Deep Underground Science and Engineering Laboratory
Site Independent Study

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1. Introduction: the goals and status of DUSEL Solicitation 1.

1.1. The Solicitation 1 process.

When the National Science Foundation (NSF) put a new process in place for the development of a Deep Underground Science and Engineering Laboratory (DUSEL) in March 2004, it called for a *community-wide, site-independent* study to establish a cross-disciplinary scientific roadmap for such a facility and identify the generic infrastructure requirements. This "Solicitation 1" (S1) activity was approved by NSF in January 2005, and is organized as follows:

- The six S1 PIs listed above are responsible for the study, in particular its scientific quality and objectivity (and are responsible for this status report).
- Three workshops have already taken place: Berkeley (Aug 04), Blacksburg (Earth Sciences, Nov 04), Boulder (Jan 05). These workshops built on the considerable work performed at the NUSEL and NESS workshops.
- We have constituted fourteen working groups, cutting across the community. Twelve of these are focusing on scientific areas that could benefit from DUSEL. They are in charge of distilling the "big questions," drawing a roadmap of high priority generic experiments, identifying the corresponding infrastructure requirements, and attempting to map out the likely evolution of the (international) demand in their subfield for underground space.
- Two of these working groups are in charge of general aspects: The infrastructure requirement/management group and an education and outreach group.
- In addition two *consulting* groups have been established: (1) A site consultation group that provides an official channel through which the eight "Solicitation 2" proponents can offer input on the S1 study and attract the attention of the PIs on issues of fairness between the sites, and (2) an initiative coordination group that includes the major stakeholders (e.g. national labs) to provide advice on how DUSEL could be coordinated with other federal government agency initiatives.

We should emphasize that the eight sites have endorsed the S1 PIs with the specific agreement that, although the site consultation group and the initiative coordination group will be able to comment on all official S1 statements (including this interim report), the final decision on the content of the S1 final report is left to PIs of the site-independent study.

Proceedings of our deliberations are systematically compiled on our web site (www.dusel.org). The general methodology, including the building of "infrastructure matrices," has been defined, and has allowed us to start identifying objectively modules, i.e. experiments of various disciplines sharing similar engineering and infrastructure requirements. Now that the Solicitation 2 (S2) proposals have been submitted, the working groups are starting in earnest to post on the same site their conclusions and scientific justification documents. We are planning a small but intensive workshop this summer, with the working group coordinators and representatives of the sites and major stakeholders, to finalize the content of the S1 final report, which will then be reviewed externally in a way similar to NRC studies. We envision this report to have the same style, and hopefully the same success as the *Quantum Universe*, a document that was very effective in explaining the science to generalists in the funding agencies, the Congress and the government.

1.2. Originality of the process

The DUSEL process is multidisciplinary from the start, covering not only physics and astrophysics but also earth sciences, biology, and engineering; it involves four directorates at NSF. NSF is the lead agency in the DUSEL program, but we hope to engage other agencies (DOE [HEP, nuclear science, basic sciences including geology and biology], NASA [astrobiology], NIH, USGS) and industry.

Our approach specifically *favors an adaptive strategy*, where modules (for instance the "deep module" and the "large cavity module") could be deployed at different times or different sites, if necessary, in order to take into account:

- The evolution of the science. This is an experimental science facility, where the next move is determined from the previous experiment, not just an observatory with powerful general facilities that are periodically upgraded. Contrary to the Laboratories of Gran Sasso (Italy), once access and minimum common facilities are established, we expect to excavate cavities as needed.
- The international environment. We do not want to duplicate existing facilities (e.g. SNOLab in Canada) if they are undersubscribed. Moreover, very large equipments, like the combination of a very large detector and neutrino beams, have the size and price tag of "megascience" items that may require international partnerships and become part of the overall negotiations between regions.
- The budgetary realities that may slow down the development. We should start with unique and the highest priority modules, without waiting for the funding of a full program. Even in tight budgetary times, it is important to open new areas of exploration, and we believe that a staged DUSEL is a good candidate. We should note that the physics community have not yet reached consensus on the relative timing of a deep module and of a large cavity module.

It is likely that DUSEL will initially start with a single site, as financially it is much more efficient to share a number of support functions (ventilation, utilities, ultra-pure water, cryogenics, technical infrastructure, low background counting facilities). This would also be the quickest way to build up the critical mass that the American underground science desperately needs. Our study assumes, however, that the Deep

Underground Science and Engineering Laboratory will not necessarily be located at a single site but may eventually involve several campuses at different locations. As the science supported by the laboratory develops, additional sites could be opened to take advantage of specific site characteristics to save on the construction of a given module or to give earth sciences access to other types of rock and geological histories. We may thus have the opportunity to take advantage, over time, of a diversity of geological settings and build a set of regional facilities relatively close to all the U.S. universities, promoting student involvement and more uniform outreach impact. In order to sustain the unifying mission of DUSEL, it would be, however, essential to implement a common scientific management and to use the most modern telecommunication techniques to mitigate the geographical dispersion.

