Report

of the

Homestake DUSEL

Program Advisory Committee

Sookie Bang

Derek Elsworth (co-chair)

Derric Iles

Ed Kearns

Josh Klein

Bill Marciano

Harry Nelson

Chris Neuzil

Bill Pariseau

Charles Ruch

Frank Sciulli (co-chair)

and

Hank Sobel

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EXECUTIVE SUMMARY

This report details a science plan for the proposed Deep Underground Science and Engineering Laboratory (DUSEL) at the Homestake mine in Lead, South Dakota. The objectives are to outline a plan for the laboratory over the next two years and to project a vision for a program in the longer term. The plan is communicated by the Homestake Mine Program Advisory Committee (PAC), but grows out of the initiatives submitted by members of the scientific community documented in more than 80 responses to a call for Letters of Interest (LOIs) by the South Dakota Science and Technology Authority (SDSTA). The wide variety of imaginative, feasible scientific initiatives in these LOIs makes clear the incisive and broad range of science that becomes possible when appropriate.

Clearly, an underground environment provides a unique opportunity for study in its own right. But a DUSEL also provides opportunities to carry out experiments in an environment that is free of the backgrounds inherent to doing science at the Earth surface -- most obviously the cosmic rays, but there are other sources of noise.

The Committee concentrated primarily on science that fits into categories involving fundamental physics questions, on the one hand, and Earth science and related subjects, on the other. But interesting and exciting prospects were proposed that do not fit simply into either of these subjects.

Many of the experiments envisioned for DUSEL address fundamental physics, and would be forefront in the U.S. science program for decades. These experiments address high profile topics identified by working groups and committees such as the APS *Multi-Divisional Neutrino Study*, and National Academies *EPP2010: Elementary Particle Physics in the 21st Century*. A particularly ambitious project that is a natural fit with DUSEL is a new long baseline neutrino beam produced at Fermilab or BNL and directed towards a 100-kiloton or larger detector at Homestake that will study neutrino oscillation as well as traditional non-accelerator physics such as proton decay and particle astrophysics.

But the potential physics programs for a U.S. DUSEL go well beyond this important prospect. In the intermediate term, experiments underground can carry out sensitive and important measurements of the solar neutrino energy spectrum, rare processes like spontaneous conversion of neutrons to antineutrons, and measurements of cross sections underlying the fusion processes producing the major sources of solar energy.

For the Early Implementation Plan (EIP), defined as a plan for projects that may be initiated over the next two years, two major areas of fundamental science are compelling. These involve neutrinoless double beta decay and detection of dark matter. Both topics are highly topical, and address fundamental questions of science.

The recent experimental results that show the neutrino spontaneously evolving from one flavor to another imply that neutrinos have mass and motivate further, different, experiments that probe the absolute mass scale. Among these, the neutrinoless double beta decay experiment is unique in also discerning whether the neutrino is its own antiparticle (also known as being a Majorana neutrino). In this class, two such experimental efforts are particularly timely and competitive to discover the phenomenon, have been approved by the community as worthy of support, and require space to carry out the work.

The cosmological discoveries that ordinary matter is only a small constituent of the universe makes compelling the need to find what the universe is composed of. Though there are many theoretical ideas in competition for explaining the unseen matter, it is highly likely that any explanation will flow from experimental discovery. The dark matter experiments look to find this thus far unseen component of matter. The topic produced the largest number of LOIs, with six independent proposed programs at various levels of development. Two are particularly promising for early deployment at Homestake, with substantial R&D already done and viability for deployment largely demonstrated, while on schedules that permit initial stages of work within the Laboratory with large detectors in the next two years.

For both double beta decay and dark matter, the large detectors will <u>require</u> protection from cosmic rays. The 4850ft level of Homestake mine will provide that protection, while providing space availability for expansion of these programs as well as incorporation of other programs.

