comfort and safety control as well as increased energy efficiency. Controls for the subsurface mechanical and pumping systems could also be tied into this system.

4.4.15 Plumbing: Plumbing systems will be designed as necessary to meet building function as well as all federal, State and local codes and regulations. Special plumbing systems such as acid waste, compressed gas delivery systems, centralized water treatment, etc. will be provided within laboratory and assembly areas that support the needs of research activities.

4.4.16 Fire protection: Fire protection will be provided to meet the requirements of the National Fire Protection Association as well as local code. It is anticipated that gaseous fire protection agents will be used to protect critical equipment and procedures as well as pre-action and wet sprinkler coverage of the entire building.

5 Site Operations and Maintenance

***5.1 Capital equipment*:** Funding is provided to replace major equipment needed for operations and maintenance of the site.

5.2 Operations: The costs shown are based on known operations of Homestake. This is the cost of keeping the mine open in a mothballed fashion. Thus all additional costs included in section 3 of this WBS are measured with respect to this baseline. This separation of operations and mining costs is presented in detail in the appendices, broken down for both the 7400-ft and 4850-ft levels.

5.3 Operations personnel: These costs are also very well known, based on actual operations personnel costs for Homestake. The detailed spreadsheets are presented in the appendices. Note that operator costs (5.3.8) are almost halved by the hoist modernization proposed in WBS section 3.1.

5.4 Maintenance personnel: These costs are also detailed in the appendices. Note that the year-five operations and maintenance costs (5.2+5.3+5.4) are $8.2M: this is the level of support needed after the improvements of WBS section 3.

6 Science operations

6.1 Capital equipment: The capital equipment shown is the equipping of the low-level counting facility, which was described in some detail in the Facilities Development section. In the appendices a spreadsheet is provided detailing the costs.

6.2 Science operations personnel: The WBS takes the personnel levels described and justified in the Facilities Development section and proposes a gradual increase of the effort, until the desired level is reached in year five. This process is described in detail in a spreadsheet included in the appendices. The year-five cost is $6.5M for the scientists and science support staff.

6.3 Other science operations: Representative costs for travel, supplies, publications, consultants (for advisory committees), and computer services are given. The budget is not a generous one: domestic travel, for example, is budgeted at $2,000/y for 25 scientists at or above the postdoc level, plus $10K for visitors.

7 Detector Operations

7.1 Detector operations personnel: The WBS assumes that major activities in detector installation are underway by the beginning of year three: key personnel on brought on board at the beginning of year two. The personnel level corresponds to that presented in the Facilities Development plan, and the assumed salaries are shown in the WBS. A more detailed spreadsheet is included in the appendices.

7.2 Other detector operations: Reasonable computer services and supplies are budgeted, and a modest amount of travel.

8 Director's Operations

8.1 Site development group: Within the Director's Office a modest team of four will handle site development issues. This team will work with the city of Lead and the state on traffic and other logistical problems associated with the creation of NUSEL and its outreach program. It will address major site issues associated with historical preservation and with integrating NUSEL's

new buildings into the site. It will handled shared maintenance issues – Barrick will continue to hold much of its site, and many road, utility, and ecological issues will need to be tackled jointly.

8.2 Administrative office: This office, within the Director's Office, will handle all of the standard personnel, financial, visitor liaison, and public relations functions of the national laboratory. By prevailing standards (e.g., Gran Sasso), the 9 FTEs is very lean. This office is also the home of the security force. A security guard/watchman is needed 24/7, and we consider two officers to be a minimum staff during normal operating hours.

8.3 Contract services: Among the services that NUSEL will likely contract out (in addition to the construction activities described elsewhere) are cafeteria, custodial, and MSHA training services.

8.4 Other operations: Funds for Director's Office operations – travels, supplies, publications, and consultants – are provided. As this office handles public relations, substantial funding is provided for publications.

WBS-2: LABORATORY EDUCATION/OUTREACH CONSTRUCTION AND OPERATIONS								
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Years 1-5**		**Salary basis ($/FTE/y)**
1 Property								
1.1 Property acquisition	$200,000	$0	$0	$0	$0	$200,000		
1.2 Environmental	$0	$0	$0	$0	$0	$0		
1.3 Easements	$50,000	$0	$0	$0	$0	$50,000		
1.4 Permits	$100,000	$0	$0	$0	$0	$100,000		
Subtotals	$350,000	$0	$0	$0	$0	$350,000		
Contingency (50%)	$175,000	$0	$0	$0	$0	$175,000		
Totals Property	$525,000	$0	$0	$0	$0	$525,000		
2 Insurance								
2.1 Liability insurance	$0	$0	$0	$0	$0	$0		
Contingency (50%)	$0	$0	$0	$0	$0	$0		
Totals Insurance	$0	$0	$0	$0	$0	$0		
3 Underground (near surface) Facility								
3.1 Near-surface visitor facility								
3.1.1 Ramp/drift excavation	$0	$0	$450,000	$900,000	$0	$1,350,000		
3.1.2 Safety/conveniences	$0	$0	$0	$350,000	$0	$350,000		
Subtotals	$0	$0	$450,000	$1,250,000	$0	$1,700,000		
Contractor markup (15%)	$0	$0	$67,500	$187,500	$0	$255,000		
Excise tax (2%)	$0	$0	$10,350	$28,750	$0	$39,100		
Contingency (40%)	$0	$0	$180,000	$500,000	$0	$680,000		
Totals near-surface facility	$0	$0	$707,850	$1,966,250	$0	$2,674,100		
EDIA (8%)	$0	$0	$56,628	$157,300	$0	$213,928		
Totals Near-surface Facility	$0	$0	$764,478	$2,123,550	$0	$2,888,028		
4 Surface Devel. Outreach								

4.1 Demolishing Ext. Structures	$0	$500,000	$0	$0	$0	$500,000		
4.2 Roads, parking	$0	$500,000	$500,000	$500,000	$0	$1,500,000		
4.3 Visitor Experience Center								
4.3.1 80.0K gsf office @ $150	$0	$2,400,000	$3,600,000	$3,600,000	$2,400,000	$12,000,000		
Subtotal surface sci. develop.	$0	$3,400,000	$4,100,000	$4,100,000	$2,400,000	$14,000,000		
Excise tax (2%)	$0	$68,000	$82,000	$82,000	$48,000	$280,000		
Contingency (40%)	$0	$1,360,000	$1,640,000	$1,640,000	$960,000	$5,600,000		
Totals	$0	$4,828,000	$5,822,000	$5,822,000	$3,408,000	$19,880,000		
EDIA (8%)	$0	$386,240	$465,760	$465,760	$272,640	$1,590,400		
Totals Surf. Devel. Outreach	$0	$5,214,240	$6,287,760	$6,287,760	$3,680,640	$21,470,400		
5. Outreach/Education Oper.								
5.1 Outreach/Educ. Personnel								
5.1.1 Director (0.2)	$36,000	$36,000	$36,000	$36,000	$36,000	$180,000		$180,000
5.1.2 Director, Ed/Out Office	$80,000	$80,000	$80,000	$80,000	$80,000	$400,000		$80,000
5.1.3 Manager, Visitor Center	$0	$70,000	$70,000	$70,000	$70,000	$280,000		$70,000
5.1.4 Manager, computing/net	$0	$70,000	$70,000	$70,000	$70,000	$280,000		$70,000
5.1.5 Manager, K-12 education	$0	$0	$70,000	$70,000	$70,000	$210,000		$70,000
5.1.6 Display design staff (0-3)	$0	$0	$0	$105,000	$105,000	$210,000		$35,000
5.1.7 K-12 education staff (0-3)	$0	$0	$0	$52,500	$105,000	$157,500		$35,000
5.1.8 Visitor Center staff (0-6)	$0	$0	$0	$90,000	$180,000	$270,000		$30,000
5.1.9 Web/int. display staff (0-4)	$0	$0	$90,000	$90,000	$180,000	$360,000		$45,000
5.1.10 Secretarial/clerical (1-2)	$25,000	$25,000	$50,000	$50,000	$50,000	$200,000		$25,000
Subtotals	$141,000	$281,000	$466,000	$713,500	$946,000	$2,547,500		
Inflation (+3%)	$141,000	$289,430	$494,379	$779,661	$1,064,731	$2,769,201		
Subtotals (+ 30% benefits)	$183,300	$376,259	$642,693	$1,013,559	$1,384,151	$3,599,962		
Contingency (10%)	$18,330	$37,626	$64,269	$101,356	$138,415	$359,996		
Subtotals	$201,630	$413,885	$706,963	$1,114,915	$1,522,566	$3,959,958		
5.2 Other Out/Ed Operations								
5.2.1 Domestic travel	$2,000	$6,000	$8,000	$8,000	$8,000	$32,000		
5.2.2 Supplies	$2,000	$6,000	$8,000	$16,000	$18,000	$50,000		
5.2.3 Documentation/Publication	$2,000	$6,000	$8,000	$16,000	$18,000	$50,000		
5.2.4 Consultants	$10,000	$12,000	$14,000	$14,000	$14,000	$64,000		
5.2.5 Computer services	$2,000	$6,000	$8,000	$18,000	$18,000	$52,000		

Subtotals	$18,000	$36,000	$46,000	$72,000	$76,000	$248,000		
Contingency (40%)	$7,200	$14,400	$18,400	$28,800	$30,400	$99,200		
Subtotals	$25,200	$50,400	$64,400	$100,800	$106,400	$347,200		
Total direct costs	$226,830	$464,285	$771,363	$1,215,715	$1,628,966	$4,307,158		
Indirect costs (15%)	$34,025	$69,643	$115,704	$182,357	$244,345	$646,074		
Total, direct+indirect	$260,855	$533,928	$887,067	$1,398,072	$1,873,311	$4,953,232		
6 Director's Operations								
6.1 Site development group								
6.1.1 Manager (0.2)	$12,000	$12,000	$12,000	$12,000	$12,000	$60,000		$60,000
6.1.2 Assistants (0.4)	$14,000	$14,000	$14,000	$14,000	$14,000	$70,000		$35,000
6.1.3 Secretarial/clerical(0.2)	$5,000	$5,000	$5,000	$5,000	$5,000	$25,000		$25,000
Subtotals	$31,000	$31,000	$31,000	$31,000	$31,000	$155,000		
Inflation (+3%)	$31,000	$31,930	$32,888	$33,875	$34,891	$164,583		
Subtotals (+30% benefits)	$40,300	$41,509	$42,754	$44,037	$45,358	$213,958		
Contingency (10%)	$4,030	$4,151	$4,275	$4,404	$4,536	$21,396		
Subtotals	$44,330	$45,660	$47,030	$48,441	$49,894	$235,354		
6.2 Contract services								
6.2.1 Cafeteria	$0	$0	$0	$0	$100,000	$100,000		
6.2.2 Custodial	$0	$0	$0	$0	$75,000	$75,000		
Subtotals	$0	$0	$0	$0	$175,000	$175,000		
Inflation (+3%)	$0	$0	$0	$0	$196,964	$196,964		
Subtotals (+30% benefits)	$0	$0	$0	$0	$256,053	$256,053		
Contractor's markup (15%)	$0	$0	$0	$0	$38,408	$38,408		
Subtotals	$0	$0	$0	$0	$294,461	$294,461		
Contingency (40%)	$0	$0	$0	$0	$117,784	$117,784		
Subtotals	$0	$0	$0	$0	$412,246	$412,246		
Total direct costs	$44,330	$45,660	$47,030	$48,441	$462,140	$647,600		
Indirect (15% - no contract)	$6,650	$6,849	$7,054	$7,266	$7,484	$35,303		
Total, direct+indirect	$50,980	$52,509	$54,084	$55,707	$469,624	$682,903		

LABORATORY COST SUMMARY: EDUCATION AND OUTREACH CONSTRUCTION AND OPERATIONS								
Property	$525,000	$0	$0	$0	$0	$525,000		
Insurance	$0	$0	$0	$0	$0	$0		
Underground (near surface)	$0	$0	$764,478	$2,123,550	$0	$2,888,028		
Surface Devel. Ed/Outreach	$0	$5,214,240	$6,287,760	$6,287,760	$3,680,640	$21,470,400		
Ed/Outreach Operations	$260,855	$533,928	$887,067	$1,398,072	$1,873,311	$4,953,232		
Director's Operations	$50,980	$52,509	$54,084	$55,707	$469,624	$682,903		
TOTALS	**$836,834**	**$5,800,677**	**$7,993,389**	**$9,865,089**	**$6,023,574**	**$30,519,563**		

WBS-2: BUDGET SUMMARY

	FY0	FY0	FY0	FY0	FY1	FY06-10
Total senior faculty	$0	$0	$0	$0	$0	$0
Postdoctoral associates	$0	$0	$0	$0	$0	$0
Graduate students	$0	$0	$0	$0	$0	$0
Undergraduates	$0	$0	$0	$0	$0	$0
Senior professional staff	$140,800	$303,644	$394,443	$406,276	$418,464	$1,663,627
Technical staff	$0	$0	$105,029	$405,675	$705,694	$1,216,398
Secret./receiv,/adm. asst.	$48,400	$49,852	$80,522	$82,938	$85,426	$347,138
Operators	$0	$0	$0	$0	$0	$0
Total salaries	$189,200	$353,496	$579,994	$894,889	$1,209,584	$3,227,163
Fringe benefits	$56,760	$106,049	$173,998	$268,467	$362,875	$968,149
Total salaries+benefits	$245,960	$459,545	$753,992	$1,163,355	$1,572,460	$4,195,312
Equipment	$0	$0	$0	$0	$0	$0
Domestic travel	$2,800	$8,400	$11,200	$11,200	$11,200	$44,800
Foreign travel	$0	$0	$0	$0	$0	$0
Materials and supplies	$2,800	$8,400	$11,200	$22,400	$25,200	$70,000
Publications	$2,800	$8,400	$11,200	$22,400	$25,200	$70,000
Consulting	$14,000	$16,800	$19,600	$19,600	$19,600	$89,600
Computer services	$2,800	$8,400	$11,200	$25,200	$25,200	$72,800
Security	$0	$0	$0	$0	$0	$0
Contract services	$0	$0	$0	$0	$412,246	$412,246
Utilities/operations costs	$0	$0	$0	$0	$0	$0
Total other direct costs	$25,200	$50,400	$64,400	$100,800	$518,646	$759,446
Total direct costs	$271,160	$509,945	$818,392	$1,264,155	$2,091,105	$4,954,758
Noncontract ind. costs	$40,674	$76,492	$122,759	$189,623	$251,829	$681,377
Total direct+indirect costs	$311,834	$586,437	$941,151	$1,453,779	$2,342,934	$5,636,135
Property/insurance costs	$525,000	$0	$0	$0	$0	$525,000
Construction contracts	$0	$5,214,240	$7,052,238	$8,411,310	$3,680,640	$24,358,428
Total costs	$836,834	$5,800,677	$7,993,389	$9,865,089	$6,023,574	$30,519,563

WBS-2: LABORATORY EDUCATION/OUTREACH CONSTRUCTION AND OPERATIONS

1 Property: These costs are discussed in WBS-1. Our assumption is that the environmental assessment will be done initially for the entire site, and that the education and outreach program will not need to budget for this activity. However, the Visitor Experience Center and the parking it will require could involve substantial property acquisition, easement, and permitting costs.

2 Insurance: We anticipate that the lab will have to acquire additional liability insurance because of increased visitor traffic due to outreach and education activities. However we enter no cost because this will depend on the details of the property arrangement between NUSEL and the state of South Dakota and/or Barrick Gold.

3 Underground (near-surface) Facility: The conceptual proposal described a rather ambitious underground experience for visitors. This has been scaled back in the current proposal, in favor of an improved surface Visitor Experience Center that we feel presents fewer liability problems. We believe, however, that a good experience can be provided that helps to illustrate the region's geology and mining history, as well as Homestake's potential for science. Our concept is an underground entrance from the visitor center into a near-surface drift constructed to illustrate the geology of the site and mining techniques, as well as the use of underground space for science experiments.

Because of the proposed Mill Street site for the Visitor Experience Center, a relatively short drift could lead visitors from the Visitor Experience Center, underground, to an opening on the Open Cut, a rather spectacular open pit that marks the point where the Homestake gold deposit intersected the surface. A viewing area could be constructed at that point. This would make a rather spectacular exit for the Visitor Experience Center.

The proposed entrance to the underground experience will use a conventional elevator. A second elevator would return the visitors to the surface, near Lead's visitor center and its Open Cut viewing area. Care would be taken to provide all the necessary safety facilities and conveniences for the general public, including younger school children. The underground tours will be guided.

For this project $300,000 is provided for vertical access, the construction of a borehole from the visitor center to the 300-ft level and the equipping of that access with an elevator. Our estimate of the cost of constructing a drift from the base of this elevator to the existing 300-ft drift – a total distance of about 700 ft – is $350,000. We also provide $500,000 to tie back to the Ross shaft via the Powder Tunnel, so that access to the science shaft is also available. This last development is an option, and could be removed. Finally, we provide $350,000 for safety and display engineering along this underground walk.

4 Surface Development for Outreach

4.1 ***Demolishing existing structures*****:** The budget provides $500,000 for demolishing existing structures on the Mill Street site and on areas designated for visitor parking.

4.2 ***Roads and parking*****:** As noted in the WBS-1 discussion, an effort will be made to route traffic to the NUSEL site efficiently, with separate routes for staff, visitors, and deliveries. A significant fraction of the costs with be associated with the Visitor Experience Center because that will, by far, constitute the greatest source of traffic. As noted before, the road and parking engineering will include off-site parking and shuttle bus options that will help minimize the impact on both NUSEL and Lead. A total of $1.5M is budgeted for anticipated costs.

4.3 ***Visitor Experience Center*****:** As discussed in the Facilities Development section, we estimate that the Visitor Experience Center will require about 80,000 gsf to accommodate an expected 200,000-400,000 visitors/year. This construction is budgeted at $150/sf, which we believe is adequate to finish the building with excellent display areas and a versatile theater. These parameters are not unlike those from the Lawrence Hall of Science, which accommodates about 260,000 visitors per year and places great emphasis on visiting school groups.

5 Outreach and Education Operations

5.1 ***Outreach and Education personnel*****:** The personnel required to staff the Outreach and Education Office was discussed in the Facilities Development section. We anticipate that the Visitor Experience Center program will begin at the start of year five. The staff is increased slowly, according to the timeliness of various activities, with the Office Director, the manager of the Visitor Center, and the manager for computing and networking being brought onboard earlier, so that they can be involved in the physical planning of the Visitor Center. The major staff categories are the display design staff (3), the K-12 education staff (3), the visitor center staff (6), and the web/interactive display staff (4). These align with the major goals of the NUSEL education and outreach program. The year-five personnel costs are $4.6M.

5.2 ***Other operations*****:** Modest travel and supplies and substantial publication costs are covered by this budget. The documentation/publication costs will cover brochures and other public information materials the Center produces to introduce itself to the region and nation.

6 Director's Operations

6.1 ***Site development group:*** This group, also positioned in the Director's Office, is described in WBS-1 in section 8.1. The Visitor Experience Center, and more generally outreach and education, is expected to play a major role in site planning and in NUSEL-Lead and NUSEL-regional interactions. Thus 20% of this group's effort is considered WBS-2 effort.

6.2 ***Contract services:*** The Visitor Experience Center will have a major impact on the cafeteria and on NUSEL's custodial needs. These contract costs are discussed in WBS-1, section 8.3. We have made an estimate of the Visitor Experience Center's share in these costs, beginning in year five.

WBS-3: LABORATORY MANAGEMENT								
	Year 1	Year 2	Year 3	Year 4	Year 5	Years 1-5		Salary basis ($/FTE/y)
1 Management office								
1.1 Personnel								
1.1.1 Laboratory director (0.1)	$18,000	$18,000	$18,000	$18,000	$18,000	$90,000		$180,000
1.1.2 Site office director (1.0)	$120,000	$120,000	$120,000	$120,000	$120,000	$600,000		$120,000
1.1.3 Site office adm. asst. (1.0)	$30,000	$30,000	$30,000	$30,000	$30,000	$150,000		$30,000
1.1.4 Other office personnel	$50,000	$50,000	$50,000	$50,000	$50,000	$250,000		
Subtotals	$218,000	$218,000	$218,000	$218,000	$218,000	$1,090,000		
Inflation (+3%)	$218,000	$224,540	$231,276	$238,214	$245,361	$1,157,392		
Subtotals (+ 30% benefits)	$283,400	$291,902	$300,659	$309,679	$318,969	$1,504,609		
Contingency (25%)	$70,850	$72,976	$75,165	$77,420	$79,742	$376,152		
Subtotals	$354,250	$364,878	$375,824	$387,099	$398,711	$1,880,761		
1.2 Other costs								
1.2.1 BOO meetings	$75,000	$75,000	$75,000	$75,000	$75,000	$375,000		
1.2.2 Site office supplies	$20,000	$20,000	$20,000	$20,000	$20,000	$100,000		
1.2.3 Documentation/Publication	$20,000	$20,000	$20,000	$20,000	$20,000	$100,000		
1.2.4 Consultants	$10,000	$10,000	$10,000	$10,000	$10,000	$50,000		
1.2.5 User Exec. Com. Travel	$15,000	$15,000	$15,000	$15,000	$15,000	$75,000		
1.2.6 Other travel to/from DC	$10,000	$10,000	$10,000	$10,000	$10,000	$50,000		
1.2.7 Insurance	$30,000	$30,000	$30,000	$30,000	$30,000	$150,000		
1.2.8 Internal audit function	$60,000	$60,000	$60,000	$60,000	$60,000	$300,000		
1.2.9 Additional DC costs	$10,000	$10,000	$10,000	$10,000	$10,000	$50,000		
1.2.10 URA corp. G&A costs	$300,000	$300,000	$300,000	$300,000	$300,000	$1,500,000		
1.2.11 Total fee (to be determ.)	$0	$0	$0	$0	$0	$0		
1.2.12 Audit	$50,000	$50,000	$50,000	$50,000	$50,000	$250,000		
Subtotals	$600,000	$600,000	$600,000	$600,000	$600,000	$3,000,000		
Contingency (25%)	$150,000	$150,000	$150,000	$150,000	$150,000	$750,000		
Subtotals	$750,000	$750,000	$750,000	$750,000	$750,000	$3,750,000		
Total direct costs	$1,104,250	$1,114,878	$1,125,824	$1,137,099	$1,148,711	$5,630,761		
Indirect costs (15%)	$165,638	$167,232	$168,874	$170,565	$172,307	$844,614		

Total, direct+indirect	$1,269,888	$1,282,109	$1,294,697	$1,307,663	$1,321,018	$6,475,376		
2 Landlord (SD) site office								
2.1 Personnel								
2.1.1 Site office director (1.0)	$120,000	$120,000	$120,000	$120,000	$120,000	$600,000		$120,000
2.1.2 Site office adm. Asst. (1.0)	$30,000	$30,000	$30,000	$30,000	$30,000	$150,000		$30,000
2.1.3 Other personnel	$50,000	$50,000	$50,000	$50,000	$50,000	$250,000		
Subtotals	$200,000	$200,000	$200,000	$200,000	$200,000	$1,000,000		
Inflation (+3%)	$200,000	$206,000	$212,180	$218,545	$225,102	$1,061,827		
Subtotals (+30% benefits)	$260,000	$267,800	$275,834	$284,109	$292,632	$1,380,375		
Contingency (25%)	$65,000	$66,950	$68,959	$71,027	$73,158	$345,093.83		
Subtotals	$325,000	$334,750	$344,793	$355,136	$365,790	$1,725,469		
2.2 Other costs								
1.2.1 Domestic travel	$20,000	$20,000	$20,000	$20,000	$20,000	$100,000		
1.2.2 Supplies	$20,000	$20,000	$20,000	$20,000	$20,000	$100,000		
1.2.3 Documentation	$10,000	$10,000	$10,000	$10,000	$10,000	$50,000		
1.2.4 Computer services	$10,000	$10,000	$10,000	$10,000	$10,000	$50,000		
Subtotals	$60,000	$60,000	$60,000	$60,000	$60,000	$300,000		
Contingency (40%)	$24,000	$24,000	$24,000	$24,000	$24,000	$120,000		
Subtotals	$84,000	$84,000	$84,000	$84,000	$84,000	$420,000		
Total direct costs	$409,000	$418,750	$428,793	$439,136	$449,790	$2,145,469		
Indirect costs (15%)	$61,350	$62,813	$64,319	$65,870	$67,469	$321,820		
Total, direct+indirect	$470,350	$481,563	$493,111	$505,007	$517,259	$2,467,290		
LABORATORY COST SUMMARY: MANAGEMENT								
Management site office	$1,269,888	$1,282,109	$1,294,697	$1,307,663	$1,321,018	$6,475,376		
Landlord (SD) site office	$470,350	$481,563	$493,111	$505,007	$517,259	$2,467,290		
TOTALS	**$1,740,238**	**$1,763,672**	**$1,787,809**	**$1,812,670**	**$1,838,277**	**$8,942,665**		

WBS-3: BUDGET SUMMARY

	FY06	FY07	FY08	FY09	FY10	FY06-10
Total senior faculty	$22,500	$23,175	$23,870	$24,586	$25,324	$119,456
Postdoctoral associates	$0	$0	$0	$0	$0	$0
Graduate students	$0	$0	$0	$0	$0	$0
Undergraduates	$0	$0	$0	$0	$0	$0
Senior professional staff	$425,000	$437,750	$450,883	$464,409	$478,341	$2,256,383
Technical staff	$0	$0	$0	$0	$0	$0
Secret./receiv,/adm. asst.	$75,000	$77,250	$79,568	$81,955	$84,413	$398,185
Operators	$0	$0	$0	$0	$0	$0
Total salaries	$522,500	$538,175	$554,320	$570,950	$588,078	$2,774,023
Fringe benefits	$156,750	$161,453	$166,296	$171,285	$176,424	$832,207
Total salaries+benefits	$679,250	$699,628	$720,616	$742,235	$764,502	$3,606,230
Equipment	$0	$0	$0	$0	$0	$0
Domestic travel	$153,000	$153,000	$153,000	$153,000	$153,000	$765,000
Foreign travel	$0	$0	$0	$0	$0	$0
Materials and supplies	$65,500	$65,500	$65,500	$65,500	$65,500	$327,500
Publications	$39,000	$39,000	$39,000	$39,000	$39,000	$195,000
Consulting	$12,500	$12,500	$12,500	$12,500	$12,500	$62,500
Computer services	$14,000	$14,000	$14,000	$14,000	$14,000	$70,000
Security	$0	$0	$0	$0	$0	$0
Contract services	$512,500	$512,500	$512,500	$512,500	$512,500	$2,562,500
Utilities/operations costs	$0	$0	$0	$0	$0	$0
Total other direct costs	$796,500	$796,500	$796,500	$796,500	$796,500	$3,982,500
Total direct costs	$1,475,750	$1,496,128	$1,517,116	$1,538,735	$1,561,002	$7,588,730
Noncontract ind. costs	$221,363	$224,419	$227,567	$230,810	$234,150	$1,138,310
Total direct+indirect costs	$1,697,113	$1,720,547	$1,744,684	$1,769,545	$1,795,152	$8,727,040
Property/insurance costs	$43,125	$43,125	$43,125	$43,125	$43,125	$215,625
Construction contracts	$0	$0	$0	$0	$0	$0
Total costs	$1,740,238	$1,763,672	$1,787,809	$1,812,670	$1,838,277	$8,942,665

WBS-3: LABORATORY MANAGEMENT

1 Management Site Office

1.1 ***Personnel*****:** If URA or a similar management entity holds the cooperative agreement for NUSEL, it will be essential for that entity to have an onsite office. This will allow the manager to work with its two principal partners, the NUSEL Director and the State of South Dakota Site Office. WBS-3 provides a Management Site Office director, an administrative assistant, and some personnel support for the DC office.

1.2 ***Other costs:*** Funds for travel, supplies, documentation/publication, consultants, insurance, and audit services are provided. Substantial travel and consultant funding will be needed for Board of Governors meetings and for periodic reviews on NUSEL construct and operations. One-sixth of URA corporate General and Administrative costs is attributed to NUSEL. This assumes that NUSEL will be about 20% the size of Fermilab. The DOE requires that URA corporate G&A costs be shared proportionately among all contracts. Details in applying this policy to NUSEL will depend on what, if any, involvement or arrangements DOE might have with NSF and URA on NUSEL. No URA management fee is entered. This fee will be negotiated with NSF.

2 South Dakota "Landlord's" Office

1.1. ***Personnel:*** We envision that, in the memorandum of understanding between management and the site office, adequate funding will be provided to the South Dakota so that it can maintain a site office. This will allow the state to monitor NUSEL activities to make sure they conform to the site agreement and to other state laws.

1.2 Other costs: Funding for standard activities is provided. Note that state participation in the Board of Governors and its relevant subcommittees, as described in the management plan, will be funded by management.

G. MINE STATUS: DEWATERING AND SITE TRANSFER ISSUES

Here we discuss briefly the status of the site and of property availability, issues that have important implications for this proposal.

In early June 2003 the Homestake Mine owner, Barrick Gold of Toronto, turned off the pumps that dewater the lower portions of the mine. This decision was opposed by our collaboration because we felt that continued maintenance of the site would be a less expensive alternative while also protecting the mine's science potential. However Barrick expressed concerns about the unknown timescale and outcome of the NUSEL approval process within the NSF. The resulting flooding is a slow process: roughly 25 years will be required to completely fill the mine. We estimate that in 18 months water will reach the important 7400-ft level. (The uncertainty on this estimate is at least a factor of two.)

Within our collaboration the earth scientists expect, with the buildup of water pressure at the 8000-ft level, that water will be forced into fissures in the rock. This recharging could threaten significant portions of the geomicrobiology program. (The water originates from higher levels in the mine, and thus disturbs the microbial conditions of the 8000-ft level.) The collaboration's hydrologists are also concerned. Prior to flooding the mine was in a steady-state condition that made it amenable to hydrological modeling. Calculations by Brian McPherson, an earth scientist who has advised our collaboration, now indicate that accurate modeling will be much more difficult. McPherson estimates that a year of measurements and theory will be needed before the feasibility of quantitative modeling, under these new conditions, can be assessed.

Physics concerns involve damage to the mine's infrastructure due to the flooding and due to the loss of ventilation in the lower portions of the mine. As ambient temperatures at depth are well above 120 F, the mine will be exposed to hot and humid conditions for a prolonged period – most likely at least two years. The task of dewatering is not trivial: severely flooded deep mines in South Africa have been dewatered, but the cost and environmental engineering requirements were substantial. After dewatering, there will be concerns about ground support conditions as well as the potential of trapped water. Thus a careful program of inspections and, quite possibly, repairs will have to be conducted. The contractor who does the underground work – both mine rehabilitation and NUSEL construction – will face additional hazards. This is why we included (but did not cost) General Conditions in the WBS-1: we should expect to pay some premium to the contractor because of adverse mine conditions. But we cannot, at this point, estimate what this additional cost for reconstruction/construction will be.