1.3. Interim report

This interim report was requested by NSF to bring up to speed the members of the site preselection (S2) panel. This document summarizes the major themes of our DUSEL deliberations so far. It is obvious that, as a community, we have not fully converged yet on a number of difficult questions of science policies, and the PIs do not think they should force conclusions on a number of issues at this time. In addition, we have not completed the full specification of the modules and their detailed engineering requirements.

We hope, however, that this snapshot of the DUSEL site-independent study will provide the members of the S2 panel with the general scientific and technical context and a broad sketch of optimal site characteristics, after which they will have to make their own recommendations.

2. Compelling scientific questions

The study has identified a number of compelling questions in particle and nuclear physics, astrophysics, subsurface geoscience and engineering, geomicrobiology and evolutionary and genomic biology that could be addressed by a DUSEL.

2.1. Particle and Nuclear Physics

The recent discoveries—made primarily in underground laboratories—that neutrinos have mass and that their flavors are strongly mixed have revolutionized current thinking. It is necessary to understand the role of neutrinos in physics by building a new "Standard Model," and to understand their place in the cosmos. There are three outstanding questions.

- Are neutrinos and antineutrinos the same particles? Alone among matter particles, neutrinos can have this property, which would have a central position in the organization of the new Standard Model. Searching for neutrinoless double beta decay using 100 kg to 1 ton detectors deep underground will allow us to answer this question. Such experiments can also provide information about neutrino mass.
- What are the relationships between the neutrinos and what are their masses? We need to understand precisely how the different neutrinos mix; in particular, we need to determine the remaining (presently unknown) mixing angle θ_{13} between neutrino mass eigenstates, the hierarchy of masses, and whether

significant violation of the CP symmetry exists among the neutrinos. This will require the combination of megaton scale detectors with neutrino beams from accelerators.

- Do protons decay?

It is expected that baryonic matter is unstable at a small level and the lifetime for proton decay is a hallmark of theories beyond the present Standard Model. The lifetime predicted by current theoretical models ranges from a factor of a few to a factor of 100 above the current limits. The large detectors under study may be able to improve the limits by approximately a factor of ten, and there is a chance for a fundamental discovery!

These questions intimately relate to the completion of our understanding of particle and nuclear physics and the mystery of matter-antimatter asymmetry in the universe. We should emphasize that new questions that could be answered by a deep underground laboratory can emerge very rapidly. Such was the case for proton decay in the late seventies when experimentalists had to scramble for space underground. The major discoveries in neutrino physics were made in detectors principally designed for proton decay.

1.2. Astrophysics

Two questions at the forefront of our consideration are:

- What is the nature of the dark matter in the universe? Is it comprised of weakly interacting massive particles (WIMPs), of a type not presently known but predicted by theories such as supersymmetry?
- What could we learn about the processes inside stars from neutrinos? In particular, what is the low-energy spectrum of neutrinos from the sun? Solar neutrinos have been important in providing new information not only about the sun but also about the fundamental properties of neutrinos.

Another astrophysical source of neutrinos is supernovae. Unfortunately supernovae are relatively rare in our galaxy (1/25–50 years), and it is difficult to justify a program solely based on this science (unless it is very cheap and requires low maintenance). However, the detection of a supernova signal from our galaxy would provide invaluable information about the details of the explosion and about neutrinos. It is also possible to measure relic supernova neutrinos from the whole history of star formation in the universe. The experimental limits are close to current estimates. It may also be possible with major detectors to detect a few neutrinos from supernovae anywhere in the local group of galaxies, and put this signal in coincidence with gravity detectors (and of course the appearance a day later of an optical signal). This would be a marvelous example of the multi-messenger astronomy that has already proven its power with Gamma Ray Bursts.

Let us also note that it would be natural, if a DUSEL is built, to locate a small accelerator underground, which could be used in nuclear cross sections important for astrophysics and cosmology.

1.3. Subsurface Geoscience

In order to understand the evolution of the ever changing Earth, we need a much more detailed understanding of the Hydrological-Thermal-Mechanical-Chemical-Biological (HTMCB) interactions taking place within rock masses, and their coupling over a large range of the physical dimensions and time scales. A deep underground laboratory with long-term access to well-characterized and instrumented, large-scale rock volumes will enable spatially and temporally detailed *in situ* investigations of these complex processes. Such observations, integrated over 10^3 m^3 rock volume at depth, are not possible from the surface or in the laboratory, yet are essential in order to evaluate the numerous existing models for these coupled processes

DUSEL is an essential strategic element in the development of geophysical tools that will make the earth transparent. Our ability to “see into the earth” and map any physical or chemical transformations from the surface or from a borehole in real time is limited by our ability to validate geophysical inversions. At DUSEL the veracity of remote sensing and cross borehole methods can be tested by mining back and comparing high-resolution geophysical images with reality. The relationship between surface measurements and subsurface deformation, rock stresses and fluid flow is particularly important for understanding the solid earth on large scale.

