SUPPLEMENTARY MATERIAL

DEEP UNDERGROUND SCIENCE AND ENGINEERING LABORATORY (DUSEL)
BERKELEY WORKSHOP, AUGUST 11–14, 2004

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10:40	11:10	Break	
11:10	12:30	Intro/Org Working groups	
		Physics working groups	E. Beier
		Bio/Geo/Engineering	Ch. Fairhurst
	include: organization/questions still open		
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12:30	13:45	Lunch	
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		Solar Neutrinos	
		Neutrinoless double beta	
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10:00	10:15	Break	
10:15	11:00	Conclusions Solicitation 1	B. Sadoulet

B. LIST OF PARTICIPANTS (105)

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C. CONTRIBUTIONS FROM THE WORKING GROUPS

This text is based on the conclusions of the working groups at the Berkeley workshop and on the contributions from a number of scientists who are not group coordinators or were not at the workshop. In many cases, these additional texts point out a number of topics that have been overlooked in the initial descriptions. We have merged in these comments trying to preserve the conciseness and the unity of style of the main text. We would like to recognize, in particular, the contributions of Bob Bodnar, Judith Hannah, Bob Hatcher, John Helston, Chris Laughton, Jeff Martoff, Bill Roggenthen, Holly Stein and Joe Wang. These broad community contributions represent a prototype of what we hope the whole study will generate.

1) Low Energy Neutrino Physics and Astrophysics

Underground Laboratories have spectacularly demonstrated their basic importance for particle physics and astrophysics via solar neutrino research in the last four decades via low energy (<15 MeV) detectors that made the fundamental discovery of neutrino oscillations. This basic step has uncovered fertile areas with high potential for new discoveries in particle physics and solar astrophysics. The advanced detector technologies stimulated by this research opens new attacks on largely open problems in the astrophysical, cosmological and geophysical sciences as well.

Neutrino luminosity of the Sun: particle physics and astrophysics

The low energy (<2MeV) solar-ν spectrum probes the dominant pp, ^{7}Be and CNO reactions that account for ~99.5% of the solar ν output that has never been observed directly. The full low-energy spectrum measures the *total luminosity of the Sun using neutrinos* (L_ν), which succinctly summarizes the predictions of the standard solar model (SSM). The measured L_ν is thus the ultimate touchstone for the SSM and beyond the SSM, since a comparison of L_ν and the total luminosity given by photons (L_γ) probes the very foundations of solar astrophysics. The current global experimental data and ν parameters do not constrain the equality $L_\nu = L_\gamma$ significantly: L_ν(inferred from experiment)/L_γ = $1.4^{+0.2}_{-0.3}(1\sigma)^{+0.7}_{-0.6}(3\sigma)$. Thus, at 3 σ, L_ν could thus be as much as 2.1 times larger or 0.8 times smaller than L_γ. $L_\nu < L_\gamma$ implies a new hidden source of energy in the Sun. Since the L_γ predates the present epoch by ~40,000 years, $L_\nu > L_\gamma$ implies, in principle, a nonsteady state and a hotter sun in the future. The measured L_ν leads to a critical test of ν physics as well, since ν. physics, correct in all details, must be applied to convert the measured fluxes to original values to make the $L_\nu \leftrightarrow L_\gamma$ comparison. The major dividends are: a definitive physics proof of LMA flavor conversion (lacking as yet), uncovering new particle physics such as nonstandard interactions, ν magnetic moments, sterile νs and CPT validity as well as setting tight limits on the ν mixing parameters θ_{12} and θ_{13}. The unique role of precision (~3%) pp (and ^{7}Be) flux measurements for particle physics and astrophysics is well recognized and prioritized high in the 2004 APS Neutrino Study.

Supernova neutrinos

The flavor budget of neutrinos from live supernovae are of critical importance to understanding the yet unresolved questions of stellar explosion models such as for supernovae. Many of the most interesting features in the supernova neutrino "light curve" are flavor specific. Solar-ν detectors are ideal for following ν_e emission while most planned detectors for solar νs are also capable of discriminating $\bar{\nu}_e$ and the flavor independent flux. Because of their low thresholds, flavor specificity, large masses, and low backgrounds, solar-ν detectors will likely be the only means for isolating the ν_e flux during the next supernova.

Relic neutrinos

The occurrence of supernovae that produce a ν flux detectable in earth devices is relatively rare. However, there should exist a diffuse, isotropic background flux of relic neutrinos from all *past* Type II SN (SNII) in the observable universe that could provide a new source of information on the basic picture of core collapse of SNII, not only locally, but especially at high red shifts (z>1). The latter is vital to test models on the rate of occurrence of SN (proportional to star formation rate and the metal enrichment rate). The very low fluxes currently mandate detection of only the $\bar{\nu}_e$ component of the flux. The planned solar-ν detectors offer one of the best hopes to their discovery, since they employ a distinctive tag to detect antineutrinos.

Geoneutrinos

Models of the Earth's interior are as yet far from definitive, and recall the rudimentary pictures of the Sun's interior at the beginning of solar neutrino research. The new technology of a kiloton scale liquid scintillation based $\bar{\nu}_e$ detector is inherently sensitive to $\bar{\nu}_e$ from U and Th decay in the Earth's interior, mainly located in the crust. A global measurement of such "geoneutrinos" with detectors at different locations on the Earth would help distinguish between several models and provide a major advance in our knowledge of the Earth's interior.

2) Double Beta Decay Experiments

The importance of the science

The recent discoveries of ν oscillations, the first demonstrations of physics beyond the standard electroweak model, provide a compelling argument for new neutrinoless double β decay experiments with substantially increased sensitivity. Such decays can only occur if νs are massive Majorana particles, and hence are their own antiparticles. The observation of this decay mode would indicate a new form of matter and would address two additional fundamental properties of neutrinos: their mass and lepton number conservation.

Both the lightness of νs and the recent discoveries of large solar and atmospheric mixing angles argue that the mechanism for ν mass generation differs fundamentally from that of the other (charged) fermions. The mass measured in double β decay, the Majorana mass, violates lepton number and is key to the most popular ν mass mechanism, the seesaw. The seesaw attributes small neutrino masses to physics residing at very high energy scales, perhaps a billion times the energies achieved in our largest accelerators. Thus ultrasensitive double β decay experiments allow us to probe physics that otherwise will remain hidden. Finally, double β decay is a fundamental nuclear decay for about 50 otherwise stable isotopes, and the nuclear structure of the decay amplitude is a fascinating many-body problem.

Open scientific questions to be addressed in S-1

There are no fundamental scientific questions that need to be addressed before proceeding with next generation double β decay experiments. We currently have in hand the technology to improving existing lifetime limits by about two orders of magnitude, but there are technical questions as to the optimal experimental course that should be followed. However, given the inherent difficulties of such measurements, it is clear that there is a need to perform more than a single experiment using a particular nucleus. We propose to build on the APS ν physics study that will soon be completed. It is likely that a staged approach will be recommended with initial 100–200 kg scale experiments aimed at probing ν masses with a few hundreds of milli-eV sensitivities. Depending on the outcome of these experiments, one would likely proceed to either more sensitive experiments, at the 1-ton scale and beyond, or for the case where neutrinoless double β decay is clearly observed, the community would likely embark on a series of similar scale measurements in different nuclei. We intend to further develop and delineate the future roadmap.