A deep underground science and engineering laboratory would allow many significant questions in Earth science, in geobiology, and in subsurface engineering to be addressed. Although a culture of large, centrally orchestrated experimental programs in these areas of science is less well developed than in other scientific communities, the proposed endeavors remain crucial to the success of a DUSEL. Proposed scientific investigations are grouped by the PAC around two principal themes: the study of deep life, and in characterizing the complex behavior of the crust. The first attempts to answer fundamental questions regarding the origins and evolution of life, at depth, in an extreme environment, where life-sustaining resources are meager. The second examines the role of the complex interactions of stress, temperature, chemistry, and biology on the response of the Earth's crust and its fluids at large spatial scales and over the long-term – both in support of science and in the safe engineering of the very large-span caverns proposed in the parallel astrophysics program.

These two areas – deep life, and coupled processes – have been enduring central themes within the deliberations of the S1[1] community, and have evolved naturally from the LOIs presented in support of the Homestake DUSEL. Experiments related to **deep life** probe the adaptation of microbes to subsurface conditions, and the limits of life in extreme terrestrial environments. They involve programs of geochemical, geobiological, and geophysical sampling and related analysis of subsurface rock and fluids, preferably at a range of locations throughout the DUSEL. Conversely, the ensemble group of "**coupled processes**" experiments would examine the complex geochemical, geobiological, and geophysical interactions in the shallow crust, and would utilize a central facility at the 4850 ft level, complete with shared laboratory infrastructure.

Foci are in developing and verifying improved methods for the characterization of rock masses, in determining structure and the properties which control the mechanical and transport behavior of rock masses and their fluids and biota at length scales of scientific interest, and also the transformation of these properties in time and space. Related to this is the desire to observe the complex processes which contribute to the transformation of rock masses, in real-time, and to develop an improved and fundamental understanding of such processes. In the short term, such experiments can also contribute to the design of proposed large chambers, including the results from purpose built experiments, and the early instrumentation of excavations.

The Committee was particularly excited to see LOIs somewhat outside both major areas of concentration, and to some extent outside the expertise of the committee. One of the most exciting involved the possibility for investigating the origins of the energy generated by the Earth's interior, expected to be from fission reactions but not fitting into any conventional model of the interior. Others involve studies of cloud formation and rotational properties of the Earth. Later informal discussions have uncovered possibilities for unique measurements involving gravitational waves, sequestration of carbon dioxide, and specialized engineering issues.

[1] Stage-1 Report commissioned by NSF-0456137 - A U.S. Deep Underground Science and Engineering Laboratory: Scientific Opportunities and Technical Requirements

The DUSEL will significantly enhance the science and technology educational opportunities within the geographical region, including access by underrepresented groups. Opportunities for enhanced education and outreach include the provision for museum and exhibit facilities, the potential development of summer institutes, the provision of prestigious postdoctoral appointments with prescribed outreach components, and the development of joint scientific appointments between laboratory and community scientists.

The committee also provided some views on early Laboratory scientific infrastructure, so as to optimally create a viable laboratory at as early a stage as possible, while making synergistic connections with educational and outreach efforts that will be an important and essential part of the Homestake center. Early availability of some shared facilities will be essential, including those for low background counting and those providing early data for safe design of the underground facility.

In conclusion, three points are worth reiterating in the strongest terms:

1. The Homestake laboratory has enough space to house as large a program as can be envisaged being supported over the foreseeable future.
2. The program, even at the earliest stages, will be scientifically productive. In the longer term, the science utilizing underground research is envisaged to grow and be even more productive.
3. The very existence of such a laboratory within the U.S. will be a spark to inventiveness in making for new ways of investigating nature involving fundamental science, geological and biological sciences, and science outside these fields.

1 INTRODUCTION

This report details the activities and the recommendations of the Program Advisory Committee (PAC) assembled to review the potential scientific program for a proposed Deep Underground Science and Engineering Laboratory (DUSEL) at the Homestake Mine in Lead, SD.

Charge: The PAC was charged to review a broad array of physics, astrophysics, life science, geoscience and engineering, and to develop a comprehensive science plan for the site. This plan was to couple the best science which made the best use of the facility. The full charge for the committee is included in Appendix A.