More generally, DUSEL will enable all the sub-disciplines of geosciences to better understand the fundamental processes underlying a number of problems of great scientific and societal importance, from ground water flow to the transport of hazardous substances, and from the formation of ore/oil deposits to the sequestration of CO_2.

A very deep science and engineering laboratory will also bring geophysicists closer to the conditions prevalent in the regions where earthquakes naturally occur and enable them to investigate rock deformation at spatial scales that are intermediate between laboratory experiments and active tectonic faults (as is currently being done by the San Andreas Fault Observatory at Depth within NSF’s Earth Scope program). DUSEL will help us answer questions such as: What are the detailed processes involved in the Earth’s crust and tectonic plate motions? What controls the onset and propagation of seismic slip on a fault? Can earthquakes be predicted?

1.4. Subsurface Engineering

A deep underground laboratory will significantly advance our fundamental understanding of the processes at work in subsurface engineering.

Traditional design of subsurface structures has relied heavily on studies and tests of rock cores and on empirical rules, but fracture systems in the rock mass, which often dominate the response to load, cannot be tested directly at small scale. Impressive developments are being made in numerical modeling and in geophysical imaging techniques, which now offer exciting possibilities to make major advances in the state of the art of rock engineering, but these methods are not yet fully validated. Availability of a dedicated, long-term underground research laboratory is the “missing element” necessary to allow these advances to be fully realized and will help address the following questions:

- What are the limits to large excavations at depth? While boreholes from the surface attain 10 km depths with ~10 cm diameters, and the deepest mine shafts reach 4 km with ~5 m diameters, the DUSEL experimental facilities may require cavity dimensions of up to 60 m by 60 m in cross section, and 180 m in length at depths from 1 km to 3 km. Much experience will be gained through the instrumentation and long-term monitoring of such cavities

- How can we improve the reliability and safety of mining and boring operations and the efficiency of recovery? Can geophysical imaging results be fed directly into subsurface mining operations to enable them to ”see” ahead into the rock and thereby improve efficiency and safety?
- How can we control contaminant transport at depth and how can we implement long-term isolation of hazardous and toxic wastes?
- What are the most efficient methods for CO_2 sequestration and hydrocarbon storage underground?

The methods developed and the experience gained in these engineering projects will have profound impact on geosciences, and DUSEL will provide the fertile ground of close collaborations between scientists and engineers, and academia and industry.

1.5. Geomicrobiology

Investigations in drilling projects and in deep mines have recently demonstrated the presence of microbes living within the rock pores to depths of up to 3 km. Although their density is small, they may constitute the most extensive living biomass on earth (and the only form of extant life on Mars). Their metabolic rate is extremely slow compared to surface microorganisms and their average lifetime may be as long as 1000 years or more! An underground laboratory with long-term access would provide a critical tool in the study of these microorganisms. Unlike boreholes drilled from the surface, DUSEL will enable for the first time sampling of the mineral/water/microbiology interface without contamination, observation of their interactions with the environment *in situ,* and a full characterization of incoming and outgoing mass and energy flux. Three important questions have emerged from previous studies:

- How does the interplay between biology and geology shape the subsurface? Do underground microbes appear to play a critical role in the HTMCB processes? Do subsurface microorganisms significantly modify porosity characteristics by dissolving and precipitating minerals or clogging pores and covering mineral surfaces with biofilms?
- What fuels the deep biosphere? Do deep microbial systems exist that are dependent upon geochemically generated energy sources (“geogas”: H_2, CH_4 and hydrocarbons depending on the rock type) and independent from the photosphere? How do such ecosystems function? Do their members interact to alter a hostile environment in order to sustain a livelihood over geologic time?
- How deeply does life extend into the Earth? Is that limit imposed by temperature, pressure, energy restrictions and fluid transport?

The proximity of clean rooms and low level counting facilities will significantly improve our ability to detect the metabolic processes of indigenous microorganisms. The synergetic partnership of physicists who are experts in low energy particle and photon counting, and molecular biologists who are developing fluorescent signaling probes will spawn the next generation of life detection and environmental monitoring technologies.

1.6. Evolutionary and Genomic Biology

The fact that the organisms living underground may have been isolated from the earth's surface biosphere for significant periods of time opens fascinating questions regarding evolution and fundamental biology.