Open infrastructure requirement questions

Reasonable information is available from recent studies for the infrastructure requirements for the short term upcoming generation of 100–200 kg scale experiments. However, substantial work needs to be done anticipating the needs for the next 10–20 years. In particular, one must take into account the two possible paths: many smaller experiments of shorter duration, or a few large experiments of long duration. Experiments must also consider and specify their tolerances to potential environmental issues, for example, mechanical sensitivity to seismic events, and optimal depths. Finally, given the fact that the time scales for current 100–200 kg size experiments are not necessarily compatible with DUSEL construction time scale, the question of relocating existing experiments to DUSEL as they evolve to larger scale experiments needs to be explored.

3) Neutrino Long Baseline Experiments

The scientific case for long baseline neutrino oscillations at DUSEL

Underground experiments in the past two decades have detected νs produced in the Sun and in the Earth's atmosphere and have shown that νs have mass and they oscillate from one species to another as they travel because of mixings. Solar and atmospheric ν experiments have demonstrated that the mass differences between the ν species are very small, on order of 10^{-5} eV^2 and 10^{-3} eV^2, respectively and two mixing angles q_{12} and q_{23} are large. The next steps in this physics are more precise measurements of the known mass and mixing parameters and determination of the unknown parameters such as q_{13}, CP violating phase d_{CP} and the ordering of the masses. This has been described by the National Research Council's Neutrino Facilities Assessment Committee in their report *Neutrinos and Beyond* [NRC 2003]. An experimental program designed to fully explore the ν sector and possible new physics will require a super ν beam produced by a high intensity proton source directed towards a very massive detector (>100 kilotons) at a distance of >1000 km. Such a super neutrino beam facility will require 1 to 2 MW upgrade of existing proton accelerators at either BNL or FNAL. Such a facility is an element of the DOE Office of Science *Facilities for the Future of Science: A Twenty Year Outlook* [DOE 2003]. The very massive detector housed in DUSEL could serve a wide array of physics topics including detection of nucleon decay, and astrophysical neutrinos. The detector is part of the strategic plan for federal research at the intersection of physics and astronomy described in *The Physics of the Universe,* a report from the National Science and Technology Council [NSTC 2004].

Open scientific questions on which the S-1 study should focus.

The most important scientific question is that of the length of the baseline and the intensity and energy spectra of potential ν beams from accelerator facilities at the national laboratories. Since the timescale for the construction of DUSEL and a super ν beam driven by a proton driver could extend well into the next decade, it is essential that the physics capability of the new program be significantly better than competing facilities and detectors. The length of the baseline and the energy of the νs determines the experiment's sensitivity to the nodes of the oscillations, and hence the ability to make precision measurements of the mixing parameters. We must also study the performance of a very large, massive detector for multiple physics purposes, in particular, accelerator νs, proton decay and super nova νs. While the cost advantages of using a single detector for multiple purposes appear obvious, the experiments under consideration must be truly superior to any that may be done before the DUSEL program comes on line.

Open questions regarding infrastructure requirements on which the S-1 study should focus.

A large multipurpose detector will need a large deep underground cavern with corresponding additional costs compared to placing a single-purpose long baseline detector on the surface or in a shallower facility. The size of the cavern that one can excavate will depend on the type of rock and the desired depth. The trade-offs between detector performance and cost need to be studied. Limitations on cavern size may lead to investigating the question of a single super large detector versus multiple smaller ones. From the viewpoint of detector cost per ton, the single larger detector will be better, but this needs to be compared with the engineering problems of the single large cavern. Finally, one detector technology choice (a liquid argon-based tracking detector) being investigated may have serious safety concerns if located underground.

4) Nucleon Decay/Atmospheric Neutrinos

Theoretical motivation

While current experiments show that the proton lifetime exceeds about 10^{33} years, its ultimate stability has been questioned since the early 1970s in the context of theoretical attempts to arrive at an unified picture of the fundamental particles—the quarks and leptons—and of their three forces: the strong, electromagnetic and weak. These attempts at unification, commonly referred to as "Grand Unification Theory" (GUT), have turned out to be supported empirically by the dramatic meeting of the strengths of the three forces. The grand unification is found to occur at high energies in the context of so-called supersymmetry, as well as by the magnitude of ν masses that is suggested by the discovery of atmospheric and solar ν oscillations. One of the crucial and generic predictions of grand unification, however, is that the proton must ultimately decay into lighter particles including leptonic matter such as a positron and a meson, revealing quark-lepton unity. From a broader viewpoint, proton decay, if found, would provide us with a unique window to view physics at truly short distances—less than 10^{-30} cm, corresponding to energies greater than 10^{16} GeV—a feature than cannot be achieved by any other means. It would provide the missing link of grand unification. Last, but not least, it would also help ascertain the origin of an excess of matter over antimatter that is crucial to the origin of life itself. Furthermore, most recently, superstring theorists who dream of unifying all four forces, including gravity beyond the scope of GUT, have shown that proton decay can occur in their theoretical framework and predicted lifetimes that are comparable to the traditional GUT predictions, effectively extending the importance of the proton decay research to the Plank scale physics.

Open scientific questions

Since the lifetime of the nucleon is unknown *a priori* (if one were to ignore theoretical guidance) and could range from just above present limits to many orders of magnitude greater, progress in this search must be measured logarithmically—increases in sensitivity by factors of a few are insufficient to motivate new experiments. Thus, continued progress in the search for nucleon decay inevitably requires much larger detectors. The decay modes of the nucleon are also unknown *a priori* and produce quite different experimental signatures; thus future detectors must be sensitive to most or all of the kinematically allowed channels. Moreover, the enormous mass and exposure required to improve significantly on existing limits (and the unknowable prospects for positive detection) underline the importance of any future experiment's ability to address other important physics questions while waiting for protons to decay. Proton decay experiments have made fundamental contributions to ν physics and particle astrophysics in the past, and any future experiment must be prepared to do the same.

Questions regarding infrastructure

Detectors which have been proposed for the next generation include megaton class water Cherenkov detectors, scintillation detectors and 100-kiloton size liquid argon detectors. Each of these has its own special infrastructure requirements. The water Cherenkov detectors require very large cavities, the liquid scintillator detectors require special handling and ventilation for the volatile liquids and the liquid Ar detectors require special ventilation and possible isolation in the event of vaporization of the cryogenic liquid. In this proposal, we intend to investigate the experimental requirements for each of the proposed detector technologies and to specify the infrastructure that would be required to build and operate these detectors. In this way, the potential laboratory sites can specify how they would satisfy these requirements in their particular site.