The Homestake project team solicited Letters of Interest (LOIs) to identify the broad range of experiments which could fit within DUSEL. LOIs were requested to meet an initial December 11, 2005 deadline. LOIs were thereafter open to updating and revision by the authors. A total of 80 LOIs were available to the PAC by the time of a February 9-11, 2006 Science Workshop in Lead, SD. This workshop was an opportunity to refine ideas and build teams to address experimental needs.

Evaluation Criteria: The LOIs were available before the Lead meeting. The presenters at the Lead workshop were asked to emphasize five principal criteria for evaluation, listed in full in Appendix B. These criteria may be summarized as the quality of the science; the fit with the anticipated Homestake infrastructure; the readiness of the project for early deployment; the readiness of the project for funding; and the ability to operate within prescribed health and safety guidelines.

The PAC deliberations focused on defining the best science that would fit the facility – with an emphasis on defining an early implementation plan (EIP). The PAC specifically interpreted the charge (Appendix A) as applied to the evaluations of the LOIs to provide a coherent science plan which:

1. Makes the best possible case for a US DUSEL;
2. Gives the best prospects of time to early science, thereby reducing the risk to NSF, and providing early science results in further strengthening the case for a US DUSEL;
3. Optimizes the use of available infrastructure, and provides a critical path to the development of shared infrastructure; and,
4. Provides a coherent framework to allow PIs to collaborate and to approach funding agencies in support of experiments.

Membership: The PAC comprised a membership representing both the physics and Earth science and engineering communities. The full committee had six members representing physics, and six representing Earth science and engineering. One additional member represented education and outreach. Kevin Lesko (LBNL and CDR PI), Bill Roggenthen (SDSM&T and CDR PI), and David Snyder (Director of SDSTA) attended meetings *ex officio*. The two principal sub-groups worked both separately and together to produce the science plan, detailed here. The complete membership is specified in Appendix C:

Schedule: The schedule followed for review of LOIs, ensuing deliberations, and the compilation of the consensus report are noted in Appendix D. LOIs were reviewed by the PAC prior to the February 9-11, 2006 workshop in Lead, SD. Subsequently, PAC members submitted initial impressions, before individual conference calls for each of the physics and Earth science and engineering thematic areas. Following this, individual members compiled and submitted "white papers" related to the themes under their purview. These white papers were compiled and circulated, prior to a two-day consensus meeting in Chicago in March. This consensus meeting allowed full discussion of the full suite of proposed experiments, and related infrastructure needs, and outlined the form of the final report. Following circulation of the final report to the PAC membership, the final report was submitted to the Homestake team in early May.

2 PHYSICS

The committee considered under this category those LOIs related to fundamental physics or cosmological science. All letters submitted under this rubric involved projects of substantial size. Many of these have been or are being studied by DOE and NSF in the context of the long term U.S. program; we have in the main attempted to conform to such priorities where they have been made, or to remain open to them as they will be made. In any event, such large scale projects, even if begun immediately, are unlikely to produce results in the period set by the EIP, so the process used by the committee should be clarified. First, the committee evaluated the scientific value, both in the short and long terms. Next, an attempt was made to evaluate the usefulness for early access to Homestake. In some instances, benefits could accrue to continuation of an ongoing program to a next logical step; in others, program collaborators were judged to benefit substantially from tests of technique, assembly of equipment, or fabrication of components in the underground environment provided at Homestake. Because of the substantial real estate that could be available at the 4850' level, the committee did not attempt prioritization of space.

