

**A U.S. DEEP UNDERGROUND SCIENCE AND ENGINEERING LABORATORY
SCIENTIFIC OPPORTUNITIES AND TECHNICAL REQUIREMENTS**

Principal Investigator: Bernard Sadoulet

Professor of Physics, University of California at Berkeley
Director, UC Institute for Nuclear and Particle Astrophysics and Cosmology

Co-Investigators:

Eugene Beier, Professor of Physics, University of Pennsylvania
Charles Fairhurst, Professor of Civil Engineering, University of Minnesota
Tullis Onstott, Professor of Geosciences, Princeton University
Hamish Robertson, Professor of Physics, University of Washington
James Tiedje, Professor of Microbiology, Michigan State University

INTRODUCTION

This proposal is in response to the site-independent solicitation issued by the National Science Foundation (“Solicitation 1”) for an integrated study of a Deep Underground Science and Engineering Laboratory (DUSEL) at one or multiple sites. This is a community-wide and cross-disciplinary effort, independent of specific sites, to develop deep underground science and engineering program planning and technical requirements, as requested by NSF. The proposal is supported by all the eight potential sites, currently known to us (there might be more), and involves physics (nuclear physics, particle physics and astrophysics), earth sciences, biology, and engineering communities. If designed properly, DUSEL will not only offer exciting opportunities for physics but also for earth and biosciences and engineering communities with significant impact on resource development and environmental management.

The PI and co-PIs have taken the initiative to gather the community-wide support for the idea of writing a single, site-independent document that would represent the community viewpoints, map the scientific and engineering program enabled by DUSEL, and provide broadly accepted criteria for site and experiment selection. In the past few months, we have developed a framework, which includes all relevant scientific and engineering fields, involves scientists from broad institutional and geographical backgrounds, and ensures that the process is site independent and driven by rigorous scientific criteria. Before submitting the final proposal, a community-wide workshop was organized in August in Berkeley with three goals:

- To finalize the DUSEL proposal in a way that is fully representative of the community;
- To identify the missing pieces of the scientific arguments for a deep underground laboratory;
- To get a head start on technical requirements that will be useful for all site-specific proposals in the second NSF solicitation expected later this year (Solicitation 2).

The supplementary materials herewith include the workshop’s program, a list of participants, and the preliminary conclusions of the working groups specially organized for the workshop.

The outcome of the proposed six-month’s study will be a report of 50–60 pages, which will

- summarize the scientific, engineering and education opportunities offered by a U.S. DUSEL within the broader international context and over a 20-year life time;
- outline roadmaps toward the corresponding objectives, grouping generic experiments with similar infrastructure needs in cross-disciplinary modules; and
- describe the technical infrastructure requirements for the broad spectrum of deep underground science and engineering.

The report—similar in style to the “Quantum Universe” report [HEPAP 2004]—will be written for nonspecialists, program officers at the various federal funding agencies, and staffers in Congress, the Office of Management and Budget (OMB), and the Office of Science and Technology Policy (OSTP). It will be complemented by 600 pages of detailed technical background documents, which will be available on the Web. This study will consolidate the diverse perspectives of the scientific and engineering communities. As already partially demonstrated at the Berkeley workshop, this process will provide a synergistic link between the various scientific fields involved, build a consensus on roadmaps and priorities, and prepare grounds for the whole community involvement in the site, or combination of sites, chosen at the end of the selection process.

We will describe the methods that we plan to use to explore the science and engineering opportunities, and to define the technical requirements and evaluate the demand for a deep underground laboratory as a function of time and the management structure. We will finish by comments on broader impacts of the proposed activity. Note that for conciseness, we do not always add “engineering” after “science.” In this proposal, engineering is considered to be an integral part of physics, earth sciences, and biology.

1. EXPLORATION OF SCIENCE AND ENGINEERING OPPORTUNITIES

Although a large amount of material on scientific justification for DUSEL exists (see References), there is still a lot of work to be done on mapping the medium- and long-range programs of underground science and specifying the infrastructure requirements.

1.1. Scientific focus

A deep underground laboratory gives us an exceptional opportunity to find answers to fundamental questions about the dark side of the earth and the cosmos; for instance,

- What is the nature of dark matter and, possibly, of dark energy?
- What are the properties of neutrinos (vs)?
- What causes matter/antimatter asymmetry and the instability of matter?
- What are the characteristics of dark life and early cellular evolution?
- How are fluid, heat, chemical and biological transport and biogeochemical processes coupled to tectonic processes?
- How can we image the underground world to have total mastery of the rock?

These questions fall in at least four broad scientific and engineering fields

1.1.1. Physics and Astrophysics

Important discoveries can be made in experiments that aim to understand the nature of the nonluminous matter—the matter that dominates the universe, in experiments that measure the fundamental properties of neutrinos, or in an experiment that tries to determine whether stable matter actually decays very slowly, beyond the lifetime of the universe. Other experiments will equally impact astrophysics and, possibly, geophysics. Among those are experiments that determine neutrino luminosity of the sun; constrain the model of the earth’s core through measurement of geoneutrinos; measure the relic supernova ns to constrain the history of star formation in the universe; or detect neutrinos from any future supernovae to understand the dynamics of the gravitational collapse of a stellar core. A small particle accelerator in the underground laboratory will address important questions in nuclear astrophysics. We also envision a facility for prototyping advanced instrumentation for use in the underground laboratory and for measuring the trace radioactivity in detector materials.

1.1.2. Molecular, Evolutionary and Geo-microbiology

Dark life, microorganisms that live sheltered beneath the planet’s surface, may be the most abundant form of life on Earth and quite possibly the universe. Experiments performed underground will be able to determine how these microorganisms alter their rock environment to

survive, how they are able to migrate great distances through rock, and how they are able to evolve or adapt to slowly changing conditions. Because the biogeochemical processes in the deep subsurface have remained the same for billions of years, the key to understanding ancient cellular evolution may reside in the genetic expression of subsurface microbial ecosystems. The interactions of microorganisms with the geological environment also have practical applications, including the long-term sequestration of CO₂, containment of radioactive wastes and immobilization of toxic metal contaminants.

1.1.3. Earth Sciences

Understanding the mechanical, thermal, hydrological, chemical and biological processes operative in the deep subsurface, and the complex interactions between them, is the key to a better understanding of the evolution of the planet and how to live in harmony with it. The forces induced by tectonic plate motion, heat, and by gravity, carried in part by the solid skeletal structure of the rock and in part by the interstitial pore fluids, are distributed nonuniformly due to the heterogeneous structure of the rock mass. Changes in the solid/fluid force distribution can promote or inhibit earthquake slip. Fluids circulating through fractures in the rock and associated dissolution/precipitation processes can produce mineral deposits or transport groundwater contaminants.