Clearly a key issue is early dewatering. If South Dakota can intervene before water reaches the 7400-ft level (the base of the #4 Winze), it will be very helpful to NUSEL. While the state has resources for dewatering ($10M provided in FY02), this is unlikely to be sufficient to complete the job. Given the alternative – additional delays and additional reconstruction – we hope NSF will consider aiding South Dakota.

The other great uncertainty affecting NUSEL-Homestake is the absence of a site agreement between South Dakota and Barrick Gold. South Dakota has stated its willingness to accept the needed portions of the Homestake site. Barrick Gold has stated its willingness to donate the property to the state. The difficulty, unresolved now for 2.5 years, is the liability protection Barrick Gold has requested. We included an item in WBS-1 for insurance, but did not estimate a cost. The costs the state will shoulder will be passed on to NUSEL, as NUSEL is the only reason the site is being transferred. Thus the required annual insurance premium will be an addition operations cost. It is also likely, over NUSEL's lifetime, that additional contributions will be required in order to build an Environmental Trust Fund for the site. This Trust would fund insurance and maintenance of the site after NUSEL has finished its life span.

Recently there have been public discussions indicating that Barrick Gold may ask that some of the existing underground infrastructure not be used by NUSEL. This may be an effort to limit company liability. The low cost of underground access in this proposal can be attributed to efficient use of Homestake infrastructure. Some of the underground facilities, as we have noted, are just a few years old. If replacing underground infrastructure proves to be a necessary condition for transfer of the site, this Reference Design will have to be modified. This will make NUSEL more expensive, but it may also allow us to improve designs (which will now be science specific).

While the flooding is a setback and possible loss of infrastructure a concern, we emphasize that Homestake remains a strong NUSEL site, regardless. A recent NSF geotechnical committee noted that the known integrity of Homestake rock is of utmost importance. It is one of the few locations in the US where large cavities have been excavated and studied.

However, clearly it is better if the dewatering commences soon and the useful underground infrastructure of Homestake is preserved. This will result in lower construction costs and shorter time to first science. NSF will be helping the science community if it can be active in such issues.

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	Master Schedule								Master Schedule							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Master Schedule																
Waste Conveyor		$0		$678,600		$1,016,891		$851,100		$2,260,000		$0				
Yates Shaft Upgrade		$0		$1,137,226		$1,798,932		$650,000		$0						
# 4 Winze Upgrade		$0		$413,754		$773,560		$465,000		$300,000		$0				
Ross Shaft Reconfiguration		$91,760		$0		$0		$3,757,015		$1,103,291		$1,261,479		$1,261,479		$1,261,479
# 6 Winze Reconfiguration		$0		$91,107		$0		$0		$0		$0		$0	22,269	$810,535
Pump Colum/Electrical Services	0	$0	5,548	$754,924	4,623	$501,871	2,157	$651,088	0	$327,149	0	$0				
#5 Shaft Ventilation Conversion																
Mine Ventilation Seals						$41,917		$41,917		$41,917		$41,917		$41,917		$41,917
4700, 4850 & 8000 Excavation	0	$0	0	$0	14,584	$747,144	15,036	$875,177	15,036	$875,177	16,040	$893,749	16,471	$650,517	0	$0
7400 Excavation	0	$0	0	$0	40,646	$1,759,859	40,590	$1,869,056	39,622	$1,799,136	44,363	$1,930,513	39,413	$1,627,071	38,691	$1,600,777
4850 Core Drilling				$72,000												
7400 Core Drilling		$0		$216,000												
7400 Level Rehabilitation	0	$0	0	$333,500												
Skipped at Ross & Trucked																
Skipped at Yates & Conveyed																
Mine Operating		$619,729		$619,729		$619,729		$619,729		$619,729		$619,729		$619,729		$619,729
	0	$711,489	5,548	$4,316,840	59,852	$7,259,903	57,783	$9,780,083	54,658	$7,326,399	60,403	$4,747,387	55,884	$4,200,713	60,960	$4,334,437

	Master Schedule								Master Schedule							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Master Schedule																
Waste Conveyor																
Yates Shaft Upgrade																
# 4 Winze Upgrade																
Ross Shaft Reconfiguration		$1,261,479		$1,261,479		$464,056		$0								
# 6 Winze Reconfiguration	19,263	$97,775		$3,465,000		$541,836		$1,201,407		$1,201,407		$1,377,099		$0		$0
Pump Colum/Electrical Services																
#5 Shaft Ventilation Conversion								$0		$93,590		$280,771				
Mine Ventilation Seals																
4700, 4850 & 8000 Excavation	0	$0	15,480	$700,249	14,196	$651,308	12,206	$464,093	10,183	$371,626						
7400 Excavation	38,691	$1,600,777	38,691	$1,600,777	31,636	$1,261,218	0	$0								
4850 Core Drilling																
7400 Core Drilling																
7400 Level Rehabilitation																
Skipped at Ross & Trucked																
Skipped at Yates & Conveyed																
Mine Operating		$619,729		$619,729		$619,729		$619,729		$619,729		$619,729		$619,729		$619,729
	57,954	$3,579,760	54,171	$7,647,235	45,832	$3,538,147	12,206	$2,285,229	10,183	$2,286,352	0	$2,277,599	0	$619,729	0	$619,729

Master Schedule

	Year 5							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Master Schedule								
Waste Conveyor								
Yates Shaft Upgrade								
# 4 Winze Upgrade								
Ross Shaft Reconfiguration								
# 6 Winze Reconfiguration								
Pump Colum/Electrical Services								
#5 Shaft Ventilation Conversion								
Mine Ventilation Seals								
4700, 4850 & 8000 Excavation								
7400 Excavation								
4850 Core Drilling								
7400 Core Drilling								
7400 Level Rehabilitation								
Skipped at Ross & Trucked								
Skipped at Yates & Conveyed								
Mine Operating		$619,729		$619,729		$619,729		$619,729
	0	$619,729	0	$619,729	0	$619,729	0	$619,729

Master Schedule

Year 1 - 5					
Year 1 Cost	Year 2 Cost	Year 3 Cost	Year 4 Cost	Year 5 Cost	Total Cost
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$2,546,591	$2,260,000	$0	$0	$0	$4,806,591
$3,586,158	$0	$0	$0	$0	$3,586,158
$1,652,314	$300,000	$0	$0	$0	$1,952,314
$3,848,775	$4,887,728	$2,987,014	$0	$0	$11,723,516
$91,107	$810,535	$5,306,017	$2,578,505	$0	$8,786,165
$1,907,884	$327,149	$0	$0	$0	$2,235,032
$0	$0	$0	$374,361	$0	$374,361
$83,833	$167,667	$0	$0	$0	$251,500
$1,622,321	$2,419,444	$1,815,651	$371,626	$0	$6,229,041
$3,628,915	$6,957,497	$4,462,773	$0	$0	$15,049,185
$72,000	$0	$0	$0	$0	$72,000
$216,000	$0	$0	$0	$0	$216,000
$333,500	$0	$0	$0	$0	$333,500
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$2,478,917	$2,478,917	$2,478,917	$2,478,917	$2,478,917	$12,394,585
$0	$0	$0	$0	$0	$0
$22,068,315	$20,608,936	$17,050,372	$5,803,409	$2,478,917	$68,009,948
123,183	231,905	170,163	10,183	0	535,434

Summary of Costs

	Subtotal	Contractors Markup @ 15%	Subtotal	Excise Tax @ 2%	Subtotal	% Contingency	Contingency	Total
Shaft Infrastructure								
Mobilization	$556,154	$83,423	$639,577	$12,792	$652,368	25%	$163,092	$815,460
Demobilization	$111,231	$16,685	$127,915	$2,558	$130,474	25%	$32,618	$163,092
Engineering	$834,230	$125,135	$959,365	$19,187	$978,552	25%	$244,638	$1,223,190
Surface Waste Handling	$4,806,591	$720,989	$5,527,580	$110,552	$5,638,131	25%	$1,409,533	$7,047,664
Yates Shaft Upgrade	$3,586,158	$537,924	$4,124,082	$82,482	$4,206,563	40%	$1,682,625	$5,889,189
# 4 Winze Upgrade	$1,952,314	$292,847	$2,245,161	$44,903	$2,290,064	40%	$916,026	$3,206,089
Ross Shaft Reconfiguration	$11,723,516	$1,758,527	$13,482,044	$269,641	$13,751,685	40%	$5,500,674	$19,252,359
# 6 Winze Reconfiguration	$8,786,165	$1,317,925	$10,104,089	$202,082	$10,306,171	40%	$4,122,468	$14,428,639
Pump/Electrical Services Boreho	$2,235,032	$335,255	$2,570,287	$51,406	$2,621,693	25%	$655,423	$3,277,116
# 5 Shaft Ventilation Conversion	$374,361	$56,154	$430,515	$8,610	$439,126	25%	$109,781	$548,907
Mine Ventilation Seals	$251,500	$37,725	$289,225	$5,785	$295,010	25%	$73,752	$368,762
Subtotal Hoisting / Infrastructure	**$33,715,637**	**$5,057,346**	**$38,772,983**	**$775,460**	**$39,548,442**	37%	**$14,470,283**	**$54,018,725**
Laboratory Facilities Development								
4850 Level Development								
4850 Accelerator	$978,821	$146,823	$1,125,644	$22,513	$1,148,157	25%	$287,039	$1,435,196
4850 Clean Room	$73,680	$11,052	$84,732	$1,695	$86,426	25%	$21,607	$108,033
4850 Materials Storage	$92,154	$13,823	$105,977	$2,120	$108,096	25%	$27,024	$135,120
4850 Lunch/Refuge Room	$33,578	$5,037	$38,615	$772	$39,387	25%	$9,847	$49,234
4850 Main Access (15' x 15')	$2,219,224	$332,884	$2,552,107	$51,042	$2,603,150	25%	$650,787	$3,253,937
4850 Ross/# 6 Connection Strip	$1,630,256	$244,538	$1,874,795	$37,496	$1,912,291	25%	$478,073	$2,390,363
4850 Vent/utility	$734,222	$110,133	$844,356	$16,887	$861,243	25%	$215,311	$1,076,553
4850 Yates station	$106,726	$16,009	$122,735	$2,455	$125,189	25%	$31,297	$156,487
4850 vent drift to #5	$188,445	$28,267	$216,712	$4,334	$221,046	25%	$55,262	$276,308
7400 Level Development								
Central Hall/Entrance	$2,390,072	$358,511	$2,748,583	$54,972	$2,803,555	25%	$700,889	$3,504,444
Exhaust/Utility	$1,891,428	$283,714	$2,175,143	$43,503	$2,218,645	25%	$554,661	$2,773,307
Main Exhaust Drift	$931,179	$139,677	$1,070,855	$21,417	$1,092,273	25%	$273,068	$1,365,341
Car Wash/Change	$153,826	$23,074	$176,900	$3,538	$180,438	25%	$45,110	$225,548
Lunch Refuge	$201,727	$30,259	$231,986	$4,640	$236,626	25%	$59,157	$295,783
Utilities	$543,851	$81,578	$625,428	$12,509	$637,937	25%	$159,484	$797,421
Geo Lab	$284,937	$42,740	$327,677	$6,554	$334,231	25%	$83,558	$417,788
Hall A (Sec/LLCF/LLCF Util)	$1,830,706	$274,606	$2,105,312	$42,106	$2,147,418	25%	$536,855	$2,684,273
Hall B (Large Hall)	$3,985,265	$597,790	$4,583,055	$91,661	$4,674,716	25%	$1,168,679	$5,843,395
Dark Matter # 1	$397,668	$59,650	$457,318	$9,146	$466,465	25%	$116,616	$583,081
Double Beta	$541,682	$81,252	$622,934	$12,459	$635,393	25%	$158,848	$794,241
Dark Matter # 2	$397,668	$59,650	$457,318	$9,146	$466,465	25%	$116,616	$583,081
Solar Nu	$690,163	$103,524	$793,688	$15,874	$809,561	25%	$202,390	$1,011,952
Seminar Room	$299,928	$44,989	$344,917	$6,898	$351,816	25%	$87,954	$439,770
Interior Machine Shop	$169,567	$25,435	$195,002	$3,900	$198,902	25%	$49,725	$248,627
Exterior Machine Shop	$0	$0	$0	$0	$0	25%	$0	$0
Refrig./Fan/Coil Room	$339,518	$50,928	$390,446	$7,809	$398,255	25%	$99,564	$497,819
Core Drilling								
4850 Program	$72,000	$10,800	$82,800	$1,656	$84,456	25%	$21,114	$105,570
7400 Program	$216,000	$32,400	$248,400	$4,968	$253,368	25%	$63,342	$316,710
7400 Level Rehabilitation								
# 4 to # 6 Winze Connection	$333,500	$50,025	$383,525	$7,671	$391,196	25%	$97,799	$488,994
8000 Level Development								
8000 Drilling area	$113,710	$17,057	$130,767	$2,615	$133,382	25%	$33,346	$166,728
8000 Anerobic room	$58,225	$8,734	$66,959	$1,339	$68,298	25%	$17,075	$85,373
Subtotal Facilities Development	**$21,899,726**	**$3,284,959**	**$25,184,685**	**$503,694**	**$25,688,379**	**25%**	**$6,422,095**	**$32,110,474**

	Subtotal	Contractors Markup @ 0%	Subtotal	Excise Tax @ 2%	Subtotal	% Contingency	Contingency	Total
Mine Operating								
Haulage	$750,200	$0	$750,200	$0	$750,200	25%	$187,550	$937,750
Other Mine Operating	$736,420	$0	$736,420	$0	$736,420	25%	$184,105	$920,525
Mine Gen	$1,393,315	$0	$1,393,315	$0	$1,393,315	25%	$348,329	$1,741,644
Vent/Cooling	$3,454,500	$0	$3,454,500	$0	$3,454,500	25%	$863,625	$4,318,125
Hoists/Shafts	$2,534,220	$0	$2,534,220	$0	$2,534,220	25%	$633,555	$3,167,775
Waste Water	$441,980	$0	$441,980	$0	$441,980	25%	$110,495	$552,475
Admin/General	$3,083,950	$0	$3,083,950	$0	$3,083,950	25%	$770,988	$3,854,938
Subtotal Operating	**$12,394,585**	**$0**	**$12,394,585**	**$0**	**$12,394,585**	**25%**	**$3,098,646**	**$15,493,231**
Project Total	**$68,009,948**	**$8,342,305**	**$76,352,253**	**$1,279,153**	**$77,631,406**	**31%**	**$23,991,024**	**$101,622,430**

	400k tons per year	Overhead & Fixed	Direct Mining Cost	200k tons 7400	200k tons 4850
Mining & Development	$2,032,352	$0	$2,032,352	$1,016,176	$1,016,176
Haulage	$375,099	$150,040	$225,059	$187,550	$187,549
Other Mine Operating	$490,947	$147,284	$343,663	$245,474	$245,473
UG Equipment	$1,159,828	$0	$1,159,828	$579,914	$579,914
Mine Gen	$928,878	$278,663	$650,215	$610,939	$317,939
Vent/Cooling	$987,000	$690,900	$296,100	$633,500	$353,500
Hoists/Shafts	$724,063	$506,844	$217,219	$489,032	$235,031
Crush/Tram	$217,541	$0	$217,541	$108,771	$108,770
Surface Disposal	$320,000	$0	$320,000	$160,000	$160,000
Waste Water	$88,396	$88,396	$0	$44,198	$44,198
Admin/General	$1,121,436	$616,790	$504,646	$560,718	$560,718
Total Manpower	$6,409,200	$2,819,200	$3,590,000	$3,229,100	$3,180,100
	$14,854,740	$5,298,117	$9,556,623	$7,865,372	$6,989,368

	Direct Mining 7400	Direct Mining 4850	Total Direct Mining
Mining & Development	$1,016,176	$1,016,176	$2,032,352
Haulage	$112,530	$112,529	$225,059
Other Mine Operating	$171,832	$171,831	$343,663
UG Equipment	$579,914	$579,914	$1,159,828
Mine Gen	$427,658	$222,557	$650,215
Vent/Cooling	$190,050	$106,050	$296,100
Hoists/Shafts	$146,710	$70,509	$217,219
Crush/Tram	$108,771	$108,770	$217,541
Surface Disposal	$160,000	$160,000	$320,000
Waste Water	$0	$0	$0
Admin/General	$252,323	$252,323	$504,646
Total Manpower	$1,808,723	$1,781,277	$3,590,000
	$4,974,686	$4,581,937	$9,556,623
Tons per year	200000	200000	400000
Cost Per ton	$24.87	$22.91	$23.89

	Operating & Fixed	Non Labor
Mining & Development	$0	$0
Haulage	$150,040	$150,040
Other Mine Operating	$147,284	$147,284
UG Equipment	$0	$0
Mine Gen	$278,663	$278,663
Vent/Cooling	$690,900	$690,900
Hoists/Shafts	$506,844	$506,844
Crush/Tram	$0	$0
Surface Disposal	$0	$0
Waste Water	$88,396	$88,396
Admin/General	$616,790	$616,790
Total Manpower	$2,819,200	$0
	$5,298,117	$2,478,917

Crew Productivity

Assume:

3	Shift per day
5	Days per week schedule
15	Mining Shifts per week schedule
52	weeks per year
780	shifts per year
400000	tons per year
780	shifts per year
513	Tons per shift

		4850 Level	7400 Level
33	Total Excavation Crew	9	24
24	Miners	6	18
9	Support	3	6
11	Total per shift	3	8
8	Miners	2	6
3	Support	1	2

513	Tons per shift
11	Total per shift
47	Tons per manshift
40%	Civil Construction Factor
28	Effective Tons Per Manshift

513	tons per shift
3	Shifts per day
1538	tons per day

513	Tons per shift
8	Miners per shift
64	Tons per manshift
40%	Civil Construction Factor
38	Effective Tons Per Manshift

1538	tons per day
5	days per week
7692	tons per week

			Miners Per Shift	Rate Per Shift	Rate Per Day	Rate Per Week	Rate Per Quarter	Rate Per Year
Other Facilities	153,003 tons	30.28%	2	77	231	1,154	15,000	60,000
7400 Facilities	352,343 tons	69.72%	6	231	692	3,462	45,000	180,000
	505,346	100.00%	8	308	923	4,615	60,000	240,000

	Yates Waste Conveyor								Yates Waste Conveyor							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Yates Waste Conveyor																
Engineering/Bid	1															
Road Access/Mobilization			1	$75,000												
Portal			1	$150,000												
Conveyor Drift			1,008	$453,600	2,184	$982,800	108	$48,600								
Borehole Cutout at Tramway Bins					455	$34,091										
Borehole Tramway to Conveyor Drift							400	$120,000								
Yates Shaft Connection							1	$50,000								
Bin Modifications @ Tramway							1	$60,000								
Power							1	$147,500								
Conveyor Installation							500	$425,000	2,500	$2,125,000						
Feeder Installation									1	$85,000						
Demobilization									1	$50,000						
		$0		$678,600		$1,016,891		$851,100		$2,260,000		$0		$0		$0

	Yates Waste Conveyor								Yates Waste Conveyor							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Yates Waste Conveyor																
Engineering/Bid																
Road Access/Mobilization																
Portal																
Conveyor Drift																
Borehole Cutout at Tramway Bins																
Borehole Tramway to Conveyor Drift																
Yates Shaft Connection																
Bin Modifications @ Tramway																
Power																
Conveyor Installation																
Feeder Installation																
Demobilization																
		$0		$0		$0		$0		$0		$0		$0		$0

Yates Waste Conveyor

	Year 5							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Yates Waste Conveyor								
Engineering/Bid								
Road Access/Mobilization								
Portal								
Conveyor Drift								
Borehole Cutout at Tramway Bins								
Borehole Tramway to Conveyor Drift								
Yates Shaft Connection								
Bin Modifications @ Tramway								
Power								
Conveyor Installation								
Feeder Installation								
Demobilization								
		$0		$0		$0		$0

Yates Waste Conveyor

	Year 1 - 5					
	Year 1	Year 2	Year 3	Year 4	Year 5	Total
	Cost	Cost	Cost	Cost	Cost	Cost
	$0	$0	$0	$0	$0	$0
Yates Waste Conveyor	$0	$0	$0	$0	$0	$0
Engineering/Bid	$0	$0	$0	$0	$0	$0
Road Access/Mobilization	$75,000	$0	$0	$0	$0	$75,000
Portal	$150,000	$0	$0	$0	$0	$150,000
Conveyor Drift	$1,485,000	$0	$0	$0	$0	$1,485,000
Borehole Cutout at Tramway Bins	$34,091	$0	$0	$0	$0	$34,091
Borehole Tramway to Conveyor Drift	$120,000	$0	$0	$0	$0	$120,000
Yates Shaft Connection	$50,000	$0	$0	$0	$0	$50,000
Bin Modifications @ Tramway	$60,000	$0	$0	$0	$0	$60,000
Power	$147,500	$0	$0	$0	$0	$147,500
Conveyor Installation	$425,000	$2,125,000	$0	$0	$0	$2,550,000
Feeder Installation	$0	$85,000	$0	$0	$0	$85,000
Demobilization	$0	$50,000	$0	$0	$0	$50,000
	$0	$0	$0	$0	$0	$0
	$0	$0	$0	$0	$0	$0
	$0	$0	$0	$0	$0	$0
	$0	$0	$0	$0	$0	$0
	$0	$0	$0	$0	$0	$0
	$0	$0	$0	$0	$0	$0
	$0	$0	$0	$0	$0	$0
	$2,546,591	$2,260,000	$0	$0	$0	$4,806,591

	Relocate Oro Hondo Fan								Relocate Oro Hondo Fan							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Relocate Oro Hondo Fan																
Engineering & Bid																
Relocate Oro Hondo Fan to # 5																
		$0		$0		$0		$0		$0		$0		$0		$0

	Relocate Oro Hondo Fan								Relocate Oro Hondo Fan							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Relocate Oro Hondo Fan																
Engineering & Bid																
Relocate Oro Hondo Fan to # 5				$93,590		$280,771										
		$0		$93,590		$280,771		$0		$0		$0		$0		$0

Relocate Oro Hondo Fan

	Year 5							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Relocate Oro Hondo Fan								
Engineering & Bid								
Relocate Oro Hondo Fan to # 5								
		$0		$0		$0		$0

Relocate Oro Hondo Fan

Year 1 - 5					
Year 1	Year 2	Year 3	Year 4	Year 5	Total
Cost	Cost	Cost	Cost	Cost	Cost
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$374,361	$0	$0	$374,361
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$374,361	$0	$0	$374,361

Relocate Oro Hondo Fan

	Days	Weeks	Tons	Total
Labor to Relocate Fan				
Total Cost & Duration	121		17.33	$138,667

	Days	Weeks	Tons	Total
Steel For Oro Hondo Cover				
Total Cost & Duration				$8,750

	Days	Weeks	Tons	Total
Steel For # 5 Shaft Collar				
Total Cost & Duration				$52,500

	Days	Weeks	Tons	Total
Concrete For # 5 Fan Installation				
Total Cost & Duration				$67,222

	Days	Weeks	Tons	Total
Shaft Construction Platform				
Total Cost & Duration				$10,000

	Days	Weeks	Tons	Total
Shaft Transition Excavation				
Total Cost & Duration				$16,000

	Days	Weeks	Tons	Total
Dirt Work				
Total Cost & Duration				$6,222

	Days	Weeks	Tons	Total
Fan & Motor Insection/Reconditioning				
Total Cost & Duration				$75,000
		Concurrent Activities		$374,361

All Facilities

Primary Access (18' x 18')

Excavation

Main Access Drift (18' x18')	1860 lf	29.45 tons/ft	54,785 tons	$24.87 per ton	$1,362,514
8' Rebars (cost included - excavation)	1860 lf	2.50 bolts/ft	4,650 bolts	$37.40 per bolt	$0
					$1,362,514

Civil

Shotcrete	1860 lf	64.80 sf/ft	120,528 sf	$6.83 per sf	$823,206
Concrete Floor	1860 lf	0.50 yd/ft	930 yd	$150.00 per yd	$139,500
Track	1860 lf	1860.00 lf	1,860 lf	$34.87 per ft	$64,852
					$1,027,558

Total Excavation	**$2,390,072**
Total Per Ton	**$43.63**
Total Per ft	**$1,284.99**

Exhaust / Utility (12' x 12')

Excavation

Exhaust / Access Drift (12' x12' x 3256')	2681 lf	13.09 tons/ft	35,097 tons	$24.87 per ton	$872,856
8' Rebars (cost included - excavation)	2681 lf	2.00 bolts/ft	5,362 bolts	$37.40 per bolt	$0
					$872,856

Civil

Shotcrete	2681 lf	43.20 sf/ft	115,819 sf	$6.83 per sf	$791,045
Concrete Floor	2681 lf	0.33 yd/ft	894 yd	$150.00 per yd	$134,050
Track	2681 lf	2681.00 lf	2,681 lf	$34.87 per ft	$93,478
					$1,018,573

Total Excavation	**$1,891,428**
Total Per Ton	**$53.89**
Total Per ft	**$705.49**

All Facilities

Main Exhaust Drift (14' x 12')

Excavation

Main Access Drift (18' x18')	1187 lf	15.27 tons/ft	18,129 tons	$24.87 per ton	$450,861
8' Rebars (cost included - excavation)	1187 lf	2.50 bolts/ft	2,968 bolts	$37.40 per bolt	$0
					$450,861

Civil

Shotcrete	1187 lf	45.60 sf/ft	54,127 sf	$6.83 per sf	$369,689
Concrete Floor	1187 lf	0.39 yd/ft	462 yd	$150.00 per yd	$69,242
Track	1187 lf	1187.00 lf	1,187 lf	$34.87 per ft	$41,387
					$480,317

Total Excavation	**$931,179**
Total Per Ton	**$51.36**
Total Per ft	**$784.48**

Car Wash/Change (1075 Cubic m)

Excavation

Car Wash Change Room (1075 cubic m)	37963 cu ft	11.00 cu ft/ton	3,451 tons	$24.87 per ton	$85,831
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$85,831

Civil

Shotcrete			7,104 sf	$6.83 per sf	$48,522
Concrete Floor	1722 sf	0.75 ft/sf	48 yd	$150.00 per yd	$7,176
Track				$34.87 per ft	$0
20' Cables - Walls	26 lf	1.00 cables per ft	26 cables	$103.70 per cable	$2,696
30' Cables - Back	56 lf	1.10 cables per ft	62 cables	$155.55 per cable	$9,601
					$67,995

Total Excavation	**$153,826**
Total Per Ton	**$44.57**

All Facilities

Lunch/Refuge (1500 Cubic m)

Excavation

Lunch/Refuge (1500 Cubic m)	52972 cu ft	11.00 cu ft/ton	4,816 tons	$24.87 per ton	$119,765
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$119,765

Civil

Shotcrete			7,535 sf	$6.83 per sf	$51,462
Concrete Floor	3229 sf	0.75 ft/sf	90 yd	$150.00 per yd	$13,455
Track				$34.87 per ft	$0
20' Cables - Walls	0 lf	1.00 cables per fl	0 cables	$103.70 per cable	$0
30' Cables - Back	66 lf	1.67 cables per fl	110 cables	$155.55 per cable	$17,045
					$81,962

Total Excavation	**$201,727**
Total Per Ton	**$41.89**

Utilities (4400 Cubic m)

Excavation

Utilities (4400 Cubic m)	155385 cu ft	11.00 cu ft/ton	14,126 tons	$24.87 per ton	$351,310
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$351,310

Civil

Shotcrete			18,299 sf	$6.83 per sf	$124,980
Concrete Floor	5382 sf	0.75 ft/sf	149 yd	$150.00 per yd	$22,425
Track				$34.87 per ft	$0
20' Cables - Walls	164 lf	1.00 cables per fl	164 cables	$103.70 per cable	$17,011
30' Cables - Back	164 lf	1.10 cables per fl	181 cables	$155.55 per cable	$28,125
					$192,540

Total Excavation	**$543,851**
Total Per Ton	**$38.50**

All Facilities

Geo Lab (2140 Cubic m)

Excavation

Geo Lab (2140 Cubic m)	75573 cu ft	11.00 cu ft/ton	6,870 tons	$24.87 per ton	$170,865
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$170,865

Civil

Shotcrete			9,257 sf	$6.83 per sf	$63,225
Concrete Floor	4628 sf	0.75 ft/sf	129 yd	$150.00 per yd	$19,285
Track				$34.87 per ft	$0
20' Cables - Walls	94 lf	0.75 cables per fl	70 cables	$103.70 per cable	$7,272
30' Cables - Back	94 lf	1.67 cables per fl	156 cables	$155.55 per cable	$24,289
					$114,072

Total Excavation	**$284,937**
Total Per Ton	**$41.47**

Hall A (sec/LLCL/Util)

Excavation

Hall A (12,750 Cubic m)	450262 cu ft	11.00 cu ft/ton	40,933 tons	$24.87 per ton	$1,018,001
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$1,018,001

Civil

Shotcrete			47,092 sf	$7.57 per sf	$356,487
Mineguard Coating			47,092	$3.83 per sf	$180,363
Concrete Floor	15392 sf	1.00 ft/sf	570 yd	$150.00 per yd	$85,513
Track			295 lf	$34.87 per ft	$10,295
20' Cables - Walls	295 lf	1.50 cables per fl	443 cables	$103.70 per cable	$45,930
30' Cables - Back	295 lf	2.92 cables per fl	862 cables	$155.55 per cable	$134,116
					$812,705

Total Excavation	**$1,830,706**
Total Per Ton	**$44.72**

All Facilities

Hall B (Large Hall)

Excavation

Hall B (35000 Cubic m)	1236013 cu ft	11.00 cu ft/ton	112,365 tons	$24.87 per ton	$2,794,514
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$2,794,514

Civil

Shotcrete			77,500 sf	$7.57 per sf	$586,676
Mineguard Coating			77,500 sf	$3.83 per sf	$296,826
Concrete Floor	17222 sf	1.00 ft/sf	638 yd	$150.00 per yd	$95,679
Track			262 lf	$34.87 per ft	$9,151
20' Cables - Walls	262 lf	3.06 cables per ft	802 cables	$103.70 per cable	$83,205
30' Cables - Back	262 lf	2.92 cables per ft	766 cables	$155.55 per cable	$119,214
					$1,190,751