5) Dark Matter

The discovery of dark matter is of fundamental importance to cosmology, astrophysics and high-energy particle physics. A broad range of observations from galaxies to superclusters and supernovae along with spectacular confirmation from the Wilkinson Microwave Anisotropy Probe of the cosmic microwave background radiation tell us that, in addition to a mysterious dark energy,nearly 90% of the matter in the universe is in some new form different from ordinary particles. So far, this matter has revealed itself only through gravity and is referred to as *dark matter* because it neither emits nor absorbs light. A leading hypothesis is that the dark matter is comprised of Weakly Interacting Massive Particles, or WIMPs, that were produced moments after the Big Bang from collisions of ordinary matter. If WIMPs are the dark matter, then their local density in our region of the Milky Way makes them detectable via scattering from atomic nuclei in a terrestrial detector. However, the interaction rate is already limited experimentally to be less than one event per day per 10 kg of detector, and the theory predicts rates as much as a thousand times lower, even for the most favored models. Detecting rates this low requires siting experiments very deep underground to shield them from the cosmic ray flux at the Earth's surface. Based on the progress of the current generation of few-kilogram-scale experiments, and the ton-scale experiments we envision they will grow to in the next decade, a new deeper site with the laboratory infrastructure and services afforded by DUSEL will be essential.

The theoretical and observational case for WIMP dark matter is extremely compelling, but the question of experimental confirmation remains open. The favored candidate for a WIMP is the so-called neutralino, the lightest neutral particle in supersymmetric extensions to the Standard Model of particle physics. The Standard Model is a powerful theory that describes the fundamental particles and forces but also appears arbitrary in several respects. Supersymmetry (SUSY) extends the Standard Model to address these shortcomings, and in doing so predicts the existence of particles that are the prime quarry of the largest experiments at Fermilab’s Tevatron and CERN’s Large Hadron Collider (LHC), and which are near-perfect WIMP candidates. The science case will be reviewed and updated in the S-1 study with regard to the latest evidence from telescopes, accelerators, and theoretical interpretations, as well as from ongoing WIMP searches. Significantly, we will address the question of how the experimental reach of anticipated searches at DUSEL compares with the expected reach of those elsewhere, and with the LHC, which begins its search for SUSY in 2007.

The most important question regarding WIMP searches is the DUSEL’s depth. Simply put, for future experiments extending the current sensitivity by at least two orders of magnitude, deeper is likely to be better because a thicker overburden better attenuates the cosmic ray muons that lead to a troublesome background of high-energy neutrons. Because both WIMPs and neutrons have the same signature—they both scatter from atomic nuclei—neutrons can fake a WIMP signal, if not efficiently vetoed. To fully understand the importance of depth for dark matter experiments, it is necessary to assess the likely reach of the experiments with regard to total exposure and other sources of background. It is these capabilities that define the level to which the neutron background should be reduced. Also, we should understand how difficult it is to detect efficiently inbound neutrons and veto them. Therefore, the study will review the trade-off of depth versus the complexity and reliability of external vetos, also keeping in view the appropriate long-term capabilities of the lab. Since the neutron background is common to all WIMP searches, the study will examine the opportunity of the WIMP experiments coexisting in a shared hall with a cavern-wide veto system. Other questions that the study will address include: the footprint, overhead space, and setup space required for the first round of experiments; expansion space leading up to a postdiscovery WIMP "telescope", for example, that could be based on a very large time-projection chamber; special needs or safety concerns, such as cryogens and flammables; requirements for material screening in a low-level counting facility; and a review of the detector R&D programs required to build these experiments.

The group will also attempt to identify other uses of underground space for cosmology and gravitational physics.

6) Nuclear Astrophysics and Underground Accelerators

One of the most important questions in nuclear astrophysics is the impact of low energy reaction processes on stellar evolution and stellar lifetime. Stellar model simulations rely on either purely theoretical reaction rates or the theoretical extrapolation of higher energy measurements for these underlying nuclear processes. With one exception, none of the nuclear reaction rates have been confirmed experimentally at the stellar energy conditions. These kinds of measurements are extremely difficult since they are handicapped by the extremely low cross section and the large cosmic ray induced background in the detectors. An underground low energy accelerator facility would provide the opportunity to study low energy reaction processes of relevance for stellar H and He burning.

A most striking recent example for the necessity and relevance for such measurements is the recent study of 14N(p,γ)15O which as the slowest reaction in the CNO cycles determines the lifetime of massive main sequence stars. While this reaction was thought to be reasonably well known in the past [Adelberger et al. 1998], a recent experimental study at the LUNA European underground accelerator in the Gran Sasso laboratory [Formicola et al. 2003] has revealed a significantly lower cross section than suspected in the beforehand not explored energy range. This result has significant impact not only for the life span of massive stars but also for interpretation of globular clusters and the age of the universe [Imbriani et al. 2004].

The uncertainties in the reaction rates impose limits on the validity of our solar model calculations through the uncertainties in the pp-chain reactions. It leaves open the interpretation of the CNO reactions for massive main sequence stars and its impact on later burning phases. It questions the basis of or description for the red giant and the asymptotic giant He and C burning phase, which are the sites for the s-process responsible for the origin of more than half of our known elements. It limits our interpretation and understanding of rapid convection processes that link the nucleosynthesis site deep inside the star with the stellar atmosphere where we can observe the freshly produced elements.

To solidify our models, our interpretations, and predictions of stars and stellar processes, we have to optimize the microscopic parameters for the nuclear engine of stars by minimizing the experimental uncertainties in the reaction rates. While proton induced reactions are targeted by the LUNA collaboration, α induced processes during stellar He and C burning would present the main challenge for a future U.S. underground accelerator facility. An underground facility would provide the opportunity to study stellar reactions at stellar energies by significant reduction of cosmic radiation background through passive shielding.

A working group on studying the possibilities for optimized design of an underground accelerator has been formed and a first workshop sponsored by the Joint Institute for Nuclear Astrophysics (JINA) has been quite successful in identifying the needs for the community (www.jinaweb.org/html/jinaworkshops.html#event3). Two options on accelerator design and needs are being debated—a high intensity light ion machine such as LUNA [Formicola 2003], or a high intensity low energy (·1 MeV/amu) heavy ion accelerator in ac-mode to provide better experimental conditions through inverse kinematics measurements. A detailed technical design and feasibility study in collaboration with accelerator physics groups will be necessary to evaluate the advantages and disadvantages for these two different approaches.

The second important aspect will be the development and planning on experimental detector equipment. This has to combine high efficiency with event identification ability to improve the background reduction conditions will be the development. LUNA experiments have shown that this capability was crucial in all experiments [Junker et al. 1998]. The working group will therefore focus on the development of low energy recoil separation techniques, 4π Si strip detector arrays (in close communication with RIA working groups) and of high energy γ-tracking techniques in collaboration with the GRETA group at Lawrence Berkeley National Laboratory.

7) Coupled Processes: Petrology, Hydrology and Geochemistry

DUSEL will provide an unprecedented opportunity to perform experiments at a wide range of spatial and temporal scales (potentially on the order of one kilometer over several decades) to evaluate the circulation of fluids and hydrological processes at depth in the Earth. This circulation is intimately linked, or "coupled," to thermal, mechanical, chemical, and biological processes in the rock mass that may have a substantial influence on the overall system response. Definition of the nature of the interactions will require extensive controlled testing.

The nature and magnitude of fluid flow and chemical transport in the crust change as the scale of observation increases. This requires geoscientists and engineers to study a complete rock mass from the micron, or even nanoscale, to the kilometer-scale. New techniques will need to be developed and tested to characterize and image the rock mass mechanical properties, hydrological properties, fluid flow paths, biological diversity, and the chemical heterogeneity of the rock-water-gas system.