The paucity of in situ experimental facilities to test the validity of numerical models severely limits the ability to predict the long-term isolation of hazardous materials. DUSEL would overcome this obstacle. DUSEL models and technical developments can then be tested through shorter-range studies in subsurface industrial or government sites, where access for research is more restricted. It is no exaggeration to say that development of the DUSEL will permit a quantum jump forward for earth sciences and engineering research, development, and technology transfer. Regardless of the site(s) selected for DUSEL, access to a large, 3D exposure of the crust will provide important opportunities to study geological history of tectonic, sedimentary, or igneous processes. DUSEL will be unprecedented, however, in that geological models based upon observations can be tested by further underground exploration. DUSEL will therefore be an interactive geological experiment, much like an active mine, but with very sophisticated scientific observations.

1.1.4. Engineering and Rock Mechanics

Traditionally associated with the extractive mineral industries, underground engineering is being applied increasingly to novel uses, (mitigation of adverse environmental consequences of surface-based industrial activities (e.g., underground location of sewage treatment plants; geological isolation of nuclear and hazardous waste; carbon sequestration; geothermal energy; etc).

Virtually all of the research envisaged for DUSEL requires access to the subsurface via underground excavations. The stability of these excavations depends on how the strength of the rock mass deteriorates over time as it is exposed to the chemical environment in the excavation. Lack of research on this central question forces current excavation support design procedures to rely heavily on empirical rules of dubious validity. The influence on the deformability and strength of the rock mass of systems of joints and other scale-dependent weakening elements, often water bearing, is the major unknown. The long-term availability at DUSEL of a dedicated research site and excavation of various sizes of cavities will provide an unprecedented opportunity to undertake the research needed to resolve this major issue.

Geophysical techniques that effectively render the rock mass “transparent” would be a major advance in observing directly the heterogeneous and discontinuous manner in which jointed and fractured rock masses deform and how fluids move through them. Novel imaging procedures offer considerable promise but further development is possible and needed. DUSEL would greatly accelerate progress towards this goal. Depending on the setting and layout of the

underground infrastructure, DUSEL may be able to accommodate seismological arrays to monitor earthquakes or electromagnetic arrays for whole earth signals. Studies of the interaction between the rheological properties of different rock formations and tectonic strain rates at depth can provide important insights into the distribution of stresses in rock, how underground observations compare with GPS surface data and how to accurately model large scale deformation.

Innovative proposals for research at DUSEL are being suggested and more are likely. It has been proposed, for instance, to conduct large-scale studies of cloud droplet and ice particle formation, growth, and interaction, in long vertical shafts at DUSEL.

1.2. Working groups

We have identified fourteen working groups and chosen two coordinators for each. All coordinators are well-known specialists in the considered disciplines:

- 1) **Low-Energy Neutrinos:** Tom Bowles (LANL) and Bruce Vogelaar (Virginia Tech)
The principal experiment in this area will be a measurement of the low energy pp ν s emitted by the Sun to measure the ν luminosity of the Sun. The group will also study measurements of geoneutrinos from the Earth's interior, of relic supernova ν s as a constraint on the history of star formation in the universe, and of contemporary supernovae to understand the dynamics of gravitational collapse of a stellar core.
- 2) **Neutrinoless Double Beta Decay:** John Wilkerson (U. of Washington) and Charles Prescott (SLAC)
Observation of neutrinoless double β decay would show that lepton number conservation is violated and that a matter particle, the ν , is its own antiparticle. If double beta decay occurs in nature, it is sensitive to a linear combination of neutrino masses, and can provide an important constraint on the absolute scale of neutrino masses.
- 3) **Long-Baseline Neutrino Experiments:** Milind Diwan (BNL) and Gina Rameika (Fermilab)
A long baseline ν experiment in the DUSEL era will measure the "small" mixing in the ν sector and could determine whether matter/antimatter symmetry is violated in the ν sector. A detector for this experiment could be made suitable for studying nucleon stability.
- 4) **Nucleon Decay/Atmospheric Neutrinos:** Hank Sobel (UC Irvine) and Chang-Kee Jung (Stony Brook)
Observation of nucleon decay would be an indication of important physics at energies well above those attainable with accelerators. A nucleon decay detector that is multipurpose would have sensitivity to some of the low energy neutrino physics studied by Working Group 1.
- 5) **Dark Matter:** Dan Akerib (Case Western Reserve U.) and Elena Aprile (Columbia U.)
This group will not only focus on the searches for dark matter but will attempt to identify other uses of underground space for cosmology and gravitational physics
- 6) **Nuclear Astrophysics and Underground Accelerators:** Michael Wiesher and Joachim Goerres (U. Notre Dame)
This group will study the potential for making important measurements for nuclear astrophysics that require a small particle accelerator and very low backgrounds. The measurements made will be applied to the understanding of nuclear reactions and other processes in stars.
- 7) **Coupled Processes:** Brian McPherson (New Mexico Tech), and Eric Sonnenthal (LBNL)
Building on our current understanding of petrology, hydrology, geochemistry and geomicrobiology, this group will focus on understanding the interactions that must be considered to explain many of the phenomena observed in geological processes.

- 8) Rock Mechanics/Seismology: Larry Costin (SNL), Paul Young (U. of Toronto)
This group will study how to integrate studies of rock deformation and stability and whole earth geophysical studies with the development of the DUSEL.
- 9) Applications: Francois Heuzé (LLNL), Jean-Claude Roegiers (U. Oklahoma)
Use of the subsurface includes many traditional (e.g. mineral extraction) and an increasing number of novel applications. This working group will examine opportunities for research in DUSEL to advance these uses.
- 10) Geomicrobiology: Tommy Phelps (ORNL), Tom Kieft (New Mexico Tech)
This group will investigate microbial community composition and dynamics, microbial physiologies and abiotic-biotic interactions, as well as pioneer the sampling strategies and insure contamination control.
- 11) Microbial Biology and Evolution: Jim Fredrickson (PNNL) and Nancy Moran (U. Arizona)
This group will focus on the fundamental questions involving molecular evolution, cellular and molecular biology, systems biology, and ancient molecules.
- 12) Low-Background Counting Facilities and Prototyping: Prisca Cushman (U. Minnesota) and Harry Miley (PNNL)
Many experiments that will be performed at DUSEL require materials with very low trace radioactivity. Assays of these materials and construction of prototype detectors can only be performed in an underground facility. The group will also explore other applications, such as earth sciences and national security.
- 13) Infrastructure requirements and management: Lee Petersen (CNA Engineers), Derek Ellsworth (Penn State U.), and David Berley (U. Maryland)
This group will define and analyze the infrastructure requirement matrices, paying attention to the commonality and differences between physics, earth science, biology and engineering and extract from these data the generic requirements for laboratory layouts underground and common infrastructure. A subgroup will deal with generic principles of management of the laboratory.
- 14) Education and Outreach: Willi Chinowski, (LBL) Susan Pfiffner (U. of Tennessee).
We have specifically chosen scientists to coordinate this working group, as we believe it important to involve scientists in the E&O effort from the beginning. The group will also enlist help of professional educators.