Total Excavation	**$3,985,265**
Total Per Ton	**$35.47**

Dark Matter # 1 (2700 Cubic m)

Excavation

Dark Matter # 1 (2700 Cubic m)	95350 cu ft	11.00 cu ft/ton	8,668 tons	$24.87 per ton	$215,577
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$215,577

Civil

Shotcrete			11,840 sf	$7.57 per sf	$89,631	
Mineguard Coating			11,840 sf	$3.83 per sf	$45,348	
Concrete Floor	3229 sf	1.00 ft/sf	120 yd	$150.00 per yd	$17,940	
Track			49 lf	$34.87 per ft	$1,716	
20' Cables - Walls	49 lf	1.00 cables per ft	49 cables	$103.70 per cable	$5,103	
30' Cables - Back	49 lf	2.92 cables per ft	144 cables	$155.55 per cable	$22,353	
					$182,091	45.79%

Total Excavation	**$397,668**
Total Per Ton	**$45.88**

All Facilities

Double Beta Decay (4000 Cubic m)

Excavation

Double Beta Decay (4000 Cubic m)	141259 cu ft	11.00 cu ft/ton	12,842 tons	$24.87 per ton	$319,373
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$319,373

Civil

Shotcrete			13,993 sf	$7.57 per sf	$105,928
Mineguard Coating			13,993 sf	$3.83 per sf	$53,594
Concrete Floor	4844 sf	1.00 ft/sf	179 yd	$150.00 per yd	$26,910
Track			49 lf	$34.87 per ft	$1,716
20' Cables - Walls	49 lf	1.00 cables per fl	49 cables	$103.70 per cable	$5,103
30' Cables - Back	49 lf	3.80 cables per fl	187 cables	$155.55 per cable	$29,058
					$222,309

Total Excavation	**$541,682**
Total Per Ton	**$42.18**

Dark Matter # 2 (2700 Cubic m)

Excavation

Dark Matter # 2 (2700 Cubic m)	95350 cu ft	11.00 cu ft/ton	8,668 tons	$24.87 per ton	$215,577
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$215,577

Civil

Shotcrete			11,840 sf	$7.57 per sf	$89,631
Mineguard Coating			11,840 sf	$3.83 per sf	$45,348
Concrete Floor	3229 sf	1.00 ft/sf	120 yd	$150.00 per yd	$17,940
Track			49 lf	$34.87 per ft	$1,716
20' Cables - Walls	49 lf	1.00 cables per fl	49 cables	$103.70 per cable	$5,103
30' Cables - Back	49 lf	2.92 cables per fl	144 cables	$155.55 per cable	$22,353
					$182,091

Total Excavation	**$397,668**
Total Per Ton	**$45.88**

All Facilities

Solar Nu (4500 Cubic m)

Excavation

Solar Nu (4500 Cubic m)	158916 cu ft	11.00 cu ft/ton	14,447 tons	$24.87 per ton	$359,295
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$359,295

Civil

Shotcrete			23,681 sf	$7.57 per sf	$179,262
Mineguard Coating			23,681 sf	$3.83 per sf	$90,697
Concrete Floor	4628 sf	1.00 ft/sf	171 yd	$150.00 per yd	$25,714
Track			131 lf	$34.87 per ft	$4,576
20' Cables - Walls	131 lf	0.00 cables per ft	0 cables	$103.70 per cable	$0
30' Cables - Back	131 lf	1.50 cables per ft	197 cables	$155.55 per cable	$30,620
					$330,868

Total Excavation	**$690,163**
Total Per Ton	**$47.77**

Seminar Room (2000 Cubic m)

Excavation

Seminar Room (2000 Cubic m)	70629 cu ft	11.00 cu ft/ton	6,421 tons	$24.87 per ton	$159,687
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$159,687

Civil

Shotcrete			9,257 sf	$6.83 per sf	$63,225
Mineguard Coating			9,257 sf	$3.83 per sf	$35,454
Concrete Floor	5382 sf	0.75 ft/sf	149 yd	$150.00 per yd	$22,425
Track			0 lf	$34.87 per ft	$0
20' Cables - Walls	82 lf	0.00 cables per ft	0 cables	$103.70 per cable	$0
30' Cables - Back	82 lf	1.50 cables per ft	123 cables	$155.55 per cable	$19,138
					$140,242

Total Excavation	**$299,928**
Total Per Ton	**$46.71**

All Facilities

Interior Machine Shop (1000 Cubic m)

Excavation

Interior Machine Shop (1000 Cubic m)	35315 cu ft	11.00 cu ft/ton	3,210 tons	$24.87 per ton	$79,843
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$79,843

Civil

Shotcrete			5,382 sf	$6.83 per sf	$36,759
Mineguard Coating			0 sf	$3.83 per sf	$0
Concrete Floor	2153 sf	0.75 ft/sf	60 yd	$150.00 per yd	$8,970
Track			164 lf	$34.87 per ft	$5,720
20' Cables - Walls	164 lf	0.00 cables per fl	0 cables	$103.70 per cable	$0
30' Cables - Back	164 lf	1.50 cables per fl	246 cables	$155.55 per cable	$38,275
					$89,723

Total Excavation	**$169,567**
Total Per Ton	**$52.82**

Exterior Machine Shop (1000 Cubic m)

Excavation

Interior Machine Shop (1000 Cubic m)	0 cu ft	11.00 cu ft/ton	0 tons	$24.87 per ton	$0
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$0

Civil

Shotcrete			0 sf	$6.83 per sf	$0
Mineguard Coating			0 sf	$3.83 per sf	$0
Concrete Floor	0 sf	0.75 ft/sf	0 yd	$150.00 per yd	$0
Track			0 lf	$34.87 per ft	$0
20' Cables - Walls	0 lf	0.00 cables per fl	0 cables	$103.70 per cable	$0
30' Cables - Back	0 lf	1.50 cables per fl	0 cables	$155.55 per cable	$0
					$0

Total Excavation	**$0**
Total Per Ton	**#DIV/0!**

All Facilities

Refrig./Fan/Coil Room (2200 Cubic m)

Excavation

Utilities (4400 Cubic m)	82667 cu ft	11.00 cu ft/ton	7,515 tons	$24.87 per ton	$186,902
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$186,902

Civil

Shotcrete			14,096 sf	$6.83 per sf	$96,276
Concrete Floor	4199 sf	1.00 ft/sf	156 yd	$150.00 per yd	$23,330
Track			160 lf	$34.87 per ft	$5,579
20' Cables - Walls	160 lf	0.00 cables per fl	0 cables	$103.70 per cable	$0
30' Cables - Back	160 lf	1.10 cables per fl	176 cables	$155.55 per cable	$27,432
					$152,616

Total Excavation	**$339,518**
Total Per Ton	**$45.18**

8000 Level Anaerobic Room

Excavation

8000 Level Anaerobic Room	12360 cu ft	11.00 cu ft/ton	1,124 tons	$30.00 per ton	$33,709
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$33,709

Civil

Shotcrete			3,283 sf	$6.83 per sf	$22,423
Concrete Floor	377 sf	1.00 ft/sf	14 yd	$150.00 per yd	$2,093
Track			0 lf	$34.87 per ft	$0
20' Cables - Walls	0 lf	0.00 cables per fl	0 cables	$103.70 per cable	$0
30' Cables - Back	0 lf	1.10 cables per fl	0 cables	$155.55 per cable	$0
					$24,516

Total Excavation	**$58,225**
Total Per Ton	**$51.82**

All Facilities

8000 Level Drilling Area

Excavation

8000 Level Drilling Area	39552 cu ft	11.00 cu ft/ton	3,596 tons	$30.00 per ton	$107,870
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$107,870

Civil

Shotcrete			sf	$6.83 per sf	$0
Concrete Floor	0 sf	1.00 ft/sf	0 yd	$150.00 per yd	$0
Track			52 lf	$34.87 per ft	$1,830
20' Cables - Walls	16 lf	1.67 cables per fl	27 cables	$103.70 per cable	$2,765
30' Cables - Back	16 lf	0.50 cables per fl	8 cables	$155.55 per cable	$1,244
					$5,840

Total Excavation	**$113,710**
Total Per Ton	**$31.62**

4850 Level Accelerator

Excavation

4850 Level Accelerator	282517 cu ft	11.00 cu ft/ton	25,683 tons	$22.91 per ton	$588,407
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$588,407

Civil

Shotcrete			29,063 sf	$6.83 per sf	$198,497
Concrete Floor	8073 sf	1.00 ft/sf	299 yd	$150.00 per yd	$44,850
Track			115 lf	$34.87 per ft	$4,004
20' Cables - Walls	115 lf	1.67 cables per fl	191 cables	$103.70 per cable	$19,846
30' Cables - Back	115 lf	0.67 cables per fl	77 cables	$155.55 per cable	$11,908
Mineguard Coating			29,063 sf	$3.83 per sf	$111,310
					$390,414

Total Excavation	**$978,821**
Total Per Ton	**$38.11**

All Facilities

4850 Level Clean Room

Excavation

4850 Level Clean Room	21189 cu ft	11.00 cu ft/ton	1,926 tons	$22.91 per ton	$44,130
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$44,130

Civil

Shotcrete			2,368 sf	$6.83 per sf	$16,174
Concrete Floor	1033 sf	0.75 ft/sf	29 yd	$150.00 per yd	$4,306
Track			0 lf	$34.87 per ft	$0
20' Cables - Walls	100 lf	0.00 cables per fl	0 cables	$103.70 per cable	$0
30' Cables - Back	100 lf	0.00 cables per fl	0 cables	$155.55 per cable	$0
Mineguard Coating			2,368 sf	$3.83 per sf	$9,070
					$29,549

Total Excavation	**$73,680**
Total Per Ton	**$38.25**

4850 Materials Storage Room

Excavation

4850 Materials Storage Room	28252 cu ft	11.00 cu ft/ton	2,568 tons	$22.91 per ton	$58,841
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$58,841

Civil

Shotcrete			3,229 sf	$6.83 per sf	$22,055
Concrete Floor	2153 sf	0.75 ft/sf	60 yd	$150.00 per yd	$8,970
Track			66 lf	$34.87 per ft	$2,288
20' Cables - Walls	100 lf	0.00 cables per fl	0 cables	$103.70 per cable	$0
30' Cables - Back	100 lf	0.00 cables per fl	0 cables	$155.55 per cable	$0
					$33,313

Total Excavation	**$92,154**
Total Per Ton	**$35.88**

All Facilities

4850 Lunch/Refuge

Excavation

4850 Lunch/Refuge	10594 cu ft	11.00 cu ft/ton	963 tons	$22.91 per ton	$22,065
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$22,065

Civil

Shotcrete			1,292 sf	$6.83 per sf	$8,822
Concrete Floor	646 sf	0.75 ft/sf	18 yd	$150.00 per yd	$2,691
Track			0 lf	$34.87 per ft	$0
20' Cables - Walls	100 lf	0.00 cables per fl	0 cables	$103.70 per cable	$0
30' Cables - Back	100 lf	0.00 cables per fl	0 cables	$155.55 per cable	$0
					$11,513

Total Excavation	**$33,578**
Total Per Ton	**$34.86**

Primary Access (15' x 15')

Excavation

Main Access Drift (18' x18')	2374 lf	20.45 tons/ft	48,559 tons	$22.91 per ton	$1,112,489
8' Rebars (cost included - excavation)	2374 lf	2.50 bolts/ft	5,935 bolts	$37.40 per bolt	$0
					$1,112,489

Civil

Shotcrete	2374 lf	54.00 sf/ft	128,196 sf	$6.83 per sf	$875,579
Concrete Floor	2374 lf	0.42 yd/ft	989 yd	$150.00 per yd	$148,375
Track	2374 lf	2374.00 lf	2,374 lf	$34.87 per ft	$82,781
					$1,106,735

Total Excavation	**$2,219,224**
Total Per Ton	**$45.70**
Total Per ft	**$934.80**

All Facilities

6 / Ross Connection (Strip to 14' x 12')

Excavation

# 6 / Ross Connection (Strip to 14' x 12')	2707 lf	7.91 tons/ft	21,410 tons	$22.91 per ton	$490,501
8' Rebars (cost included - excavation)	2707 lf	2.50 bolts/ft	6,768 bolts	$37.40 per bolt	$0
					$490,501

Civil

Shotcrete	2707 lf	48.00 sf/ft	129,936 sf	$6.83 per sf	$887,463
Concrete Floor	2707 lf	0.39 yd/ft	1,053 yd	$150.00 per yd	$157,908
Track	2707 lf	2707.00 lf	2,707 lf	$34.87 per ft	$94,384
					$1,139,755

Total Excavation	**$1,630,256**
Total Per Ton	**$76.14**
Total Per ft	**$602.24**

Enlarge Yates Station (Strip to 15' x 15')

Excavation

# 6 / Ross Connection (Strip to 14' x 12')	131 lf	7.91 tons/ft	1,038 tons	$40.00 per ton	$41,518
8' Rebars (cost included - excavation)	131 lf	2.50 bolts/ft	328 bolts	$37.40 per bolt	$0
					$41,518

Civil

Shotcrete	131 lf	54.00 sf/ft	7,087 sf	$6.83 per sf	$48,402
Concrete Floor	131 lf	0.39 yd/ft	51 yd	$150.00 per yd	$7,655
Track	131 lf	131.23 lf	131 lf	$69.73 per ft	$9,151
					$65,208

Total Excavation	**$106,726**
Total Per Ton	**$102.82**
Total Per ft	**$813.25**

All Facilities

4700 Hoist Room Access (12' x 12')

Excavation

4700 Hoist Room Access (12' x 12')	230 lf	13.09 tons/ft	3,006 tons	$22.91 per ton	$68,878
8' Rebars (cost included - excavation)	230 lf	2.00 bolts/ft	459 bolts	$37.40 per bolt	$0
					$68,878

Civil

Shotcrete	230 lf	43.20 sf/ft	9,921 sf	$6.83 per sf	$67,762
Concrete Floor	230 lf	0.33 yd/ft	77 yd	$150.00 per yd	$11,483
Track	230 lf	229.66 lf	230 lf	$34.87 per ft	$8,007
					$87,253

Total Excavation	**$156,130**
Total Per Ton	**$51.93**
Total Per ft	**$679.84**

4700 # 6 Winze Hoist Room

Excavation

4700 # 6 Winze Hoist Room	211888 cu ft	11.00 cu ft/ton	19,263 tons	$22.91 per ton	$441,305
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$441,305

Civil

Shotcrete			15,180 sf	$6.83 per sf	$103,679
Concrete Floor	5382 sf	0.75 ft/sf	399 yd	$150.00 per yd	$59,925
Track			82 lf	$34.87 per ft	$2,860
20' Cables - Walls	82 lf	1.67 cables per ft	137 cables	$103.70 per cable	$14,176
30' Cables - Back	82 lf	1.83 cables per ft	150 cables	$155.55 per cable	$23,390
Mineguard Coating			2,368 sf	$3.83 per sf	$9,070
					$213,100

Total Excavation	**$654,405**
Total Per Ton	**$33.97**

All Facilities

4700 Hoist Room Rope Raise (12' x 12')

Excavation

4700 Hoist Room Rope Raise (12' x 12')	115 lf	13.09 tons/ft	1,503 tons	$40.00 per ton	$60,129
8' Rebars (cost included - excavation)	115 lf	2.00 bolts/ft	230 bolts	$37.40 per bolt	$0
					$60,129

Civil

Shotcrete	115 lf	48.00 sf/ft	5,512 sf	$6.83 per sf	$37,646
Concrete Floor	115 lf	0.00 yd/ft	0 yd	$150.00 per yd	$0
Track	115 lf	0.00 lf	0 lf	$34.87 per ft	$0
					$37,646

Total Excavation	**$97,775**
Total Per Ton	**$65.04**
Total Per ft	**$851.48**

4850 Vent Drift (15' x 12')

Excavation

4850 Vent Drift (15' x 12')	780 lf	10.55 tons/ft	8,225 tons	$22.91 per ton	$188,445
8' Rebars (cost included - excavation)	780 lf	2.00 bolts/ft	1,560 bolts	$37.40 per bolt	$0
					$188,445

Civil

Shotcrete	780 lf	0.00 sf/ft	0 sf	$6.83 per sf	$0
Concrete Floor	780 lf	0.00 yd/ft	0 yd	$150.00 per yd	$0
Track	780 lf	0.00 lf	0 lf	$34.87 per ft	$0
					$0

Total Excavation	**$188,445**
Total Per Ton	**$22.91**
Total Per ft	**$241.60**

All Facilities

Above 4850 Borehole Cutout

Excavation

Above 4850 Borehole Cutout	10171 cu ft	11.00 cu ft/ton	925 tons	$30.00 per ton	$27,738
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$27,738

Civil

Shotcrete			0 sf	$6.83 per sf	$0
Concrete Floor	517 sf	1.50 ft/sf	29 yd	$150.00 per yd	$4,306
Track			0 lf	$34.87 per ft	$0
20' Cables - Walls	0 lf	1.67 cables per fl	0 cables	$103.70 per cable	$0
30' Cables - Back	0 lf	1.83 cables per fl	0 cables	$155.55 per cable	$0
Mineguard Coating			0 sf	$3.83 per sf	$0
					$4,306

Total Excavation	**$32,044**
Total Per Ton	**$34.66**

Below 4850 Borehole Cutout

Excavation

Below 4850 Borehole Cutout	10171 cu ft	11.00 cu ft/ton	925 tons	$35.00 per ton	$32,361
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$32,361

Civil

Shotcrete			0 sf	$6.83 per sf	$0
Concrete Floor	517 sf	1.50 ft/sf	29 yd	$150.00 per yd	$4,306
Track			0 lf	$34.87 per ft	$0
20' Cables - Walls	0 lf	1.67 cables per fl	0 cables	$103.70 per cable	$0
30' Cables - Back	0 lf	1.83 cables per fl	0 cables	$155.55 per cable	$0
Mineguard Coating			0 sf	$3.83 per sf	$0
					$4,306

Total Excavation	**$36,667**
Total Per Ton	**$39.66**

All Facilities

Above 4850 Target Out

Excavation

Above 4850 Target Out	6780 cu ft	11.00 cu ft/ton	616 tons	$30.00 per ton	$18,492
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$18,492

Civil

Shotcrete			0 sf	$6.83 per sf	$0
Concrete Floor	0 sf	1.50 ft/sf	0 yd	$150.00 per yd	$0
Track			0 lf	$34.87 per ft	$0
20' Cables - Walls	0 lf	1.67 cables per fl	0 cables	$103.70 per cable	$0
30' Cables - Back	0 lf	1.83 cables per fl	0 cables	$155.55 per cable	$0
Mineguard Coating			0 sf	$3.83 per sf	$0
					$0

Total Excavation	**$18,492**
Total Per Ton	**$30.00**

Below 4850 Target Out

Excavation

Below 4850 Target Out	6780 cu ft	11.00 cu ft/ton	616 tons	$35.00 per ton	$21,574
8' Rebars (cost included - excavation)			0 bolts	$37.40 per bolt	$0
					$21,574

Civil

Shotcrete			0 sf	$6.83 per sf	$0
Concrete Floor	0 sf	1.50 ft/sf	0 yd	$150.00 per yd	$0
Track			0 lf	$34.87 per ft	$0
20' Cables - Walls	0 lf	1.67 cables per fl	0 cables	$103.70 per cable	$0
30' Cables - Back	0 lf	1.83 cables per fl	0 cables	$155.55 per cable	$0
Mineguard Coating			0 sf	$3.83 per sf	$0
					$0

Total Excavation	**$21,574**
Total Per Ton	**$35.00**

All Facilities

7400 Level Rehab

Excavation

7400 Level Rehab	0 cu ft	11.00 cu ft/ton	0 tons	$35.00 per ton	$0
Rock Bolt	1000 lf	3.00 bolts per ft	3,000 bolts	$24.00 per bolt	$72,000
					$72,000

Civil

Shotcrete			0 sf	$6.83 per sf	$0
Concrete Floor	0 sf	1.50 ft/sf	0 yd	$150.00 per yd	$0
Track			7500 lf	$34.87 per ft	$261,500
20' Cables - Walls	0 lf	1.67 cables per fl	0 cables	$103.70 per cable	$0
30' Cables - Back	0 lf	1.83 cables per fl	0 cables	$155.55 per cable	$0
Mineguard Coating			0 sf	$3.83 per sf	$0
					$261,500

Total Rehab	**$333,500**
Total Cost per Foot	**$44.47**

7400 Facilities

Description	Tons	Cost
Central Hall/Entrance	54,785	$2,390,072
Exhaust/Utility	35,097	$1,891,428
Main Exhaust Drift	18,129	$931,179
Car Wash/Change	3,451	$153,826
Lunch Refuge	4,816	$201,727
Utilities	14,126	$543,851
Geo Lab	6,870	$284,937
Hall A (Sec/LLCF/LLCF Util)	40,933	$1,830,706
Hall B (Large Hall)	112,365	$3,985,265
Dark Matter # 1	8,668	$397,668
Double Beta	12,842	$541,682
Dark Matter # 2	8,668	$397,668
Solar Nu	14,447	$690,163
Seminar Room	6,421	$299,928
Interior Machine Shop	3,210	$169,567
Exterior Machine Shop	0	$0
Refrig./Fan/Coil Room	7,515	$339,518
Subtotal	352,343	$15,049,185

4700, 4850 & 8000 Facilities

Description	Tons	Cost
4850 Accelerator	25,683	$978,821
4850 Clean Room	1,926	$73,680
4850 Materials Storage	2,568	$92,154
4850 Lunch/Refuge Room	963	$33,578
4850 Main Access (15' x 15')	48,559	$2,219,224
4850 Ross/# 6 Connection Stripping	21,410	$1,630,256
4850 Lab Vent/Utility (12' x 12')	14,138	$734,222
4850 Yates Station	1,038	$106,726
4850 Vent Drift to # 5 Shaft	8,225	$188,445
4700 Hoist Room Drift	3,006	$156,130
4700 Hoist Room	19,263	$654,405
4700 Hoist Rope Raise	1,503	$97,775
8000 Anearobic Room	1,124	$58,225
8000 Drilling Area	3,596	$113,710
Subtotal	153,003	$7,137,351

Ross & # 6 Pump & Electrical Service Holes

Description		Tons	Cost
Tramway Cutout		925	$32,044
1250 Level Target Out		616	$18,492
1250 Borehole Cutout		925	$32,044
2450 Level Target Out		616	$18,492
2450 Borehole Cutout		925	$32,044
3650 Level Target Out		616	$18,492
3650 Borehole Cutout		925	$32,044
5000 Level Target Out		616	$21,574
5000 Borehole Cutout		925	$36,667
5900 Level Target Out		616	$21,574
5900 Borehole Cutout		925	$36,667
6800 Level Target Out		616	$21,574
6800 Borehole Cutout		925	$36,667
7400 Level Target Out		616	$21,574
7400 Borehole Cutout		925	$36,667
8000 Level Target Out		616	$21,574
	Subtotal	12,328	$438,187

	Ross @ # 6 Pump/Electrical Service								Ross @ # 6 Pump/Electrical Service							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Ross @ # 6 Pump/Electrical Service																
Engineering/Bid																
Tramway Cutout			925	$32,044												
1250 Level Cutout & Target Out			1,541	$50,536												
2450 Level Cutout & Target Out			1,541	$50,536												
3650 Level Cutout & Target Out			1,541	$50,536												
5000 Level Cutout & Target Out					1,541	$58,241										
5900 Level Cutout & Target Out					1,541	$58,241										
6800 Level Cutout & Target Out					1,541	$58,241										
7400 Level Cutout & Target Out							1,541	$58,241								
8000 Level Target Out							616	$21,574								
Hole Drilling Surface to 8000 Level				$244,125				$244,125								
Pipe Installation Surface to 8000 Level				$327,149		$327,149		$327,149		$327,149						
	0	$0	5,548	$754,924	4,623	$501,871	2,157	$651,088	0	$327,149	0	$0	0	$0	0	$0

	Ross @ # 6 Pump/Electrical Service								Ross @ # 6 Pump/Electrical Service							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Ross @ # 6 Pump/Electrical Service																
Engineering/Bid																
Tramway Cutout																
1250 Level Cutout & Target Out																
2450 Level Cutout & Target Out																
3650 Level Cutout & Target Out																
5000 Level Cutout & Target Out																
5900 Level Cutout & Target Out																
6800 Level Cutout & Target Out																
7400 Level Cutout & Target Out																
8000 Level Target Out																
Hole Drilling Surface to 8000 Level																
Pipe Installation Surface to 8000 Leve																
	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0

Ross @ # 6 Pump/Electrical Service

	Year 5								Year 1 - 5					
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Year 1	Year 2	Year 3	Year 4	Year 5	Total
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Cost	Cost	Cost	Cost	Cost	Cost
									$0	$0	$0	$0	$0	$0
Ross @ # 6 Pump/Electrical Service									$0	$0	$0	$0	$0	$0
Engineering/Bid									$0	$0	$0	$0	$0	$0
Tramway Cutout									$32,044	$0	$0	$0	$0	$32,044
1250 Level Cutout & Target Out									$50,536	$0	$0	$0	$0	$50,536
2450 Level Cutout & Target Out									$50,536	$0	$0	$0	$0	$50,536
3650 Level Cutout & Target Out									$50,536	$0	$0	$0	$0	$50,536
5000 Level Cutout & Target Out									$58,241	$0	$0	$0	$0	$58,241
5900 Level Cutout & Target Out									$58,241	$0	$0	$0	$0	$58,241
6800 Level Cutout & Target Out									$58,241	$0	$0	$0	$0	$58,241
7400 Level Cutout & Target Out									$58,241	$0	$0	$0	$0	$58,241
8000 Level Target Out									$21,574	$0	$0	$0	$0	$21,574
Hole Drilling Surface to 8000 Level									$488,250	$0	$0	$0	$0	$488,250
Pipe Installation Surface to 8000 Leve									$981,446	$327,149	$0	$0	$0	$1,308,595
									$0	$0	$0	$0	$0	$0
									$0	$0	$0	$0	$0	$0
									$0	$0	$0	$0	$0	$0
									$0	$0	$0	$0	$0	$0
									$0	$0	$0	$0	$0	$0
									$0	$0	$0	$0	$0	$0
									$0	$0	$0	$0	$0	$0
	0	$0	0	$0	0	$0	0	$0	$1,907,884	$327,149	$0	$0	$0	$2,235,032

Pump Column & Electrical Services Holes

	Days	Weeks	Tons	Total
Tramway Cutout				
Total Cost & Duration	6	0.80	925	$32,044
1250 Target Out				
Total Cost & Duration	4	0.53	616	$18,492
1250 Borehole Cutout				
Total Cost & Duration	6	0.80	925	$32,044
2450 Target Out				
Total Cost & Duration	4	0.53	616	$18,492
2450 Borehole Cutout				
Total Cost & Duration	6	0.80	925	$32,044
3650 Target Out				
Total Cost & Duration	4	0.53	616	$18,492
3650 Borehole Cutout				
Total Cost & Duration	6	0.80	925	$32,044

	Days	Weeks	Tons	Total
5000 Target Out				
Total Cost & Duration	4		0.53	616 $21,574

	Days	Weeks	Tons	Total
5000 Borehole Cutout				
Total Cost & Duration	6		0.80	925 $36,667

	Mine Doors & Walls								Mine Doors & Walls							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Mine Doors & Walls																
Procurement																
Install Seals						$41,917		$41,917		$41,917		$41,917		$41,917		$41,917
		$0		$0		$41,917		$41,917		$41,917		$41,917		$41,917		$41,917

	Mine Doors & Walls								Mine Doors & Walls							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Mine Doors & Walls																
Procurement																
Install Seals																
		$0		$0		$0		$0		$0		$0		$0		$0

Mine Doors & Walls

	Year 5							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Mine Doors & Walls								
Procurement								
Install Seals								
		$0		$0		$0		$0

Mine Doors & Walls

Year 1 - 5					
Year 1	Year 2	Year 3	Year 4	Year 5	Total
Cost	Cost	Cost	Cost	Cost	Cost
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$83,833	$167,667	$0	$0	$0	$251,500
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$83,833	$167,667	$0	$0	$0	$251,500

Mine Doors & Walls

	Days	Weeks	Seals	Total
Mine Doors & Seals				
Total Cost & Duration	497	71.00	71	$251,500
	1.3616438			

	4850 Core Drilling								4850 Core Drilling							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
4850 Core Drilling																
Engineering & Bid																
4850 Drilling (7200 ft BQ)				$72,000												
		$0		$72,000		$0		$0		$0		$0		$0		$0

	4850 Core Drilling								4850 Core Drilling							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
4850 Core Drilling																
Engineering & Bid																
4850 Drilling (7200 ft BQ)																
		$0		$0		$0		$0		$0		$0		$0		$0

4850 Core Drilling

	Year 5							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost
4850 Core Drilling								
Engineering & Bid								
4850 Drilling (7200 ft BQ)								
		$0		$0		$0		$0

4850 Core Drilling

Year 1 - 5					
Year 1	Year 2	Year 3	Year 4	Year 5	Total
Cost	Cost	Cost	Cost	Cost	Cost
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$72,000	$0	$0	$0	$0	$72,000
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$72,000	$0	$0	$0	$0	$72,000

4850 Level Core Drilling

	Days	Weeks	Feet	Total
4850 Core Drilling				
Total Cost & Duration		4.00	7,200	$72,000
	28			

	7400 Core Drilling								7400 Core Drilling							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
7400 Core Drilling																
Engineering & Bid																
7400 Drilling (14,400 ft BQ)				$216,000												
		$0		$216,000		$0		$0		$0		$0		$0		$0

	7400 Core Drilling								7400 Core Drilling							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
7400 Core Drilling																
Engineering & Bid																
7400 Drilling (14,400 ft BQ)																
		$0		$0		$0		$0		$0		$0		$0		$0

7400 Core Drilling

	Year 5							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost
7400 Core Drilling								
Engineering & Bid								
7400 Drilling (14,400 ft BQ)								
		$0		$0		$0		$0

7400 Core Drilling

Year 1 - 5					
Year 1	Year 2	Year 3	Year 4	Year 5	Total
Cost	Cost	Cost	Cost	Cost	Cost
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$216,000	$0	$0	$0	$0	$216,000
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$216,000	$0	$0	$0	$0	$216,000

7400 Level Core Drilling

	Days	Weeks	Feet	Total
7400 Diamond Drilling				
Total Cost & Duration	56	8.00	14,400	$216,000