- What can we learn on evolution and genomics? Does the deep subsurface harbor primitive life processes today? Is there any genetic difference between deep subsurface microorganisms and their closest relatives on the surface?
- On the earth's surface, life is everywhere and the environment selects, but in the deep subsurface this may simply not be true. How do these microbes evolve, given their very low population density, the absence of predators, their extremely low metabolic rate, their longevity and the high ambient radiation? Does genetic exchange occur, and if so, do phages participate in this process?
- What is the role of the subsurface biosphere in earth's life cycle? It has been suggested that life on the earth's surface may have come from underground, or that the subsurface has acted as refuge during surface mass-extinction events and life is surviving to colonize the planet once the environment has become favorable. Can we test these hypotheses? Underground investigations will also help us to determine what signs of subsurface life we should search for on Mars.
- Is there dark life, or life not as we know it? Does unique biochemistry, e.g. non-nucleic acid-based, exist in isolated subsurface niches and can we detect unambiguous molecular signatures for such processes?

Needless to say, these fundamental questions may also lead to applications of great interest in the biotechnology and pharmaceutical sectors. For example, the underground may harbor a reservoir of unexpected and very useful pharmaceuticals or enzymes.

These investigations will have the complementary requirements to those for geomicrobiology. They will call on a broad array of competences in fundamental biology and will have a need for microscopic and biomolecular analysis facilities, including DNA sequencing, transcriptome and proteomic facilities. A combination of on- and off-site capabilities are envisioned to meet these needs.

3. **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 public. 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 from the start. Infrastructure and coordinated efforts are fundamental for the development of innovative programs, which should target

- undergraduate learning and postgraduate research;
- involvement of the local population, community officials, and legislators;
- public at large and informal education;
- K-12 students and teachers;

- broader opportunities and participation of women and underrepresented minority groups.

DUSEL will offer a truly remarkable 21st century multidisciplinary teaching, learning, and sharing community for students, teachers, scientists, officials, legislators and the public. Both surface facilities and supervised underground access are essential, and 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.

4. **Infrastructure requirements**

In order to put the DUSEL project in perspective, we should first note that there are several physical sciences facilities of intermediate depths in the world, although they are oversubscribed. Small facilities are available at Frejus, in the Modane tunnel (to be potentially extended), and Baksan, both around 4700 meter water equivalent [m.w.e.[1]] (~1750 m in rock). The large laboratory at Gran Sasso is at 3800 m.w.e. (~1400 m in rock), and the Japanese Kamioka laboratories are at 2700 m.w.e. (~1000 m in rock). Smaller facilities are available at Boulby (U.K), a salt mine at 3200 m.w.e. and in Canfranc (Spain) at 2450 m.w.e.. Figure 1 shows the world laboratories currently in use for physics. Limited facilities for hydrological and microbial studies in fractured granite are available at Aspö, Sweden, to a depth of 1200 m.w.e, (480 m in rock).

Several countries (Belgium, Canada, France, Sweden, Switzerland) have developed Underground Research Laboratories (URLs) [typically ~500m deep] for research related to long-term isolation of radioactive waste. In a number of these cases, consideration is now being given to use of these facilities for more general research in the geosciences and in microbiology. These URLs could complement, in part, studies in DUSEL. The URL at Yucca Mountain, Nevada, USA, would not be available for such general research, since it is intended, should research studies prove successful, to develop the site for permanent isolation of radioactive waste.

4.1. Depth requirement

Remembering that all facilities may not have to be at the same site, the depth requirements can be summarized as follows:

- A clear motivation for DUSEL is to create a unique facility in the world, which would provide physicists, astrophysicists, earth scientists and biologists with *readily accessible, long-term observation platforms and experimental facilities at great depth* (typically 6000 meter water equivalent or more, i.e. 2200 m, or more, in rock). The only other very deep facility in the world would be SNOlab, under construction in an active nickel mine in Sudbury, Canada. The depth requirement for geomicrobiology is primarily a temperature requirement to access fluids ranging from 80° to 120°C. The corresponding depth is set by the local geothermal gradient. In general for all geoscience experiments the greater the depth, the easier will be the access to these high temperature regimes.
- The depth of the large cavity proton decay/long baseline detector will be limited by the characteristics of the rock and economic considerations. Although many

[1] One m.w.e. corresponds to $(1/\rho)$ meters in rock of average density ρ . Thus, for rock of average density 2.7, 1 m.w.e. is equal to 0.37m depth in rock

discussions focus on a megaton water Cerenkov detector, we should note that smaller detectors such as 100 kTon liquid argon or scintillator set ups are also interesting possibilities. Their smaller mass is compensated by a larger amount of information or a lower threshold. *For proton decay and long-baseline neutrino physics, there is a consensus that a depth of at least 1500 m.w.e. is required* (with some dependence on the type of detectors). However in order for these detectors to have also sensitivity to other rare processes, we may want to locate them *as deep as economically possible*. For example, the relatively shallow depth of Kamioka (2700 m.w.e., 1080 m in rock) is a limiting factor in the application of the KamLAND detector to direct detection of solar neutrinos, owing to cosmogenic radionuclides produced in the detector. From the rock mechanics point of view, deeper is of course more challenging but more informative.