The following examples illustrate typical science modules that could be developed in investigation of hydrology, coupled processes and geochemistry.

- Fluid flow and transport – meter to kilometer-scale volumes aimed at assessing the factors and processes critical to evaluating quantitative understanding of movement through fractures and rock masses at all scales. Evaluation of fracture roughness, aperture, and their response to changing stress regimes is critical for assessing flow and transport rates, and advancing current understanding regarding quantification of flow at various scales.
- Flow dynamics through and along fault zones – development of experiments at various scales aimed at assessing the nature and role of thrust faults and how they may influence flow and compartmentalize aquifer systems. Faults are ubiquitous in most crystalline and sedimentary rock environments and we must identify the role these features play in influencing flow and transport locally and at the basin scale. The nature of faults and their influence on flow and transport is dependent on lithology, structural history, diagenesis, mode of deformation, and fluid chemistry and temperatures.
- Hydrocarbon reservoir analysis – create a hydrocarbon reservoir in well-characterized rock in kilometer scale for the purpose of better understanding of transport and geophysical imaging from the surface and boreholes, particularly along the fringes of the reservoir where current imaging techniques are often inadequate. The reservoir can be "mined" to evaluate the success of various existing and new imaging techniques to identify the extent of hydrocarbon reservoirs.
- Biostimulation – Microorganisms are active in virtually all groundwater systems and are capable of catalyzing redox reactions between available chemical constituents in their environment. This involves shuttling electrons between electron donors and electron

acceptors with the transformation of the parent constituent and the generation of intermediate and final end-products. Development of controlled experiments using, for example, hydrocarbons as electron donors can help to better quantify how microbiologically mediated redox processes can control contaminant transport by varying the valence state of chemical constituents and thereby affecting a contaminant's reactivity, bioavailability, solubility, and mobility.

- Geochemical characterization of waters – The geochemistry of waters in rocks at depth is important to many aspects of understanding earth system evolution, microbiological evolution in extreme environments, and past climates, as well as being a key issue in studies of water quality, carbon sequestration, and groundwater remediation. The evolution of waters as they move from the surface and react with rocks is an important research area in geochemistry, but there are ongoing debates regarding the effective rates of such processes. DUSEL will allow for the characterization of waters over large spatial scales and how they change temporally in ways that have not been previously attempted. The geochemical characterization of waters at depth is problematic because surface-based boreholes usually modify the chemistry of water during drilling, and the natural heterogeneity in different flowpaths (e.g., fracture vs. the rock matrix) is difficult to assess. DUSEL will enable detailed characterization of the geochemistry and age of natural waters in different flowpaths at various depths, through sample collection during mining and by the use of shorter specially designed boreholes. It will be possible to test new in-situ methods of geochemical and isotopic analyses. In addition, the effects of mining-related activities on water geochemistry will also be monitored through geochemical and isotopic measurements, which will allow for predictive and comparative modeling of the response of geochemical systems to hydrological and rock mechanical perturbations.

Moreover, DUSEL provides interesting opportunities for investigation of a wide variety of petrological issues, including:

- Level and spatial heterogeneity of the radioactivity of host rocks enclosing physics experiments—essential data for knowledge of background radiation.
- Quantity, spatial variability, and anisotropy of heat production and thermal conductivity in the host rocks—information required for geophysical modeling of surface heat flow.
- Magnetic properties of the rocks and their spatial variability and anisotropy—data required for interpretation of surface anomalies.
- Strain distribution in deformed rocks—data required to delineate deformation processes.

8) Rock Mechanics and Geophysics

Geophysics, in general, involves the application of physical laws and principles to study of the Earth, and hence encompasses more specialized disciplines such as rock mechanics and tectonophysics. Our proposed study will focus on issues and problems where DUSEL offers special opportunities for scientific advance. In rock mechanics, for example, lack of understanding of how the strength of rock masses change as a function of scale, both in size and time (duration of loading), has been the central problem for over four decades, most frequently in connection with the design of underground excavations. As the size of a rock structure (excavation, foundation) is increased, the in-situ behavior of the rock becomes more and more dominated by joints and other large-scale discontinuities. Thus, if the rock-mass behavior is to be understood, it is essential to undertake large-scale tests in situ. The wide range of excavation size available at DUSEL, provides an exceptional opportunity to advance understanding on this critical problem.

The gravitational and tectonic forces acting on the rock at depth are partitioned between the "stresses" in the solid rock and the hydrostatic pressure of the fluid in the rock pores. Excavation changes the distribution of the solid forces and fluid pressures and introduces the rock to a changed chemical environment. Subtle chemical and biological changes at rock grain contacts ("stress corrosion"), both in the solid rock and at contacts within joints, weaken the mass progressively.[1] The so-called post-peak region, in which the rock mass strength begins to decrease as the rock starts to disintegrate and behave more and more as a "discontinuum," is of most concern. The concepts of continuum mechanics, "stress and strain," are invalid in this region.

The "failing" part of the rock mass structure is surrounded by the much larger region of rock that is responding elastically to the "natural forces." Energy released as the elastic region "unloads" with the collapse of the failing region may be greater than the failing region can accept. The excess energy is used to accelerate the failure process. Depending on the scale of the collapse, this may be manifested as an earthquake[2] or as a rock-burst. The loading rate may range from very high, as in blasting and nuclear explosions, to extremely low, as in the rheological deformation processes in plate tectonics.

The state of stress at depth is determined by the rheological response of the rock to plate deformations. Most in-situ stress information to date has been derived from tests in boreholes from the surface. DUSEL will provide a unique opportunity to examine the variation of stress over a large volume of rock in different formations, all in the same tectonic strain environment. This would add greatly to understanding of stress variation at depth. It should also be noted that the sites proposed to date for DUSEL cover a variety of tectonic environments that offer opportunities to address world-class problems in crustal evolution.

Isolation from surface background "noise" suggests that DUSEL would be a good location for a considerable number of sensitive detection systems, such as seismological arrays for detection of earthquakes and electromagnetic arrays for whole Earth signals. Surface-based geophysical surveys of underground formations and rock structure are used widely in exploration. Direct access to the underground at DUSEL will provide an opportunity to verify the accuracy of the identification of underground structures, as derived from the surface observations, and to examine ways to reduce inaccuracies.

Experimental study of the response of the rock mass to applied loads is complicated by the fact that rock is "opaque." Instruments installed to detect force and deformation distributions at specific points may be installed in the wrong locations, especially when investigating the heterogeneous post-peak deformation behavior of rock and fluid flow through fractured rock. A "view" of the deformation, and transport (both water and heat) over the entire volume of failing ground, is needed. Impressive progress in making the rock more transparent has already been made by using microseismic networks, tomography, and related techniques, but more can and should be done. DUSEL is the ideal laboratory to pursue these opportunities.