	7400 Excavations								7400 Excavations							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
7400 Excavations																
Engineering for Facilities																
Bid																
Mobilization																
Central Hall/Entrance					6,848	$298,759	6,848	$298,759	6,848	$298,759	6,848	$298,759	6,848	$298,759	6,848	$298,759
Exhaust/Utility Drift					4,387	$236,429	4,387	$236,429	4,387	$236,429	4,387	$236,429	4,387	$236,429	4,387	$236,429
Main Exhaust Drift							9,064	$465,589	9,064	$465,589						
Car Wash/Change							3,451	$153,826								
Lunch Refuge							4,816	$201,727								
Utilities Room					14,126	$543,851										
Geo Lab					3,435	$142,468	3,435	$142,468								
Hall A (Sec/LLCF/LLCF Util)									5,117	$228,838	5,117	$228,838	5,117	$228,838	5,117	$228,838
Hall B (Large Hall)									5,618	$199,263	14,046	$498,158	18,727	$664,211	18,727	$664,211
Dark Matter # 1					4,334	$198,834	2,167	$99,417	2,167	$99,417						
Double Beta							6,421	$270,841	6,421	$270,841						
Dark Matter # 2											4,334	$198,834	4,334	$198,834		
Solar Nu															3,612	$172,541
Seminar Room											6,421	$299,928				
Interior Machine Shop											3,210	$169,567				
Exterior Machine Shop					0	$0										
Refrig./Fan/Coil Room					7,515	$339,518										
	0	$0	0	$0	40,646	$1,759,859	40,590	$1,869,056	39,622	$1,799,136	44,363	$1,930,513	39,413	$1,627,071	38,691	$1,600,777

	7400 Excavations								7400 Excavations							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
7400 Excavations																
Engineering for Facilities																
Bid																
Mobilization																
Central Hall/Entrance	6,848	$298,759	6,848	$298,759												
Exhaust/Utility Drift	4,387	$236,429	4,387	$236,429												
Main Exhaust Drift																
Car Wash/Change																
Lunch Refuge																
Utilities Room																
Geo Lab																
Hall A (Sec/LLCF/LLCF Util)	5,117	$228,838	5,117	$228,838	10,233	$457,677										
Hall B (Large Hall)	18,727	$664,211	18,727	$664,211	17,791	$631,000										
Dark Matter # 1																
Double Beta																
Dark Matter # 2																
Solar Nu	3,612	$172,541	3,612	$172,541	3,612	$172,541										
Seminar Room																
Interior Machine Shop																
Exterior Machine Shop																
Refrig./Fan/Coil Room																
	38,691	$1,600,777	38,691	$1,600,777	31,636	$1,261,218	0	$0	0	$0	0	$0	0	$0	0	$0

7400 Excavations

	Year 5							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost
7400 Excavations								
Engineering for Facilities								
Bid								
Mobilization								
Central Hall/Entrance								
Exhaust/Utility Drift								
Main Exhaust Drift								
Car Wash/Change								
Lunch Refuge								
Utilities Room								
Geo Lab								
Hall A (Sec/LLCF/LLCF Util)								
Hall B (Large Hall)								
Dark Matter # 1								
Double Beta								
Dark Matter # 2								
Solar Nu								
Seminar Room								
Interior Machine Shop								
Exterior Machine Shop								
Refrig./Fan/Coil Room								
	0	$0	0	$0	0	$0	0	$0

7400 Excavations

	Year 1 - 5					
	Year 1	Year 2	Year 3	Year 4	Year 5	Total
	Cost	Cost	Cost	Cost	Cost	Cost
	$0	$0	$0	$0	$0	$0
7400 Excavations	$0	$0	$0	$0	$0	$0
Engineering for Facilities	$0	$0	$0	$0	$0	$0
Bid	$0	$0	$0	$0	$0	$0
Mobilization	$0	$0	$0	$0	$0	$0
Central Hall/Entrance	$597,518	$1,195,036	$597,518	$0	$0	$2,390,072
Exhaust/Utility Drift	$472,857	$945,714	$472,857	$0	$0	$1,891,428
Main Exhaust Drift	$465,589	$465,589	$0	$0	$0	$931,179
Car Wash/Change	$153,826	$0	$0	$0	$0	$153,826
Lunch Refuge	$201,727	$0	$0	$0	$0	$201,727
Utilities Room	$543,851	$0	$0	$0	$0	$543,851
Geo Lab	$284,937	$0	$0	$0	$0	$284,937
Hall A (Sec/LLCF/LLCF Util)	$0	$915,353	$915,353	$0	$0	$1,830,706
Hall B (Large Hall)	$0	$2,025,843	$1,959,422	$0	$0	$3,985,265
Dark Matter # 1	$298,251	$99,417	$0	$0	$0	$397,668
Double Beta	$270,841	$270,841	$0	$0	$0	$541,682
Dark Matter # 2	$0	$397,668	$0	$0	$0	$397,668
Solar Nu	$0	$172,541	$517,622	$0	$0	$690,163
Seminar Room	$0	$299,928	$0	$0	$0	$299,928
Interior Machine Shop	$0	$169,567	$0	$0	$0	$169,567
Exterior Machine Shop	$0	$0	$0	$0	$0	$0
Refrig./Fan/Coil Room	$339,518	$0	$0	$0	$0	$339,518
	$3,628,915	$6,957,497	$4,462,773	$0	$0	$15,049,185

7400 Excavations

	Days	Weeks	Tons	Total
Central Hall Entrance				
Total Cost & Duration	111	15.83	54,785	$2,390,072
Exaust/Utility Drift				
Total Cost & Duration	71	10.14	35,097	$1,891,428
Main Exaust Drift				
Total Cost & Duration	37	5.24	18,129	$931,179
Car Wash/Change				
Total Cost & Duration	7	1.00	3,451	$153,826
Lunch/Refuge				
Total Cost & Duration	10	1.39	4,816	$201,727
Utilities Room				
Total Cost & Duration	29	4.08	14,126	$543,851
Geo Lab				
Total Cost & Duration	14	1.98	6,870	$284,937

	Days	Weeks	Tons	Total
Hall A (Sec/LLCF/LLCF Util)				
Total Cost & Duration	83	11.83	40,933	$1,830,706
Hall B (Large Hall)				
Total Cost & Duration	227	32.46	112,365	$3,985,265
Dark Matter # 1				
Total Cost & Duration	18	2.50	8,668	$397,668
Double Beta				
Total Cost & Duration	26	3.71	12,842	$541,682
Dark Matter # 2				
Total Cost & Duration	18	2.50	8,668	$397,668
Solar Nu				
Total Cost & Duration	29	4.17	14,447	$690,163
Seminar Room				
Total Cost & Duration	13	1.85	6,421	$299,928

	Days	Weeks	Tons	Total	
Interior Machine Shop					
Total Cost & Duration	6		0.93	3,210	$169,567

	Days	Weeks	Tons	Total	
Exterior Machine Shop					
Total Cost & Duration	0		0.00	0	$0

	Days	Weeks	Tons	Total	
Refrig./Fan/Coil Room					
Total Cost & Duration	15		2.17	7,515	$339,518

	7400 Level Rehab								7400 Level Rehab							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
7400 Level Rehab																
Engineering/Bid																
Procurement																
Track/ Ditch				$261,500												
Rockbolt				$72,000												
		$0		$333,500		$0		$0		$0		$0		$0		$0

	7400 Level Rehab								7400 Level Rehab							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
7400 Level Rehab																
Engineering/Bid																
Procurement																
Track/ Ditch																
Rockbolt																
		$0		$0		$0		$0		$0		$0		$0		$0

7400 Level Rehab

	Year 5							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost
7400 Level Rehab								
Engineering/Bid								
Procurement								
Track/ Ditch								
Rockbolt								
		$0		$0		$0		$0

7400 Level Rehab

Year 1 - 5					
Year 1	Year 2	Year 3	Year 4	Year 5	Total
Cost	Cost	Cost	Cost	Cost	Cost
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$261,500	$0	$0	$0	$0	$261,500
$72,000	$0	$0	$0	$0	$72,000
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$333,500	$0	$0	$0	$0	$333,500

7400 Level Rehab/ Track

	Days	Weeks	Footage	Total
Retrack 7400 Level				
Total Cost & Duration	78	11.11	7,500	$261,500

	Days	Weeks	Bolts	Total
Rock Bolting				
Total Cost & Duration	14	2.00	3,000	$72,000

	Other Excavations								Other Excavations							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Other Excavations																
Engineering for Facilities																
Bid																
Mobilization																
4850 Lab Access					2,023	$92,468	4,047	$184,935	4,047	$184,935	4,047	$184,935	4,047	$184,935		
4850 Materials Storage					2,568	$92,154										
4850 Lunch/Refuge					963	$33,578										
4850 Accelerator							3,853	$146,823	3,853	$146,823	3,853	$146,823	7,705	$293,646		
4850 Clean Room					1,926	$73,680										
4850 Yates Station											1,038	$106,726				
4850 Ross / # 6 Connection					3,568	$271,709	7,137	$543,419	7,137	$543,419	3,568	$271,709				
4850 Lab Vent/Utility					3,535	$183,556					3,535	$183,556				
8000 Anearobic Room													1,124	$58,225		
8000 Drilling Platform													3,596	$113,710		
4700 Hoist Room Access																
4700 Hoist Room																
4700 Hoist Room Roper Raise																
4850 Vent Drift to #5 Shaft																
	0	$0	0	$0	14,584	$747,144	15,036	$875,177	15,036	$875,177	16,040	$893,749	16,471	$650,517	0	$0

	Other Excavations								Other Excavations							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Other Excavations																
Engineering for Facilities																
Bid																
Mobilization																
4850 Lab Access			8,093	$369,871	8,093	$369,871	8,093	$369,871	6,070	$277,403						
4850 Materials Storage																
4850 Lunch/Refuge																
4850 Accelerator			3,853	$146,823	2,568	$97,882										
4850 Clean Room																
4850 Yates Station																
4850 Ross / # 6 Connection																
4850 Lab Vent/Utility			3,535	$183,556	3,535	$183,556										
8000 Anearobic Room																
8000 Drilling Platform																
4700 Hoist Room Access																
4700 Hoist Room																
4700 Hoist Room Roper Raise																
4850 Vent Drift to #5 Shaft							4,113	$94,223	4,113	$94,223						
	0	$0	15,480	$700,249	14,196	$651,308	12,206	$464,093	10,183	$371,626	0	$0	0	$0	0	$0

Other Excavations

	Year 5								Year 1 - 5					
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Year 1	Year 2	Year 3	Year 4	Year 5	Total
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Cost	Cost	Cost	Cost	Cost	Cost
									$0	$0	$0	$0	$0	$0
Other Excavations									$0	$0	$0	$0	$0	$0
Engineering for Facilities									$0	$0	$0	$0	$0	$0
Bid									$0	$0	$0	$0	$0	$0
Mobilization									$0	$0	$0	$0	$0	$0
4850 Lab Access									$277,403	$554,806	$1,109,612	$277,403	$0	$2,219,224
4850 Materials Storage									$92,154	$0	$0	$0	$0	$92,154
4850 Lunch/Refuge									$33,578	$0	$0	$0	$0	$33,578
4850 Accelerator									$146,823	$587,293	$244,705	$0	$0	$978,821
4850 Clean Room									$73,680	$0	$0	$0	$0	$73,680
4850 Yates Station									$0	$106,726	$0	$0	$0	$106,726
4850 Ross / # 6 Connection									$815,128	$815,128	$0	$0	$0	$1,630,256
4850 Lab Vent/Utility									$183,556	$183,556	$367,111	$0	$0	$734,222
8000 Anearobic Room									$0	$58,225	$0	$0	$0	$58,225
8000 Drilling Platform									$0	$113,710	$0	$0	$0	$113,710
4700 Hoist Room Access									$0	$0	$0	$0	$0	$0
4700 Hoist Room									$0	$0	$0	$0	$0	$0
4700 Hoist Room Roper Raise									$0	$0	$0	$0	$0	$0
4850 Vent Drift to #5 Shaft									$0	$0	$94,223	$94,223	$0	$188,445
									$0	$0	$0	$0	$0	$0
									$0	$0	$0	$0	$0	$0
									$0	$0	$0	$0	$0	$0
	0	$0	0	$0	0	$0	0	$0	$1,622,321	$2,419,444	$1,815,651	$371,626	$0	$6,229,041

Other Excavations

	Days	Weeks	Tons	Total
4850 Lab Main Access				
Total Cost & Duration	295	42.08	48,559	$2,219,224
4850 Materials Storage				
Total Cost & Duration	16	2.23	2,568	$92,154
4850 Lunch Refuge				
Total Cost & Duration	6	0.83	963	$33,578
4850 Accelerator				
Total Cost & Duration	156	22.26	25,683	$978,821
4850 Clean Room				
Total Cost & Duration	12	1.67	1,926	$73,680
4850 Yates Station				
Total Cost & Duration	6	0.90	1,038	$106,726
4850 Ross / # 6 Connection				
Total Cost & Duration	130	18.56	21,410	$1,630,256

	Days	Weeks	Tons	Total
8000 Anearobic Room				
Total Cost & Duration	7	0.97	1,124	$58,225

	Days	Weeks	Tons	Total
8000 Drilling Platform				
Total Cost & Duration	22	3.12	3,596	$113,710

	Days	Weeks	Tons	Total
4850 Vent Drift				
Total Cost & Duration	50	7.13	8,225	$188,445

	# 6 Winze Upgrade								# 6 Winze Upgrade							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
# 6 Winze Upgrade																
Engineering	1															
Procurement - Shaft Materials																
Engineering for Hoist Upgrades	1															
8000 Skip Pocket Rebuild			1	$55,553												
4850 Skip Dump & Chute Repair			1	$35,553												
Mobilization																
4700 Hoist Room Access															3,006	$156,130
Hoist Room															19,263	$654,405
Hoist Room Rope Raise																
Install New Hoist																
4700 Shaft Conversion for new Hoist																
4550 Hoist Room Re-Configuration																
Automate Ore Hoist																
Construction Platform																
Concurrent Shaft Activities																
Station Rebuilds																
Conveyances																
Management & Local Admin																
		$0		$91,107		$0		$0		$0		$0		$0	22,269	$810,535

	# 6 Winze Upgrade								# 6 Winze Upgrade							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
# 6 Winze Upgrade																
Engineering																
Procurement - Shaft Materials																
Engineering for Hoist Upgrades																
8000 Skip Pocket Rebuild																
4850 Skip Dump & Chute Repair																
Mobilization																
4700 Hoist Room Access																
Hoist Room																
Hoist Room Rope Raise	19,263	$97,775														
Install New Hoist			1	$3,465,000												
4700 Shaft Conversion for new Hoist					1	$90,107										
4550 Hoist Room Re-Configuration					1	$78,883										
Automate Ore Hoist					1	$300,000										
Construction Platform					1	$72,846										
Concurrent Shaft Activities							150	$979,790	150	$979,790	150	$979,790				
Station Rebuilds							5	$133,617	5	$133,617	5	$133,617				
Conveyances											2	$175,692				
Management & Local Admin																
							63	$88,000	63	$88,000	63	$88,000				
	19,263	$97,775		$3,465,000		$541,836		$1,201,407		$1,201,407		$1,377,099		$0		$0

6 Winze Upgrade

	Year 5								Year 1 - 5					
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Year 1	Year 2	Year 3	Year 4	Year 5	Total
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Cost	Cost	Cost	Cost	Cost	Cost
									$0	$0	$0	$0	$0	$0
# 6 Winze Upgrade									$0	$0	$0	$0	$0	$0
Engineering									$0	$0	$0	$0	$0	$0
Procurement - Shaft Materials									$0	$0	$0	$0	$0	$0
Engineering for Hoist Upgrades									$0	$0	$0	$0	$0	$0
8000 Skip Pocket Rebuild									$55,553	$0	$0	$0	$0	$55,553
4850 Skip Dump & Chute Repair									$35,553	$0	$0	$0	$0	$35,553
Mobilization									$0	$0	$0	$0	$0	$0
4700 Hoist Room Access									$0	$156,130	$0	$0	$0	$156,130
Hoist Room									$0	$654,405	$0	$0	$0	$654,405
Hoist Room Rope Raise									$0	$0	$97,775	$0	$0	$97,775
Install New Hoist									$0	$0	$3,465,000	$0	$0	$3,465,000
4700 Shaft Conversion for new Hoist									$0	$0	$90,107	$0	$0	$90,107
4550 Hoist Room Re-Configuration									$0	$0	$78,883	$0	$0	$78,883
Automate Ore Hoist									$0	$0	$300,000	$0	$0	$300,000
Construction Platform									$0	$0	$72,846	$0	$0	$72,846
Concurrent Shaft Activities									$0	$0	$979,790	$1,959,581	$0	$2,939,371
Station Rebuilds									$0	$0	$133,617	$267,233	$0	$400,850
Conveyances									$0	$0	$0	$175,692	$0	$175,692
Management & Local Admin									$0	$0	$0	$0	$0	$0
									$0	$0	$88,000	$176,000	$0	$264,000
									$0	$0	$0	$0	$0	$0
		$0		$0		$0		$0	$91,107	$810,535	$5,306,017	$2,578,505	$0	$8,786,165

6 Winze Maintenance/Hoist Upgrades

Assumptions		
Excavation Rate	1,154	tons per week
Mobilization (equipment)	$125,000	ea
Replace Steel	20	pcs
Rock Bolting	80	sets
Change Guides	450	sets
Guide Alignment	3600	ft
Move Counterweight/Utilities		
Lacing/Blocking/Bar & Clean	450	full sets
Steel Reconfiguration	450	
8000 Skip Pocket Rebuild	1	ea
Station Rebuilds	15	ea
Move Hoists/Maintenance	2	ea
Construction Platform	1	ea
Conveyances	2	ea
Admin/Management	1	ea
Demobilization	$75,000	ea

	crew	shifts	labor	material	Total
Replace Steel					
6 people excluding hoist operators	6	1.00	$1,542	$1,503	$3,045
Inspection Shift (1 in 10)	6	0.10	$154	$0	$154
Total per Unit		1.10	$1,696	$1,503	$3,199
20					
Total Cost & Duration		22	$33,913	$30,062.50	$63,976
3 Shifts per day		7			

	crew	shifts	labor	material	Total
Reconfigure Steel					
6 people excluding hoist operators	6	0.50	$771	$603	$1,374
Inspection Shift (1 in 10)	6	0.05	$77	$0	$77
Total per Unit		0.55	$848	$603	$1,451
450					
Total Cost & Duration		248	$381,522	$271,406.25	$652,928
3 Shifts per day		83			

	crew	shifts	labor	material	Total
Rock Bolting					
6 people excluding hoist operators & yard	6	0.50	$771	$2,082	$2,853
Inspection Shift (1 in 10)	6	0.05	$77	$0	$77
Total per Unit		0.55	$848	$2,082	$2,930
80					
Total Cost & Duration		44	$67,826	$166,595.20	$234,421
3 Shifts per day		15			

	crew	shifts	labor	material	Total
Replace Guides					
6 people excluding hoist operators & yard	6	0.13	$193	$1,050	$1,243
Inspection Shift (1 in 10)	6	0.01	$19	$0	$19
Total per Unit		0.14	$212	$1,050	$1,262
450					
Total Cost & Duration		62	$95,380	$472,500	$567,880
3 Shifts per day		21			

	crew	shifts	labor	material	Total
Guide Alignment					
6 people excluding hoist operators & yard	6	0.01	$11	$4	$15
Inspection Shift (1 in 10)	6	0.00	$1	$0	$1
Total per Unit		0.01	$12	$4	$16
3600					
Total Cost & Duration		29	$44,885	$13,500	$58,385
3 Shifts per day		10			

	crew	shifts	labor	material	Total
Lacing Replacement/Bar/Clean/Blocking					
6 people excluding hoist operators	6	0.50	$771	$1,454	$2,225
Inspection Shift (1 in 10)	6	0.05	$77	$0	$77
Total per Unit		0.55	$848	$1,454	$2,302
450					
Total Cost & Duration		248	$381,522	$654,498	$1,036,020
3 Shifts per day		83			

	crew	shifts	labor	material	Total
8000 Skip Pocket Rebuild					
4 people excluding hoist operators & yard	4	20.00	$20,553	$35,000	$55,553
Inspection Shift (1 in 10)	4	0.00	$0	$0	$0
Total per Unit		20.00	$20,553	$35,000	$55,553
1					
Total Cost & Duration		20	$20,553	$35,000	$55,553
2 Shifts per day		7			

	crew	shifts	labor	material	Total
4850 Skip Dump & Haulage Chute Repair					
6 people excluding hoist operators & yard	4	20.00	$20,553	$15,000	$35,553
Inspection Shift (1 in 10)	4	0.00	$0	$0	$0
Total per Unit		20.00	$20,553	$15,000	$35,553
1					
Total Cost & Duration		20	$20,553	$15,000	$35,553
3 Shifts per day		10			

	Days	Weeks	Tons	Total
# 6 Winze Hoist Room Access				
Total Cost & Duration		2.61	3,006	$156,130
	18			

	Days	Weeks	Tons	Total
# 6 Winze Hoist Room Excavation				
Total Cost & Duration		16.69	19,263	$654,405
	117			

	Days	Weeks	Tons	Total
# 6 Winze Hoist Rope Raise				
Total Cost & Duration		2.61	1,503	$97,775
	18			

	crew	shifts	labor	material	Total
4700 Shaft Conversion - New Hoist					
4 people excluding hoist operators & yard	4	40.00	$41,107	$49,000	$90,107
Inspection Shift (1 in 10)	4	0.00	$0	$0	$0
Total per Unit		40.00	$41,107	$49,000	$90,107
1					
Total Cost & Duration		40	$41,107	$49,000	$90,107
3 Shifts per day		13			

		Days	Total
Hoist			
(from Dynatec Original Proposal)	days	60	$3,465,000

		Days	Total
Automate Ore Hoist			
(from Dynatec Original Proposal)	days	20	$300,000

	crew	shifts	labor	material	Total
Reconfigure 4550 Hoist Room					
4 people excluding hoist operators & yard	4	50.00	$51,383	$27,500	$78,883
Inspection Shift (1 in 10)	4	0.00	$0	$0	$0
Total per Unit		50.00	$51,383	$27,500	$78,883
1					
Total Cost & Duration		50	$51,383	$27,500	$78,883
3 Shifts per day		17			

	crew	shifts	labor	material	Total
Management& Local Admin.					
Supply	4	189.75	$234,000	$30,000	$264,000
Admin					
Manager					
Total per Unit		189.75	$234,000	$30,000	$264,000
1					
Total Cost & Duration		190	$234,000	$30,000	$264,000
1 Shifts per day		190			

	crew	shifts	labor	material	Total
Station Rebuilds					
Crew of 3 excluding hoist & yard	3	17.00	$15,723	$11,000	$26,723
Total per Unit		17.00	$15,723	$11,000	$26,723
15					
Total Cost & Duration		255	$235,850	$165,000	$400,850
1 Shifts per day		255			

	crew	shifts	labor	material	Total
Construction Platform					
Assemble/Hang in Shaft	5	10.00	$12,846	$60,000	$72,846
Total per Unit		10.00	$12,846	$60,000	$72,846
1					
Total Cost & Duration		10	$12,846	$60,000	$72,846
3 Shifts per day		3			

	crew	shifts	labor	material	Total
Conveyances					
Assemble/Hang in Shaft	5	10.00	$12,846	$75,000	$87,846
Total per Unit		10.00	$12,846	$75,000	$87,846
2					
Total Cost & Duration		20	$25,692	$150,000	$175,692
3 Shifts per day		7			

	crew	shifts	labor	material	Total
Reconfigure Utilities & Counterweights					
6 people excluding hoist operators	6	0.25	$385	$300	$685
Inspection Shift (1 in 10)	6	0.03	$39	$0	$39
Total per Unit		0.28	$424	$300	$724
450					
Total Cost & Duration		124	$190,761	$135,000.00	$325,761
3 Shifts per day		41			

Concurrent Shaft Activities

Total Cost & Duration					$2,939,371
1 Shifts per day		259			
		2.8731209	quarters		

	Yates Shaft Upgrade								Yates Shaft Upgrade							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Yates Shaft Upgrade																
Assessment/Bid	1															
Procurement - Shaft Materials	1															
Final Engineering - Hoists/Bids	1															
Mobilization			1	$87,000												
Replace Big Timber			30	$220,493												
Ground Control			20	$141,762												
Replace Gudes			100	$87,971												
Guide Alignment					1,000	$84,952										
Lacing Replacement					50	$50,178										
4850 Skip Pocket Rebuild					1	$219,059										
Surface Temp Crushing/Truck Load					1	$118,162										
Automate/Upgrade Ore Hoist			1	$600,000	1	$650,000										
Automate/Upgrade Man Hoist					1	$600,000	1	$650,000								
4850 Dump Conversion					1	$51,581										
Demobilization					1	$25,000										
		$0		$1,137,226		$1,798,932		$650,000		$0		$0		$0		$0

	Yates Shaft Upgrade								Yates Shaft Upgrade							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Yates Shaft Upgrade																
Assessment/Bid																
Procurement - Shaft Materials																
Final Engineering - Hoists/Bids																
Mobilization																
Replace Big Timber																
Ground Control																
Replace Gudes																
Guide Alignment																
Lacing Replacement																
4850 Skip Pocket Rebuild																
Surface Temp Crushing/Truck Load																
Automate/Upgrade Ore Hoist																
Automate/Upgrade Man Hoist																
4850 Dump Conversion																
Demobilization																
		$0		$0		$0		$0		$0		$0		$0		$0

Yates Shaft Upgrade

	Year 5							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Yates Shaft Upgrade								
Assessment/Bid								
Procurement - Shaft Materials								
Final Engineering - Hoists/Bids								
Mobilization								
Replace Big Timber								
Ground Control								
Replace Gudes								
Guide Alignment								
Lacing Replacement								
4850 Skip Pocket Rebuild								
Surface Temp Crushing/Truck Load								
Automate/Upgrade Ore Hoist								
Automate/Upgrade Man Hoist								
4850 Dump Conversion								
Demobilization								
		$0		$0		$0		$0

Yates Shaft Upgrade

Year 1 - 5					
Year 1	Year 2	Year 3	Year 4	Year 5	Total
Cost	Cost	Cost	Cost	Cost	Cost
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$87,000	$0	$0	$0	$0	$87,000
$220,493	$0	$0	$0	$0	$220,493
$141,762	$0	$0	$0	$0	$141,762
$87,971	$0	$0	$0	$0	$87,971
$84,952	$0	$0	$0	$0	$84,952
$50,178	$0	$0	$0	$0	$50,178
$219,059	$0	$0	$0	$0	$219,059
$118,162	$0	$0	$0	$0	$118,162
$1,250,000	$0	$0	$0	$0	$1,250,000
$1,250,000	$0	$0	$0	$0	$1,250,000
$51,581	$0	$0	$0	$0	$51,581
$25,000	$0	$0	$0	$0	$25,000
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$3,586,158	$0	$0	$0	$0	$3,586,158

Yates Shaft Maintenance/Hoist Upgrades

Assumptions
Crew of 5 Includes Supervision

Mobilization (equipment)	$50,000.00	ea
Replace Big Timber Including Lacing	50	pcs
Rock Bolting Including Lacing	30	sets
Change Guides	100	ea
Guide Alignment	1000	ft
4850 Skip Pocket Rebuild	1	ea
Lacing	50	full sets
Automate / Repairs to Yates Hoists	2	ea
Temporary Crushing / Truck Loading	1	ea

	crew	shifts	labor	material	Total
Replace Big Timber Including Lacing					
4 people excluding hoist operators & yard	5	3.00	$2,698	$1,648	$4,346
Inspection Shift (1 in 14)	5	0.07	$64	$0	$64
Total per Unit		3.07	$2,762	$1,648	$4,410
50					
Total Cost & Duration		154	$138,093	$82,400	$220,493
3 Shifts per day		51			

	crew	shifts	labor	material	Total
Rock Bolting Including Lacing					
4 people excluding hoist operators & yard	5	3.00	$2,698	$1,758	$4,456
Inspection Shift (1 in 10)	5	0.30	$270	$0	$270
Total per Unit		3.30	$2,967	$1,758	$4,725
30					
Total Cost & Duration		99	$89,021.74	$52,740	$141,762
3 Shifts per day		33			

	crew	shifts	labor	material	Total
Replace Guides					
4 people excluding hoist operators & yard	5	0.33	$300	$550	$850
Inspection Shift (1 in 14)	5	0.03	$30	$0	$30
Total per Unit		0.37	$330	$550	$880
100					
Total Cost & Duration		37	$32,971.01	$55,000	$87,971
3 Shifts per day		12			

	crew	shifts	labor	material	Total
Guide Alignment					
4 people excluding hoist operators & yard	5	0.06	$50	$30	$80
Inspection Shift (1 in 14)	5	0.01	$5	$0	$5
Total per Unit		0.06	$55	$30	$85
1000					
Total Cost & Duration		61	$54,951.69	$30,000	$84,952
3 Shifts per day		20			

	crew	shifts	labor	material	Total

Lacing Replacement					
4 people excluding hoist operators & yard	5	0.50	$450	$509	$959
Inspection Shift (1 in 14)	5	0.05	$45	$0	$45
Total per Unit		0.55	$495	$509	$1,004
50					
Total Cost & Duration		28	$24,728.26	$25,450	$50,178
3 Shifts per day		9			

	crew	shifts	labor	material	Total
Skip Pocket Rebuild					
6 people excluding hoist operators & yard	6	60.00	$64,743	$150,000	$214,743
Inspection Shift (1 in 14)	4	6.00	$4,316	$0	$4,316
Total per Unit		66.00	$69,059	$150,000	$219,059
1					
Total Cost & Duration		66	$69,059.29	$150,000	$219,059
3 Shifts per day		22			

	crew	shifts	labor	material	Total
Crushing & Bin Conveyor					
6 people excluding hoist operators & yard	4	60.00	$43,162	$75,000	$118,162
Inspection Shift (1 in 14)	4	0.00	$0	$0	$0
Total per Unit		60.00	$43,162	$75,000	$118,162
1					
Total Cost & Duration		60	$43,162.06	$75,000	$118,162
3 Shifts per day		20			