The charge of these working groups is to

- Summarize the scientific opportunities: What are the big questions that can be addressed by DUSEL in a unique way?
- Develop roadmaps establishing the likely evolution of the subfields and the succession of generic experiments or experimental/observational facilities. The working groups will obviously look into the results of previous workshops and reports and focus on missing components—important aspects not yet studied, points of disagreements, etc. Very likely, these will be the medium- and long-range projections.
- Participate in the definition of the infrastructure requirement matrices and fill them for each discipline.
- Work with other working groups to identify “modules” (set of generic experiments with similar or compatible infrastructure requirements).
- Identify within each discipline the most significant education and outreach opportunities.

It is clear that the work and needs of many working groups strongly overlap and that the groups will benefit from common meetings. For instance, the dark matter and neutrinoless double beta decay searches face very similar low radioactivity and neutron background issues,

and their infrastructure needs are substantially the same as those of some solar neutrino experiments studied by Group 1. It is likely that the long baseline neutrino program and the nucleon decay will share the same sets of very large detectors (megaton water Cherenkov and/or hundred-kiloton liquid argon). The design of these large detectors will most certainly attempt to allow their use for solar neutrino and neutrino from supernovae collapse. In the earth sciences arena, substantial overlap exists between coupled processes, rock mechanics and geomicrobiology. This list of working groups may be extended or modified according to needs, and a number of sub-groups will undoubtedly be spawned during the process.

1.3. Workshops

In order to bring together this large and cross-disciplinary community, we are proposing a series of workshops, in addition to the one held in Berkeley, August 11–14, 2004 (see Supplementary Material):

1.3.1. Earth science workshop in November 2004.

A consensus emerging at and after the Berkeley workshop has been that earth scientists need a workshop by themselves (to be financed in part by the use of the 90-day pre-award expenditure clause) as soon as this fall. The purpose of this workshop would be to start constructing scientific roadmaps for the deep underground earth science research and identify a series of generic experiments and experimental or observational facilities. Because of the DUSEL history, there has been less time for these discussions among scientists in the geology, biology, and engineering fields than in the physics/astrophysics community. Having a specialized workshop before the general meeting described below will help the earth science communities to find a common voice and better define their infrastructure needs.

1.3.2. General workshop in January 2005

Preliminary conclusions of the working groups will be presented at a workshop to be held at a central location, possibly Denver. We envision five focal points:

- Engaging a broad cross-section of biologists specialized in evolution, cellular and molecular biology, genomics, proteomics, and system biology;
- Aligning the conclusions of the working groups and amplifying common themes and synergies;
- Identifying cross-disciplinary modules, based on the roadmaps elaborated by the working groups and the corresponding infrastructure-requirement matrices
- Discussing generic laboratory infrastructure needs
- First look at the likely evolution of the demand for underground facilities

1.3.3. Conclusion workshop in March 2005, in the Washington DC area

This workshop will focus on the overall conclusions of the study and streamline the overall message—big questions, broad modules, priorities, generic needs for common infrastructure, and organization. We are considering organizing this workshop in College Park, MD, to allow the program officers from NSF and other federal agencies potentially involved easy access.

2. INFRASTRUCTURE NEEDS, MODULES, AND GENERIC LABORATORY CHARACTERISTICS

Determination of infrastructure requirements, modules, and generic laboratory characteristics follows 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 are the linkages between the technical requirement of the first step and the module development of the last step. Additional details may be found in Section 2.1 below.

In order to provide a strong evaluation of needs and requirements, we are proposing to involve as collaborators, engineers familiar with the technical details of underground laboratories, even though we will have to pay for their services. The engineering team, selected with the approval of the Site Consultation Group (see 4.2. below), will be led by Lee Petersen. As a member of Charles Nelson & Associates (CNA) Consulting Engineers, a well-known underground engineering firm, Mr. Petersen has a unique experience in the engineering of underground research laboratories. The consortium he has set up with Dale Holland of Dunham Associates Consulting Engineering and Greg Hulne of Miller Dunwiddie, Architects brings together a full range of expertise in civil engineering, mechanical/electrical engineering, and architecture needed to map the technical requirements for a deep underground science and engineering laboratory. Members of this team have a long history of collaboration with scientists. They have been active in the design of the presently operating laboratories at the Soudan and Sudbury mines and are contributing to the studies of the infrastructure for prospective underground sites—Icicle Creek, San Jacinto, and Kimballton. We believe that their personality and involvement in multiple studies guarantee their objectivity.

2.1. 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. Following is a partial list of these requirements and design criteria:

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

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 Req'd.)	Electrical Power (kW)	"Clean" Areas (class)	Special/Additional Facilities
MOON	Solar neutrino	>2500	11x8x6	10	Toxic, flammable liquids/cryogenics			80	Yes	
LENS	Solar neutrino	>3800	16x16x16	1	Flammable scintillation			250	Yes	
HYBRID	Solar neutrino	7000	80x18x19	None	None			Modest	No	
HERON	Solar neutrino	4500	m radius, 20m high cy	None	Large volume cryogenics			600 Peak, 125 Avg.	Yes	
CLEAN	Solar neutrino	4500	5m radius, 20m high cy	None	Large volume			100 Avg.	Yes	
TPC	Solar neutrino	~2500	30x21x21	1	High pressure gas/cryogenics			70 Avg.	No	
Majorana	Double beta decay		5x4x3 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
			4x4x3 m ³							
EXO	Double beta decay		5x5x5 m ³	<1000000	Large volume liquid xenon/cryogenics, Rn		Yes	10 to 25	Yes	Xenon containment, cryogenic purification system, machine shop, low level counting, Rn-free matl. Storage, DI water system
			5x4x3 m ³							
MOON	Double beta decay		4x4x3 m ³	<1000000	Rn		Yes	10 to 25	Yes	Machine shop, low level counting, Rn-free matl. Storage, DI water system
			5x8x5 m ³							
			8x11x6 m ³							

Some potential research areas have well-developed descriptions of specific experiments, while others 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 above.