Considerable progress has been made in analytical and numerical procedures to describe the "mechanics of discontinua," but lack of field data is the major obstacle to further progress. DUSEL will provide an opportunity to overcome this barrier. DUSEL can also serve the mining and civil engineering industry as a "proving ground," allowing new technologies to be tried and tested before they are exposed to the vagaries and constraints of an industrial application**.**

DUSEL could also become a cornerstone component in the training of future generations of geoscientists. Simply by visiting or working underground, student geoscientists will have

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[1] The combination of increasing tectonic forces and stress corrosion on fault asperity contacts can give rise to earthquakes. Collapse of pillars in long-abandoned underground mines is a serious and worsening hazard worldwide.

[2] Although details differ, the overall process of time-dependent weakening of a joint is essentially similar to that described here for a rock mass. Earthquakes result from unstable energy releases due to dynamic slip on a fault.

achieved a much deeper appreciation of rock *in situ*, in all its complexity, than could ever have been accomplished through classroom lectures alone.

9) Applications

Availability of a deep underground laboratory dedicated to research in the basic and applied geosciences will attract considerable industrial interest. This is especially the case in the petroleum industry, which must rely heavily on surface interpretation to assess and control the dominantly underground procedures used in petroleum exploration and development. DUSEL would be an ideal site, for example, for study of the fundamental processes in hydraulic fracturing, and their control; direct observation of the vibratory motion of drill bits during cutting at the bottom of holes drilled from the surface; direct study (in porous–permeable formations) of the efficiency of secondary and tertiary recovery techniques. The proposal to store liquid CO_2 (carbon sequestration) in underground formations could also benefit from direct study underground-provided that the specific formations at DUSEL are amenable to such research.

Notes of other working groups suggest various research applications. Other applications will certainly be offered as more of the earth sciences community learns of the DUSEL proposal. The imaginative proposal to use vertical shafts at DUSEL for study of cloud physics is a good example of a topic that would not occur to the great majority of earth scientists. According to the authors of this proposal "The creation of a DUSEL would allow the construction of a cloud physics chamber within a vertical shaft that extends for hundreds of meters. Such a chamber would provide an environment where clouds could form naturally (on specified aerosol distributions) and be monitored over depths not achievable in normal laboratories. The ability to observe the vertical variation of cloud particles sizes and interactions over larger depths will give us the capacity to determine the details of this transformation to precipitation for the first time."

The following examples illustrate the wide variety of applications that have been suggested already for DUSEL: creation of artificial hydrocarbon accumulations or even artificial mineral deposits to study the geochemistry of these systems; low background counting facilities for homeland security applications; laboratories for biomedical studies involving radiological techniques; and underground manufacturing facilities to reduce the effect of cosmic radiation on the product.

Further discussion of the potential of DUSEL for advances in the earth sciences and engineering can be found in the EarthLab report [2003].

10) Geomicrobiology

The interactions between the biosphere and the lithosphere have been identified as a high priority for scientific research and training by several blue-ribbon panels (e.g., the American Academy of Microbiology [Nealson and Ghiorse 2001]). These interactions are critically important to understanding the Earth's subsurface, which represents the largest component volumetrically of the Earth's biosphere and possibly the majority of the Earth's biomass. The full extent, diversity, and metabolic potential of the deep biosphere remain largely unexplored. A major attraction of DUSEL for the study of subsurface geomicrobiology is the prospect of a dedicated research facility that offers continuous, long-term access to deep (> 2 km) subsurface environments. Previous studies of the subsurface have been limited to boreholes drilled from the surface, and sampling in deep mines. Boreholes yield limited sample-quantity and information, and they are limited by cost and technology to relatively shallow depths. Sampling in deep active mines is subject to the whims of the mining companies, and sample sites are compromised by mining and are available for only limited time. As described in the EarthLab report to the NSF [2003], the availability of deep subsurface sites in a government sponsored facility devoted to scientific research will enable interdisciplinary groups of scientists to answer fundamental questions regarding the limits of life in the biosphere, the functioning of deep earth ecosystems, and the potential for using deep subsurface microbes and their products to solve societal problems.

Major research questions that can be addressed at DUSEL include: (1) What are the limits of life with regard to depth, heat, pressure, and other parameters in the deep biosphere? (2) What are the sources of carbon and energy for microbes in the deep subsurface? (3) Are indigenous deep groundwater communities fueled by abiogenic energy sources (e.g., H_2) that are independent of surface ecosystem processes (e.g., photosynthesis)? (4) What adaptations do subsurface microorganisms have for nutrient acquisition, reproduction, macromolecular stability, survival, and repair under the extreme conditions of the deep subsurface? (5) What are the rates of evolution in hydrogeologically sequestered subsurface environments and what can be learned about microbial evolution from these microbes? (6) How do microorganisms influence the precipitation and dissolution of minerals? (7) What is the phylogenetic and metabolic diversity of microbes in the subsurface and what is the potential for exploiting these metabolic capabilities for useful purposes? (8) What are the long-term effects of human activities (e.g., mining, underground repositories, groundwater pollution) on the deep biosphere?

The Earthlab Report describes general types of experiments to be conducted in a deep underground facility like DUSEL. As for other proposed geological investigations, sites with varied lithologies and geochemistries will afford the greatest opportunities for testing deep biosphere hypotheses. One focus of study will be a series of deep boreholes originating at deep (2–2.5 km) underground sites and penetrating to depths where the ambient temperature exceeds 121°C, i.e., to the bottom of the biosphere. The boreholes will be cored, sampled, for groundwater, and instrumented for long-term study. The ideal site(s) for these experiments will be pristine, unmined rock having mineralogy and groundwater chemistry with potential for generating H_2 and other microbial energy sources. Sources of ancient groundwater (>1 Ma, preferably >100 Ma) will be especially useful for testing hypotheses about ancient life and survival adaptations. Geomicrobiological studies will begin with initial site characterization and will continue to exploit samples of opportunity as the facility is developed. Many of the geomicrobiological questions will be addressed in collaboration with other geoscientists, e.g., in coupled processes experiments carried out in intensely sampled, highly instrumented volumes of rock that are accessed from tunnels at multiple depths.

11) Microbial Biology and Evolution

The major reason for having a molecular biology and evolution working group is to extend the value of a deep underground laboratory to a broader biological research community than has so far been associated with subsurface bioscience. In doing so, we have considered the fields of *systems biology*—as applied to microorganisms functioning under very different constraints than typically investigated in this emerging field—*molecular evolution*, *ancient molecules,* and *advanced technologies,* for exploring this niche and the activity of sparse, often energy-limited populations. This working group is coordinated with, but extends from, the geomicrobiology group to build a subcellular and molecular-level understanding of deep-earth microbial populations. Geomicrobiologists have gained insights from exploratory investigations of boreholes and deep mines on how these populations function and how long they have been isolated from the surface, and have identified many microbes in these environments that are physiologically and phylogenetically distinct from surface environments. Undoubtedly, the deep terrestrial subsurface will continue to yield unique microbes and insights into the sources of energy and nutrients that provide for their continued existence.