	# 4 Winze Upgrade								# 4 Winze Upgrade							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
# 4 Winze Upgrade																
Assessment/Bid	1															
Procurement - Shaft Materials	1															
Engineering for Hoist Upgrades	1															
Mobilization			1	$25,000												
7400 Pumps & Column to 21 Ledge			1	$103,960												
Replace Steel			30	$114,978												
Ground Control			20	$88,438												
Replace Guides			100	$81,377												
Guide Alignment					500	$36,981										
Lacing Replacement					100	$160,468										
7400 Skip Pocket Rebuild					1	$74,530										
4850 Skip Dump & Chutes					1	$51,581										
Ore Hoist Upgrades/Maint					1	$250,000	1	$250,000								
Man Hoist Upgrades/Maint					1	$200,000	1	$200,000	1	$300,000						
Demobilization							1	$15,000								
		$0		$413,754		$773,560		$465,000		$300,000		$0		$0		$0

	# 4 Winze Upgrade								# 4 Winze Upgrade							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
# 4 Winze Upgrade																
Assessment/Bid																
Procurement - Shaft Materials																
Engineering for Hoist Upgrades																
Mobilization																
7400 Pumps & Column to 21 Ledge																
Replace Steel																
Ground Control																
Replace Guides																
Guide Alignment																
Lacing Replacement																
7400 Skip Pocket Rebuild																
4850 Skip Dump & Chutes																
Ore Hoist Upgrades/Maint																
Man Hoist Upgrades/Maint																
Demobilization																
		$0		$0		$0		$0		$0		$0		$0		$0

4 Winze Upgrade

	Year 5							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost
# 4 Winze Upgrade								
Assessment/Bid								
Procurement - Shaft Materials								
Engineering for Hoist Upgrades								
Mobilization								
7400 Pumps & Column to 21 Ledge								
Replace Steel								
Ground Control								
Replace Guides								
Guide Alignment								
Lacing Replacement								
7400 Skip Pocket Rebuild								
4850 Skip Dump & Chutes								
Ore Hoist Upgrades/Maint								
Man Hoist Upgrades/Maint								
Demobilization								
		$0		$0		$0		$0

4 Winze Upgrade

	Year 1 - 5					
	Year 1	Year 2	Year 3	Year 4	Year 5	Total
	Cost	Cost	Cost	Cost	Cost	Cost
	$0	$0	$0	$0	$0	$0
# 4 Winze Upgrade	$0	$0	$0	$0	$0	$0
Assessment/Bid	$0	$0	$0	$0	$0	$0
Procurement - Shaft Materials	$0	$0	$0	$0	$0	$0
Engineering for Hoist Upgrades	$0	$0	$0	$0	$0	$0
Mobilization	$25,000	$0	$0	$0	$0	$25,000
7400 Pumps & Column to 21 Ledge	$103,960	$0	$0	$0	$0	$103,960
Replace Steel	$114,978	$0	$0	$0	$0	$114,978
Ground Control	$88,438	$0	$0	$0	$0	$88,438
Replace Guides	$81,377	$0	$0	$0	$0	$81,377
Guide Alignment	$36,981	$0	$0	$0	$0	$36,981
Lacing Replacement	$160,468	$0	$0	$0	$0	$160,468
7400 Skip Pocket Rebuild	$74,530	$0	$0	$0	$0	$74,530
4850 Skip Dump & Chutes	$51,581	$0	$0	$0	$0	$51,581
Ore Hoist Upgrades/Maint	$500,000	$0	$0	$0	$0	$500,000
Man Hoist Upgrades/Maint	$400,000	$300,000	$0	$0	$0	$700,000
Demobilization	$15,000	$0	$0	$0	$0	$15,000
	$0	$0	$0	$0	$0	$0
	$0	$0	$0	$0	$0	$0
	$0	$0	$0	$0	$0	$0
	$0	$0	$0	$0	$0	$0
	$1,652,314	$300,000	$0	$0	$0	$1,952,314

4 Winze Maintenance/Hoist Upgrades

Assumptions

Mobilization (equipment)	$25,000	ea
Replace Steel Including Lacing	30	pcs
Rock Bolting Including Lacing	20	sets
Change Guides	100	ea
Guide Alignment	500	ft
7400 Skip Pocket Rebuild	1	ea
Lacing	100	full sets
Automate / Repairs to Yates Hoists	2	ea
Crushing / Bin Conveyor	1	ea
Demobilization	$15,000	ea

	crew	shifts	labor	material	Total
Replace Steel Including Lacing					
4 people excluding hoist operators & yard	4	3.00	$2,158	$1,623	$3,781
Inspection Shift (1 in 14)	4	0.07	$51	$0	$51
Total per Unit		3.07	$2,209	$1,623	$3,833
30					
Total Cost & Duration		92	$66,285	$48,694	$114,978
3 Shifts per day		31			

	crew	shifts	labor	material	Total
Rock Bolting Including Lacing					
4 people excluding hoist operators & yard	4	3.00	$2,158	$2,048	$4,206
Inspection Shift (1 in 10)	4	0.30	$216	$0	$216
Total per Unit		3.30	$2,374	$2,048	$4,422
20					
Total Cost & Duration		66	$47,478.26	$40,960	$88,438
3 Shifts per day		22			

	crew	shifts	labor	material	Total
Replace Guides					
4 people excluding hoist operators & yard	4	0.33	$240	$550	$790
Inspection Shift (1 in 14)	4	0.03	$24	$0	$24
Total per Unit		0.37	$264	$550	$814
100					
Total Cost & Duration		37	$26,376.81	$55,000	$81,377
3 Shifts per day		12			

	crew	shifts	labor	material	Total
Guide Alignment					
4 people excluding hoist operators & yard	4	0.06	$40	$30	$70
Inspection Shift (1 in 14)	4	0.01	$4	$0	$4
Total per Unit		0.06	$44	$30	$74
500					
Total Cost & Duration		31	$21,980.68	$15,000	$36,981
3 Shifts per day		10			

	crew	shifts	labor	material	Total
Lacing Replacement					
4 people excluding hoist operators & yard	4	0.25	$180	$1,245	$1,425
Inspection Shift (1 in 14)	4	0.25	$180	$0	$180
Total per Unit		0.50	$360	$1,245	$1,605
100					
Total Cost & Duration		50	$35,968.38	$124,500	$160,468
3 Shifts per day		17			

	crew	shifts	labor	material	Total
Skip Pocket Rebuild					
6 people excluding hoist operators & yard	6	30.00	$32,372	$40,000	$72,372
Inspection Shift (1 in 14)	4	3.00	$2,158	$0	$2,158
Total per Unit		33.00	$34,530	$40,000	$74,530
1					
Total Cost & Duration		33	$34,529.64	$40,000	$74,530
3 Shifts per day		11			

	crew	shifts	labor	material	Total
4850 Skip Dump & Haulage Chute Repair					
6 people excluding hoist operators & yard	4	30.00	$21,581	$30,000	$51,581
Inspection Shift (1 in 14)	4	0.00	$0	$0	$0
Total per Unit		30.00	$21,581	$30,000	$51,581
1					
Total Cost & Duration		30	$21,581	$30,000	$51,581
3 Shifts per day		10			

	Ross Shaft Upgrade								Ross Shaft Upgrade							
	Year 1								Year 2							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Ross Shaft Upgrade																
Assessment/Bid	1															
Procurement - Shaft Materials	1		1		1											
Engineering for Shaft/Hoist Upgrades	1		1		1											
4850 Pocket Rebuild	1	$55,553														
Temporary Crushing & Truck Load	1	$36,207														
Mobilization							1	$280,000								
Construction Platform					1	$0	1	$72,846								
Collar Modifications							80	$67,688								
Automate/Upgrade Ore Hoist							1	$1,250,000								
Automate/Upgrade Manhoist							1	$1,250,000								
Headframe Modifications							1	$769,960								
Grouting									80	$112,522						
Concurent Reconstruction Activities									139	$924,249	138.8	$924,249	138.8	$924,249	138.8	$924,249
Station Rebuilds											5.4	$270,710	5.4	$270,710	5.4	$270,710
Conveyances																
Guide Alignment																
Local Management & Admin							1	$66,520	1	$66,520	1	$66,520	1	$66,520	1	$66,520
Demobilization																
		$91,760		$0		$0		$3,757,015		$1,103,291		$1,261,479		$1,261,479		$1,261,479

	Ross Shaft Upgrade								Ross Shaft Upgrade							
	Year 3								Year 4							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4		Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Ross Shaft Upgrade																
Assessment/Bid																
Procurement - Shaft Materials																
Engineering for Shaft/Hoist Upgrades																
4850 Pocket Rebuild																
Temporary Crushing & Truck Load																
Mobilization																
Construction Platform																
Collar Modifications																
Automate/Upgrade Ore Hoist																
Automate/Upgrade Manhoist																
Headframe Modifications																
Grouting																
Concurent Reconstruction Activities	138.8	$924,249	138.8	$924,249												
Station Rebuilds	5.4	$270,710	5.4	$270,710												
Conveyances					2	$175,692										
Guide Alignment					5,100	$121,844										
Local Management & Admin	1	$66,520	1	$66,520	1	$66,520										
Demobilization					1	$100,000										
		$1,261,479		$1,261,479		$464,056		$0		$0		$0		$0		$0

Ross Shaft Upgrade

	Year 5							
	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Ross Shaft Upgrade								
Assessment/Bid								
Procurement - Shaft Materials								
Engineering for Shaft/Hoist Upgrades								
4850 Pocket Rebuild								
Temporary Crushing & Truck Load								
Mobilization								
Construction Platform								
Collar Modifications								
Automate/Upgrade Ore Hoist								
Automate/Upgrade Manhoist								
Headframe Modifications								
Grouting								
Concurent Reconstruction Activities								
Station Rebuilds								
Conveyances								
Guide Alignment								
Local Management & Admin								
Demobilization								
		$0		$0		$0		$0

Ross Shaft Upgrade

Year 1 - 5					
Year 1	Year 2	Year 3	Year 4	Year 5	Total
Cost	Cost	Cost	Cost	Cost	Cost
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0
$55,553	$0	$0	$0	$0	$55,553
$36,207	$0	$0	$0	$0	$36,207
$280,000	$0	$0	$0	$0	$280,000
$72,846	$0	$0	$0	$0	$72,846
$67,688	$0	$0	$0	$0	$67,688
$1,250,000	$0	$0	$0	$0	$1,250,000
$1,250,000	$0	$0	$0	$0	$1,250,000
$769,960	$0	$0	$0	$0	$769,960
$0	$112,522	$0	$0	$0	$112,522
$0	$3,696,995	$1,848,498	$0	$0	$5,545,493
$0	$812,130	$541,420	$0	$0	$1,353,549
$0	$0	$175,692	$0	$0	$175,692
$0	$0	$121,844	$0	$0	$121,844
$66,520	$266,081	$199,561	$0	$0	$532,162
$0	$0	$100,000	$0	$0	$100,000
$0	$0	$0	$0	$0	$0
$3,848,775	$4,887,728	$2,987,014	$0	$0	$11,723,516

Ross Shaft / Hoist Upgrades

Assumptions

Crew Includes Supervision		
Mobilization (equipment)	$280,000	ea
Replace Lacing/Bar/Clean/Blocking	833	full sets
Reconfigure Steel	833	full sets
Relocate Utilities	833	full sets
Replace Steel	60	full sets
Rock Bolting	167	full sets
Replace Guides	833	full sets
Guide Alignment	5100	ft
Gadding	100	full sets
Collar Modifications	13	lf
Grouting	80	lf
Station Rebuilds	34	stations
Headframe Modifications	1	ea
Construction Platiform	1	ea
New Conveyances	2	ea
Automate / Upgrade Hoists	2	ea
Temp Crushing / Truck load	1	ea
Supervision/Local Admin	4	people
Demobilization	$100,000	ea

	crew	shifts	labor	material	Total
Lacing Replacement/Bar/Clean/Blocking					
5 People excluding hoist operators	6	0.50	$848	$1,324	$2,172
Inspection Shift (1 in 10)	6	0.05	$85	$0	$85
Total per Unit		0.55	$933	$1,324	$2,257
833					
Total Cost & Duration		458	$776,863	$1,102,892	$1,879,755
3 Shifts per day		153			

	crew	shifts	labor	material	Total
Reconfigure Steel					
5 People excluding hoist operators	6	0.50	$848	$838	$1,685
Inspection Shift (1 in 10)	6	0.05	$85	$0	$85
Total per Unit		0.55	$933	$838	$1,770
833					
Total Cost & Duration		458	$776,863	$697,638	$1,474,501
3 Shifts per day		153			

	crew	shifts	labor	material	Total
Relocate Utilities					
5 People excluding hoist operators	6	0.15	$254	$210	$464
Inspection Shift (1 in 10)	6	0.02	$25	$0	$25
Total per Unit		0.17	$280	$210	$490
833					
Total Cost & Duration		137	$233,059	$174,930	$407,989
3 Shifts per day		46			

Replace Steel Including Lacing					
5 People excluding hoist operators	6	1.00	$1,696	$2,543	$4,238
Inspection Shift (1 in 10)	6	0.07	$121	$0	$121
Total per Unit		1.07	$1,817	$2,543	$4,360
60					
Total Cost & Duration		64	$109,006	$152,565	$261,571
3 Shifts per day		21			
	crew	shifts	labor	material	Total
Rock Bolting					
5 People excluding hoist operators	6	0.50	$848	$2,189	$3,037
Inspection Shift (1 in 10)	6	0.05	$85	$0	$85
Total per Unit		0.55	$933	$2,189	$3,122
166.6					
Total Cost & Duration		92	$155,373	$364,687	$520,060
3 Shifts per day		31			
	crew	shifts	labor	material	Total
Replace Guides					
5 People excluding hoist operators	6	0.13	$212	$630	$842
Inspection Shift (1 in 10)	6	0.01	$21	$0	$21
Total per Unit		0.14	$233	$630	$863
833					
Total Cost & Duration		115	$194,216	$524,790	$719,006
3 Shifts per day		38			
	crew	shifts	labor	material	Total
Guide Alignment					
7 People excluding hoist operators	7	0.01	$19	$30	$49
Inspection Shift (1 in 10)	5	0.00	$1	$0	$1
Total per Unit		0.01	$21	$30	$51
5100					
Total Cost & Duration		55	$105,978	$153,000	$258,978
3 Shifts per day		18			
	crew	shifts	labor	material	Total
Gadding					
5 People excluding hoist operators	6	2.50	$4,239	$1,170	$5,409
Inspection Shift (1 in 10)	6	0.25	$424	$0	$424
Total per Unit		2.75	$4,663	$1,170	$5,833
100					
Total Cost & Duration		275	$466,304	$117,000	$583,304
3 Shifts per day		92			
	crew	shifts	labor	material	Total
Collar Modifications					
5 People excluding hoist operators	5	3.00	$4,239	$838	$5,077
Inspection Shift (1 in 10)	5	0.30	$424	$0	$424
Total per Unit		3.30	$4,663	$838	$5,501
13.33333333					
Total Cost & Duration		44	$62,174	$11,167	$73,341

3 Shifts per day		15			
	crew	shifts	labor	material	Total
Grouting					
5 People excluding hoist operators	5	0.50	$707	$700	$1,407
Inspection Shift (1 in 10)	5	0.05	$71	$0	$71
Total per Unit		0.55	$777	$700	$1,477
80					
Total Cost & Duration		44	$62,174	$56,000	$118,174
3 Shifts per day		15			
	crew	shifts	labor	material	Total
Station Rebuilds					
3 people excluding hoist operators	3	27.00	$22,891	$19,000	$41,891
Inspection Shift (1 in 10)		0.00	$0	$0	$0
Total per Unit		27.00	$22,891	$19,000	$41,891
34					
Total Cost & Duration		918	$778,304	$646,000	$1,424,304
2 Shifts per day		459			
	crew	shifts	labor	material	Total
Headframe Modifications					
6 people excluding hoist operators & yard	12	120.00	$406,957	$400,000	$806,957
Inspection Shift (1 in 10)	4	0.00	$0	$0	$0
Total per Unit		120.00	$406,957	$400,000	$806,957
1					
Total Cost & Duration		120	$406,957	$400,000	$806,957
1 Shifts per day		120			
	crew	shifts	labor	material	Total
Construction Platform					
Assemble/Hang in Shaft	5	10.00	$14,130	$60,000	$74,130
Total per Unit		10.00	$14,130	$60,000	$74,130
1					
Total Cost & Duration		10	$14,130	$60,000	$74,130
3 Shifts per day		3			
	crew	shifts	labor	material	Total
Conveyances					
Assemble/Hang in Shaft	5	10.00	$14,130	$75,000	$89,130
Total per Unit		10.00	$14,130	$75,000	$89,130
2					
Total Cost & Duration		20	$28,261	$150,000	$178,261
3 Shifts per day		7			
	crew	shifts	labor	material	Total
Temporary Crushing & Truck Load					
Install Conveyor	4	30.00	$33,913	$35,000	$68,913

Total per Unit		30.00	$33,913	$35,000	$68,913
	0.55				
	Total Cost & Duration	17	$18,652	$19,250	$37,902
	3 Shifts per day	6			

Direct Crew Cost			
Crew		5	people
Hourly Rate	$	22.48	Including F
Cost per Hour	$	112.40	
Shift Length		8	
Cost per shift	**$**	**899.21**	per shift
Support Crew Cost			
Supply & Admin		1	
Maintenance		1	
Supervision/Admin		2	
Support Crew Size		4	people
Cost per Hour	$	30.00	
Fringe		30%	
Cost per Hour	$	156.00	
Shift Length		8	
Cost per shift	**$**	**1,248.00**	per shift
Total Crew Cost Per Shift	**$**	**2,147.21**	total per sh

Ross Shaft Length	5000	ft
Set Length	6	ft
Sets	833	sets

Assumptions

Labor

Lacing		
Remove/Clean/Bar/Install New		
Change Lacing Every Set		
Lacing Duration	0.50	shift/set
Blocking/Alignment		
Remove/Align/Install New		
Change Blocking Every Set	0.75	shift/set
Change Steel		
Replace Every	15.00	th set
Set Replacement Duration	4.00	shifts
Shifts per set	0.27	shifts per set
Bolting		
Rock Bolt Every 5th Set		
Rock Bolt Duration	1.00	shifts
Shifts per set	0.20	shifts per set
Guides		
Remove Old (12' Length)	0.13	shifts/set
Install New/Align (24' length)	0.25	shifts/set
	0.38	
Utilities		
Remove Old/ Install New	0.50	shifts/set

Total Shifts Per Set		**2.59**
Total Sets		**833.33**
Total Shifts		**2159.72**
Labor Cost Per Shift		**$2,147.21**
Total Labor Cost		**$4,637,376.04**
Material Cost Per Set	**$**	**2,475.88**
Total Sets		**833.33**
Total Material	**$**	**2,063,229.17**
Total Cost		**$6,700,605.21**

Material

Perimeter	14		Dividers	6	
	14			12	
	19			12	
	19			30	
	66	ft		60	ft
Steel	126				
Factor	1.25				
	157.5				
lbs/ft	25				
	3937.5	lbs/set			
	0.35	$/lb			
	$ 1,378.13	set			
Guides	8	ft/ft			
weight	30	lbs/ft			
total weight/ft	240	lbs/ft			
ft/set	6	ft/ft			
weight per set	1440	lbs/ft			
factor	1.25				
total per set	1800				
	0.35	$/lb			
	$ 630.00	set			
Lacing	$ 1,300.00	per set			
Blocking	$ 200.00	per set			
Rock Bolts	$ 154.00	per set			
Steel	$ 91.88	per set			
Utility Hangers	$ 100.00	per set			
Guides	$ 630.00	per set			
Total Set	$ 2,475.88				

Station Rebuilds

Labor		
Stations 1100 to 5000	26	
Skip Pockets & Misc.	8	
Total Stations	34	

Material		
Fabricated Track	$	6,000.00
Fabricated Doors/Snow Shed	$	4,000.00
Electrical	$	3,000.00
Walls/Doors	$	6,000.00
	$	19,000.00

Station Labor			
Change Steel Snow Shed		2	shifts
Blow Pipe & Clean		4	shifts
Rock Bolt		2	shifts
Track		6	shifts
Air Doors/Walls		10	shifts
Station Doors		1	shifts
Electrical		2	shifts
		27	shifts
Crew Size		3	people
Hourly Rate	$	25.00	per hour
Fringe		40%	
Cost per Hour	$	105.00	per hour
Shift Length		8	hours
Cost per Shift	$	840.00	
Shifts per Station		27	
Labor Cost Per Station	$	22,680.00	
Material Cost Per Station	$	19,000.00	
Total Cost Per Station	$	41,680.00	
Stations		34	
Total Station Cost	**$**	**1,417,120.00**	

Gadding

Gadding Labor			
Interval 2900 to 3500 Level		600	lf
Shaft Sets		100	sets
Shifts per Set		3	
Total Shifts		300	
Labor Cost Per Shift	$	2,147.21	
Total Labor Cost	**$**	**214,720.95**	
Material Cost per Set	$	1,020.00	
Total Material Cost	**$**	**102,000.00**	
Total Gadding	**$**	**316,720.95**	

Misc. Bolts & Equipment		
70 bolts Plus Screen	$	770.00
Misc Material	$	250.00
	$	1,020.00

Hoist & Headframe Modifications

Hoist Automation/MG Sets	$	2,000,000.00
Hoist M&R	$	250,000.00
Headframe Modifications	$	600,000.00
Total Surface	**$**	**2,850,000.00**

Conveyances

Construction Platiforms	$	75,000.00
New Cages	$	120,000.00
Counterweights	$	50,000.00
Total Conveyance	**$**	**245,000.00**

Reconfigure Shaft

Labor			
Shifts per set		2	
Labor Cost per Shift	$	2,147.21	
Labor Cost Per Set	$	4,294.42	
Total Sets		833	sets
Total Labor		**$3,578,682**	
Material		**$227,865**	
Headframe		**$750,000**	
		$4,556,547	

Material		
Steel Per Set	25	ft
Weight per foot	25	lbs
Subtotal	625	
Factor	1.25	
	781.25	lbs/set
	0.35	$/lb
Steel Per Set	$273.44	per set
Total Sets	833	
Total Steel	**$227,864.58**	

Basic Ross Shaft Rebuild
Summary

Shaft Reconditioning		$6,700,605
Station Rebuilds		$1,417,120
Gadding		$316,721
Hoist & Headframe		$2,850,000
Conveyances		$245,000
	Subtotal	$11,529,446
	Contingency	25%
	Total	$14,411,808

Ross Reconfiguration
Summary

Labor		$3,578,682
Material		$227,865
Headframe		$750,000
	Subtotal	$4,556,547
	Contingency	25%
	Total	$5,695,684

TIMELINE FOR LLCF
UPDATED 6/30/03

	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
UTILITIES						
Rn-free air	0	100	380	0	0	480
Rn-free N2, LN2	0	80	100	0	0	180
Cu electroforming	0	0	20	100	0	120
Machine Shop	0	0	0	300	0	300
Water purification	0	0	170	220	240	630
Scintil. Purification	0	0	0	0	500	500
subtotals	0	180	670	620	740	2210
INSTRUMENTATION						
HPGe systems	100	150	800	215	100	1365
Alpha/beta systems	0	100	220	200	200	720
"Rn" systems	0	100	180	190	150	620
Leaching/emanation	0	50	250	0	0	300
Passive shields	0	0	0	285	285	570
Modular water system	0	0	205	240	200	645
"Mini-CTF"	0	0	0	360	400	760
subtotals	100	400	1655	1490	1335	4980
SECURE COUNTING LAB						
subtotals	0	100	225	250	250	825
SURFACE COUNTING FACILITIES						
subtotals	0	0	400	680	720	1800
totals	100	680	2950	3040	3045	9815

LLCF INSTRUMENTATION COSTS
UPDATED 6/25/03

	Qty	Unit Cost	Total
Ultra-low LC Lab			
Modular water system			
Reentrant ports	9	$15,000	$135,000
Lifting systems	9	$10,000	$90,000
PMTs, bases, cables	6	$10,000	$60,000
Electronics/DAQ	6	$35,000	$210,000
Det water plugs	3	$20,000	$60,000
Sample prep lab	1	$30,000	$30,000
Mini CTF	1	$760,000	$760,000
Leaching/Emanation lab	1	$300,000	$300,000
DAQ rooms/offices	6	$10,000	$60,000
subtotal			$1,705,000
Low-level Counting Lab			
HPGe			
Single crystal detectors	6	$120,000	$720,000
Segmented detectors	2	$150,000	$300,000
Shields Pb and Cu	8	$40,000	$320,000
AKXR			
Synthesis system	1	$60,000	$60,000
Counters	20	$8,000	$160,000
Shields	8	$30,000	$240,000
Electronics/DAQ	8	$20,000	$160,000
Alpha/Beta			
Counters	8	$30,000	$240,000
Electronics/DAQ	8	$60,000	$480,000
Sam	1	$25,000	$25,000
Passive Shields			
Shields	2	$250,000	$500,000
DAQ offices	2	$20,000	$40,000
Cranes	1	$30,000	$30,000
subtotal			$3,275,000
Secure Lab Counting			
Systems	0.5	$1,650,000	$825,000
Surface Counting Facility	1	$1,800,000	$1,800,000
TOTAL			$7,605,000

UTILITIES COSTS
UPDATED 6/25/03

	Cost
Rn-free air 400 m3/hr	$480,000
KN2, N2 purification	$180,000
"SNO" water system	$630,000
Scintillator purification	$500,000
Cu electroforming	$120,000
Machine shop	$300,000
Total	$2,210,000

Year 1 Personnel

Site Operations and Administration

	Annual Wage (Base)	Year 1 1st Qtr	Year 1 2nd Qtr	Year 1 3rd Qtr	Year 1 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 1 Wage (Base)	Year 1 Wage (Loaded)
Senior Personnel											
						0					
Operations/Maintenance Manager	$100,000	1	1	1	1	12	$8,333	$130,000	$10,833	$100,000	$130,000
Safety/Envir./Security Manager	$75,000	1	1	1	1	12	$6,250	$97,500	$8,125	$75,000	$97,500
Admin Manager	$75,000	1	1	1	1	12	$6,250	$97,500	$8,125	$75,000	$97,500
						0	$0	$0	$0	$0	$0
Total Senior Personnel		**3**	**3**	**3**	**3**	**36**	**$20,833**			**$250,000**	**$325,000**
Other Personnel											
Mine Engineer/Geologist	$65,000	1	1	2	2	18	$5,417	$84,500	$7,042	$97,500	$126,750
Environmental Engineer	$65,000		1	1	1	9	$5,417	$84,500	$7,042	$48,750	$63,375
Safety Technician	$45,000	1	1	1	1	12	$3,750	$58,500	$4,875	$45,000	$58,500
Surveyor/Engineering Technician	$45,000		1	1	1	9	$3,750	$58,500	$4,875	$33,750	$43,875
Operations Planner/Supervisor	$55,000		1	1	1	9	$4,583	$71,500	$5,958	$41,250	$53,625
Shaft Planner/Supervisor	$55,000	1	1	1	1	12	$4,583	$71,500	$5,958	$55,000	$71,500
Secretarial/Clerical	$25,000	1	1	1	1	12	$2,083	$32,500	$2,708	$25,000	$32,500
Accounting/Purchasing/MIS	$45,000	1	1	2	2	18	$3,750	$58,500	$4,875	$67,500	$87,750
						0	$0	$0	$0	$0	$0
Total Other Personnel		**5**	**8**	**10**	**10**	**99**	**$33,333**			**$413,750**	**$537,875**
Other Operators											$413,750
						0					
Hoist Operators	$35,000	12	24	24	24	252	$2,917	$45,500	$3,792	$735,000	$955,500
Shaft	$35,000	9	18	18	18	189	$2,917	$45,500	$3,792	$551,250	$716,625
Crusher Operators/Shaft	$35,000	2	2	2	2	24	$2,917	$45,500	$3,792	$70,000	$91,000
Yard/Warehouse	$35,000	2	2	2	2	24	$2,917	$45,500	$3,792	$70,000	$91,000
Mine Construction	$35,000	2	2	2	2	24	$2,917	$45,500	$3,792	$70,000	$91,000
						0	$0	$0	$0	$0	$0
Total Other Operators		**27**	**48**	**48**	**48**	**513**	**$14,583**			**$1,496,250**	**$1,945,125**

Total Senior Personnel	3	3	3	3	36	$20,833		$250,000	$325,000
Total Other Personnel	5	8	10	10	99	$33,333		$413,750	$537,875
Total Other Operators	27	48	48	48	513	$14,583		$1,496,250	$1,945,125
Total	**35**	**59**	**61**	**61**	**648**	**$68,750**		**$2,160,000**	**$2,808,000**

Year 2 Personnel

Site Operations and Administration

	Annual Wage (Base)	Year 2 1st Qtr	Year 2 2nd Qtr	Year 2 3rd Qtr	Year 2 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 2 Wage (Base)	Year 2 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Operations/Maintenance Manager	$103,000	1	1	1	1	12	$8,583	$133,900	$11,158	$103,000	$133,900
Safety/Envir./Security Manager	$77,250	1	1	1	1	12	$6,438	$100,425	$8,369	$77,250	$100,425
Admin Manager	$77,250	1	1	1	1	12	$6,438	$100,425	$8,369	$77,250	$100,425
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**3**	**3**	**3**	**3**	**36**	**$21,458**			**$257,500**	**$334,750**
Mine Engineer/Geologist	$66,950	2	2	2	2	24	$5,579	$87,035	$7,253	$133,900	$174,070
Environmental Engineer	$66,950	1	1	1	1	12	$5,579	$87,035	$7,253	$66,950	$87,035
Safety Technician	$46,350	2	2	2	2	24	$3,863	$60,255	$5,021	$92,700	$120,510
Surveyor/Engineering Technician	$46,350	1	1	1	1	12	$3,863	$60,255	$5,021	$46,350	$60,255
Operations Planner/Supervisor	$56,650	1	1	1	1	12	$4,721	$73,645	$6,137	$56,650	$73,645
Shaft Planner/Supervisor	$56,650	1	1	1	1	12	$4,721	$73,645	$6,137	$56,650	$73,645
Secretarial/Clerical	$25,750	1	1	1	1	12	$2,146	$33,475	$2,790	$25,750	$33,475
Accounting/Purchasing/MIS	$46,350	2	2	2	2	24	$3,863	$60,255	$5,021	$92,700	$120,510
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**11**	**11**	**11**	**11**	**132**	**$34,333**			**$571,650**	**$743,145**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Hoist Operators	$36,050	24	15	15	15	207	$3,004	$46,865	$3,905	$621,863	$808,421
Shaft	$36,050	18	18	18	18	216	$3,004	$46,865	$3,905	$648,900	$843,570
Crusher Operators/Shaft	$36,050	2	2	2	2	24	$3,004	$46,865	$3,905	$72,100	$93,730
Yard/Warehouse	$36,050	2	2	2	2	24	$3,004	$46,865	$3,905	$72,100	$93,730
Mine Construction	$36,050	2	2	2	2	24	$3,004	$46,865	$3,905	$72,100	$93,730
	$0					0	$0	$0	$0	$0	$0
Total Other Operators		**48**	**39**	**39**	**39**	**495**	**$15,021**			**$1,487,063**	**$1,933,181**
Total Senior Personnel		3	3	3	3	36	$21,458			$257,500	$334,750
Total Other Personnel		11	11	11	11	132	$34,333			$571,650	$743,145
Total Other Operators		48	39	39	39	495	$15,021			$1,487,063	$1,933,181
Total		**62**	**53**	**53**	**53**	**663**	**$70,813**			**$2,316,213**	**$3,011,076**