This matrix contains information about six possible solar neutrino experiments and three double beta decay experiments (all information extracted from the Lead-workshop white paper [Lead, SD, 2001]). While a single row and column matrix is probably inadequate to represent information about all research areas and all requirements, the example matrix illustrates the kind of information that needs to be collected.

An important outcome of the Berkeley workshop was a clear understanding of the need to verify information. Previous experiences have shown that much of the information received must be independently verified. The CNA team will have a primary role in this verification.

2.2. The building of modules

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 envision four steps:

- Identify primary technical requirements. We anticipate that the infrastructure-requirement 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, essential to the experiment, would be difficult, costly or impossible to satisfy unless provided at the module level.
- Identify technical requirement relationships. In this step, we must integrate the individual experiment top-ten lists 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 are indifferent.
- Develop relationship diagrams indicating modules. Once the relationship matrix is created, relationship diagrams indicating modules will be created.

2.3. Generic laboratory characteristics

An important aspect of a site-independent study is the recognition that there is more than one optimal solution. Obvious differences in approaches include: vertical vs. horizontal access, a single site vs. several sites, small experiments only vs. small and large, construction as you go vs. generic halls. The choice is not within the scope of solicitation 1, but the study will list a few generic scenarios with a number of self-consistent design criteria; for example, access dimensions and weight-carrying capabilities, number of people to move in and out, access hours, control of electric noise, vibrations, dust, generic cost of maintenance, etc. We will look into existing facilities in the world for guidance on requirements for administrative and technical support, for example, or scientists attached to the site.

We will also define the precautions that need to be taken during the exploration and construction phases to guarantee that at least some parts of the laboratory remain virgin for biology studies. We will also identify the instrumentation required to maximize the scientific return of the excavation itself for rock mechanics and engineering.

2.4. Need for R&D, low background counting facilities and underground construction and prototyping space

The low background counting facility should be one of the first facilities established in DUSEL so that it can contribute to the development and instrumentation of the experiments that are limited by backgrounds from trace radioactivity. A plan must be developed that will allow an

early commissioning of this facility and a growth path to respond to the needs of experiments that will develop as DUSEL matures. The working group and construction experts will study the special requirements of this laboratory such as cleanliness, cryogenic capability, and chemical handling issues. It will also identify the facilities needed before DUSEL may be available, so that experiments can be ready when DUSEL starts.

2.5. Laboratory management

Finally, we propose to list a few characteristics of a management structure that are essential to ensure the optimal scientific output of the facilities, the handling of the multidisciplinary and international aspects, and the inclusion of education and outreach from the start of the program.

3. UNIQUENESS AND INTERNATIONAL CONTEXT

We believe that this study must establish the need for a U.S. national underground facility (or set of facilities) in the international context. We are planning to approach this complex issue in three different ways, providing data necessary to frame the decision of the funding agencies.

3.1. Unique Characteristics

What characteristics would make a U.S. national underground facility, or set of facilities, unique? A preliminary list compiled at the Berkeley workshop include:

- The greatest depth in the world (if indeed available) for ultra-low high-energy neutron background experiments and for long-duration biological studies of microorganisms at large depth
- An underground site combining a very large detector and a neutrino superbeam
- An unprecedented long-term access for deep-site earth science observations, experimentation, including the possibility of “mining back” to check *in situ* the information provided by imaging and other remote-sensing methods.
- The strategic advantage of a U.S. national site in terms of leadership in frontier science, scientist training in frontier fields, engineering innovations (particularly in underground engineering), and involvement of U.S. industry and homeland security.

This preliminary list will have to be critically reviewed and expanded during the course of the study.

3.2. Evolution of the demand

Our current study will establish a catalog of possible experiments and their likely time scale. We will ask the working groups to include financial, manpower, and timeline information in the generic infrastructure matrix—the projected cost, likely number of U.S. and foreign scientists involved, anticipated start-up date, duration.

Obviously, summing these requests will lead to an overestimate of the likely demand for an underground space, as a number of experiments currently considered will not be funded within a reasonable extrapolation of the funding and the number of scientists available, or the currently envisioned timescale may be overly optimistic. However, with the collected estimates of cost and people, we can recalculate the numbers to bring them within the bounds of the possible. We will also have to make provisions for unforeseeable future experiments in the long-term planning. In sum, this exercise will give us a handle of the likely evolution, with no doubt large error bars.

We will consult with the Particle Physics and Astrophysics Research Council (PPARC), which is conducting a similar study in the UK, and the directors of the National Gran Sasso (Italy) and Modane (France) laboratories.

3.3. International context

Once we know the likely demand, we will be able to estimate how this demand can be split between the various facilities worldwide. The first step is to summarize the capabilities of the existing facilities worldwide and their current extensions. We will then have to factor in the fact that second- and third-generation experiments are likely to be very international. For instance, it

is difficult to imagine more than one 1-ton ^{76}Ge double β experiment. Comparison with the international evolution of accelerator and large astrophysics experiments and large earth science projects will be used as a guide.

The combination of these three points—the uniqueness of a U.S. facility (or facilities), growing demand, and intellectual collaboration with the facilities worldwide—should present a strong argument to NSF for the establishment of a U.S. deep underground laboratory.

4. MANAGEMENT OF THE PROPOSED STUDY

A key question is how to guarantee that the NSF-granted six-month project (probably December 2004 through May 2005) will present a fair and unbiased science case that is acceptable to all the competing sites and all scientific fields but is not watered down to the lowest common denominator. The following is our plan of organization:

4.1. The PI team: the Science Executive Committee

We have formed a Science Executive Committee composed of the six principal investigators, who have widely recognized science credentials and community consensus-building experience. Collectively, they represent geographic and institutional diversity of the community involved and a broad cross-section of the scientific fields. After consultation with the EarthLab Steering Committee, we have decided to have two earth science representatives among the PIs: Charles Fairhurst for geology and related engineering applications; and Tullis Onstott for geomicrobiology, a flagship program for DUSEL. We have also involved a prestigious microbiologist James Tiedje, to stimulate the interest of the microbial, cellular, and molecular-evolution communities about the exciting opportunities offered by DUSEL.

It was generally felt that in order to gain full confidence from the community, the Science Executive Committee members should not be strongly associated with any site (i.e., they should not be members of a site-specific proposal team in the NSF competition #2) but be acceptable nonetheless to each of the site teams. The members of the committee will be responsible for the coordination of the project and for guaranteeing the excellence of the science and fairness of the process (with respect to the sites and the disciplines). As co-investigators, they will answer directly to NSF.