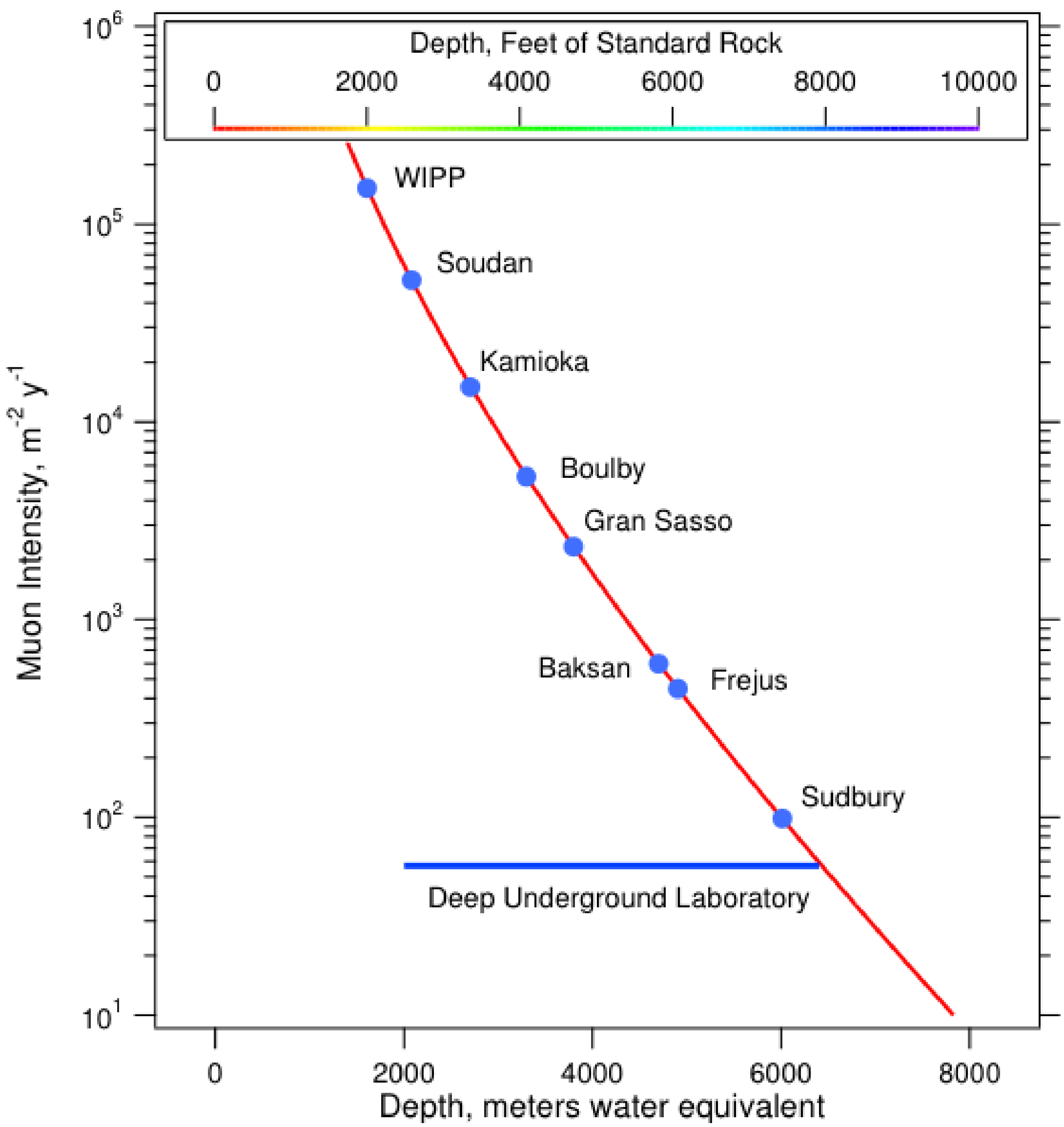

Figure 1. Underground laboratories currently in use for physics.

- Whether the access is horizontal or vertical, along the way it will be natural to locate *facilities at intermediate depths*. Facilities which do not need the full depth will be cheaper to excavate and faster to access.

4.2. Rock type

The physics or astrophysics programs do not depend strongly on the rock type (provided that the rock is strong enough to accommodate the large cavity module, if such module is to be constructed). The radioactivity of the rock is often easy to shield, except in very large unshielded experiments where a low uranium and thorium content would be important. *Radon mitigation will also be important.* Techniques similar to those at existing underground laboratories appear to be applicable in most rock types.

From the point of view of earth sciences, some research questions are specific to the rock type (e.g. igneous, metamorphic and sedimentary rocks) and others cut across rock type. We came to a consensus that *very important results could be obtained in earth sciences, biology and engineering investigations regardless of the rock type*. Eventually (perhaps in combination with worldwide deep facilities), the earth scientists, biologists and engineers would like to have access to deep rock environments that span a range of physical, chemical and biological properties. This may be a motivation to support more than one DUSEL site.