Year 3 Personnel

Site Operations and Administration

	Annual Wage (Base)	Year 3 1st Qtr	Year 3 2nd Qtr	Year 3 3rd Qtr	Year 3 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 3 Wage (Base)	Year 3 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Operations/Maintenance Manager	$106,090	1	1	1	1	12	$8,841	$137,917	$11,493	$106,090	$137,917
Safety/Envir./Security Manager	$79,568	1	1	1	1	12	$6,631	$103,438	$8,620	$79,568	$103,438
Admin Manager	$79,568	1	1	1	1	12	$6,631	$103,438	$8,620	$79,568	$103,438
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**3**	**3**	**3**	**3**	**36**	**$22,102**			**$265,225**	**$344,793**
Mine Engineer/Geologist	$68,959	2	2	2	2	24	$5,747	$89,646	$7,471	$137,917	$179,292
Environmental Engineer	$68,959	1	1	1	1	12	$5,747	$89,646	$7,471	$68,959	$89,646
Safety Technician	$47,741	2	2	2	2	24	$3,978	$62,063	$5,172	$95,481	$124,125
Surveyor/Engineering Technician	$47,741	1	1	1	1	12	$3,978	$62,063	$5,172	$47,741	$62,063
Operations Planner/Supervisor	$58,350	1	1	1	1	12	$4,862	$75,854	$6,321	$58,350	$75,854
Shaft Planner/Supervisor	$58,350	1	1	1	1	12	$4,862	$75,854	$6,321	$58,350	$75,854
Secretarial/Clerical	$26,523	1	1	1	1	12	$2,210	$34,479	$2,873	$26,523	$34,479
Accounting/Purchasing/MIS	$47,741	2	2	2	2	24	$3,978	$62,063	$5,172	$95,481	$124,125
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**11**	**11**	**11**	**11**	**132**	**$35,363**			**$588,800**	**$765,439**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Hoist Operators	$37,132	15	15	9	9	144	$3,094	$48,271	$4,023	$445,578	$579,251
Shaft	$37,132	18	18	18	12	198	$3,094	$48,271	$4,023	$612,670	$796,471
Crusher Operators/Shaft	$37,132	2	2	2	0	18	$3,094	$48,271	$4,023	$55,697	$72,406
Yard/Warehouse	$37,132	2	2	2	2	24	$3,094	$48,271	$4,023	$74,263	$96,542
Mine Construction	$37,132	2	2	2	2	24	$3,094	$48,271	$4,023	$74,263	$96,542
	$0					0	$0	$0	$0	$0	$0
Total Other Operators		**39**	**39**	**33**	**25**	**408**	**$15,471**			**$1,262,471**	**$1,641,212**
Total Senior Personnel		3	3	3	3	36	$22,102			$265,225	$344,793
Total Other Personnel		11	11	11	11	132	$35,363			$588,800	$765,439
Total Other Operators		39	39	33	25	408	$15,471			$1,262,471	$1,641,212
Total		**53**	**53**	**47**	**39**	**576**	**$72,937**			**$2,116,496**	**$2,751,444**

Year 4 Personnel

Site Operations and Administration

	Annual Wage (Base)	Year 4 1st Qtr	Year 4 2nd Qtr	Year 4 3rd Qtr	Year 4 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 4 Wage (Base)	Year 4 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Operations/Maintenance Manager	$109,273	1	1	1	1	12	$9,106	$142,055	$11,838	$109,273	$142,055
Safety/Envir./Security Manager	$81,955	1	1	1	1	12	$6,830	$106,541	$8,878	$81,955	$106,541
Admin Manager	$81,955	1	1	1	1	12	$6,830	$106,541	$8,878	$81,955	$106,541
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**3**	**3**	**3**	**3**	**36**	**$22,765**			**$273,182**	**$355,136**
Mine Engineer/Geologist	$71,027	2	2	2	2	24	$5,919	$92,335	$7,695	$142,055	$184,671
Environmental Engineer	$71,027	1	1	1	1	12	$5,919	$92,335	$7,695	$71,027	$92,335
Safety Technician	$49,173	2	2	2	2	24	$4,098	$63,925	$5,327	$98,345	$127,849
Surveyor/Engineering Technician	$49,173	1	1	1	1	12	$4,098	$63,925	$5,327	$49,173	$63,925
Operations Planner/Supervisor	$60,100	1	1	1	1	12	$5,008	$78,130	$6,511	$60,100	$78,130
Shaft Planner/Supervisor	$60,100	1	1	1	1	12	$5,008	$78,130	$6,511	$60,100	$78,130
Secretarial/Clerical	$27,318	1	1	1	1	12	$2,277	$35,514	$2,959	$27,318	$35,514
Accounting/Purchasing/MIS	$49,173	2	2	2	2	24	$4,098	$63,925	$5,327	$98,345	$127,849
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**11**	**11**	**11**	**11**	**132**	**$36,424**			**$606,463**	**$788,403**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Hoist Operators	$38,245	9	9	6	6	90	$3,187	$49,719	$4,143	$286,841	$372,893
Shaft	$38,245	12	12	12	12	144	$3,187	$49,719	$4,143	$458,945	$596,629
Crusher Operators/Shaft	$38,245	0	0	0	0	0	$3,187	$49,719	$4,143	$0	$0
Yard/Warehouse	$38,245	2	2	2	2	24	$3,187	$49,719	$4,143	$76,491	$99,438
Mine Construction	$38,245	2	2	2	2	24	$3,187	$49,719	$4,143	$76,491	$99,438
	$0					0	$0	$0	$0	$0	$0
Total Other Operators		**25**	**25**	**22**	**22**	**282**	**$15,936**			**$898,768**	**$1,168,398**
Total Senior Personnel		3	3	3	3	36	$22,765			$273,182	$355,136
Total Other Personnel		11	11	11	11	132	$36,424			$606,463	$788,403
Total Other Operators		25	25	22	22	282	$15,936			$898,768	$1,168,398
Total		**39**	**39**	**36**	**36**	**450**	**$75,125**			**$1,778,413**	**$2,311,937**

Year 5 Personnel

Site Operations and Administration

	Annual Wage (Base)	Year 5 1st Qtr	Year 5 2nd Qtr	Year 5 3rd Qtr	Year 5 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 5 Wage (Base)	Year 5 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Operations/Maintenance Manager	$112,551	1	1	1	1	12	$9,379	$146,316	$12,193	$112,551	$146,316
Safety/Envir./Security Manager	$84,413	1	1	1	1	12	$7,034	$109,737	$9,145	$84,413	$109,737
Admin Manager	$84,413	1	1	1	1	12	$7,034	$109,737	$9,145	$84,413	$109,737
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**3**	**3**	**3**	**3**	**36**	**$23,448**			**$281,377**	**$365,790**
Mine Engineer/Geologist	$73,158	2	2	2	2	24	$6,097	$95,105	$7,925	$146,316	$190,211
Environmental Engineer	$73,158	1	1	1	1	12	$6,097	$95,105	$7,925	$73,158	$95,105
Safety Technician	$50,648	2	2	2	2	24	$4,221	$65,842	$5,487	$101,296	$131,685
Surveyor/Engineering Technician	$50,648	1	1	1	1	12	$4,221	$65,842	$5,487	$50,648	$65,842
Operations Planner/Supervisor	$61,903	1	1	1	1	12	$5,159	$80,474	$6,706	$61,903	$80,474
Shaft Planner/Supervisor	$61,903	1	1	1	1	12	$5,159	$80,474	$6,706	$61,903	$80,474
Secretarial/Clerical	$28,138	1	1	1	1	12	$2,345	$36,579	$3,048	$28,138	$36,579
Accounting/Purchasing/MIS	$50,648	2	2	2	2	24	$4,221	$65,842	$5,487	$101,296	$131,685
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**11**	**11**	**11**	**11**	**132**	**$37,517**			**$624,657**	**$812,055**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Hoist Operators	$39,393	6	6	6	6	72	$3,283	$51,211	$4,268	$236,357	$307,264
Shaft	$39,393	12	12	12	12	144	$3,283	$51,211	$4,268	$472,714	$614,528
Crusher Operators/Shaft	$39,393	0	0	0	0	0	$3,283	$51,211	$4,268	$0	$0
Yard/Warehouse	$39,393	2	2	2	2	24	$3,283	$51,211	$4,268	$78,786	$102,421
Mine Construction	$39,393	2	2	2	2	24	$3,283	$51,211	$4,268	$78,786	$102,421
	$0					0	$0	$0	$0	$0	$0
Total Other Operators		**22**	**22**	**22**	**22**	**264**	**$16,414**			**$866,642**	**$1,126,634**
Total Senior Personnel		3	3	3	3	36	$23,448			$281,377	$365,790
Total Other Personnel		11	11	11	11	132	$37,517			$624,657	$812,055
Total Other Operators		22	22	22	22	264	$16,414			$866,642	$1,126,634
Total		**36**	**36**	**36**	**36**	**432**	**$77,379**			**$1,772,676**	**$2,304,479**

5 Year Personnel Summary

Site Operations and Administration

	Year 1		Year 2		Year 3		Year 4		Year 5		Year 1 - 5
	No	Total	No	Total	No	Total	No	Total	No	Total	Total
Senior Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Operations/Maintenance Manager	1	$100,000	1	$103,000	1	$106,090	1.0	$109,273	1	$112,551	$530,914
Safety/Envir./Security Manager	1	$75,000	1	$77,250	1	$79,568	1.0	$81,955	1	$84,413	$398,185
Admin Manager	1	$75,000	1	$77,250	1	$79,568	1.0	$81,955	1	$84,413	$398,185
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Senior Personnel	**3**	**$250,000**	**3**	**$257,500**	**3**	**$265,225**	**3.0**	**$273,182**	**3**	**$281,377**	**$1,327,284**
Other Personnel											
Mine Engineer/Geologist	1.5	$97,500	2	$133,900	2	$137,917	2.0	$142,055	2	$146,316	$657,688
Environmental Engineer	0.75	$48,750	1	$66,950	1	$68,959	1.0	$71,027	1	$73,158	$328,844
Safety Technician	1	$45,000	2	$92,700	2	$95,481	2.0	$98,345	2	$101,296	$432,822
Surveyor/Engineering Technician	0.75	$33,750	1	$46,350	1	$47,741	1.0	$49,173	1	$50,648	$227,661
Operations Planner/Supervisor	0.75	$41,250	1	$56,650	1	$58,350	1.0	$60,100	1	$61,903	$278,252
Shaft Planner/Supervisor	1	$55,000	1	$56,650	1	$58,350	1.0	$60,100	1	$61,903	$292,002
Secretarial/Clerical	1	$25,000	1	$25,750	1	$26,523	1.0	$27,318	1	$28,138	$132,728
Accounting/Purchasing/MIS	1.5	$67,500	2	$92,700	2	$95,481	2.0	$98,345	2	$101,296	$455,322
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Other Personnel	**8.25**	**$413,750**	**11**	**$571,650**	**11**	**$588,800**	**11.0**	**$606,463**	**11**	**$624,657**	**$2,805,320**
Other Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Hoist Operators	21	$735,000	17.25	$621,863	12	$445,578	7.5	$286,841	6	$236,357	$2,325,638
Shaft	15.75	$551,250	18	$648,900	16.5	$612,670	12.0	$458,945	12	$472,714	$2,744,479
Crusher Operators/Shaft	2	$70,000	2	$72,100	1.5	$55,697	0.0	$0	0	$0	$197,797
Yard/Warehouse	2	$70,000	2	$72,100	2	$74,263	2.0	$76,491	2	$78,786	$371,640
Mine Construction	2	$70,000	2	$72,100	2	$74,263	2.0	$76,491	2	$78,786	$371,640
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Other Operators	**42.75**	**$1,496,250**	**41.25**	**$1,487,063**	**34**	**$1,262,471**	**23.5**	**$898,768**	**22**	**$866,642**	**$6,011,193**
Total Senior Personnel	3	$250,000	3	$257,500	3	$265,225	3	$273,182	3	$281,377	$1,327,284
Total Other Personnel	8.25	$413,750	11	$571,650	11	$588,800	11.0	$606,463	11	$624,657	$2,805,320
Total Other Operators	42.75	$1,496,250	41.25	$1,487,063	34	$1,262,471	23.5	$898,768	22	$866,642	$6,011,193
Total	**54**	**$2,160,000**	**55.25**	**$2,316,213**	**48**	**$2,116,496**	**37.5**	**$1,778,413**	**36**	**$1,772,676**	**$10,143,798**

Year 1 Personnel

Site Maintenance

	Annual Wage (Base)	Year 1 1st Qtr	Year 1 2nd Qtr	Year 1 3rd Qtr	Year 1 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 1 Wage (Base)	Year 1 Wage (Loaded)
Senior Personnel											
						0					
						0	$0	$0	$0	$0	$0
						0	$0	$0	$0	$0	$0
						0	$0	$0	$0	$0	$0
						0	$0	$0	$0	$0	$0
Total Senior Personnel		**0**	**0**	**0**	**0**	**0**	**$0**			**$0**	**$0**
Other Personnel											
Mechanical Plant Engineer	$65,000	1	1	1	1	12	$5,417	$84,500	$7,042	$65,000	$84,500
Electrical Planner/Supervisor	$55,000	1	1	2	2	18	$4,583	$71,500	$5,958	$82,500	$107,250
Field Maintenance Supervisor	$55,000	1	1	1	1	12	$4,583	$71,500	$5,958	$55,000	$71,500
Maintenance Planner	$45,000	1	1	1	1	12	$3,750	$58,500	$4,875	$45,000	$58,500
						0	$0	$0	$0	$0	$0
Total Other Personnel		**4**	**4**	**5**	**5**	**54**	**$18,333**			**$247,500**	**$321,750**
Other Operators											$247,500
						0					
Surface Electrician	$40,000	1	1	1	1	12	$3,333	$52,000	$4,333	$40,000	$52,000
Underground Electrician	$40,000	3	3	3	3	36	$3,333	$52,000	$4,333	$120,000	$156,000
Maintenance Technician	$40,000	4	4	4	4	48	$3,333	$52,000	$4,333	$160,000	$208,000
Field Maintenance	$40,000	4	4	4	4	48	$3,333	$52,000	$4,333	$160,000	$208,000
Mine Maint (Ground Control/Track)	$40,000	0	2	4	4	30	$3,333	$52,000	$4,333	$100,000	$130,000
						0	$0	$0	$0	$0	$0
Total Other Operators		**12**	**14**	**16**	**16**	**174**	**$16,667**			**$580,000**	**$754,000**

Total Senior Personnel	0	0	0	0	0	$0			$0	$0
Total Other Personnel	4	4	5	5	54	$18,333			$247,500	$321,750
Total Other Operators	12	14	16	16	174	$16,667			$580,000	$754,000
Total	**16**	**18**	**21**	**21**	**228**	**$35,000**			**$827,500**	**$1,075,750**

Year 2 Personnel

Site Maintenance

	Annual Wage (Base)	Year 2 1st Qtr	Year 2 2nd Qtr	Year 2 3rd Qtr	Year 2 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 2 Wage (Base)	Year 2 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**0**	**0**	**0**	**0**	**0**	**$0**			**$0**	**$0**
Mechanical Plant Engineer	$66,950	1	1	1	1	12	$5,579	$87,035	$7,253	$66,950	$87,035
Electrical Planner/Supervisor	$56,650	2	2	2	2	24	$4,721	$73,645	$6,137	$113,300	$147,290
Field Maintenance Supervisor	$56,650	1	1	1	1	12	$4,721	$73,645	$6,137	$56,650	$73,645
Maintenance Planner	$46,350	1	1	1	1	12	$3,863	$60,255	$5,021	$46,350	$60,255
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**5**	**5**	**5**	**5**	**60**	**$18,883**			**$283,250**	**$368,225**
Other Operators											
	$0					0	$0	$0	$0	$0	$0
Surface Electrician	$41,200	1	1	1	1	12	$3,433	$53,560	$4,463	$41,200	$53,560
Underground Electrician	$41,200	3	3	3	3	36	$3,433	$53,560	$4,463	$123,600	$160,680
Maintenance Technician	$41,200	4	4	4	4	48	$3,433	$53,560	$4,463	$164,800	$214,240
Field Maintenance	$41,200	4	4	4	4	48	$3,433	$53,560	$4,463	$164,800	$214,240
Mine Maint (Ground Control/Track)	$41,200	4	4	4	4	48	$3,433	$53,560	$4,463	$164,800	$214,240
	$0					0	$0	$0	$0	$0	$0
Total Other Operators		**16**	**16**	**16**	**16**	**192**	**$17,167**			**$659,200**	**$856,960**

Total Senior Personnel	0	0	0	0	0	$0			$0	$0
Total Other Personnel	5	5	5	5	60	$18,883			$283,250	$368,225
Total Other Operators	16	16	16	16	192	$17,167			$659,200	$856,960
Total	**21**	**21**	**21**	**21**	**252**	**$36,050**			**$942,450**	**$1,225,185**

Year 3 Personnel

Site Maintenance

	Annual Wage (Base)	Year 3 1st Qtr	Year 3 2nd Qtr	Year 3 3rd Qtr	Year 3 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 3 Wage (Base)	Year 3 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**0**	**0**	**0**	**0**	**0**	**$0**			**$0**	**$0**
Mechanical Plant Engineer	$68,959	1	1	1	1	12	$5,747	$89,646	$7,471	$68,959	$89,646
Electrical Planner/Supervisor	$58,350	2	2	2	2	24	$4,862	$75,854	$6,321	$116,699	$151,709
Field Maintenance Supervisor	$58,350	1	1	1	1	12	$4,862	$75,854	$6,321	$58,350	$75,854
Maintenance Planner	$47,741	1	1	1	1	12	$3,978	$62,063	$5,172	$47,741	$62,063
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**5**	**5**	**5**	**5**	**60**	**$19,450**			**$291,748**	**$379,272**
Other Operators											
	$0					0	$0	$0	$0	$0	$0
Surface Electrician	$42,436	1	1	1	1	12	$3,536	$55,167	$4,597	$42,436	$55,167
Underground Electrician	$42,436	3	3	3	3	36	$3,536	$55,167	$4,597	$127,308	$165,500
Maintenance Technician	$42,436	4	4	4	4	48	$3,536	$55,167	$4,597	$169,744	$220,667
Field Maintenance	$42,436	4	4	4	4	48	$3,536	$55,167	$4,597	$169,744	$220,667
Mine Maint (Ground Control/Track)	$42,436	4	4	4	4	48	$3,536	$55,167	$4,597	$169,744	$220,667
	$0					0	$0	$0	$0	$0	$0
Total Other Operators		**16**	**16**	**16**	**16**	**192**	**$17,682**			**$678,976**	**$882,669**
Total Senior Personnel		0	0	0	0	0	$0			$0	$0
Total Other Personnel		5	5	5	5	60	$19,450			$291,748	$379,272
Total Other Operators		16	16	16	16	192	$17,682			$678,976	$882,669
Total		**21**	**21**	**21**	**21**	**252**	**$37,132**			**$970,724**	**$1,261,941**

Year 4 Personnel

Site Maintenance

	Annual Wage (Base)	Year 4 1st Qtr	Year 4 2nd Qtr	Year 4 3rd Qtr	Year 4 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 4 Wage (Base)	Year 4 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**0**	**0**	**0**	**0**	**0**	**$0**			**$0**	**$0**
Mechanical Plant Engineer	$71,027	1	1	1	1	12	$5,919	$92,335	$7,695	$71,027	$92,335
Electrical Planner/Supervisor	$60,100	2	2	2	2	24	$5,008	$78,130	$6,511	$120,200	$156,260
Field Maintenance Supervisor	$60,100	1	1	1	1	12	$5,008	$78,130	$6,511	$60,100	$78,130
Maintenance Planner	$49,173	1	1	1	1	12	$4,098	$63,925	$5,327	$49,173	$63,925
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**5**	**5**	**5**	**5**	**60**	**$20,033**			**$300,500**	**$390,650**
Other Operators											
	$0					0	$0	$0	$0	$0	$0
Surface Electrician	$43,709	1	1	1	1	12	$3,642	$56,822	$4,735	$43,709	$56,822
Underground Electrician	$43,709	3	3	3	3	36	$3,642	$56,822	$4,735	$131,127	$170,465
Maintenance Technician	$43,709	4	4	4	4	48	$3,642	$56,822	$4,735	$174,836	$227,287
Field Maintenance	$43,709	4	4	4	4	48	$3,642	$56,822	$4,735	$174,836	$227,287
Mine Maint (Ground Control/Track)	$43,709	4	4	4	4	48	$3,642	$56,822	$4,735	$174,836	$227,287
	$0					0	$0	$0	$0	$0	$0
Total Other Operators		**16**	**16**	**16**	**16**	**192**	**$18,212**			**$699,345**	**$909,149**
Total Senior Personnel		0	0	0	0	0	$0			$0	$0
Total Other Personnel		5	5	5	5	60	$20,033			$300,500	$390,650
Total Other Operators		16	16	16	16	192	$18,212			$699,345	$909,149
Total		**21**	**21**	**21**	**21**	**252**	**$38,245**			**$999,845**	**$1,299,799**

Year 5 Personnel

Site Maintenance

	Annual Wage (Base)	Year 5 1st Qtr	Year 5 2nd Qtr	Year 5 3rd Qtr	Year 5 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 5 Wage (Base)	Year 5 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**0**	**0**	**0**	**0**	**0**	**$0**			**$0**	**$0**
Mechanical Plant Engineer	$73,158	1	1	1	1	12	$6,097	$95,105	$7,925	$73,158	$95,105
Electrical Planner/Supervisor	$61,903	2	2	2	2	24	$5,159	$80,474	$6,706	$123,806	$160,948
Field Maintenance Supervisor	$61,903	1	1	1	1	12	$5,159	$80,474	$6,706	$61,903	$80,474
Maintenance Planner	$50,648	1	1	1	1	12	$4,221	$65,842	$5,487	$50,648	$65,842
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**5**	**5**	**5**	**5**	**60**	**$20,634**			**$309,515**	**$402,369**
Other Operators											
	$0					0	$0	$0	$0	$0	$0
Surface Electrician	$45,020	1	1	1	1	12	$3,752	$58,526	$4,877	$45,020	$58,526
Underground Electrician	$45,020	3	3	3	3	36	$3,752	$58,526	$4,877	$135,061	$175,579
Maintenance Technician	$45,020	4	4	4	4	48	$3,752	$58,526	$4,877	$180,081	$234,106
Field Maintenance	$45,020	4	4	4	4	48	$3,752	$58,526	$4,877	$180,081	$234,106
Mine Maint (Ground Control/Track)	$45,020	4	4	4	4	48	$3,752	$58,526	$4,877	$180,081	$234,106
	$0					0	$0	$0	$0	$0	$0
Total Other Operators		**16**	**16**	**16**	**16**	**192**	**$18,758**			**$720,326**	**$936,423**
Total Senior Personnel		0	0	0	0	0	$0			$0	$0
Total Other Personnel		5	5	5	5	60	$20,634			$309,515	$402,369
Total Other Operators		16	16	16	16	192	$18,758			$720,326	$936,423
Total		**21**	**21**	**21**	**21**	**252**	**$39,393**			**$1,029,841**	**$1,338,793**

5 Year Personnel Summary

Site Maintenance

	Year 1		Year 2		Year 3		Year 4		Year 5		Year 1 - 5
	No	Total	No	Total	No	Total	No	Total	No	Total	Total
Senior Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Senior Personnel	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0.0**	**$0**	**0**	**$0**	**$0**
Other Personnel											
Mechanical Plant Engineer	1	$65,000	1	$66,950	1	$68,959	1.0	$71,027	1	$73,158	$345,094
Electrical Planner/Supervisor	1.5	$82,500	2	$113,300	2	$116,699	2.0	$120,200	2	$123,806	$556,505
Field Maintenance Supervisor	1	$55,000	1	$56,650	1	$58,350	1.0	$60,100	1	$61,903	$292,002
Maintenance Planner	1	$45,000	1	$46,350	1	$47,741	1.0	$49,173	1	$50,648	$238,911
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Other Personnel	**4.5**	**$247,500**	**5**	**$283,250**	**5**	**$291,748**	**5.0**	**$300,500**	**5**	**$309,515**	**$1,432,512**
Other Operators											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Surface Electrician	1	$40,000	1	$41,200	1	$42,436	1.0	$43,709	1	$45,020	$212,365
Underground Electrician	3	$120,000	3	$123,600	3	$127,308	3.0	$131,127	3	$135,061	$637,096
Maintenance Technician	4	$160,000	4	$164,800	4	$169,744	4.0	$174,836	4	$180,081	$849,462
Field Maintenance	4	$160,000	4	$164,800	4	$169,744	4.0	$174,836	4	$180,081	$849,462
Mine Maint (Ground Control/Track)	2.5	$100,000	4	$164,800	4	$169,744	4.0	$174,836	4	$180,081	$789,462
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Other Operators	**14.5**	**$580,000**	**16**	**$659,200**	**16**	**$678,976**	**16.0**	**$699,345**	**16**	**$720,326**	**$3,337,847**
Total Senior Personnel	0	$0	0	$0	0	$0	0	$0	0	$0	$0
Total Other Personnel	4.5	$247,500	5	$283,250	5	$291,748	5.0	$300,500	5	$309,515	$1,432,512
Total Other Operators	14.5	$580,000	16	$659,200	16	$678,976	16.0	$699,345	16	$720,326	$3,337,847
Total	**19**	**$827,500**	**21**	**$942,450**	**21**	**$970,724**	**21.0**	**$999,845**	**21**	**$1,029,841**	**$4,770,359**

Year 1 Personnel

Science Operations

	Annual Wage (Base)	Year 1 1st Qtr	Year 1 2nd Qtr	Year 1 3rd Qtr	Year 1 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 1 Wage (Base)	Year 1 Wage (Loaded)
Senior Personnel											
						0					
Laboratory Director	$180,000	0.7	0.7	0.7	0.7	8.4	$15,000	$234,000	$19,500	$126,000	$163,800
A.D. Science	$150,000					0	$12,500	$195,000	$16,250	$0	$0
A.D. Operations	$150,000	1	1	1	1	12	$12,500	$195,000	$16,250	$150,000	$195,000
Senior Scientist	$125,000					0	$10,417	$162,500	$13,542	$0	$0
Associate Scientist	$100,000					0	$8,333	$130,000	$10,833	$0	$0
Assistant Scientist	$75,000					0	$6,250	$97,500	$8,125	$0	$0
						0	$0	$0	$0	$0	$0
Total Senior Personnel		**1.7**	**1.7**	**1.7**	**1.7**	**20.4**	**$65,000**			**$276,000**	**$358,800**
Other Personnel											$276,000
						0					
Post Doctoral Associates	$45,000					0	$3,750	$58,500	$4,875	$0	$0
Graduate Students	$20,000					0	$1,667	$26,000	$2,167	$0	$0
Undergraduate Students	$15,000					0	$1,250	$19,500	$1,625	$0	$0
Secretarial/Receiving	$25,000	2	2	2	2	24	$2,083	$32,500	$2,708	$50,000	$65,000
Librarian	$40,000					0	$3,333	$52,000	$4,333	$0	$0
Machinist/Electronics/Glass	$40,000					0	$3,333	$52,000	$4,333	$0	$0
Draftsman	$35,000					0	$2,917	$45,500	$3,792	$0	$0
Low-level counting	$60,000					0	$5,000	$78,000	$6,500	$0	$0
Chemists	$50,000					0	$4,167	$65,000	$5,417	$0	$0
Computing	$40,000					0	$3,333	$52,000	$4,333	$0	$0
						0	$0	$0	$0	$0	$0
Total Other Personnel		**2**	**2**	**2**	**2**	**24**	**$30,833**			**$50,000**	**$65,000**
Total Senior Personnel		1.7	1.7	1.7	1.7	20.4	$65,000		0	$276,000	$358,800
Total Other Personnel		2	2	2	2	24	$30,833		0	$50,000	$65,000
Total		**3.7**	**3.7**	**3.7**	**3.7**	**44.4**	**$95,833**		**0**	**$326,000**	**$423,800**

Year 2 Personnel

Science Operations

	Annual Wage (Base)	Year 2 1st Qtr	Year 2 2nd Qtr	Year 2 3rd Qtr	Year 2 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 2 Wage (Base)	Year 2 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Laboratory Director	$185,400	0.7	0.7	0.7	0.7	8.4	$15,450	$241,020	$20,085	$129,780	$168,714
A.D. Science	$154,500	1	1	1	1	12	$12,875	$200,850	$16,738	$154,500	$200,850
A.D. Operations	$154,500	1	1	1	1	12	$12,875	$200,850	$16,738	$154,500	$200,850
Senior Scientist	$128,750					0	$10,729	$167,375	$13,948	$0	$0
Associate Scientist	$103,000					0	$8,583	$133,900	$11,158	$0	$0
Assistant Scientist	$77,250					0	$6,438	$100,425	$8,369	$0	$0
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**2.7**	**2.7**	**2.7**	**2.7**	**32.4**	**$66,950**			**$438,780**	**$570,414**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Post Doctoral Associates	$46,350					0	$3,863	$60,255	$5,021	$0	$0
Graduate Students	$20,600					0	$1,717	$26,780	$2,232	$0	$0
Undergraduate Students	$15,450					0	$1,288	$20,085	$1,674	$0	$0
Secretarial/Receiving	$25,750	4	4	4	4	48	$2,146	$33,475	$2,790	$103,000	$133,900
Librarian	$41,200	1	1	1	1	12	$3,433	$53,560	$4,463	$41,200	$53,560
Machinist/Electronics/Glass	$41,200	3	3	3	3	36	$3,433	$53,560	$4,463	$123,600	$160,680
Draftsman	$36,050	1	1	1	1	12	$3,004	$46,865	$3,905	$36,050	$46,865
Low-level counting	$61,800	1	1	1	1	12	$5,150	$80,340	$6,695	$61,800	$80,340
Chemists	$51,500	1	1	1	1	12	$4,292	$66,950	$5,579	$51,500	$66,950
Computing	$41,200	2	2	2	2	24	$3,433	$53,560	$4,463	$82,400	$107,120
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**13**	**13**	**13**	**13**	**156**	**$31,758**			**$499,550**	**$649,415**