The deep terrestrial subsurface is aphotic and the microbial inhabitants represent “dark life” functioning largely independent of sunlight and interactions with eukaryotes. They depend on energy and nutrients from kerogen (ancient organic matter), inorganic sources associated with the host rocks and associated fluids, and a range of other abiotic sources such as H_2 from radiolysis and hydrocarbon gases from crustal inorganic carbon sources. Microbial populations are typically characterized as being sparse, isolated in tiny pores, slow growing/respiring (i.e., long doubling times), and sometimes starved or resource-limited relative to their surface-dwelling counterparts and other times not. The deep earth, therefore, offers a wide variety of very unique environments for molecular biology studies because of the opportunity to access populations that have been isolated from the surface environment for quantifiably very long times (thousands to millions of years) and with different resource and population constraints. Hence they provide a particularly exciting opportunity for evolutionary studies.

Major research questions

We envision that a range of fundamental science inquiries could benefit from investigations of deep terrestrial subsurface microbial populations especially when dovetailed with fundamental geomicrobial investigations. For example, evolution-related questions could include: (1) Knowing how long subsurface organisms have been separated from surface ecosystems, can evolutionary rates be quantified? (2) Do subsurface microbes exhibit a genomic signature characteristic of small population sizes? (3) Is the mutational profile, inferred from sequence analyses, distinctive, reflecting expected differences in mutagenic processes? (4) Do subsurface microbes show much greater spatial structuring of populations and smaller genetic population sizes? (5) If so, how does this link to processes of genome evolution? (6) Are genomes reduced in size and “streamlined” relative to their surface counterparts? (7) Do the remaining genes evolve faster or more slowly than the surface counterparts? (8) What role do phage, lateral gene transfer and other evolutionary mechanisms play in evolution? (9) How has genome content evolved in the absence of host and higher cell densities? (10) Do subsurface microorganisms lack signaling genes, quorum sensing, and gene islands? (11) How have populations adapted to a very different stress regime, since some stresses are nonexistent such as UV and oxidative stresses, heat shock, day or seasonal cycles, but other stresses such as nutrient and energy deprivation or dehydration are expected to be intense and exposure to low levels of lithology-associated sources of radiation would be more or less continuous? The biological mechanisms required for performing the evolutionary adaptations for subsurface life are also expected to present surprises. For example, how do cells optimize their access to nutrient resources while avoiding pollution of their microenvironment, how to they coordinate their biochemical capacities to succeed, do they have special mechanisms to maintain their vital macromolecules and what physiological energy state do they maintain?

The deep biosphere likely harbors ancient biomolecules that can provide new insights into the early evolution of life and into organic biosignatures preserved in ancient rocks. In the marine realm the biogeochemical processes and the microbial ecosystem responsible for the processes evolved during the Precambrian from a methane and sulfide dominated environment to an oxygenated one with the advent of photosynthesis [Anbar 2002 #2]. This is arguably not the case of the anaerobic microbial environments deep in the crust. The geochemical processes operating in the crust have remained the same for billions of years and it’s likely that the biological interactions at work in the early Earth are still occurring today in the deep subsurface and may they manifest themselves in subtle molecular clues. For example, one particularly intriguing study identified a novel group I intron in a $tRNA^{Leu}$(UAA) gene of a *Proteobacteria* isolated from a deep terrestrial subsurface environment by Vepritskiy et al. [2002]. The authors speculated that the deep terrestrial subsurface might select for genome streamlining and harbor organisms with a higher probability than their surface counterparts of retaining genetic features associated with ancestor organisms.

The presence of subsurface microorganisms within rock has another implication with respect to the characterization of the early evolution of life. Organic geochemists have been recovering and characterizing biomarkers from early Precambrian sedimentary rock and interpreting these biomarkers as the remains of ancient life forms. It is entirely possible that some of the biomarkers may simply be the result of subsurface microorganisms inhabiting the rock quite recently and studies will be required to discriminate between ancient versus modern biomarkers present in rocks.

DUSEL could provide a unique opportunity for advanced technology that avoids contamination of samples (this would be of vital importance to future NASA planetary missions), for greatly improved geologic and chemical characterization of the terrestrial subsurface habitat and for detecting a greater breadth of biology, including novel prokaryotes as well as the viruses and lower eukaryotes. DUSEL would also enable a range of technical advances needed to study these populations at the cellular and molecular levels including genome sequencing of single cells, strategies for probing in situ physiology and electron flow, development of in situ chemostats or push-pull bead technology for in situ activity measures. An underground laboratory would also provide an unprecedented opportunity for obtaining samples of sufficient biomass for functional genomics investigations including gene expression and proteome analyses, and develop means to sort out different states in the live-dead continuum within populations as well as gene reporter systems for assaying in situ activity. DUSEL would offer a range of potential opportunities for a broad range of evolutionary, molecular and cell biologists interested in a new and unique type of local biological system and, especially for young scientists, could be a career opportunity. Depending upon the site selected for DUSEL the results of these studies would have general implications for the global subsurface biosphere.

12) Low Background Counting Facilities and Prototyping

Scientific case for LLCF in DUSEL

The Low Level Counting Facility (LLCF) is a critical and cross-cutting component of DUSEL that includes production measurement facilities and a modest amount of reconfigurable space for R&D in low background counting technology. Such a facility, linked with co-located underground fabrication capability, should provide materials and controls 1000-fold lower than a surface facility and an order of magnitude lower in contamination and at lower total cost than the partial and unorganized network of LLC technology available today. The current LLC technology was developed as an adjunct to the cutting edge underground experiments and is already insufficient for identified needs, especially access to HPGe gamma screening. Immediate improvement in the current infrastructure is necessary to ensure that the experiments being designed now for DUSEL have a location in which to test their prototypes and improved screening for their materials. This should be coordinated with the eventual LLCF designed for DUSEL.

The production measurement facility will be capable of performing radiometric materials screening (α, β, γ for solids, liquids, and gases) for all major DUSEL experiments, as well as functions of experiment calibration, quality control, DUSEL facility radiological control and a type of pure science measurement; scientists have identified potential uses such as ultrasensitive radiotracer detection for bio- and geoscience research and other critical environmental research. The LLCF may also provide first limits on physics processes, as happened in the case of the first double-β decay limits. Other users of the LLCF may include the national security research community.

Open science questions for the S-1 study:

The most important questions about the LLCF revolve around the suite of technologies required vs. those available. For instance, today there is no solution for ultralow background surface contamination analysis. Such contamination is frequently a beta-emitter and would require new technology to develop efficient low-background beta counting. This has an impact on dark matter and other low-energy experiments. A major question to answer will be the importance of screening as-built subassemblies; it is common to screen components such as bulk copper or resistors, but screening of as-built parts would be a major improvement in quality assurance, and would drive the inclusion of Central Test Facility–like gross counters with large part size capability. One suggestion for a wider application of LLCF has been the measurement of impurities in cryogenic materials used as shielding or active components of experiments, especially to nonradiometric measurements. This could be controversial, as some techniques for this may have no special benefit to being underground for this measurement. However, on-site capability would lower total experiment cost and could have broader application to earth sciences, such as dating the last surface contact of a ground water by β emitting cosmogenic isotopes. Another application question has arisen related to the use of the LLCF to advance diagnostic uses of low-level radioisotopes in medical science, achieving the diagnostic benefit with little or no biologically significant dose to the patient.