4.3. Pristine regimes

The experimental facilities of the physicists will likely be located within dry, impermeable zones of the rock, which are most suitable from a maintenance and safety perspective. In contrast, any of the earth science and biology experiments requires access to substantial rock volumes (~10^3 to 10^6 m^3) that have not been dewatered (deep water is essential for biologists) or de-stressed. These requirements simply mean that *experimental bays or tunnels for earth scientists and biologists that are proximal to water-bearing zones should be located some distance from the physics facilities*. Biology experiments that focus on indigenous life or life not as we know it, require access to *absolutely pristine rock volumes*. Great precautions should be taken to insure that they have not been contaminated by either DUSEL site exploration and construction or prior mining activities.

Earth science investigations will span *a variety of physical scales*. These range from the use of DUSEL to define rock heterogeneities throughout a very large block of rock (km^3) and to provide ultra-deep (many km) drilled access for geobiologists and solid earth scientists, to the desire for long-term (>20 years) access to smaller pristine blocks.

4.4. Distance from accelerators

A large cavity module, to be used for neutrino oscillation experiments (likely combined with proton decay searches), should be located sufficiently far from an accelerator to allow the measurement of two oscillation cycles if possible and to be sensitive to matter effects that give direct information on the mass hierarchy. In the scenarios that have been most studied so far (neutrino beam of approximately 3 GeV energy, produced by the proton drivers at BNL or Fermilab), *there is a broad optimum around 2500km and distances between 1000km and 5000km are adequate*. Shorter baselines will require lower energy beams; however, not enough progress has yet been made in such designs to allow a complete comparison. An extreme approach presently favored in Europe for the short baseline between CERN and Modane (130km) is to use very low-energy (300 MeV) electron neutrino beams from radioactive nuclei ("beta beams").

4.5. Access

The major themes in our discussion can be summarized as follows:

- Horizontal versus vertical access: *The science outlined above can be accommodated by both types of access*, provided that a hoist has sufficient capacity. It would be desirable to accommodate ISO transport containers (6.1 m [l] x 2.4 m [w] x 2.6 m [h]).
- Twenty-four hours per day, 7 days per week, 365 days per year access to the underground experiments is a universal wish, but there might be some restrictions that may limit this; emergency access, however, must always be available. Most experiments (including very low temperature experiments) could be automated (at some financial and efficiency cost); it should be noted, however, that a major experiment (IMB) catastrophically failed during a weekend, when there was no access.
- *Guaranteed long-term access for at least 30 years*: Major experiments in physics will naturally have lifetime of 10–20 years, and some earth science or geomicrobiology investigations will have similar time scales. Moreover, the investment of NSF in the facility cannot probably be justified unless such minimum time can be guaranteed.
- Personnel access: A critical aspect is the free access to both U.S. and non-U.S. nationals. Technical and scientific personnel (including undergraduates and possibly high school students involved in experiments) will have to receive appropriate safety training, which will be site dependent. The amount of safety training needed for casual technical personnel (hired for small work) will probably depend on the type of access. The supervised underground access of school students and the public—for instance, to an easily accessible underground observation deck—is highly desirable for education and outreach purposes.
- Ease of access to the sites, proximity to universities and to major airports, dormitories or guest houses close by are obviously desirable aspects.

4.6. Safety and specific requirements

Safety considerations are obviously essential and the selected site(s) will have to develop proactive policies that meet or exceed the relevant codes. These may lead to restrictions of certain types of materials (e.g. banning of low-flash point flammable liquids or high toxicity materials). DUSEL and any proposed experiments in it would also be subject, presumably, to supervision by MSHA and OSHA[2] officials.

A particular problem could be to accommodate medium- to large-mass cryogenic systems (liquid argon, neon or helium) proposed for solar neutrino, dark matter, and proton decay/long baseline. Another significant safety threat could exist from water and

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[2] MSHA Mine Health and Safety Administration; OSHA Occupational Safety and Health Administration; both are branches of the U.S. Department of Labor.

gas-bearing zones, natural or induced as part of an experiment (such as CO_2 sequestration) where earth science or biology experiments are being performed. Safety protocols in the case of high pressure release from multiple boreholes or tunnel collapse are an essential component of any experimental module.

Our recommendation is that if strong scientific arguments require an activity that could be potentially dangerous, *the laboratory must work actively with the experimenters and experts in underground safety* to ensure adequate protection of the personnel involved, the rest of the laboratory and the environment. Such potentials and associated safety measures may have to be described at the time of impact statements.

4.7. Management aspects

We concluded that it is essential for the laboratory program to be *under the direction of and managed by scientists*. A number of standard approaches exist as documented in the preliminary management report posted on our web site (www.dusel.org). Should DUSEL involve several sites, it would be important to have them under the same scientific management, following a multi-campus model, to prevent duplication and provide a common focus to the U.S. underground program.