4.2. Working groups and working group coordinators

As described above, we are organizing a number of scientific working groups. Each working group will be led by two scientists (or engineers), recognized specialists in their field, who should complement each other as closely as possible in terms of technical requirements, institutions, geography, and site involvement. It is not essential that they be site-attachment free, but, as we are striving to have a balance that guarantees a site-independent report, that they be committed to objectivity. The coordinators will

- Lead the working-group activities between August 2004 and June 2005, communicating with all scientists involved in the group through emails, websites, and conference calls, and by organizing discussions at workshops.
- Inform all Solicitation 1 participants about conclusions, as they develop, and coordinate with the PIs by holding regular phone meetings.
- Coordinate the draft writing of the relevant segment of the final study report (typically three pages per discipline), including technical appendices (e.g., technical requirement matrices) and web-based reference materials (expected to be around 30 pages).
- Interact with the report-writing team (which will include scientists and a scientific communicator).
- Answer the questions raised during the NRC-style review of the final report.

Up to three delegates from each site team, including at least one physicist and an earth scientist, will form a Site Consultation Group. The group will give input and participate in

various stages of the process—choice/veto of the PI/coPIs, handling of different options, proposed scientific and priority choices, equal treatment of the sites, etc. The Site Consultation Group will have access to all information and will provide the PI team with their comments on the final report. (It also has had full access to and opportunity to comment on this proposal.) The Site Consultation Group does not, however, oversee the writing of any documents of the study, in particular those of science or facility requirements, lest the site-independent document appear to be unduly influenced. We do not want, though, to water down the final report, and the Solicitation 1 PIs should remain free to make any scientifically based recommendations, even if they may tilt the balance in the funding agencies' subsequent choices.

The current composition of the Site Consultation Group is as follows:

Cascades: Wick Haxton, John Wilkerson (U. of Washington), Phil Long (PNNL)

Henderson Mine: Chang-Kee Jung (SUNY Stony Brook), Mark Kuchta (Colorado School of Mines), and Bob Wilson (Colorado State U.)

Homestake: Kevin Lesko and Willi Chinowsky (LBNL/UCB)

Kimballton: R. Bruce Vogelaar, Bob Bodnar (Virginia Tech), and Tommy Phelps (ORNL)

San Jacinto: Hank Sobel and Bill Kropp (UC Irvine)

Soudan: Marvin L. Marshak and Earl A. Peterson (U. Minnesota)

Sudbury: Andrew Hime (LANL) and David Sinclair (Carleton U.)

WIPP: Roger Nelson and Lloyd Piper

4.3. Initiative Coordination Group

In a similar fashion, we propose to constitute an Initiative Coordination Group, with the national labs and other institutions, to help align the DUSEL study with major national initiatives, often supported by other federal agencies. Typical examples of potential initiatives that interact strongly with DUSEL include: long base neutrino supported by the Department of Energy (DOE), in which both Fermilab and Brookhaven National Laboratory are interested; the new “Secure Earth” initiative in which a rapidly growing number of national laboratories are involved; and low radioactive background counting, promoted by the Pacific Northwest National Laboratory. A number of the DOE labs have strong interest in underground science.

The goal of the Initiative Coordination Group, (acting also as consultative body), is to prevent negative interaction between DUSEL and these initiatives, and to point out possible biases in the study; that is, unsubstantiated statements, which appear to favor one institution, site, or one version of an initiative over another, without deep scientific reasons. We believe that this group will also have a powerful influence on making other federal agencies interested in the DUSEL initiative, which, under the directives of OSTP, is coordinated by NSF.

The group's currently participating institutions and corresponding representatives are:

BNL – Tom Kirk and Nicolas Samios;

Fermilab – Kenneth Stanfield and Hugh Montgomery; and

LBNL – G.S. Bodvarsson and James Symmons.

We are in the process of inviting LANL, ORNL, PNNL, and SLAC to participate in this group.

The Initiative Coordination Group will usually meet together with the Site Consultation Group and the PI team either in person or by telephone. However, the Site Consultation Group has asked for the option of meeting alone with the PIs to discuss, for example, unresolved matters of rivalry between the sites.

4.4. NRC-style final review

As a further guarantee of the objectivity of the final report, we intend to have an external review process in the style adopted by the National Research Council; that is, two months before the submission of the final document, the Science Executive Committee will ask a number of

referees to comment on a final draft, and the various working groups will be asked to respond to objections or modify their text according to the referees' recommendations.

4.5. Administrative management

The proposed grant will be administered by the Institute for Nuclear and Particle Astrophysics and Cosmology (INPAC), an official multicampus research unit of the University of California, headquartered in Berkeley and directed by Bernard Sadoulet. It will provide a convenient management location for the study and a small staff accustomed to contacts with other universities, consultant agreements and subcontracts, education and outreach events, workshop organization, and travel reimbursements.

We do not believe that this will prejudice the study in any way. INPAC researchers in the field of particle astrophysics are from the eight UC campuses and the three national laboratories managed by the University of California. These scientists have a diverse set of scientific interests and they are involved in at least five of the eight sites currently interested in the competition.

5. QUALIFICATION OF THE PRINCIPAL INVESTIGATORS AND RESULTS OF PREVIOUS SUPPORT

Eugene W. Beier served for nine years as the principal investigator of a ten faculty–member grant from the Department of Energy. For the past fourteen years he has been co-spokesperson (with Hamish Robertson) of the United States scientists participating in the Sudbury Neutrino Observatory project. He has been Chair of the American Physical Society's Division of Particles and Fields, as well as a member of the DOE/NSF High Energy Physics Advisory Panel (HEPAP), Particle Physics Project Prioritization Panel (P5), the Scientific Assessment Group for Non-Accelerator Physics (SAGENAP), the International Committee on Future Accelerators (ICFA), and a number of National Research Council panels and sub-panels.

Charles Fairhurst has expertise in rock mechanics, mining engineering and underground construction, and design of high level nuclear waste repositories. He has been a major leader in developing the field of rock mechanics, having introduced the first formal graduate-degree program in rock mechanics in the U.S. in 1958, at the University of Minnesota. He served as President of the International Society for Rock Mechanics from 1991-1995 and was founder-President of the American Underground-Space Association (AUA), now the U.S. representative in the International Tunnelling Association. He founded the interdisciplinary Underground Space Center at the University of Minnesota in 1976 to examine scientific, technical, social and psychological aspects of underground space use and occupancy. In 1982, he founded Itasca Consulting Group Inc, which is now the international leader in numerical modeling codes for geo-mechanics. He is a member of the U.S. National Academy of Engineering and the Royal Swedish Academy of Engineering Sciences.