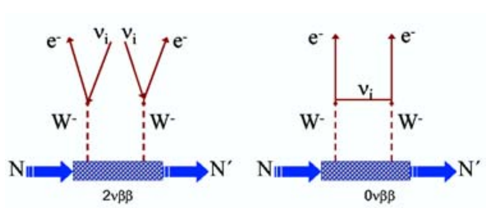
2.1 Neutrinoless Double Beta Decay

2.1.1 Scientific Motivation

The discovery of neutrino oscillations taught us that the Standard Model must be modified to incorporate the existence of neutrino mass. The modification can occur in two ways: neutrinos can be Dirac particles like the other fundamental fermions, in which case we must add new right-handed neutrino fields, or neutrinos can be Majorana particles (essentially, the neutrino is its own antiparticle) in which case we must have processes which violate total lepton number by two units.

The implications of Majorana neutrinos may be far-reaching. The most popular (and simplest) hypothesis for the tiny experimental neutrino masses is the "see-saw mechanism", which explains the small masses relative to those of other fermions as a consequence of a very heavy right-handed neutrino state imparting the Majorana nature to neutrinos. This heavy right-handed state thus sets the scale for the light neutrinos we see. Observing Majorana electron neutrinos could be indirect *experimental* evidence for new physics at a higher energy scale than we can possibly directly probe today.

In addition, some models of Majorana neutrinos have indicated that they may play a role in the asymmetry between matter and antimatter in the Universe, an element in solving one of the great outstanding problems in cosmology.



Neutrinoless double beta decay experiments seek to determine whether neutrinos are Majorana particles by observing explicit lepton number violation. As shown in the left panel of the figure, some even-even nuclei are capable of undergoing two simultaneous β-decays, with the emission of two electrons and two neutrinos ($2\nu\beta\beta$). If neutrinos are their own antiparticles, the process in the right panel of the figure is also possible, and the two electrons are emitted with no accompany neutrinos ($0\nu\beta\beta$). The violation of lepton number occurs in the internal line of the figure's right panel.

It is important to note that any clear observation of $0\nu\beta\beta$ would signal new physics. However, a non-observation does not rule out the possibility that neutrinos could still have a Majorana nature, because many other reasons could lead to a null result. The decay rate for $0\nu\beta\beta$ depends on a mass parameter obtained as an average over the neutrino eigenmasses, weighted by appropriate mixing factors (U_{ei}) that connect the eigenstates with the electron neutrino:

$$M_{0\nu\beta\beta} \simeq \sum_i m_i U_{ei}^2 \equiv \langle m_{\beta\beta} \rangle .$$

This dependence means that if neutrinos were too light, the rate would be too small to see. Given our current knowledge of the mass differences (Δm^2) and mixing angles from oscillation experiments, we already know that a positive observation from the next generation of double beta decay experiments requires either that the neutrino masses are degenerate (the Δm^2's are very small compared to the absolute masses) or that the lightest of the neutrino mass eigenstates is the third one, ν_3, which has the smallest ν_e flavor content.

One further interpretation issue is that the calculation of the $0\nu\beta\beta$ rate also depends on the nuclear transition matrix element, which may not be well known. The uncertainties due to nuclear matrix elements thus argues that more than one nucleus be used in the search for $0\nu\beta\beta$. Differing experimental difficulties also argue that multiple technologies be used.

2.1.2 Letters of Interest: EXO and Majorana

Two double beta decay LOIs were submitted to Homestake, both of which have been endorsed by the recent Neutrino Scientific Assessment Group (NuSAG) report[2] as experiments that should be pursued with significant funding and effort from the U.S.

LOI 49

The EXO experiment uses a large enriched (*85%*) liquid ^{136}Xe sample as both the initial state nucleus and the detection material. EXO detects the electrons by collecting charge from ionization and light produced by scintillation, A planned upgrade would substantially reduce backgrounds by tagging the recoiling final state ^{136}Ba nucleus through laser fluorescence. The prototype EXO-200, which has about 200 kg of enriched Xenon, is fully funded and is being built. It will begin taking data at WIPP sometime in 2006. The goal of this first phase is partly to gain experience in running the detector underground, partly to observe the "normal" double beta decay process ($2\nu\beta\beta$), and partly to improve current limits on $0\nu\beta\beta$ down to an effective neutrino mass $\langle m_{\beta\beta} \rangle \sim 330\ meV$.