Open questions regarding infrastructure requirements

A complete analysis of screening type and throughput needed for proposed and possible DUSEL activities is required to determine the floor space, suppression of particulates and Rn, and other infrastructure requirements. LLCF will require clean air and because it may house some chemical sample preparation, it may require specialized exhaust air capability. In general, however, the LLCF will likely not require spectacular mining, power, or other development or operational support. Aside from common chemical hazards and moderate quantities of liquid N_2 for cooling Ge detectors, there should not be unusual hazards associated with the LLCF. Careful analysis and enumeration of currently known hazards, however, must establish whether this expectation is true.

Early identification of the DUSEL activities will allow for an LLCF plan that begins immediately, providing locations in which experiments can test prototypes and screen prototype materials in preparation for those DUSEL technology and science choices that cannot wait for the final facility to be in place. A first step in this process would be the establishment of an integrated database and scheduling tool that can provide users with detailed information on the availability and sensitivity of instrumentation at existing sites. This organizing entity can eventually become the scheduling arm of the DUSEL LLCF. It will also confirm the need for additional short-term facilities and optimize their configuration. Such a short-term facility could serve as R&D for the final LLCF at DUSEL, as well as reduce the throughput load on LLCF when the final facility is built.

13) Common Infrastructure , Laboratory Layout and Management

A. Infrastructure

Background

The Common Infrastructure and Laboratory Layout working groups were combined just prior to their meetings on Friday. The combined-group meeting was led by Lee Petersen, with assistance from Greg Hulne and Gene Sieve, and was attended by a mixed group of physicists, bioscientists, geoscientists and geoengineers. Several members of the site consultation group also participated.

Petersen, Hulne and Sieve first described typical DUSEL layouts, design rules-of-thumb and the design process, and attendees followed with a discussion of design process, possible compatibilities and incompatibilities, and timeline issues related to construction sequence, expansion and remodeling.

Design process

Determination of infrastructure requirements, modules, and generic laboratory characteristics follow naturally from the science and engineering research program. The principal steps in the process are:

- Collect technical requirements for the various scientific and engineering research to be conducted at DUSEL
- Identify primary technical requirements
- Identify technical requirement relationships
- Develop the relationship matrix
- Develop relationship diagrams indicating modules

The middle three steps link the technical requirement of the first step and the module development of the last step. Additional details can be found below.

Infrastructure requirement matrix

The infrastructure requirements and other design criteria for the various science and engineering components of the research program must be collected from the working groups and experiment developers. The following is a partial list of these requirements and design criteria:

- Occupancy
- Access from surface & from/to adjacent areas underground
- Depth / shielding
- Size / volume / shape of caverns
- Environment control
- Power, communications, lighting
- Special systems
- Containment
- Common / storing / staging / assembly / prototyping
- Rock environment

Some potential research areas have well-developed descriptions of specific experiments, while other research areas are still in the concept phase.

The infrastructure requirements and design criteria will be collected in a so-called infrastructure requirement matrix. A preliminary infrastructure requirement matrix is shown below. This matrix contains information about six possible solar ν experiments and three double β decay experiments (all information extracted from the Lead meeting white paper). While a single row and column matrix is probably inadequate for representing information about all

Experiment	Category	Depth / Shielding (mwe)	Space, area or volume (m^2 or m^3) l*w*h unless specified	Radon Background (mBq/m^3)	Hazardous Materials	Ventilation	Stable Temp. (A/C Reqd.)	Electrical Power (kW)	"Clean" Areas (class)	Special/Additional Facilities
MOON	Solar neutrino	>2500	11x8x6	10	Toxic, flammable liquids/cryogens			80	Yes	
LENS	Solar neutrino	>3800	16x16x16	1	Fammable scintillation			250	Yes	
HYBRID	Solar neutrino	7000	80x18x19	None	None			Modest	No	
HERON	Solar neutrino	4500	m radius, 20m high cy	None	Large volume cryogens			600 Peak, 125 Avg.	Yes	
CLEAN	Solar neutrino	4500	5m radius, 20m high c	None	Large volume			100 Avg.	Yes	
TPC	Solar neutrino	~2500	30x21x21	1	High pressure gas/cryogens			70 Avg.	No	
Majorana	Double beta decay		5x4x3 m^3 4x4x3 m^3	<1000000	Rn, acids & plating baths from Cu electroforming		Yes	10 to 25	Yes	UG Cu electroforming facility, UG Ge crystal growth & detector, machine shop, low level counting, Rn-free matl. Storage, DI water system
EXO	Double beta decay		5x5x5 m^3 5x4x3 m^3 4x4x3 m^3	<1000000	Large volume liquid xenon/cryogens, Rn		Yes	10 to 25	Yes	Xenon containment, cryogenic purification system, machine shop, low level counting, Rn-free matl. Storage, DI water system
MOON	Double beta decay		5x8x5 m^3 8x11x6 m^3	<1000000	Rn		Yes	10 to 25	Yes	Machine shop, low level counting, Rn-free matl. Storage, DI water system

research areas and all requirements, the example matrix illustrates the kind of information to be collected.

An important outcome of the Berkeley workshop was a clear understanding of the information verification needs. Previous efforts to summarize information for physics experiments have shown that much of the information received must be independently verified.

Module development

In this context, modules are groupings of experimental functions with common or at least compatible infrastructure requirements and design criteria. Some physics experiment commonalities are obvious (e.g., amount of shielding, radon control and clean conditions), but determining commonalities and incompatibilities across all science and engineering disciplines requires a structured approach. We propose four steps:

- Identify primary technical requirements. We anticipate that the infrastructure requirements matrices may contain more than 100 requirements and criteria. Hence, we must identify, for each research discipline, a short list (say ten items) of primary technical requirements. Such primary requirements would be essential to the experiment, and be difficult, costly or impossible to satisfy unless provided in modular fashion.
- Identify technical requirement relationships. In this step, we must integrate the individual top ten experiments into a list of more than ten and less than twenty DUSEL-wide requirements. This integration will require close cooperation between the scientific working groups, PIs and engineering team.
- Develop the relationship matrix. The relationship matrix is a graphical representation of the compatibilities and incompatibilities between experiments. Each experiment or other research endeavor is both a row and a column in the triangular relationship matrix, where each matrix entry indicates whether the experiments have a strong commonality, weak commonality, strong incompatibility, weak incompatibility or indifference.
- Develop relationship diagrams indicating modules. Once the relationship matrix is created, relationship diagrams indicating modules will be created.

Laboratory layout key points

The following key points were discussed by the working group attendees:

- Information verification. Previous efforts to summarize information for physics experiments have shown that much of the information received must be independently verified.
- Multiple vs. shared caverns. This discussion was about the advantages and disadvantages of a DUSEL with multiple single-purpose caverns (like SNOLAB and Kamoika) or shared-use caverns (like Gran Sasso). No consensus emerged from the discussion.
- Accelerator incompatibilities. The group consensus was that an accelerator was incompatible with many physics experiments.
- Cleanliness issues. This discussion was about how to provide clean research areas. Should most or all of the laboratory be clean (like SNOLAB and the current Cascades site layout) or should only limited portions of the laboratory be clean? No consensus emerged from the discussion.
- Earth sciences input necessary. The discussions clearly indicated that significant input from the earth science disciplines is necessary, in order to provide the desired research opportunities.
- 3D access for bioscience, geoscience and engineering. Discussions during this working group session and at other times during the workshop clearly indicated the need for 3D access for the nonphysics disciplines.
- Multiple depth. The group discussed the issues of providing experimental spaces at multiple depths at a single facility.