T.C. Onstott has spent the past 10 years focusing on subsurface biogeochemical processes, initially as a scientific investigator in DOE's Subsurface Science Program. For the past 6 years he has lead an NSF/NASA supported multi-institutional investigation into deep subsurface microbiology utilizing the ultradeep gold mines of South Africa. Simultaneously, he established a DOE supported multi-institutional field site for bacterial transport and biostimulation within an aerobic and anaerobic shallow aquifer. He currently is co-lead investigator of the NASA supported astrobiology center investigating permafrost/subpermafrost microbial processes in an Arctic gold mine.

Hamish Robertson is the Scientific Director of the Center for Experimental Nuclear Physics and Astrophysics at the University of Washington. He is co-spokesperson (with Eugene Beier) of the United States scientists participating in the Sudbury Neutrino Observatory project and was Scientific Director of the project during 2003–2004. He has been Chair of the American Physical Society's Division of Nuclear Physics, as well as Chair of the DOE Nuclear Science Advisory Committee (NSAC), a member of the Scientific Assessment Group for Non-Accelerator Physics

(SAGENAP), and a member of a number of National Research Council panels. Dr. Robertson is a member of the National Academy of Science and a Fellow of the American Academy of Arts and Sciences.

Bernard Sadoulet works at the interface between cosmology and particle physics. In the last 20 years, he has focused on the search for Weakly Interactive Massive Particles (WIMPs), which may constitute the dark matter in the universe, and on the development of the novel low-temperature detection technologies needed for this task. He is the spokesperson of the NSF/DOE Cryogenic Dark Matter Search (CDMS) experiment, which is currently running in the Soudan mine and has recently published the best WIMP limit in the world (by a factor of 4). He was the director of one of the first generation NSF Science and Technology Centers—the Center for Particle Astrophysics—which had a profound impact on the measurement of the cosmic microwave background, the detection of dark energy and the search for WIMPs. He has served on numerous NRC committees dealing with particle astrophysics (most recently, on the Turner Committee), the Scientific Assessment Group for Non-Accelerator Physics (SAGENAP), and on the Scientific Committee of the Gran Sasso underground laboratory in Italy. He was a member of the Bahcall Committee on Underground Science.

James Tiedje has expertise in microbiology, especially in diversity, phylogeny, genomics and physiology. He has been a major leader in developing the field of microbial ecology, served as the first President of the International Society for Microbial Ecology, is the current President of the American Society for Microbiology, and serves on the NRC Board on Life Sciences. He has developed and still leads the multidisciplinary Center for Microbial Ecology, one of the original NSF Science and Technology Centers. This center shaped the field of microbial community dynamics, arguably lead the field of experimental evolution, automated and advanced the ribosomal database, the world's major tool for microbial phylogeny and identification, and, on the application side, provided the pace-setting field tests of bioaugmentation for clean-up of solvent contaminated aquifers. Relevant to the DUSEL project, he co-leads a joint project with a multidisciplinary U.S.-Russian team to explore the genomic basis of microbial adaptation to life in ancient Siberian permafrost.

6. BROADER IMPACTS

This six-month study will have broader impacts than just the study of the characteristics needed by an underground laboratory. It will broadly advertise the unique opportunities of DUSEL. Ten abstracts have been submitted to the American Geophysical Union (AGU) December meeting. A DUSEL session will take place at the American Physical Society April meeting. We are requesting sessions at the spring meetings of AGU and the American Society of Microbiology. The study will also connect naturally with the underground science workshop organized at the Institute of Nuclear Theory in June and July 2005.

6.1. Multidisciplinary Science

Building on the first contacts of NeSS 2002, the Berkeley workshop continued to demonstrate the intense intellectual vitality of scientists from different fields gathered around the same project. The study provides an exciting opportunity for the physics, earth, and biological science communities to explore new interfaces.

This is particularly true in biology. Going beyond the small group of geomicrobiologists, whose pioneering work revealed that the subsurface is alive and with sometimes novel microbes, we will involve a much broader biology community with expertise in evolution, cell and molecular biology, genomics and proteomics, and systems biology. It is not often that biologists get to explore new frontiers in the field. DUSEL can provide such an opportunity and engage many disciplines of contemporary biology to probe the new ways these unique populations have succeeded. Equally important are the expected interactions among the various earth scientists

and biologists. The understanding of the subsurface ecosystem is a result of the interplay of conditions, chemistries, and catalysts. The study will inspire new introductions among scientists around a new knowledge frontier, and will lead to new collaborations and insights.

6.2. Involvement of private industry and other sectors

Major opportunities exist for industry participation (worldwide) in DUSEL. Thus, the ability to have simultaneous surface and a large underground volume access offers unprecedented opportunity for improvement of petroleum technology, both in exploration and in production. Although sedimentary rock formations will be more favorable for some applications, there are many opportunities in other rock types, e.g., correlation of underground observation of hydraulic fracture propagation, using acoustic emission sensors, with surface tiltmeter measurements. Directional-drilling control techniques could be perfected; drill-bit induced vibrations could be studied directly at depth using surface drill rigs. The National Institute for Occupational Safety and Health (NIOSH), responsible for health and safety mines, would have opportunities not currently available to it. The Department of Energy OCRWM (Office of Radioactive Waste Management) could find DUSEL more convenient for R&D studies (e.g., drift degradation research) during the next two decades or so, when activities at Yucca Mountain focus on repository construction. Excavation equipment manufacturers could use DUSEL for equipment research. The Department of Defense is interested in underground excavation studies for a variety of purposes. Homeland Security would also be interested in the attributes of underground excavations for a number of applications. DUSEL will be an internationally unique facility and is likely to draw research interest from a wide community of potential users.

6.3. Education and outreach

The Berkeley workshop demonstrated a broad consensus among physicists, earth scientists and engineers that education and outreach (E&O) should be incorporated from the start in the design, construction and operation of the Deep Underground Science and Engineering Laboratory. The fascination with our universe—the cosmos, our planet, life, and elementary components of matter—offer DUSEL an exceptional opportunity to provide a unified program that integrates education and outreach (E&O) with the multidisciplinary research accomplished underground. As already emphasized in both the final report of the International Workshop on Neutrinos and Subterranean Science [NeSS 2002] and the EarthLab Plan [2003], DUSEL will give educators, students, and the public the opportunity to experience working science-facilities in ways that advance their knowledge and understanding of science and technology, and change their attitudes toward learning. DUSEL has, therefore, great potential to educate and mentor the next generation of scientists and teachers from diverse backgrounds.