LOI 61

The source and detector material Majorana is enriched (86%) ^{76}Ge crystals. Ge has been used by other double beta decay experiments in the past, and thus is the basis of a well-established technology. The initial goal would be construction of a 180 kg detector capable of seeing a $0\nu\beta\beta$ signal down to $\langle m_{\beta\beta} \rangle$ ~100 meV. The big advantage of Germanium is its excellent energy resolution, ~0.2%, which allows large background rejection from both ambient radioactivity and from the "irreducible" $2\nu\beta\beta$ background. In addition, pulse shape discrimination can be used to further reduce ambient backgrounds. Nevertheless, Majorana will require ultra-clean materials and a reasonable depth to achieve these goals.

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[2] Reported (September 2005) to the Nuclear Science Advisory Committee and the High Energy Physics Advisory Panel for the DOE and NSF.

2.1.3 Recommendations

These experiments represent excellent physics at the very forefront of the field. They are both outstanding opportunities for Homestake. We recommend that the lab plan on housing both experiments. Any early needs -- such as the underground copper electroforming planned by Majorana for their cryostats -- should be accommodated as soon as funding and space is available.

2.2 Dark Matter (DM) Detectors

2.2.1 Science

We now understand that approximately 25% of the universe is made from non-baryonic material that does not form stars. Two proposed types of thus far unobserved elementary particles could satisfy the properties of this so-called dark matter: WIMPs (weakly interacting massive particles) and axions. The experiments considered for the underground lab are devoted to detection of WIMPs. The neutralino, the lightest of the hypothesized particles in many supersymmetric extensions of the Standard Model, is a candidate for this WIMP. A neutralino would interact with ordinary matter with a cross section characteristic of the electroweak scale. Even given this tiny cross-section, WIMPs could be detected by observing their interactions with ordinary matter. The collision rate depends linearly on the local WIMP density. The detectors proposed here are designed to be sensitive enough to observe the extremely small energy deposition while discriminating against other particle interactions which might simulate a WIMP collision. The proposals span a range of detector target materials and discrimination techniques.

In general, dark matter searches require the most shielding and therefore require the most depth. Cosmic ray muons, a pernicious producer of neutrons which constitute the principle background to these searches, are attenuated substantially by material overburden.

The WIMPs would be detected by observing the energy deposited when a WIMP elastically scatters from a target material nucleus. A larger nucleus is generally preferred, benefiting from the coherent enhancement to the WIMP elastic-scattering cross-section. In addition, the energy of the recoiling nucleus is maximized when the target nucleus mass equals the WIMP mass. The three most common experimental techniques that have been exploited for detection of this energy are ionization, scintillation and phonon emission. The most sensitive detectors generally use a combination of two of these three possibilities. By comparing signals from the two emissions in each event, it is possible to discriminate the desired nuclear recoils, which could be due to WIMPs or neutrons, from electron recoil backgrounds that arise from photons and electrons.

2.2.2 Letters of Interest

LOI 22 – SuperCDMS

The CDMS collaboration is currently one of the leading DM groups in the world. They have developed arrays of cryogenic germanium and silicon detectors employing both phonon and ionization detection. Their on-going detector development has led to the current operation of CDMS-II in the Soudan mine, which has produced some of the most stringent limits on WIMP cross-sections. When complete, CDMS-II is expected to have cross section sensitivity close to 10^{-44} cm^2.

The next step in this program is called SuperCDMS, with a first stage 25kg detector. The collaboration is currently committed to installing this first stage in SNOLAB in late 2007. Installation of a next stage detector at Homestake might begin after completion of the 25kg detector operation. Thus any Homestake operations would be in the long term: 2010 or later.