Total Senior Personnel	2.7	2.7	2.7	2.7	32.4	$66,950		0	$438,780	$570,414
Total Other Personnel	13	13	13	13	156	$31,758		0	$499,550	$649,415
Total	15.7	15.7	15.7	15.7	188.4	$98,708		0	**$938,330**	**$1,219,829**

Year 3 Personnel

Science Operations

	Annual Wage (Base)	Year 3 1st Qtr	Year 3 2nd Qtr	Year 3 3rd Qtr	Year 3 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 3 Wage (Base)	Year 3 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Laboratory Director	$190,962	0.7	0.7	0.7	0.7	8.4	$15,914	$248,251	$20,688	$133,673	$173,775
A.D. Science	$159,135	1	1	1	1	12	$13,261	$206,876	$17,240	$159,135	$206,876
A.D. Operations	$159,135	1	1	1	1	12	$13,261	$206,876	$17,240	$159,135	$206,876
Senior Scientist	$132,613	2	2	2	2	24	$11,051	$172,396	$14,366	$265,225	$344,793
Associate Scientist	$106,090	2	2	2	2	24	$8,841	$137,917	$11,493	$212,180	$275,834
Assistant Scientist	$79,568	2	2	2	2	24	$6,631	$103,438	$8,620	$159,135	$206,876
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**8.7**	**8.7**	**8.7**	**8.7**	**104.4**	**$68,959**			**$1,088,483**	**$1,415,028**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Post Doctoral Associates	$47,741	4	4	4	4	48	$3,978	$62,063	$5,172	$190,962	$248,251
Graduate Students	$21,218	4	4	4	4	48	$1,768	$27,583	$2,299	$84,872	$110,334
Undergraduate Students	$15,914	2	2	2	2	24	$1,326	$20,688	$1,724	$31,827	$41,375
Secretarial/Receiving	$26,523	6	6	6	6	72	$2,210	$34,479	$2,873	$159,135	$206,876
Librarian	$42,436	2	2	2	2	24	$3,536	$55,167	$4,597	$84,872	$110,334
Machinist/Electronics/Glass	$42,436	5	5	5	5	60	$3,536	$55,167	$4,597	$212,180	$275,834
Draftsman	$37,132	1	1	1	1	12	$3,094	$48,271	$4,023	$37,132	$48,271
Low-level counting	$63,654	2	2	2	2	24	$5,305	$82,750	$6,896	$127,308	$165,500
Chemists	$53,045	2	2	2	2	24	$4,420	$68,959	$5,747	$106,090	$137,917
Computing	$42,436	5	5	5	5	60	$3,536	$55,167	$4,597	$212,180	$275,834
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**33**	**33**	**33**	**33**	**396**	**$32,711**			**$1,246,558**	**$1,620,525**
Total Senior Personnel		8.7	8.7	8.7	8.7	104.4	$68,959			$1,088,483	$1,415,028
Total Other Personnel		33	33	33	33	396	$32,711			$1,246,558	$1,620,525
Total		**41.7**	**41.7**	**41.7**	**41.7**	**500.4**	**$101,670**			**$2,335,041**	**$3,035,553**

Year 4 Personnel

Science Operations

	Annual Wage (Base)	Year 4 1st Qtr	Year 4 2nd Qtr	Year 4 3rd Qtr	Year 4 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 4 Wage (Base)	Year 4 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Laboratory Director	$196,691	0.7	0.7	0.7	0.7	8.4	$16,391	$255,698	$21,308	$137,684	$178,989
A.D. Science	$163,909	1	1	1	1	12	$13,659	$213,082	$17,757	$163,909	$213,082
A.D. Operations	$163,909	1	1	1	1	12	$13,659	$213,082	$17,757	$163,909	$213,082
Senior Scientist	$136,591	4	4	4	4	48	$11,383	$177,568	$14,797	$546,364	$710,273
Associate Scientist	$109,273	4	4	4	4	48	$9,106	$142,055	$11,838	$437,091	$568,218
Assistant Scientist	$81,955	4	4	4	4	48	$6,830	$106,541	$8,878	$327,818	$426,164
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**14.7**	**14.7**	**14.7**	**14.7**	**176.4**	**$71,027**			**$1,776,774**	**$2,309,806**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Post Doctoral Associates	$49,173	8	8	8	8	96	$4,098	$63,925	$5,327	$393,382	$511,396
Graduate Students	$21,855	8	8	8	8	96	$1,821	$28,411	$2,368	$174,836	$227,287
Undergraduate Students	$16,391	4	4	4	4	48	$1,366	$21,308	$1,776	$65,564	$85,233
Secretarial/Receiving	$27,318	6	6	6	6	72	$2,277	$35,514	$2,959	$163,909	$213,082
Librarian	$43,709	2	2	2	2	24	$3,642	$56,822	$4,735	$87,418	$113,644
Machinist/Electronics/Glass	$43,709	8	8	8	8	96	$3,642	$56,822	$4,735	$349,673	$454,574
Draftsman	$38,245	1	1	1	1	12	$3,187	$49,719	$4,143	$38,245	$49,719
Low-level counting	$65,564	2	2	2	2	24	$5,464	$85,233	$7,103	$131,127	$170,465
Chemists	$54,636	3	3	3	3	36	$4,553	$71,027	$5,919	$163,909	$213,082
Computing	$43,709	5	5	5	5	60	$3,642	$56,822	$4,735	$218,545	$284,109
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**47**	**47**	**47**	**47**	**564**	**$33,692**			**$1,786,609**	**$2,322,591**

Total Senior Personnel	14.7	14.7	14.7	14.7	176.4	$71,027		$1,776,774	$2,309,806
Total Other Personnel	47	47	47	47	564	$33,692		$1,786,609	$2,322,591
Total	**61.7**	**61.7**	**61.7**	**61.7**	**740.4**	**$104,720**		**$3,563,383**	**$4,632,398**

Year 5 Personnel

Science Operations

	Annual Wage (Base)	Year 5 1st Qtr	Year 5 2nd Qtr	Year 5 3rd Qtr	Year 5 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 5 Wage (Base)	Year 5 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Laboratory Director	$202,592	0.7	0.7	0.7	0.7	8.4	$16,883	$263,369	$21,947	$141,814	$184,358
A.D. Science	$168,826	1	1	1	1	12	$14,069	$219,474	$18,290	$168,826	$219,474
A.D. Operations	$168,826	1	1	1	1	12	$14,069	$219,474	$18,290	$168,826	$219,474
Senior Scientist	$140,689	4	4	4	4	48	$11,724	$182,895	$15,241	$562,754	$731,581
Associate Scientist	$112,551	4	4	4	4	48	$9,379	$146,316	$12,193	$450,204	$585,265
Assistant Scientist	$84,413	4	4	4	4	48	$7,034	$109,737	$9,145	$337,653	$438,948
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**14.7**	**14.7**	**14.7**	**14.7**	**176.4**	**$73,158**			**$1,830,077**	**$2,379,101**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Post Doctoral Associates	$50,648	10	10	10	10	120	$4,221	$65,842	$5,487	$506,479	$658,423
Graduate Students	$22,510	10	10	10	10	120	$1,876	$29,263	$2,439	$225,102	$292,632
Undergraduate Students	$16,883	5	5	5	5	60	$1,407	$21,947	$1,829	$84,413	$109,737
Secretarial/Receiving	$28,138	6	6	6	6	72	$2,345	$36,579	$3,048	$168,826	$219,474
Librarian	$45,020	2	2	2	2	24	$3,752	$58,526	$4,877	$90,041	$117,053
Machinist/Electronics/Glass	$45,020	8	8	8	8	96	$3,752	$58,526	$4,877	$360,163	$468,212
Draftsman	$39,393	1	1	1	1	12	$3,283	$51,211	$4,268	$39,393	$51,211
Low-level counting	$67,531	2	2	2	2	24	$5,628	$87,790	$7,316	$135,061	$175,579
Chemists	$56,275	5	5	5	5	60	$4,690	$73,158	$6,097	$281,377	$365,790
Computing	$45,020	5	5	5	5	60	$3,752	$58,526	$4,877	$225,102	$292,632
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**54**	**54**	**54**	**54**	**648**	**$34,703**			**$2,115,957**	**$2,750,744**
Total Senior Personnel		14.7	14.7	14.7	14.7	176.4	$73,158			$1,830,077	$2,379,101
Total Other Personnel		54	54	54	54	648	$34,703			$2,115,957	$2,750,744
Total		**68.7**	**68.7**	**68.7**	**68.7**	**824.4**	**$107,861**			**$3,946,034**	**$5,129,844**

5 Year Personnel Summary

Science Operations

	Year 1		Year 2		Year 3		Year 4		Year 5		Year 1 - 5
	No	Total	No	Total	No	Total	No	Total	No	Total	Total
Senior Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Laboratory Director	0.7	$126,000	0.7	$129,780	0.7	$133,673	0.7	$137,684	0.7	$141,814	$668,951
A.D. Science	0	$0	1	$154,500	1	$159,135	1.0	$163,909	1	$168,826	$646,370
A.D. Operations	1	$150,000	1	$154,500	1	$159,135	1.0	$163,909	1	$168,826	$796,370
Senior Scientist	0	$0	0	$0	2	$265,225	4.0	$546,364	4	$562,754	$1,374,343
Associate Scientist	0	$0	0	$0	2	$212,180	4.0	$437,091	4	$450,204	$1,099,474
Assistant Scientist	0	$0	0	$0	2	$159,135	4.0	$327,818	4	$337,653	$824,606
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Senior Personnel	**1.7**	**$276,000**	**2.7**	**$438,780**	**8.7**	**$1,088,483**	**14.7**	**$1,776,774**	**14.7**	**$1,830,077**	**$5,410,115**
Other Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Post Doctoral Associates	0	$0	0	$0	4	$190,962	8.0	$393,382	10	$506,479	$1,090,823
Graduate Students	0	$0	0	$0	4	$84,872	8.0	$174,836	10	$225,102	$484,810
Undergraduate Students	0	$0	0	$0	2	$31,827	4.0	$65,564	5	$84,413	$181,804
Secretarial/Receiving	2	$50,000	4	$103,000	6	$159,135	6.0	$163,909	6	$168,826	$644,870
Librarian	0	$0	1	$41,200	2	$84,872	2.0	$87,418	2	$90,041	$303,531
Machinist/Electronics/Glass	0	$0	3	$123,600	5	$212,180	8.0	$349,673	8	$360,163	$1,045,615
Draftsman	0	$0	1	$36,050	1	$37,132	1.0	$38,245	1	$39,393	$150,820
Low-level counting	0	$0	1	$61,800	2	$127,308	2.0	$131,127	2	$135,061	$455,296
Chemists	0	$0	1	$51,500	2	$106,090	3.0	$163,909	5	$281,377	$602,876
Computing	0	$0	2	$82,400	5	$212,180	5.0	$218,545	5	$225,102	$738,227
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Other Personnel	**2**	**$50,000**	**13**	**$499,550**	**33**	**$1,246,558**	**47.0**	**$1,786,609**	**54**	**$2,115,957**	**$5,698,673**
Total Senior Personnel	1.7	$276,000	2.7	$438,780	8.7	$1,088,483	14.7	$1,776,774	14.7	$1,830,077	$5,410,115
Total Other Personnel	2	$50,000	13	$499,550	33	$1,246,558	47.0	$1,786,609	54	$2,115,957	$5,698,673
Total	**3.7**	**$326,000**	**15.7**	**$938,330**	**41.7**	**$2,335,041**	**61.7**	**$3,563,383**	**68.7**	**$3,946,034**	**$11,108,788**

Year 1 Personnel

Detector Operations

	Annual Wage (Base)	Year 1 1st Qtr	Year 1 2nd Qtr	Year 1 3rd Qtr	Year 1 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 1 Wage (Base)	Year 1 Wage (Loaded)
Senior Personnel											
						0					
Assistant Manager	$75,000					0	$6,250	$97,500	$8,125	$0	$0
						0	$0	$0	$0	$0	$0
Total Senior Personnel		**0**	**0**	**0**	**0**	**0**	**$6,250**			**$0**	**$0**
Other Personnel											
						0	$0	$0	$0	$0	$0
Mechanical/process engineer	$65,000					0	$5,417	$84,500	$7,042	$0	$0
Secretarial/Clerical	$25,000					0	$2,083	$32,500	$2,708	$0	$0
						0	$0	$0	$0	$0	$0
Total Other Personnel		**0**	**0**	**0**	**0**	**0**	**$7,500**			**$0**	**$0**
Other Operators											$0
						0					
Maintenance mechanic	$40,000					0	$3,333	$52,000	$4,333	$0	$0
Professional operators	$40,000					0	$3,333	$52,000	$4,333	$0	$0
Underground assembly	$40,000					0	$3,333	$52,000	$4,333	$0	$0
Large assembly	$40,000					0	$3,333	$52,000	$4,333	$0	$0
Transportation	$35,000					0	$2,917	$45,500	$3,792	$0	$0
						0	$0	$0	$0	$0	$0
Total Other Operators		**0**	**0**	**0**	**0**	**0**	**$16,250**			**$0**	**$0**
Total Senior Personnel		0	0	0	0	0	$6,250			$0	$0
Total Other Personnel		0	0	0	0	0	$7,500			$0	$0
Total Other Operators		0	0	0	0	0	$16,250			$0	$0
Total		**0**	**0**	**0**	**0**	**0**	**$30,000**			**$0**	**$0**

Year 2 Personnel

Detector Operations

	Annual Wage (Base)	Year 2 1st Qtr	Year 2 2nd Qtr	Year 2 3rd Qtr	Year 2 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 2 Wage (Base)	Year 2 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Assistant Manager	$77,250					0	$6,438	$100,425	$8,369	$0	$0
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**0**	**0**	**0**	**0**	**0**	**$6,438**			**$0**	**$0**
	$0					0	$0	$0	$0	$0	$0
Mechanical/process engineer	$66,950	1	1	1	1	12	$5,579	$87,035	$7,253	$66,950	$87,035
Secretarial/Clerical	$25,750	1	1	1	1	12	$2,146	$33,475	$2,790	$25,750	$33,475
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**2**	**2**	**2**	**2**	**24**	**$7,725**			**$92,700**	**$120,510**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Maintenance mechanic	$41,200					0	$3,433	$53,560	$4,463	$0	$0
Professional operators	$41,200	1	1	1	1	12	$3,433	$53,560	$4,463	$41,200	$53,560
Underground assembly	$41,200					0	$3,433	$53,560	$4,463	$0	$0
Large assembly	$41,200					0	$3,433	$53,560	$4,463	$0	$0
Transportation	$36,050					0	$3,004	$46,865	$3,905	$0	$0
	$0					0	$0	$0	$0	$0	$0
Total Other Operators		**1**	**1**	**1**	**1**	**12**	**$16,738**			**$41,200**	**$53,560**
Total Senior Personnel		0	0	0	0	0	$6,438			$0	$0
Total Other Personnel		2	2	2	2	24	$7,725			$92,700	$120,510
Total Other Operators		1	1	1	1	12	$16,738			$41,200	$53,560
Total		**3**	**3**	**3**	**3**	**36**	**$30,900**			**$133,900**	**$174,070**

Year 3 Personnel

Detector Operations

	Annual Wage (Base)	Year 3 1st Qtr	Year 3 2nd Qtr	Year 3 3rd Qtr	Year 3 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 3 Wage (Base)	Year 3 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Assistant Manager	$79,568	1	1	1	1	12	$6,631	$103,438	$8,620	$79,568	$103,438
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**1**	**1**	**1**	**1**	**12**	**$6,631**			**$79,568**	**$103,438**
	$0					0	$0	$0	$0	$0	$0
Mechanical/process engineer	$68,959	2	2	2	2	24	$5,747	$89,646	$7,471	$137,917	$179,292
Secretarial/Clerical	$26,523	1	1	1	1	12	$2,210	$34,479	$2,873	$26,523	$34,479
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**3**	**3**	**3**	**3**	**36**	**$7,957**			**$164,440**	**$213,771**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Maintenance mechanic	$42,436	2	2	2	2	24	$3,536	$55,167	$4,597	$84,872	$110,334
Professional operators	$42,436	1	1	1	1	12	$3,536	$55,167	$4,597	$42,436	$55,167
Underground assembly	$42,436	1	1	1	1	12	$3,536	$55,167	$4,597	$42,436	$55,167
Large assembly	$42,436	1	1	1	1	12	$3,536	$55,167	$4,597	$42,436	$55,167
Transportation	$37,132	1	1	1	1	12	$3,094	$48,271	$4,023	$37,132	$48,271
	$0					0	$0	$0	$0	$0	$0
Total Other Operators		**6**	**6**	**6**	**6**	**72**	**$17,240**			**$249,312**	**$324,105**
Total Senior Personnel		1	1	1	1	12	$6,631			$79,568	$103,438
Total Other Personnel		3	3	3	3	36	$7,957			$164,440	$213,771
Total Other Operators		6	6	6	6	72	$17,240			$249,312	$324,105
Total		**10**	**10**	**10**	**10**	**120**	**$31,827**			**$493,319**	**$641,314**

Year 4 Personnel

Detector Operations

	Annual Wage (Base)	Year 4 1st Qtr	Year 4 2nd Qtr	Year 4 3rd Qtr	Year 4 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 4 Wage (Base)	Year 4 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Assistant Manager	$81,955	1	1	1	1	12	$6,830	$106,541	$8,878	$81,955	$106,541
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**1**	**1**	**1**	**1**	**12**	**$6,830**			**$81,955**	**$106,541**
	$0					0	$0	$0	$0	$0	$0
Mechanical/process engineer	$71,027	2	2	2	2	24	$5,919	$92,335	$7,695	$142,055	$184,671
Secretarial/Clerical	$27,318	1	1	1	1	12	$2,277	$35,514	$2,959	$27,318	$35,514
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**3**	**3**	**3**	**3**	**36**	**$8,195**			**$169,373**	**$220,184**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Maintenance mechanic	$43,709	2	2	2	2	24	$3,642	$56,822	$4,735	$87,418	$113,644
Professional operators	$43,709	3	3	3	3	36	$3,642	$56,822	$4,735	$131,127	$170,465
Underground assembly	$43,709	3	3	3	3	36	$3,642	$56,822	$4,735	$131,127	$170,465
Large assembly	$43,709	3	3	3	3	36	$3,642	$56,822	$4,735	$131,127	$170,465
Transportation	$38,245	1	1	1	1	12	$3,187	$49,719	$4,143	$38,245	$49,719
	$0					0	$0	$0	$0	$0	$0
Total Other Operators		**12**	**12**	**12**	**12**	**144**	**$17,757**			**$519,045**	**$674,759**
Total Senior Personnel		1	1	1	1	12	$6,830			$81,955	$106,541
Total Other Personnel		3	3	3	3	36	$8,195			$169,373	$220,184
Total Other Operators		12	12	12	12	144	$17,757			$519,045	$674,759
Total		**16**	**16**	**16**	**16**	**192**	**$32,782**			**$770,373**	**$1,001,484**

Year 5 Personnel

Detector Operations

	Annual Wage (Base)	Year 5 1st Qtr	Year 5 2nd Qtr	Year 5 3rd Qtr	Year 5 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 5 Wage (Base)	Year 5 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Assistant Manager	$84,413	1	1	1	1	12	$7,034	$109,737	$9,145	$84,413	$109,737
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**1**	**1**	**1**	**1**	**12**	**$7,034**			**$84,413**	**$109,737**
	$0					0	$0	$0	$0	$0	$0
Mechanical/process engineer	$73,158	2	2	2	2	24	$6,097	$95,105	$7,925	$146,316	$190,211
Secretarial/Clerical	$28,138	1	1	1	1	12	$2,345	$36,579	$3,048	$28,138	$36,579
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**3**	**3**	**3**	**3**	**36**	**$8,441**			**$174,454**	**$226,790**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Maintenance mechanic	$45,020	2	2	2	2	24	$3,752	$58,526	$4,877	$90,041	$117,053
Professional operators	$45,020	3	3	3	3	36	$3,752	$58,526	$4,877	$135,061	$175,579
Underground assembly	$45,020	3	3	3	3	36	$3,752	$58,526	$4,877	$135,061	$175,579
Large assembly	$45,020	3	3	3	3	36	$3,752	$58,526	$4,877	$135,061	$175,579
Transportation	$39,393	1	1	1	1	12	$3,283	$51,211	$4,268	$39,393	$51,211
	$0					0	$0	$0	$0	$0	$0
Total Other Operators		**12**	**12**	**12**	**12**	**144**	**$18,290**			**$534,617**	**$695,002**
Total Senior Personnel		1	1	1	1	12	$7,034			$84,413	$109,737
Total Other Personnel		3	3	3	3	36	$8,441			$174,454	$226,790
Total Other Operators		12	12	12	12	144	$18,290			$534,617	$695,002
Total		**16**	**16**	**16**	**16**	**192**	**$33,765**			**$793,484**	**$1,031,529**

5 Year Personnel Summary

Detector Operations

	Year 1		Year 2		Year 3		Year 4		Year 5		Year 1 - 5
	No	Total	No	Total	No	Total	No	Total	No	Total	Total
Senior Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Assistant Manager	0	$0	0	$0	1	$79,568	1.0	$81,955	1	$84,413	$245,935
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Senior Personnel	**0**	**$0**	**0**	**$0**	**1**	**$79,568**	**1.0**	**$81,955**	**1**	**$84,413**	**$245,935**
Other Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Mechanical/process engineer	0	$0	1	$66,950	2	$137,917	2.0	$142,055	2	$146,316	$493,238
Secretarial/Clerical	0	$0	1	$25,750	1	$26,523	1.0	$27,318	1	$28,138	$107,728
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Other Personnel	**0**	**$0**	**2**	**$92,700**	**3**	**$164,440**	**3.0**	**$169,373**	**3**	**$174,454**	**$600,966**
Other Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Maintenance mechanic	0	$0	0	$0	2	$84,872	2.0	$87,418	2	$90,041	$262,331
Professional operators	0	$0	1	$41,200	1	$42,436	3.0	$131,127	3	$135,061	$349,824
Underground assembly	0	$0	0	$0	1	$42,436	3.0	$131,127	3	$135,061	$308,624
Large assembly	0	$0	0	$0	1	$42,436	3.0	$131,127	3	$135,061	$308,624
Transportation	0	$0	0	$0	1	$37,132	1.0	$38,245	1	$39,393	$114,770
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Other Operators	**0**	**$0**	**1**	**$41,200**	**6**	**$249,312**	**12.0**	**$519,045**	**12**	**$534,617**	**$1,344,174**
Total Senior Personnel	0	$0	0	$0	1	$79,568	1	$81,955	1	$84,413	$245,935
Total Other Personnel	0	$0	2	$92,700	3	$164,440	3.0	$169,373	3	$174,454	$600,966
Total Other Operators	0	$0	1	$41,200	6	$249,312	12.0	$519,045	12	$534,617	$1,344,174
Total	**0**	**$0**	**3**	**$133,900**	**10**	**$493,319**	**16.0**	**$770,373**	**16**	**$793,484**	**$2,191,075**

Year 1 Personnel

Administrative Operations

	Annual Wage (Base)	Year 1 1st Qtr	Year 1 2nd Qtr	Year 1 3rd Qtr	Year 1 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 1 Wage (Base)	Year 1 Wage (Loaded)
Senior Personnel											
						0					
Administrative office director	$70,000	1	1	1	1	12	$5,833	$91,000	$7,583	$70,000	$91,000
Personnel officer	$60,000	1	1	1	1	12	$5,000	$78,000	$6,500	$60,000	$78,000
Financial officer	$60,000	1	1	1	1	12	$5,000	$78,000	$6,500	$60,000	$78,000
Visitor liaison officer	$60,000					0	$5,000	$78,000	$6,500	$0	$0
Public information officer	$60,000					0	$5,000	$78,000	$6,500	$0	$0
Site development manager	$60,000	0.8	0.8	0.8	0.8	9.6	$5,000	$78,000	$6,500	$48,000	$62,400
						0	$0	$0	$0	$0	$0
Total Senior Personnel		**3.8**	**3.8**	**3.8**	**3.8**	**45.6**	**$30,833**			**$238,000**	**$309,400**
Other Personnel											$238,000
						0					
Office assistants	$30,000	2	2	2	2	24	$2,500	$39,000	$3,250	$60,000	$78,000
Security guards	$30,000	4	4	4	4	48	$2,500	$39,000	$3,250	$120,000	$156,000
Site development assistants	$35,000	1.6	1.6	1.6	1.6	19.2	$2,917	$45,500	$3,792	$56,000	$72,800
Site develop. secretary/clerical	$25,000	0.8	0.8	0.8	0.8	9.6	$2,083	$32,500	$2,708	$20,000	$26,000
						0	$0	$0	$0	$0	$0
Total Other Personnel		**8.4**	**8.4**	**8.4**	**8.4**	**100.8**	**$10,000**			**$256,000**	**$332,800**

Total Senior Personnel	3.8	3.8	3.8	3.8	45.6	$30,833		0	$238,000	$309,400
Total Other Personnel	8.4	8.4	8.4	8.4	100.8	$10,000		0	$256,000	$332,800
Total	**12.2**	**12.2**	**12.2**	**12.2**	**146.4**	**$40,833**		**0**	**$494,000**	**$642,200**

Year 2 Personnel

Administrative Operations

	Annual Wage (Base)	Year 2 1st Qtr	Year 2 2nd Qtr	Year 2 3rd Qtr	Year 2 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 2 Wage (Base)	Year 2 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Administrative office director	$72,100	1	1	1	1	12	$6,008	$93,730	$7,811	$72,100	$93,730
Personnel officer	$61,800	1	1	1	1	12	$5,150	$80,340	$6,695	$61,800	$80,340
Financial officer	$61,800	1	1	1	1	12	$5,150	$80,340	$6,695	$61,800	$80,340
Visitor liaison officer	$61,800	1	1	1	1	12	$5,150	$80,340	$6,695	$61,800	$80,340
Public information officer	$61,800	1	1	1	1	12	$5,150	$80,340	$6,695	$61,800	$80,340
Site development manager	$61,800	0.8	0.8	0.8	0.8	9.6	$5,150	$80,340	$6,695	$49,440	$64,272
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**5.8**	**5.8**	**5.8**	**5.8**	**69.6**	**$31,758**			**$368,740**	**$479,362**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Office assistants	$30,900	4	4	4	4	48	$2,575	$40,170	$3,348	$123,600	$160,680
Security guards	$30,900	8	8	8	8	96	$2,575	$40,170	$3,348	$247,200	$321,360
Site development assistants	$36,050	1.6	1.6	1.6	1.6	19.2	$3,004	$46,865	$3,905	$57,680	$74,984
Site develop. secretary/clerical	$25,750	0.8	0.8	0.8	0.8	9.6	$2,146	$33,475	$2,790	$20,600	$26,780
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**14.4**	**14.4**	**14.4**	**14.4**	**172.8**	**$10,300**			**$449,080**	**$583,804**
Total Senior Personnel		5.8	5.8	5.8	5.8	69.6	$31,758		0	$368,740	$479,362
Total Other Personnel		14.4	14.4	14.4	14.4	172.8	$10,300		0	$449,080	$583,804
Total		20.2	20.2	20.2	20.2	242.4	$42,058		0	**$817,820**	**$1,063,166**

Year 3 Personnel

Administrative Operations

	Annual Wage (Base)	Year 3 1st Qtr	Year 3 2nd Qtr	Year 3 3rd Qtr	Year 3 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 3 Wage (Base)	Year 3 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Administrative office director	$74,263	1	1	1	1	12	$6,189	$96,542	$8,045	$74,263	$96,542
Personnel officer	$63,654	1	1	1	1	12	$5,305	$82,750	$6,896	$63,654	$82,750
Financial officer	$63,654	1	1	1	1	12	$5,305	$82,750	$6,896	$63,654	$82,750
Visitor liaison officer	$63,654	1	1	1	1	12	$5,305	$82,750	$6,896	$63,654	$82,750
Public information officer	$63,654	1	1	1	1	12	$5,305	$82,750	$6,896	$63,654	$82,750
Site development manager	$63,654	0.8	0.8	0.8	0.8	9.6	$5,305	$82,750	$6,896	$50,923	$66,200
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**5.8**	**5.8**	**5.8**	**5.8**	**69.6**	**$32,711**			**$379,802**	**$493,743**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Office assistants	$31,827	4	4	4	4	48	$2,652	$41,375	$3,448	$127,308	$165,500
Security guards	$31,827	8	8	8	8	96	$2,652	$41,375	$3,448	$254,616	$331,001
Site development assistants	$37,132	1.6	1.6	1.6	1.6	19.2	$3,094	$48,271	$4,023	$59,410	$77,234
Site develop. secretary/clerical	$26,523	0.8	0.8	0.8	0.8	9.6	$2,210	$34,479	$2,873	$21,218	$27,583
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**14.4**	**14.4**	**14.4**	**14.4**	**172.8**	**$10,609**			**$462,552**	**$601,318**
Total Senior Personnel		5.8	5.8	5.8	5.8	69.6	$32,711			$379,802	$493,743
Total Other Personnel		14.4	14.4	14.4	14.4	172.8	$10,609			$462,552	$601,318
Total		**20.2**	**20.2**	**20.2**	**20.2**	**242.4**	**$43,320**			**$842,355**	**$1,095,061**

Year 4 Personnel

Administrative Operations

	Annual Wage (Base)	Year 4 1st Qtr	Year 4 2nd Qtr	Year 4 3rd Qtr	Year 4 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 4 Wage (Base)	Year 4 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Administrative office director	$76,491	1	1	1	1	12	$6,374	$99,438	$8,287	$76,491	$99,438
Personnel officer	$65,564	1	1	1	1	12	$5,464	$85,233	$7,103	$65,564	$85,233
Financial officer	$65,564	1	1	1	1	12	$5,464	$85,233	$7,103	$65,564	$85,233
Visitor liaison officer	$65,564	1	1	1	1	12	$5,464	$85,233	$7,103	$65,564	$85,233
Public information officer	$65,564	1	1	1	1	12	$5,464	$85,233	$7,103	$65,564	$85,233
Site development manager	$65,564	0.8	0.8	0.8	0.8	9.6	$5,464	$85,233	$7,103	$52,451	$68,186
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**5.8**	**5.8**	**5.8**	**5.8**	**69.6**	**$33,692**			**$391,196**	**$508,555**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Office assistants	$32,782	4	4	4	4	48	$2,732	$42,616	$3,551	$131,127	$170,465
Security guards	$32,782	8	8	8	8	96	$2,732	$42,616	$3,551	$262,254	$340,931
Site development assistants	$38,245	1.6	1.6	1.6	1.6	19.2	$3,187	$49,719	$4,143	$61,193	$79,551
Site develop. secretary/clerical	$27,318	0.8	0.8	0.8	0.8	9.6	$2,277	$35,514	$2,959	$21,855	$28,411
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**14.4**	**14.4**	**14.4**	**14.4**	**172.8**	**$10,927**			**$476,429**	**$619,358**
Total Senior Personnel		5.8	5.8	5.8	5.8	69.6	$33,692			$391,196	$508,555
Total Other Personnel		14.4	14.4	14.4	14.4	172.8	$10,927			$476,429	$619,358
Total		**20.2**	**20.2**	**20.2**	**20.2**	**242.4**	**$44,620**			**$867,625**	**$1,127,913**