Our study will address the following questions: (1) How should E&O be organized to reach local and national communities? (2) What are the challenges for DUSEL to effectively contribute to workforce and diversity development? (3) How do we identify and commit local and national partners to engage actively in education and outreach? (4) How should local populations and underrepresented minorities be recruited into DUSEL science? (5) What kind of infrastructure is needed to bring people to the site, and the site to the public? (6) How should the underground facilities be made attractive and stimulating? (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 thus provide an opportunity for the scientific and engineering community working alongside education specialists to build a solid and lively E&O program. It will deepen our understanding of how to articulate such program in the broader efforts to improve our education system and general understanding of science, and how to develop more effectively a larger and more diverse workforce.

We also propose to experiment during this study with teleconferenced cross-disciplinary, multi-institutional seminar for graduate students and postdocs. We are planning a deep science and engineering lecture series at UCB in spring 2005, fully webcast and with internet-based multi-way teleconferencing capabilities. Our goal is to broaden the education of next-generation underground scientists and engineers and enhance interactions between physicists and earth scientists. This could be a prototype of DUSEL contribution to graduate education.

6.4. Involvement of local institutions and communities

The success of DUSEL will depend on the partnerships built with the local institutions, schools, industries and community organizations. These partnerships will not only advance the construction of the laboratory, but also contribute to the economy of and science education in the local communities.

The opportunities are particularly rich in the education area. 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. In any case, DUSEL should fully involve local minority serving institutions.

7. CONCLUSIONS

At the end of this complex process, we will attempt to deliver a fairly simple message. We will try to identify the “big scientific questions” along the provisional theme of “illuminating the dark side of the earth and the cosmos.” We will define the scientific activities at the underground frontier—the most sensitive detectors searching for the most feeble signals from matter and the universe, the deepest observatory of the earth crust and of the dark life it contains, the most flexible “sand box” to gain mastery of the rock. We will characterize the likely impact of the DUSEL enterprise on society; for example, the training of the next generations of scientists and engineers, the strategic importance of a U.S. DUSEL, and the opportunities for international partnerships.

We will also strive to come up with a simple set of benchmarks and recommendations along the following lines (yet to be critically reviewed):

- Unique characteristics for a DUSEL site or set of sites
- Flexibility/evolution/expansion
- Multidisciplinary science and organization
- Need for R&D and prototyping (pre-DUSEL, at DUSEL)
- Control of laboratory management by the scientists—unrestricted access for non-U.S. nationals
- NSF leadership, multiple-agency involvement
- Single site or multiple sites under the same management umbrella
- Education and outreach included from the start
- Partnership with local community/institutions (and minority-serving schools)
- International coordination

Our goal is to define a viable path that does not bog down the process in overcomplex requirements, which would make establishing DUSEL an administrative nightmare or a too expensive proposition. It is in this context that we stress the importance of defining modules, sketched to show how a phased development could take place, and identify, when possible, an initial suite of generic experiments.

Finally, we see this study as a partnership between the scientific community and NSF, where we try to develop together the right concepts for the underground adventure.

SUPPLEMENTARY MATERIAL

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

Table of content

- A. Berkeley workshop program, p. 1–2
- B. Berkeley workshop list of participants, p. 3–5
- C. Contributions from the working groups, p. 6–26

A. PROGRAM

Wednesday	11	August	
8:30	8:40	Welcome	B. Sadoulet
8:40	9:40	Neutrinos	S. Freedman
9:40	10:40	Geology/Engineering	D. Ellsworth
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	
		technical requirement matrix/modules/central facilities/edu	
12:30	13:45	Lunch	
13:45	15:45	Working groups 1	
		Solar Neutrinos	
		Neutrinoless double beta	
		Long Baseline Neutrinos	
		Hydrology	
		Rock mechanics	
		Biogeology methods	
15:45	16:15	Break	
16:15	18:15	Working groups 1	
20:30	22:00	Miscellaneous groups	
		Solicitation 1 proposal	B. Sadoulet
Thursday	12	August	
8:30	8:45	Solicitation 1	B. Sadoulet
8:45	9:30	GeoBiology	T. Phelps
9:30	10:15	Proton decay	H. Sobel
10:15	10:45	Break	
10:45	11:30	Dark Matter and Astrophysics	D. Akerib
11:30	12:30	Reports Working groups	
		10 minutes/working group	
12:30	13:45	Lunch	
13:45	15:15	Working groups 2	
		Proton Decay/atmosph. Neut	
		Dark Matter	

		Geochemistry	
		Micr/Molecular Biology	
		Applications	
15:15	15:45	Break	
15:45	17:00	Working groups 2	
17:00	18:30	Miscellaneous groups	
		Education	Chinowsky/Pfiffner
		Working group coordinators	Sadoulet
		determinig modules	
Friday	13	August	
8:30	10:00	Reports Working groups	
		10 minutes/working group	
10:00	10:15	Modules organization	
10:15	10:45	Break	
10:45	12:30	Module working groups	
		Deep/low background	Akerib
		Large/relatively shallow	Kropp
		Earth science dedicated	Sonnethal
12:30	13:45	Lunch	
13:45	14:45	Reports Working groups	
		10 minutes/working group	
14:45	15:45	Facilities Working groups	
		Lab Layout	Petersen
		Support/ Surface facilities	Hulme/Sieve
		Management	Berley
		Demand and international	Sadoulet
15:45	16:15	Break	
16:15	17:15	Facilities Working groups	
17:15	18:15	Reports Working groups	
		10 minutes/working group	
19:00	22:30	Banquet	
Saturday	14	August	
8:30	9:15	Conclusions/Physics	E. Beier
9:15	10:00	Conclusions/Geo/bio/Eng	Ch. Fairhurst
10:00	10:15	Break	
10:15	11:00	Conclusions Solicitation 1	B. Sadoulet