LOI 48 - ZEPLIN

ZEPLIN entails a liquid Xenon detector employing detection of both ionization and scintillation emissions with low energy thresholds and good background rejection. Liquid Xenon is available in large quantities with both odd and even spin isotopes. It has high density and high atomic number, thus enabling a compact experimental design with a high event rate. The ZEPLIN collaboration is operating ZEPLIN-II (Z-II), mass 30kg, in the Boulby mine and ZEPLIN-III (Z-III), mass 7kg, in a surface lab. They expect completion in 2005 with an ultimate DM search sensitivity at the 10^{-43} – 10^{-44} cm^2 level. During commissioning of Z-II and Z-III, they have established detection of two energy emission types. The ionization from nuclear recoil with a neutron source produces a light yield as expected. An intermediate detector called Z-IV/MAX (100 – 1000 kg) is currently planned to be built starting in 2008/2009 at SNOLAB. The design of this intermediate detector uses Z-II and Z-III technology.

The U.S. groups in this collaboration plus some groups from the larger collaboration are involved in testing new ideas and technology for an ultimate detector they call (just plain) ZEPLIN. The new technology includes implementing charge gain in the liquid Xenon using nano-tips. This subset of the larger collaboration is proposing a design test which could take place at Homestake in middle or late 2008 with a 200 kg detector. UCLA has applied for NSF continuation funds to the existing grant, and DOE R&D funding, to pursue these ideas. Successful demonstration could lead to a detector of the multi-ton scale at Homestake by about 2010, with a sensitivity goal below 10^{-46} cm^2.

LOI 56 - Mini-CLEAN

Mini-CLEAN proposed a 100 kg detector that may use both liquid neon (LNe) and liquid argon (LAr). In both cases, nuclear recoil due to dark matter scattering is discriminated from Compton Scattering background by pulse shape discrimination. If the discrimination is as powerful as expected, a one year exposure with LAr would be sensitive to a 100 GeV WIMP with a cross section of 10^{-45} cm^2, competitive with other non-prototype experiments worldwide. Argon has a larger nucleus than neon, so the coherent enhancement to the WIMP elastic-scattering cross-section is bigger and it is more efficient for converting nuclear recoils into scintillation light, allowing for a lower WIMP detection threshold.

The technical challenges to proceeding with a full-scale CLEAN detector require constructing the proposed small scale Mini-CLEAN prototype. The full detector would be very large, about half the size of SNO and operate at 27K (LNe mode), or 87K (LAr mode). In addition, it will be necessary to understand the properties of scintillation light in LNe and to test the purification and light collection in a large detector. Assembly and initial testing of Mini-CLEAN will occur at Yale before transporting underground.

The collaboration has done a preliminary investigation of most of the relevant technical issues. Photomultiplier tube (PMT) operation at LNe temperatures shows promising results. A cryogenic setup is under construction at Yale for testing longer term stability in the cold environment. Measurements of scintillation in LNe have been done but to date, the PMTs have not been immersed in the liquid so that corrections for the interface are required. This means that so far, the anticipated photoelectron yield is largely based on estimates. The measurements imply, however, that there will be a large signal for low energy recoils. Measurements of the absorption coefficient of cold charcoal imply that all important impurities can be removed. The next step is to show that this produces small absorption and therefore good light collection in a sizable detector. Some pulse shape discrimination measurements with LNe have been done. The results look good, but it is necessary to repeat the tests with lower energies and more realistic light collection. In the case of LAr, pulse shape discrimination studies at Los Alamos (simulation and experiment) indicate that pulse shape discrimination alone should work for the WIMP search. More work is necessary, however, to demonstrate this for lower thresholds and a large detector size.

Mini-CLEAN is now under design with construction expected in summer 2006. The tests on the surface are expected to take 1.5 years, so that reassembly underground could proceed in early 2008. An ADR proposal has been submitted to DOE for additional funding. The funding for engineering support and 1.5 post-docs will come through existing LDRD funds at Los Alamos.