Year 5 Personnel

Administrative Operations

	Annual Wage (Base)	Year 5 1st Qtr	Year 5 2nd Qtr	Year 5 3rd Qtr	Year 5 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 5 Wage (Base)	Year 5 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Administrative office director	$78,786	1	1	1	1	12	$6,565	$102,421	$8,535	$78,786	$102,421
Personnel officer	$67,531	1	1	1	1	12	$5,628	$87,790	$7,316	$67,531	$87,790
Financial officer	$67,531	1	1	1	1	12	$5,628	$87,790	$7,316	$67,531	$87,790
Visitor liaison officer	$67,531	1	1	1	1	12	$5,628	$87,790	$7,316	$67,531	$87,790
Public information officer	$67,531	1	1	1	1	12	$5,628	$87,790	$7,316	$67,531	$87,790
Site development manager	$67,531	0.8	0.8	0.8	0.8	9.6	$5,628	$87,790	$7,316	$54,024	$70,232
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**5.8**	**5.8**	**5.8**	**5.8**	**69.6**	**$34,703**			**$402,932**	**$523,812**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Office assistants	$33,765	4	4	4	4	48	$2,814	$43,895	$3,658	$135,061	$175,579
Security guards	$33,765	8	8	8	8	96	$2,814	$43,895	$3,658	$270,122	$351,159
Site development assistants	$39,393	1.6	1.6	1.6	1.6	19.2	$3,283	$51,211	$4,268	$63,028	$81,937
Site develop. secretary/clerical	$28,138	0.8	0.8	0.8	0.8	9.6	$2,345	$36,579	$3,048	$22,510	$29,263
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**14.4**	**14.4**	**14.4**	**14.4**	**172.8**	**$11,255**			**$490,722**	**$637,938**
Total Senior Personnel		5.8	5.8	5.8	5.8	69.6	$34,703			$402,932	$523,812
Total Other Personnel		14.4	14.4	14.4	14.4	172.8	$11,255			$490,722	$637,938
Total		**20.2**	**20.2**	**20.2**	**20.2**	**242.4**	**$45,958**			**$893,654**	**$1,161,750**

5 Year Personnel Summary

Administrative Operations

	Year 1		Year 2		Year 3		Year 4		Year 5		Year 1 - 5
	No	Total	No	Total	No	Total	No	Total	No	Total	Total
Senior Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Administrative office director	1	$70,000	1	$72,100	1	$74,263	1.0	$76,491	1	$78,786	$371,640
Personnel officer	1	$60,000	1	$61,800	1	$63,654	1.0	$65,564	1	$67,531	$318,548
Financial officer	1	$60,000	1	$61,800	1	$63,654	1.0	$65,564	1	$67,531	$318,548
Visitor liaison officer	0	$0	1	$61,800	1	$63,654	1.0	$65,564	1	$67,531	$258,548
Public information officer	0	$0	1	$61,800	1	$63,654	1.0	$65,564	1	$67,531	$258,548
Site development manager	0.8	$48,000	0.8	$49,440	0.8	$50,923	0.8	$52,451	0.8	$54,024	$254,839
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Senior Personnel	**3.8**	**$238,000**	**5.8**	**$368,740**	**5.8**	**$379,802**	**5.8**	**$391,196**	**5.8**	**$402,932**	**$1,780,671**
Other Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Office assistants	2	$60,000	4	$123,600	4	$127,308	4.0	$131,127	4	$135,061	$577,096
Security guards	4	$120,000	8	$247,200	8	$254,616	8.0	$262,254	8	$270,122	$1,154,193
Site development assistants	1.6	$56,000	1.6	$57,680	1.6	$59,410	1.6	$61,193	1.6	$63,028	$297,312
Site develop. secretary/clerical	0.8	$20,000	0.8	$20,600	0.8	$21,218	0.8	$21,855	0.8	$22,510	$106,183
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Other Personnel	**8.4**	**$256,000**	**14.4**	**$449,080**	**14.4**	**$462,552**	**14.4**	**$476,429**	**14.4**	**$490,722**	**$2,134,783**
Total Senior Personnel	3.8	$238,000	5.8	$368,740	5.8	$379,802	5.8	$391,196	5.8	$402,932	$1,780,671
Total Other Personnel	8.4	$256,000	14.4	$449,080	14.4	$462,552	14.4	$476,429	14.4	$490,722	$2,134,783
Total	**12.2**	**$494,000**	**20.2**	**$817,820**	**20.2**	**$842,355**	**20.2**	**$867,625**	**20.2**	**$893,654**	**$3,915,454**

Year 1 Personnel

Outreach and Education Operations

	Annual Wage (Base)	Year 1 1st Qtr	Year 1 2nd Qtr	Year 1 3rd Qtr	Year 1 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 1 Wage (Base)	Year 1 Wage (Loaded)
Senior Personnel											
						0					
Lab director	$180,000	0.2	0.2	0.2	0.2	2.4	$15,000	$234,000	$19,500	$36,000	$46,800
Outreach/Education Office director	$80,000	1	1	1	1	12	$6,667	$104,000	$8,667	$80,000	$104,000
Manager, Visitor Center	$70,000					0	$5,833	$91,000	$7,583	$0	$0
Manager, computing/networks	$70,000					0	$5,833	$91,000	$7,583	$0	$0
Manager, K-12 education	$70,000					0	$5,833	$91,000	$7,583	$0	$0
Manager, site development	$60,000	0.2	0.2	0.2	0.2	2.4	$5,000	$78,000	$6,500	$12,000	$15,600
						0	$0	$0	$0	$0	$0
Total Senior Personnel		**1.4**	**1.4**	**1.4**	**1.4**	**16.8**	**$44,167**			**$128,000**	**$166,400**
Other Personnel											$128,000
						0					
Display design staff	$35,000					0	$2,917	$45,500	$3,792	$0	$0
K-12 education staff	$35,000					0	$2,917	$45,500	$3,792	$0	$0
Visitor center staff	$30,000					0	$2,500	$39,000	$3,250	$0	$0
Web/internet displat staff	$45,000					0	$3,750	$58,500	$4,875	$0	$0
Secretary/clerical	$25,000	1	1	1	1	12	$2,083	$32,500	$2,708	$25,000	$32,500
Secretary/clerical, site develop.	$25,000	0.2	0.2	0.2	0.2	2.4	$2,083	$32,500	$2,708	$5,000	$6,500
Assistants, site development	$35,000	0.4	0.4	0.4	0.4	4.8	$2,917	$45,500	$3,792	$14,000	$18,200
						0	$0	$0	$0	$0	$0
Total Other Personnel		**1.6**	**1.6**	**1.6**	**1.6**	**19.2**	**$19,167**			**$44,000**	**$57,200**
Total Senior Personnel		1.4	1.4	1.4	1.4	16.8	$44,167		0	$128,000	$166,400
Total Other Personnel		1.6	1.6	1.6	1.6	19.2	$19,167		0	$44,000	$57,200
Total		**3**	**3**	**3**	**3**	**36**	**$63,333**		**0**	**$172,000**	**$223,600**

Year 2 Personnel

Outreach and Education Operations

	Annual Wage (Base)	Year 2 1st Qtr	Year 2 2nd Qtr	Year 2 3rd Qtr	Year 2 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 2 Wage (Base)	Year 2 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Lab director	$185,400	0.2	0.2	0.2	0.2	2.4	$15,450	$241,020	$20,085	$37,080	$48,204
Outreach/Education Office director	$82,400	1	1	1	1	12	$6,867	$107,120	$8,927	$82,400	$107,120
Manager, Visitor Center	$72,100	1	1	1	1	12	$6,008	$93,730	$7,811	$72,100	$93,730
Manager, computing/networks	$72,100	1	1	1	1	12	$6,008	$93,730	$7,811	$72,100	$93,730
Manager, K-12 education	$72,100					0	$6,008	$93,730	$7,811	$0	$0
Manager, site development	$61,800	0.2	0.2	0.2	0.2	2.4	$5,150	$80,340	$6,695	$12,360	$16,068
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**3.4**	**3.4**	**3.4**	**3.4**	**40.8**	**$45,492**			**$276,040**	**$358,852**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Display design staff	$36,050					0	$3,004	$46,865	$3,905	$0	$0
K-12 education staff	$36,050					0	$3,004	$46,865	$3,905	$0	$0
Visitor center staff	$30,900					0	$2,575	$40,170	$3,348	$0	$0
Web/internet displat staff	$46,350					0	$3,863	$60,255	$5,021	$0	$0
Secretary/clerical	$25,750	1	1	1	1	12	$2,146	$33,475	$2,790	$25,750	$33,475
Secretary/clerical, site develop.	$25,750	0.2	0.2	0.2	0.2	2.4	$2,146	$33,475	$2,790	$5,150	$6,695
Assistants, site development	$36,050	0.4	0.4	0.4	0.4	4.8	$3,004	$46,865	$3,905	$14,420	$18,746
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**1.6**	**1.6**	**1.6**	**1.6**	**19.2**	**$19,742**			**$45,320**	**$58,916**
Total Senior Personnel		3.4	3.4	3.4	3.4	40.8	$45,492		0	$276,040	$358,852
Total Other Personnel		1.6	1.6	1.6	1.6	19.2	$19,742		0	$45,320	$58,916
Total		5	5	5	5	60	$65,233		0	**$321,360**	**$417,768**

Year 3 Personnel

Outreach and Education Operations

	Annual Wage (Base)	Year 3 1st Qtr	Year 3 2nd Qtr	Year 3 3rd Qtr	Year 3 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 3 Wage (Base)	Year 3 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Lab director	$190,962	0.2	0.2	0.2	0.2	2.4	$15,914	$248,251	$20,688	$38,192	$49,650
Outreach/Education Office director	$84,872	1	1	1	1	12	$7,073	$110,334	$9,194	$84,872	$110,334
Manager, Visitor Center	$74,263	1	1	1	1	12	$6,189	$96,542	$8,045	$74,263	$96,542
Manager, computing/networks	$74,263	1	1	1	1	12	$6,189	$96,542	$8,045	$74,263	$96,542
Manager, K-12 education	$74,263	1	1	1	1	12	$6,189	$96,542	$8,045	$74,263	$96,542
Manager, site development	$63,654	0.2	0.2	0.2	0.2	2.4	$5,305	$82,750	$6,896	$12,731	$16,550
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**4.4**	**4.4**	**4.4**	**4.4**	**52.8**	**$46,856**			**$358,584**	**$466,159**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Display design staff	$37,132					0	$3,094	$48,271	$4,023	$0	$0
K-12 education staff	$37,132					0	$3,094	$48,271	$4,023	$0	$0
Visitor center staff	$31,827					0	$2,652	$41,375	$3,448	$0	$0
Web/internet displat staff	$47,741	2	2	2	2	24	$3,978	$62,063	$5,172	$95,481	$124,125
Secretary/clerical	$26,523	2	2	2	2	24	$2,210	$34,479	$2,873	$53,045	$68,959
Secretary/clerical, site develop.	$26,523	0.2	0.2	0.2	0.2	2.4	$2,210	$34,479	$2,873	$5,305	$6,896
Assistants, site development	$37,132	0.4	0.4	0.4	0.4	4.8	$3,094	$48,271	$4,023	$14,853	$19,308
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**4.6**	**4.6**	**4.6**	**4.6**	**55.2**	**$20,334**			**$168,683**	**$219,288**

Total Senior Personnel		4.4	4.4	4.4	4.4	52.8	$46,856			$358,584	$466,159
Total Other Personnel		4.6	4.6	4.6	4.6	55.2	$20,334			$168,683	$219,288
Total		**9**	**9**	**9**	**9**	**108**	**$67,190**			**$527,267**	**$685,447**

Year 4 Personnel

Outreach and Education Operations

	Annual Wage (Base)	Year 4 1st Qtr	Year 4 2nd Qtr	Year 4 3rd Qtr	Year 4 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 4 Wage (Base)	Year 4 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Lab director	$196,691	0.2	0.2	0.2	0.2	2.4	$16,391	$255,698	$21,308	$39,338	$51,140
Outreach/Education Office director	$87,418	1	1	1	1	12	$7,285	$113,644	$9,470	$87,418	$113,644
Manager, Visitor Center	$76,491	1	1	1	1	12	$6,374	$99,438	$8,287	$76,491	$99,438
Manager, computing/networks	$76,491	1	1	1	1	12	$6,374	$99,438	$8,287	$76,491	$99,438
Manager, K-12 education	$76,491	1	1	1	1	12	$6,374	$99,438	$8,287	$76,491	$99,438
Manager, site development	$65,564	0.2	0.2	0.2	0.2	2.4	$5,464	$85,233	$7,103	$13,113	$17,047
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**4.4**	**4.4**	**4.4**	**4.4**	**52.8**	**$48,262**			**$369,342**	**$480,144**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Display design staff	$38,245	3	3	3	3	36	$3,187	$49,719	$4,143	$114,736	$149,157
K-12 education staff	$38,245	1.5	1.5	1.5	1.5	18	$3,187	$49,719	$4,143	$57,368	$74,579
Visitor center staff	$32,782	3	3	3	3	36	$2,732	$42,616	$3,551	$98,345	$127,849
Web/internet displat staff	$49,173	2	2	2	2	24	$4,098	$63,925	$5,327	$98,345	$127,849
Secretary/clerical	$27,318	2	2	2	2	24	$2,277	$35,514	$2,959	$54,636	$71,027
Secretary/clerical, site develop.	$27,318	0.2	0.2	0.2	0.2	2.4	$2,277	$35,514	$2,959	$5,464	$7,103
Assistants, site development	$38,245	0.4	0.4	0.4	0.4	4.8	$3,187	$49,719	$4,143	$15,298	$19,888
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**12.1**	**12.1**	**12.1**	**12.1**	**145.2**	**$20,944**			**$444,194**	**$577,452**
Total Senior Personnel		4.4	4.4	4.4	4.4	52.8	$48,262			$369,342	$480,144
Total Other Personnel		12.1	12.1	12.1	12.1	145.2	$20,944			$444,194	$577,452
Total		**16.5**	**16.5**	**16.5**	**16.5**	**198**	**$69,206**			**$813,535**	**$1,057,596**

Year 5 Personnel

Outreach and Education Operations

	Annual Wage (Base)	Year 5 1st Qtr	Year 5 2nd Qtr	Year 5 3rd Qtr	Year 5 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 5 Wage (Base)	Year 5 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Lab director	$202,592	0.2	0.2	0.2	0.2	2.4	$16,883	$263,369	$21,947	$40,518	$52,674
Outreach/Education Office director	$90,041	1	1	1	1	12	$7,503	$117,053	$9,754	$90,041	$117,053
Manager, Visitor Center	$78,786	1	1	1	1	12	$6,565	$102,421	$8,535	$78,786	$102,421
Manager, computing/networks	$78,786	1	1	1	1	12	$6,565	$102,421	$8,535	$78,786	$102,421
Manager, K-12 education	$78,786	1	1	1	1	12	$6,565	$102,421	$8,535	$78,786	$102,421
Manager, site development	$67,531	0.2	0.2	0.2	0.2	2.4	$5,628	$87,790	$7,316	$13,506	$17,558
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**4.4**	**4.4**	**4.4**	**4.4**	**52.8**	**$49,710**			**$380,422**	**$494,549**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
Display design staff	$39,393	3	3	3	3	36	$3,283	$51,211	$4,268	$118,178	$153,632
K-12 education staff	$39,393	3	3	3	3	36	$3,283	$51,211	$4,268	$118,178	$153,632
Visitor center staff	$33,765	6	6	6	6	72	$2,814	$43,895	$3,658	$202,592	$263,369
Web/internet displat staff	$50,648	4	4	4	4	48	$4,221	$65,842	$5,487	$202,592	$263,369
Secretary/clerical	$28,138	2	2	2	2	24	$2,345	$36,579	$3,048	$56,275	$73,158
Secretary/clerical, site develop.	$28,138	0.2	0.2	0.2	0.2	2.4	$2,345	$36,579	$3,048	$5,628	$7,316
Assistants, site development	$39,393	0.4	0.4	0.4	0.4	4.8	$3,283	$51,211	$4,268	$15,757	$20,484
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**18.6**	**18.6**	**18.6**	**18.6**	**223.2**	**$21,572**			**$719,200**	**$934,960**
Total Senior Personnel		4.4	4.4	4.4	4.4	52.8	$49,710			$380,422	$494,549
Total Other Personnel		18.6	18.6	18.6	18.6	223.2	$21,572			$719,200	$934,960
Total		**23**	**23**	**23**	**23**	**276**	**$71,282**			**$1,099,622**	**$1,429,509**

5 Year Personnel Summary

Outreach and Education Operations

	Year 1		Year 2		Year 3		Year 4		Year 5		Year 1 - 5
	No	Total	No	Total	No	Total	No	Total	No	Total	Total
Senior Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Lab director	0.2	$36,000	0.2	$37,080	0.2	$38,192	0.2	$39,338	0.2	$40,518	$191,129
Outreach/Education Office director	1	$80,000	1	$82,400	1	$84,872	1.0	$87,418	1	$90,041	$424,731
Manager, Visitor Center	0	$0	1	$72,100	1	$74,263	1.0	$76,491	1	$78,786	$301,640
Manager, computing/networks	0	$0	1	$72,100	1	$74,263	1.0	$76,491	1	$78,786	$301,640
Manager, K-12 education	0	$0	0	$0	1	$74,263	1.0	$76,491	1	$78,786	$229,540
Manager, site development	0.2	$12,000	0.2	$12,360	0.2	$12,731	0.2	$13,113	0.2	$13,506	$63,710
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Senior Personnel	**1.4**	**$128,000**	**3.4**	**$276,040**	**4.4**	**$358,584**	**4.4**	**$369,342**	**4.4**	**$380,422**	**$1,512,388**
Other Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Display design staff	0	$0	0	$0	0	$0	3.0	$114,736	3	$118,178	$232,915
K-12 education staff	0	$0	0	$0	0	$0	1.5	$57,368	3	$118,178	$175,547
Visitor center staff	0	$0	0	$0	0	$0	3.0	$98,345	6	$202,592	$300,937
Web/internet displat staff	0	$0	0	$0	2	$95,481	2.0	$98,345	4	$202,592	$396,418
Secretary/clerical	1	$25,000	1	$25,750	2	$53,045	2.0	$54,636	2	$56,275	$214,707
Secretary/clerical, site develop.	0.2	$5,000	0.2	$5,150	0.2	$5,305	0.2	$5,464	0.2	$5,628	$26,546
Assistants, site development	0.4	$14,000	0.4	$14,420	0.4	$14,853	0.4	$15,298	0.4	$15,757	$74,328
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Other Personnel	**1.6**	**$44,000**	**1.6**	**$45,320**	**4.6**	**$168,683**	**12.1**	**$444,194**	**18.6**	**$719,200**	**$1,421,397**
Total Senior Personnel	1.4	$128,000	3.4	$276,040	4.4	$358,584	4.4	$369,342	4.4	$380,422	$1,512,388
Total Other Personnel	1.6	$44,000	1.6	$45,320	4.6	$168,683	12.1	$444,194	18.6	$719,200	$1,421,397
Total	**3**	**$172,000**	**5**	**$321,360**	**9**	**$527,267**	**16.5**	**$813,535**	**23**	**$1,099,622**	**$2,933,785**

Management Operations

	Annual Wage (Base)	Year 1 1st Qtr	Year 1 2nd Qtr	Year 1 3rd Qtr	Year 1 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 1 Wage (Base)	Year 1 Wage (Loaded)
Senior Personnel											
						0					
Laboratory Director	$180,000	0.1	0.1	0.1	0.1	1.2	$15,000	$234,000	$19,500	$18,000	$23,400
Management site office director	$120,000	1	1	1	1	12	$10,000	$156,000	$13,000	$120,000	$156,000
Manag. site office adm. asst.	$30,000	1	1	1	1	12	$2,500	$39,000	$3,250	$30,000	$39,000
Other office personnel	$50,000	1	1	1	1	12	$4,167	$65,000	$5,417	$50,000	$65,000
						0	$0	$0	$0	$0	$0
Landlord site office director	$120,000	1	1	1	1	12	$10,000	$156,000	$13,000	$120,000	$156,000
Landlord site office adm. asst.	$30,000	1	1	1	1	12	$2,500	$39,000	$3,250	$30,000	$39,000
Other office personnel	$50,000	1	1	1	1	12	$4,167	$65,000	$5,417	$50,000	$65,000
						0	$0	$0	$0	$0	$0
Total Senior Personnel		**6.1**	**6.1**	**6.1**	**6.1**	**73.2**	**$48,333**			**$418,000**	**$543,400**
Other Personnel											$318,000
						0					
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**0**	**0**	**0**	**0**	**0**	**$0**			**$0**	**$0**
Total Senior Personnel		6.1	6.1	6.1	6.1	73.2	$48,333		0	$418,000	$543,400
Total Other Personnel		0	0	0	0	0	$0		0	$0	$0
Total		**6.1**	**6.1**	**6.1**	**6.1**	**73.2**	**$48,333**		**0**	**$418,000**	**$543,400**

Management Operations

	Annual Wage (Base)	Year 2 1st Qtr	Year 2 2nd Qtr	Year 2 3rd Qtr	Year 2 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 2 Wage (Base)	Year 2 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Laboratory Director	$185,400	0.1	0.1	0.1	0.1	1.2	$15,450	$241,020	$20,085	$18,540	$24,102
Management site office director	$123,600	1	1	1	1	12	$10,300	$160,680	$13,390	$123,600	$160,680
Manag. site office adm. asst.	$30,900	1	1	1	1	12	$2,575	$40,170	$3,348	$30,900	$40,170
Other office personnel	$51,500	1	1	1	1	12	$4,292	$66,950	$5,579	$51,500	$66,950
	$0					0	$0	$0	$0	$0	$0
Landlord site office director	$123,600	1	1	1	1	12	$10,300	$160,680	$13,390	$123,600	$160,680
Landlord site office adm. asst.	$30,900	1	1	1	1	12	$2,575	$40,170	$3,348	$30,900	$40,170
Other office personnel	$51,500	1	1	1	1	12	$4,292	$66,950	$5,579	$51,500	$66,950
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**6.1**	**6.1**	**6.1**	**6.1**	**73.2**	**$49,783**			**$430,540**	**$559,702**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**0**	**0**	**0**	**0**	**0**	**$0**			**$0**	**$0**
Total Senior Personnel		6.1	6.1	6.1	6.1	73.2	$49,783		0	$430,540	$559,702
Total Other Personnel		0	0	0	0	0	$0		0	$0	$0
Total		6.1	6.1	6.1	6.1	73.2	$49,783		0	**$430,540**	**$559,702**

Management Operations

	Annual Wage (Base)	Year 3 1st Qtr	Year 3 2nd Qtr	Year 3 3rd Qtr	Year 3 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 3 Wage (Base)	Year 3 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Laboratory Director	$190,962	0.1	0.1	0.1	0.1	1.2	$15,914	$248,251	$20,688	$19,096	$24,825
Management site office director	$127,308	1	1	1	1	12	$10,609	$165,500	$13,792	$127,308	$165,500
Manag. site office adm. asst.	$31,827	1	1	1	1	12	$2,652	$41,375	$3,448	$31,827	$41,375
Other office personnel	$53,045	1	1	1	1	12	$4,420	$68,959	$5,747	$53,045	$68,959
	$0					0	$0	$0	$0	$0	$0
Landlord site office director	$127,308	1	1	1	1	12	$10,609	$165,500	$13,792	$127,308	$165,500
Landlord site office adm. asst.	$31,827	1	1	1	1	12	$2,652	$41,375	$3,448	$31,827	$41,375
Other office personnel	$53,045	1	1	1	1	12	$4,420	$68,959	$5,747	$53,045	$68,959
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**6.1**	**6.1**	**6.1**	**6.1**	**73.2**	**$51,277**			**$443,456**	**$576,493**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**0**	**0**	**0**	**0**	**0**	**$0**			**$0**	**$0**
Total Senior Personnel		6.1	6.1	6.1	6.1	73.2	$51,277			$443,456	$576,493
Total Other Personnel		0	0	0	0	0	$0			$0	$0
Total		**6.1**	**6.1**	**6.1**	**6.1**	**73.2**	**$51,277**			**$443,456**	**$576,493**

Management Operations

	Annual Wage (Base)	Year 4 1st Qtr	Year 4 2nd Qtr	Year 4 3rd Qtr	Year 4 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 4 Wage (Base)	Year 4 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Laboratory Director	$196,691	0.1	0.1	0.1	0.1	1.2	$16,391	$255,698	$21,308	$19,669	$25,570
Management site office director	$131,127	1	1	1	1	12	$10,927	$170,465	$14,205	$131,127	$170,465
Manag. site office adm. asst.	$32,782	1	1	1	1	12	$2,732	$42,616	$3,551	$32,782	$42,616
Other office personnel	$54,636	1	1	1	1	12	$4,553	$71,027	$5,919	$54,636	$71,027
	$0					0	$0	$0	$0	$0	$0
Landlord site office director	$131,127	1	1	1	1	12	$10,927	$170,465	$14,205	$131,127	$170,465
Landlord site office adm. asst.	$32,782	1	1	1	1	12	$2,732	$42,616	$3,551	$32,782	$42,616
Other office personnel	$54,636	1	1	1	1	12	$4,553	$71,027	$5,919	$54,636	$71,027
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**6.1**	**6.1**	**6.1**	**6.1**	**73.2**	**$52,815**			**$456,760**	**$593,788**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**0**	**0**	**0**	**0**	**0**	**$0**			**$0**	**$0**
Total Senior Personnel		6.1	6.1	6.1	6.1	73.2	$52,815			$456,760	$593,788
Total Other Personnel		0	0	0	0	0	$0			$0	$0
Total		**6.1**	**6.1**	**6.1**	**6.1**	**73.2**	**$52,815**			**$456,760**	**$593,788**

Management Operations

	Annual Wage (Base)	Year 5 1st Qtr	Year 5 2nd Qtr	Year 5 3rd Qtr	Year 5 4th Qtr	Employee Months	Monthly Wage (Base)	Annual Wage (Loaded)	Monthly Wage (Loaded)	Year 5 Wage (Base)	Year 5 Wage (Loaded)
Senior Personnel											
	$0					0	$0	$0	$0	$0	$0
Laboratory Director	$202,592	0.1	0.1	0.1	0.1	1.2	$16,883	$263,369	$21,947	$20,259	$26,337
Management site office director	$135,061	1	1	1	1	12	$11,255	$175,579	$14,632	$135,061	$175,579
Manag. site office adm. asst.	$33,765	1	1	1	1	12	$2,814	$43,895	$3,658	$33,765	$43,895
Other office personnel	$56,275	1	1	1	1	12	$4,690	$73,158	$6,097	$56,275	$73,158
	$0					0	$0	$0	$0	$0	$0
Landlord site office director	$135,061	1	1	1	1	12	$11,255	$175,579	$14,632	$135,061	$175,579
Landlord site office adm. asst.	$33,765	1	1	1	1	12	$2,814	$43,895	$3,658	$33,765	$43,895
Other office personnel	$56,275	1	1	1	1	12	$4,690	$73,158	$6,097	$56,275	$73,158
	$0					0	$0	$0	$0	$0	$0
Total Senior Personnel		**6.1**	**6.1**	**6.1**	**6.1**	**73.2**	**$54,400**			**$470,463**	**$611,601**
Other Personnel											
	$0					0	$0	$0	$0	$0	$0
	$0					0	$0	$0	$0	$0	$0
Total Other Personnel		**0**	**0**	**0**	**0**	**0**	**$0**			**$0**	**$0**
Total Senior Personnel		6.1	6.1	6.1	6.1	73.2	$54,400			$470,463	$611,601
Total Other Personnel		0	0	0	0	0	$0			$0	$0
Total		**6.1**	**6.1**	**6.1**	**6.1**	**73.2**	**$54,400**			**$470,463**	**$611,601**

Management Operations

	Year 1		Year 2		Year 3		Year 4		Year 5		Year 1 - 5
	No	Total	No	Total	No	Total	No	Total	No	Total	Total
Senior Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Laboratory Director	0.1	$18,000	0.1	$18,540	0.1	$19,096	0.1	$19,669	0.1	$20,259	$95,564
Management site office director	1	$120,000	1	$123,600	1	$127,308	1.0	$131,127	1	$135,061	$637,096
Manag. site office adm. asst.	1	$30,000	1	$30,900	1	$31,827	1.0	$32,782	1	$33,765	$159,274
Other office personnel	1	$50,000	1	$51,500	1	$53,045	1.0	$54,636	1	$56,275	$265,457
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Landlord site office director	1	$120,000	1	$123,600	1	$127,308	1.0	$131,127	1	$135,061	$637,096
Landlord site office adm. asst.	1	$30,000	1	$30,900	1	$31,827	1.0	$32,782	1	$33,765	$159,274
Other office personnel	1	$50,000	1	$51,500	1	$53,045	1.0	$54,636	1	$56,275	$265,457
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Senior Personnel	**6.1**	**$418,000**	**6.1**	**$430,540**	**6.1**	**$443,456**	**6.1**	**$456,760**	**6.1**	**$470,463**	**$2,219,219**
Other Personnel											
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total Other Personnel	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0.0**	**$0**	**0**	**$0**	**$0**
Total Senior Personnel	6.1	$418,000	6.1	$430,540	6.1	$443,456	6.1	$456,760	6.1	$470,463	$2,219,219
Total Other Personnel	0	$0	0	$0	0	$0	0.0	$0	0	$0	$0
Total	**6.1**	**$418,000**	**6.1**	**$430,540**	**6.1**	**$443,456**	**6.1**	**$456,760**	**6.1**	**$470,463**	**$2,219,219**