B. LIST OF PARTICIPANTS (105)

FIRST NAME	LAST NAME	INSTITUTION
Daniel	Akerib	CWRU
Elizabeth	Arscott	UC Berkeley
Laura	Baudis	UFlorida
Dennis	Bazylinski	Iowa State Univ
Eugene	Beier	Univ. Pennsylvania
David	Berley	University of Maryland
Fred	Bernthal	Universities Research Asso.
Mary	Bishai	Brookhaven Nat'l Lab.
Robert J.	Bodnar	Virginia Tech
Bo	Bodvarsson	LBNL
Corale L.	Brierley	Brierley Consultancy LLC
Paul	Brink	Stanford University
William	Bugg	University of Tennessee
Thomas J.	Burbey	Virginia Tech
Frank	Calaprice	Princeton University
Melissa	Campbell	SD Sch of Mines & Tech
Thomas	Campbell	SD Sch of Mines & Tech
Yuen-Dat	Chan	LBNL
William	Chinowsky	UCB/LBNL
Ken	Chow	LBNL
Patrick	Chuang	Univ. Calif. Santa Cruz
David	Cline	UCLA, Physics & Ast.
Mark	Conrad	LBNL
Miguel	Daal	UC Berkeley
Syd	De Vries	Dynatec Mining Corp.
Miland	Diwan	BNL
Thomas	Doe	Golder Associates
David M.	Doolin	Tinobox LLC
Derek	Ellsworth	Pennsylvania State Univ.
Charles	Fairhurst	University of Minnesota
Jeff	Filipini	UC Berkeley
Prof. Frederick A.	Frey	Mass. Inst. Technology
S.	Friedman	UCB/LBNL
Maochen	Ge	Pennsylvania State Uni.
Donald W.	Gentry	PolyMet Mining Corp.
Leslie	Gertsch	U. Missouri-Rolla
Jordan	Goodman	University of Maryland
Richard J.	Gowen	SD Sci & Tech. Auth
Bezalel	Haimson	University of Wisconsin
Robert	Hatcher	U. Tennessee-Knoxville

Wick	Haxton	INT, Univ. Wash.
Terry C.	Hazen	LBNL
John	Helsdon	S.D. Sch. Mines & Techn.
Reyco	Henning	LBNL
Andrew	Hime	Los Alamos Nati'l Lab
Gregory	Hulne	Miller Dunwiddie Architects
Dr. P.	Ila	Mass. Inst. Technology
Matthias	Imhof	Virginia Tech
Chang Kee	Jung	SUNY Stonybrook
Thomas L.	Kieft	New Mexico Inst. Min&Tec
Thomas B. W.	Kirk	Brookhaven Nat'l Lab
Richard	Kroeger	Naval Research Laboratory
William	Kropp	UC Irvine
Mark	Kuchta	Colorado School of Mines
Kenneth	Lande	University of Pennsylvania
Robert	Lanou	Brown University
Christopher	Laughton	Fermi Nat'l Accel. Lab
Kevin T.	Lesko	LBNL
Philip	Long	Pacific Northwest Nat'l Lab
Al	Lu	UC Berkeley
Ernie	Majer	LBNL
Alfred K.	Mann	Univ. Pennsylvania
Marvin	Marshak	University of Minnesota
C.J.	Martoff	Temple University
Gordon	Matheson	Virginia Tech
Matthew	Mauldon	Virginia Tech
Dan	McKinsey	Yale University
Douglas	Michael	Caltech
Harry	Miley	Pacific Northwest Nat'l Lab.
Larry	Murdoch	Clemson University
Misac	Nabighian	Colorado School of Mines
Uriel	Nauenberg	University of Colorado
Bill	Noordermeer	Office of SD State Engr.
Ugur	Ozbay	Colorado School of Mines
D. Lee	Petersen	CNA Consulting Engineers
Earl	Peterson	University of Minnesota
Susan	Pfiffner	University of Tennessee
Tommy J.	Phelps	Oak Ridge Nat'l Lab
Alan	Poon	LBNL
Raju	Raghavan	Virginia Tech
Regina	Rameika	Fermi Nati'l Accelerator Lab
William M.	Roggenthen	SD Sch. Of Mines
Jamison	Rounds	State of South Dakota
Bernard	Sadoulet	UC Berkeley

Rohit	Salve	LBL
Gail	Schmidt	SAIC
Kate	Scholberg	Duke University/MIT
Benjamin C.	Shen	Univ. Calif. Riverside
Tom	Shutt	Princeton University
Gene	Sieve	Dunham Assoc. Con. Eng.
David	Sinclair	Carleton University, SNOLAB
Hank	Sobel	UC Irvine
Abner	Soffer	Colorado State University
Eric	Sonnenthal	LBL
Kyle	Sundqvist	UC Berkeley
James	Symons	LBL-NSD
Walter	Toki	Colorado State University
Roger	Turpening	Michigan Tech. Univ.
R. Bruce	Vogelaar	Virginia Tech
Joe	Wang	LBL
Herb	Wang	U. Wisconsin-Madison
Chester (Skip)	Watts	Radford University
Erik	Westman	Virginia Tech
John	Wilkerson	Univ. Washington
Paul A.	Witherspoon	LBL

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, ${}^7\text{Be}$ and CNO reactions that account for $\sim 99.5\%$ 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: $L_\nu(\text{inferred from experiment})/L_\gamma = 1.4^{+0.2}_{-0.3}(1\sigma)^{+0.7}_{-0.6}(3\sigma)$. Thus, at 3σ , 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_ν predates the present epoch by $\sim 40,000$ 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_e 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 ν s and CPT validity as well as setting tight limits on the ν mixing parameters θ_{12} and θ_{13} . The unique role of precision ($\sim 3\%$) pp (and ${}^7\text{Be}$) 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 ν s 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 ν s 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 ν s 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 ν s produced in the Sun and in the Earth's atmosphere and have shown that ν s 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} eV² and 10^{-3} eV², respectively and two mixing angles θ_{12} and θ_{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 θ_{13} , CP violating phase δ_{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 ν s 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 ν s, proton decay and super nova ν s. 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 cryogenics 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 $^{14}\text{N}(p,\gamma)^{15}\text{O}$ 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 earthquake² 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

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 CO₂ (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., H₂) 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 H₂ 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 H₂ 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 do 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 N₂ 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/cryogenics			80	Yes	
LENS	Solar neutrino	>3800	16x16x16	1	Flammable scintillation			250	Yes	
HYBRID	Solar neutrino	7000	80x18x19	None				Modest	No	
HERON	Solar neutrino	4500	m radius, 20m high cy	None	Large volume cryogenics			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/cryogenics			70 Avg.	No	
Majorana	Double beta decay		5x4x3 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
			4x4x3 m ³							
EXO	Double beta decay		5x5x5 m ³	<1000000	Large volume liquid xenon/cryogenics, Rn		Yes	10 to 25	Yes	Xenon containment, cryogenic purification system, machine shop, low level counting, Rn-free matl. Storage, DI water system
			5x4x3 m ³							
			4x4x3 m ³							
MOON	Double beta decay		5x8x5 m ³	<1000000	Rn		Yes	10 to 25	Yes	Machine shop, low level counting, Rn-free matl. Storage, DI water system
			8x11x6 m ³							

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 Kamohika) 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)
- Material 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.