This does not necessarily prevent private ownership of the sites. Some mining companies have shown a remarkable degree of openness and collaboration with the scientists, and there may be clear technical and financial advantages for the science in such arrangements (use of existing infrastructure, maintenance and safety assumed by the owner, payment of only the marginal cost of operation). However, we should remember that such private operations are for profit; financial decisions from stockholders and liability issues may override a genuine interest of the current management. Some of the wishes described above may be more difficult to meet; for example, (a) 24-hour/7-day access, (b) guaranteed long-term access, (c) restriction on types of detectors (e.g. large cryogenic detectors), (d) freedom of enquiry in the geoscience and biological area with restrictions imposed to protect proprietary information or mining operation (e.g. water and gas ingress), (e) open access for the education and outreach programs. Even in the case of public ownership, potential restrictions may surface when sharing the space with other activities. It is too early to seek detailed guarantees from site owners at this stage, but it will be necessary to secure them at the stage of Solicitation 3.

In conclusion, specific configurations and institutional arrangements, their advantages and drawbacks, are the subjects of passionate discussions within the community and may indeed have significant impact on the overall efficiency, capital expenditures and operational costs of the scientific program. However, in the multi-site, adaptive approach that we propose, *it is not necessary for a site to be able to meet all infrastructure requirements*. Financial considerations may also impose constraints at least in the initial stages of a given project. *The primary criterion for the viability of a site is the capability to accomodate some of the frontier science at reasonable cost and risk.* The evaluation and comparison of specific site capabilities and constraints is the responsibility of the Solicitation 2 or 3 process.

5. Preliminary definition of modules

Table I
Provisional module definition.
The last column identifies potential sub-modules.

Module	Science	Main Requirements	Potential additional requirements
Very Deep module	Double beta decay Solar neutrinos Dark matter Small geomechanical experiments Earthquake studies Deepest limits of dark life	≥ 6000 m.w.e (2400m in rock) dust control radon control low e.m. noise pristine rock for microbiology	10kton cryogenic liquids (He, Ne)
Very Large Cavern module: 1Mton	Combination in same detector of • Proton decay • Long-baseline neutrino physics. • Supernova physics • 3D monitoring of rock deformation	As deep as economically feasible: ≥1500 m.w.e ≥1000km from accelerator (see text)	100 kton liquid Ar 100 kton scintillator
Very Large Block Earth Science Experiments	HTMCB experimentsover multiple correlation lengths Imaging technology development, mine-back validation. Sequestration studies	Water bearing zones Pristine and non pristine Span all depth range available at the site	Remote oil deposit simulation (sedimentary rock)
Intermediate depths	Some solar neutrinos Radioactive screening Prototyping Clean room Fabrication/assembly E&O observation deck	Typically 2000-4000 m.w.e. (800-1600m in rock)	Accelerator Shaft experiments (vertical access or ventilation shafts)
Common underground spaces	Offices and interaction spaces Teleconference rooms Small machine and electronics shops	At main underground levels Excellent internet connectivity	
Surface buildings	Experiment specific and common support facilities. Offices/conference rooms E&O classrooms	Scale depends on site remoteness Excellent internet connectivity	

We are engaged in a detailed engineering definition of the modules based on the requirements of the high priority generic experiments, but it is already clear from our discussions that we can identify the modules as in Table I.

At (or close) to the surface, the experiment specific support will include for instance remote monitoring and control of most experiments, onsite laboratories for time sensitive geo-bioanalyses, core characterization and archive facility. The common support facilities include functions such as shipping and receiving, machine and electronics shops, assembly areas, vehicle maintenance services, change rooms and showers, Health and Safety and Support Plants (electric power, ventilation and water).

6. International Aspects

The questions summarized above are at the forefront of research in physical sciences, earth sciences, engineering and biology. In many cases—like neutrinos, dark matter or geomicrobiology—they represent new frontiers that researchers from all over the world are eager to explore. Cavities for megaton detectors will require leading-edge engineering. This science and engineering effort is truly international, with the usual mix of collaboration and competition of scientists worldwide, and the combination of partnerships and national programs for large equipments. As a very large project, DUSEL will require both regional (the North American continent for instance) and between regions (Americas, Europe, Eastern Asia) coordination. We will distinguish two different aspects of the program, which, following the adaptive strategy that we propose, can be decoupled in time and in space.

6.1. The Deep Underground Module (+ Intermediate depth and large block modules)

As argued before, one of the goals of the DUSEL project is to provide a very deep facility unique in the world, with the possibility of intermediate depths and large-scale earth science and engineering experiments.

Such a facility would be really unique if it offered the best conditions for multidisciplinary science, with no restriction of geosciences and biology; easy, 24/7 access; availability for at least 30 years; possibilities for expansion; science flexibility to accommodate essential experiments, even if complex (and expensive) safety setups are required; and a vibrant education and outreach program.