LOI 59 – XENON100/1000

XENON is a well-developed liquid Xenon project utilizing both scintillation and ionization yield. The operation of both 3 and 10 kg detectors has demonstrated essentially all of the necessary technology including discrimination between electron and nuclear recoils. XENON10 was made operational at Columbia and is now being reassembled at the Gran Sasso lab in order to understand backgrounds and shielding requirements. It should begin operation in 2006. Results from the shielded 10 kg detector in Gran Sasso will determine the design of the planned 100 kg module.

The collaboration has completed a three year R&D effort funded by DOE and NSF. A proposal for XENON100/1000 will be submitted late this year, with a possible construction start in Homestake in 2007. The XENON1000 sensitivity is projected to be 10^{-46} cm^2.

LOI 63 - DRIFT

Earth's rotation creates a small velocity difference of the laboratory relative to any ambient WIMPs, causing periodicity in the cross section. The DRIFT detector hopes to further exploit the predicted day/night modulation of a WIMP signal by providing a detector with directional sensitivity. The technology involves a Negative Ion Time Projection Chamber (NITPC), operating with carbon disulfide gas at low pressure (.05 - .3 atm) to extend the range of the recoil nucleus track to a few mm. Electron capture by the electronegative gas reduces track diffusion. They employ a 2D readout plus timing to get 3D reconstruction. The background discrimination is based on measuring energy deposition along the track.

DRIFT-I (D-I) operation from 2002-2004 demonstrated safe, stable, and long-term underground operation along with capacity for event characterisation and discrimination. Neutrons from the surrounding rock were identified and measured, while verifying high gamma discrimination ($>10^6$). Some technical and engineering difficulties (DAQ, MWPCs, fatigue) were encountered, but the numerous design and engineering lessons from the tests were applied to the multi-detector DRIFT-II, presently under construction.

DRIFT II (D-II) is to be a three or more detector system, each a NITPC with 1 m^3 fiducial volume. It has an improved vessel design, improved (3D) track reconstruction (anode, grid and z-drift), low noise and an improved gas system all while achieving an overall factor of 5 cost reduction per module relative to D-I. A single D-II module (167g target) is projected to have a sensitivity of 10^{-42} cm^2 in one year and the100 kg D-III sensitivity would reach 10^{-45} cm^2 in one year. A possibility exists of adding 50% **Xe** to the gas to improve the sensitivity by another factor of five. Construction and installation of the second two modules is underway with full operation expected in early 2006. Operation of D-II is expected to continue for three years while simultaneously designing D-III.

The R&D issues for the expansion to this next step, D-III, include questions like mass production, head-tail discrimination, improved resolution readout (higher pressure = lower volume) and alternative gases or mixtures. The plan is for D-III to achieve 100 kg using 1 kg modules. A first stage of D-III, 10 modules, could begin installation in SNOLAB or Homestake in 2007, with completion and operation in 2008. The staged installation of the remainder of D-III would proceed after evaluation of this first stage, estimated to begin in 2010.

The DRIFT program is currently being funded by NSF in the U.S. and PPARK in the U.K. Other European funding may also become available. Proposals for D-III are to be submitted this year. While operation is planned to continue in the Boulby mine for the next three years, the future of that facility is uncertain and the collaboration is exploring other opportunities.

LOI 72 - SIGN

SIGN intends to employ high pressure (>100 bars) Neon gas. The gas phase and consequent high electron mobility would allow exploitation of both ionization and scintillation modes.

This small group has already achieved both charge and light collection, showing that a low threshold of about 1 keV is possible. Preliminary work with a neutron source demonstrated discrimination between neutrons and electrons using the collected charge and the scintillation light, with additional discrimination provided from the pulse shape of the scintillation light.

A conceptual design of a low radioactivity high pressure vessel exists. The next step is to use a monochromatic neutron beam to determine the absolute light and charge output as a function of recoil energy for a variety of gas mixtures. Without this step, the actual sensitivity cannot be established.

This is second year of a DOE ADR grant. Although no formal collaboration as yet exists, they have funding to begin design and construction of a 50-100 kg detector. The current work is being done at UCLA and Texas A&M and a prototype is expected to be available by the end of 2006. They plan to submit a proposal for an experiment this summer after further tests establish the sensitivity. Underground testing of a 50 - 100kg detector in 2007 is possible if funding for this is secured.