- Timeline.
- Site characterization/review process.

Surface facilities

The group brainstormed the necessary surface support facilities, producing the following list:

- Administrative offices and conference rooms
- Visitor center/classroom
- Assembly space
- Labs (chem, bio, rock)
- Materiall handling/storage
- Computer/data hubs
- Library/media center
- Lodging/housing
- Medical facility/clinic
- Mechanical/electrical rooms
- Utility connections
- Core storage
- Support equipment
- Rock disposal, etc.
- Ventilation plant
- Water treatment and circulation plant
- Transport (e.g., cage) and maintenance center.

Underground support services

The group brainstormed the necessary underground support facilities, producing the following list:

- Administrative offices
- Locker/breakroom/cafeteria
- Storage
- Computer/data hubs
- Classrooms
- Fab/machine shop
- Mechanical/electrical rooms
- Medical facility/clinic
- Refuge bays
- Observation gallery
- Labs
- Emergency evacuation facilities

B. Principles of Management

The management of the future underground laboratory facilities is site-dependent. A unique management structure can only be selected once the site or sites have been chosen. Yet some preferences already exist among prospective participating scientists and some principles can be established now.

Current consensus.

At the Berkeley workshop the attendees agreed on a management structure with certain definable characteristics:

- Scientists and engineers should manage the laboratory facilities. The contractor(s) operating the program should have strong ties to the scientific and engineering community.

- The laboratory facilities should be open. The facilities should be accessible to all the scientists and engineers authorized by the laboratory management. Certain pockets of the facilities may be areas of proprietary research or government classified research, perhaps related to homeland security. These isolated areas should not intrude upon the operations of other areas of the facilities nor should they restrict the accessibility for the scientists working there.
- The facilities should employ an in-house scientific and engineering staff. The staff participating in experiments would be a resource of advice to the management. The staff could be a cohesive force among all the experiments at the facilities by serving as a conduit of knowledge and experience from one experiment to another.
- Research and development of instruments should be an important function of the facilities. The in-house staff would serve as an essential element in the R&D program.
- The facilities should also employ a person trained in education and public outreach to coordinate E&O activities at the site with off-site investigators performing experiments on site.

Open questions.

The resolution of some of the remaining open questions depends upon the specific sites chosen, but many can be resolved before, irrespective of the sites. Some of the questions are listed below.

- As with most of the existing underground laboratories, the owner of the site and the operator of the laboratory are not the same. The interrelation between site owner and laboratory management are site dependent. Examples of functions for which one or both of these entities could be responsible are: the safety of personnel and equipment (including air and water treatment, fire safety and drills); the excavation of caves and drifts; maintenance of the structural integrity of excavations; drilling of boreholes and archiving of cores; and common services such as electricity, water, ventilation, communications; the operation and maintenance of the underground transport; the surface facilities and infrastructure. What are mechanisms for handling these shared responsibilities?
- There is a possibility of multiple sites, especially at the beginning of the program. Should there be central management—one laboratory that oversees the R&D and experimental program of a large coordinated program?
- Many underground experiments by U.S. participants are now performed abroad. How should these be handled in the context of a growing U.S. program? What mechanisms should be implemented for international cooperation?
- It is anticipated that the research underground will be funded by more than one federal agency and among several disciplinary units within those agencies. Defining the prospective scope of the experiments and R&D will aid the government to organize itself in support of this new, growing field of underground research.

Focus of the study.

The study will reach out to a broader community than the attendees of the Berkeley S-1 Workshop. Other workshops under this grant are anticipated. At these workshops the consensus of the entire community will be sought and the desired general characteristics of the facilities and their management will be defined.

Examples of management mechanisms will be examined in detail. The study will draw from the experience of existing underground sites and other large laboratories worldwide. The desirable staff requirements and the scope of the R&D at the facilities will be studied. The study will consider an evolving management with a changing organization as the activities change from construction project(s) to a large set of major ongoing experiments and development projects for future experiments. The study will also examine the nature of international cooperation and its progression as the research program matures.

14) Education and Outreach

Understanding our universe—the cosmos, our planet, and elementary components of matter—is of great importance to both scientists and the general populace. The public's fascination with and eagerness to learn more about natural phenomena offer DUSEL an exceptional opportunity to provide a unified program that integrates education and outreach (E&O) with the multidisciplinary research accomplished at the underground laboratory. This project has a great potential to educate and mentor the next generation of scientists and teachers and to expand the much-needed diversity in the workforce.

Activities and facilities for E&O should be incorporated into any DUSEL design. Both the final report of the International Workshop on Neutrinos and Subterranean Science [NeSS 2002] and the EarthLab Plan [2003] emphasize the unique opportunity a deep underground laboratory presents for developing and fostering an arena of accessible resources, in which educators, students, and the public can experience working-science facilities in ways that advance their knowledge and understanding of science and technology, and change their attitudes toward learning. Coordinated, funded education and outreach infrastructure and efforts from the start of the project are fundamental for the development of integrated programs.

Questions that need to be addressed are: (1) How should E&O be organized to reach local and national communities? (2) What are the strategies for workforce development, diversity and technology transfer? (3) What partners are committed to engage actively in education and outreach? (4) What is needed to bring people to the site? (5) How should local populations and underrepresented minorities be recruited into DUSEL science? (6) How should the underground facilities be made attractive and stimulating to cultivate and propagate fields of science? (7) How can tours and local housing be arranged for officials, media, participating research students and scientists? And, (8) how should E&O activities be designed so that they provide support in coordination, logistics, mentorship, and materials to students, scientists, and the community?

DUSEL will offer a truly remarkable 21st century multidisciplinary teaching, learning, and sharing community for students, teachers, scientists, officials, legislators and the public. Programs will include formal and informal education for K-12 and junior-college students, and career development for the teaching staff. Inreach and exchange activities for undergraduate and graduate students and scientists actively participating in the research will enhance multidisciplinary science and cultural exposure. DUSEL will aim to build educational partnerships with universities, minority-serving institutions, schools, industries, local populations, and other local and national organizations. Increasing diversity in the science and education arenas and improving public outreach should be critical goals for DUSEL. The possible location of the site(s) in less-developed parts of the country and/or close to Native American communities will likely enhance the impact of the E&O programs. Outreach to the public will integrate research and education through the use and development of digital media (website, virtual tours, operations and experimentations), visitor center or museum, and telecommunications to expand remote science education and joint science experiments.

Dedicated staff and representation on the lab's Project Advisory Committee will be necessary to support DUSEL as a multidisciplinary research and education facility and to provide evaluation and assessment of its E&O programs. Surface and underground facilities will be required. Such infrastructure may include a visitor center or museum, housing, laboratories, offices, classrooms, digital media, remote access, video-conferencing and underground tracking. Flexibility should be key in DUSEL design and operations to allow for E&O growth and future adjustments as DUSEL develops in decades to come.