We should, of course, be aware that another very deep facility will be available at SNOlab (2007, at 6010 m.w.e. [2092 m depth] in the INCO nickel mine. Although we do not know yet the expansion capability of SNOlab (this is the subject of one of the Solicitation 2 proposals), it is unlikely that all the conditions described above can be fully met. Smaller facilities exist at Modane, France (currently 450 m^2 with possibility of expansion by 2009 to 1000 m^2, 15,000 m^3 at 4700 m.w.e. [1750 m depth], and Baksan, Russia (which is very difficult to access).

The strategic advantages for a DUSEL in the U.S. territory include the following: (1) The importance of a unified institutional underground science in the U.S. to the advancement of research, as opposed to scattered and isolated efforts as guests of other nations, cannot be overestimated; (2) a premier facility on U.S. soil will more readily allow U.S. teams to play central roles in major projects; (3) U.S. teams will take lead roles in development of new engineering, mining and detection technologies, and in technology transfer to the private sector; (4) it will attract the most exciting projects; and

(5) it will maximize the impact on training of scientists and engineers and the outreach to schools, local populations and the public. Finally, DUSEL will be complementary to other major U.S. initiatives, such as Earth Scope, SecurEarth, Ocean Deep Drilling, and NEON (biosphere).

Before proceeding however, it is necessary to check that the likely demand in the U.S. and worldwide will justify DUSEL. The investment is sizeable, even if it is amortized over 30–50 years, and does not compete directly with the funding of experiments (through the use of a M.R.E.F.C. line item in the NSF budget). Our study *has not yet completed* this important evaluation, which needs to be realistic (not just a summation of all the dreams) and take into account the size and growth of the scientific community involved and the likely evolution of the budgets.

Many members of our study strongly believe that such a high demand in physical sciences will exist, for the growth of the community is fast and because some of the fundamental science questions move underground for answers, in a mode complementary to accelerator-based physics. The facility will open new fields of study to the earth scientists, engineers and biologists. The likelihood of surprises in the current program will also make it desirable to rapidly deploy new underground experiments. It is often argued that the existing facilities are chronically oversubscribed, and that this trend is likely to become worse. As shown by the current generation of physical sciences experiments and the proposed program in earth sciences and biology, large projects, which often last at least for 10 or 15 years, may prevent emerging science and novel ideas from finding available space unless enough space is provided or expansion capability built in the project. It is essential, however, to test this intuition, before concluding that a deep U.S. laboratory with a broader range of capabilities than the SNOLab can offer is indeed needed. In any case, DUSEL should have strong collaboration agreements with SNOLab.

6.2. The Large Cavity Module

The large cavity module presents different challenges. It is unlikely that SNOLab can accommodate such a facility (whatever its distance to accelerators). The combination of a very large detector, neutrino beam, and proton driver (≥$1 billion) may promote such a project to the megascience category. The size of the investment may require collaboration between the regions to afford even one of these large detector-accelerator combinations in the world. It is likely that the decision in such case would involve a global intergovernmental negotiation. Note that an existing underground laboratory in the U.S. able to accommodate such a project could be a major asset in this process.

Although the site-independent study has not converged on a specific recommendation on international partnerships, there is much discussion internationally of putting in place a mechanism similar to that in place for the International Linear Collider (ILC), under the auspices of ICFA a subcommittee of HEPAP. Although the price tag is much smaller, there is clearly an advantage to interregionally coordinate the R&D still needed for the combination of a very large detector and a neutrino beam. Further emulating the common design process already in place for the ILC, may provide an international funding path for a major program, which otherwise could be quite uncertain.

7. Conclusions

To conclude, DUSEL will address compelling scientific questions in a broad cross section of science ranging from particle and nuclear physics and astrophysics to subsurface geosciences, engineering and biology. Even in a tight budgetary environment, it is essential to open new windows onto the natural world. DUSEL science is certainly an excellent example of a facility that will bring critical mass to new and exciting endeavors.

The main recommendation of our site-independent study is that the primary criterion for the preselection of sites be their potential to accommodate an exciting frontier science program for at least the next 30 years and provide vibrant education and outreach activities. While we are not suggesting that the physics should be compromised. There is a considerable added value in accommodating a broad cross section of earth sciences, engineering and biology, both for the progress in these disciplines and the synergies that will undoubtedly be stimulated across the fields.

We have pointed out broad optimal regions in the implementation parameters. However, these numbers should not be interpreted too rigidly, as even within the currently envisioned program, we are still lacking the full optimization of the site characteristics, the detailed performance of the proposed detectors and, for the associated neutrino beams, the capabilities of realistic accelerator designs. Such parameters can, *a fortiori*, offer at most a general guidance for the totally new scientific programs, which DUSEL will undoubtedly stimulate and which we cannot yet imagine.

In this general science-driven context, the evaluation and comparison of specific site capabilities and constraints is the responsibility of the Solicitation 2 or 3 process.