2.2.3 Recommendations

The Homestake Early Implementation Plan encourages the use of the facility for the development of new ideas as well as for the installation of mature experimental programs. The seven experimental programs discussed in the Dark Matter category include both cases. In addition to the interest expressed in the LOIs submitted to Homestake, several of these groups have shown interest in the new SNOLAB facility. Five of them have been invited to install their detectors in SNOLAB, including SuperCDMS, ZEPLIN IV/MAX, Mini-CLEAN, XENON and DRIFT-III. Thus far, SuperCDMS and ZEPLIN IV/MAX have accepted the invitations and intend to install their next stage detectors in SNOLAB towards the latter part of 2007. Based on those decisions, those LOIs are not considered to be candidates for the Homestake Early Implementation Plan. However, the laboratories prepared at the 4850 foot depth could easily be extensive enough so that space should not be an issue should any of these programs eventually prefer to be relocated to the Homestake site.

The five remaining proposals are the new technology ZEPLIN proposal, Mini-CLEAN, XENON-100, DRIFT and SIGN. In our judgment the XENON-100 program and the Mini-CLEAN program are the two most likely to require underground space during the early program. Both programs are quite advanced, with strong collaborations and good expectations for continued funding. The new-technology ZEPLIN and SIGN experiments are in early R&D stages and, while it is possible they can usefully employ the underground space during this period, projections are more uncertain. The schedule for DRIFT largely depends on the future of the Boulby mine.

In summary, while the new Homestake lab could comfortably house all of the dark matter proposals that were discussed, and while we encourage the proponents to continue their efforts to reach a stage where underground deployment at Homestake will be useful, we believe that two of these groups can realistically be expected in Homestake during the early implementation period. These are XENON100 and Mini-CLEAN. Since both groups were also invited to install their detectors in SNOLAB, collaboration decisions will be necessary.

2.3 Long Baseline Neutrino and Proton Decay

2.3.1 Science

The physics case for a very large multipurpose underground detector can be roughly divided into two parts: 1) a stand-alone search for proton decay and supernova neutrinos along with measurements of atmospheric and perhaps solar neutrinos and 2) very long baseline neutrino oscillation studies using an intense neutrino beam originating from Fermilab or Brookhaven (distances of 1280km and 2540km from Homestake respectively).

A primary goal of the stand alone program with the very large detector would be the search for proton instability in a variety of potential decay modes with sensitivity reaching to about 10^{35} yr, i.e. at least a factor of 10 beyond the capabilities of Super Kamiokande, currently the largest operational (25kton fiducial mass) water detector. That requirement defines the minimum size for the next generation proton decay detector. So, for example, the next generation water Cherenkov detector should ultimately be 250kton or larger, while a liquid Argon (LA) detector could be smaller because of its better acceptance and better background rejection for many decay modes. With either massive detector, one could also significantly improve atmospheric neutrino oscillation measurements and solar neutrino studies (if good resolution were achieved). In addition, for a supernova in our galaxy (expected about every 30 years), of order 10^5 neutrino events would be recorded in 10's of seconds. Such measurements would teach us much about the dynamics of supernovae and the fundamental properties of neutrinos. Cosmic neutrinos left over from supernova emissions integrated over the lifetime of the universe may also be discernable, thereby probing cosmological evolutionary models. Finally, a very large detector could simulataneously search for exotic phenomena such as neutron-antineutron oscillations in nuclei and proton decay catalysis, a super heavy magnetic monopole signature. Overall, the discovery potential of a very large detector is rich, broad and at the frontier of contemporary elementary particle research.

The very long baseline neutrino oscillation aspect of a big detector program offers potential for major advances. Building on the discoveries of neutrino oscillation studies using solar, atmospheric and reactor neutrinos, it would measure much more precisely neutrino mixing angles and mass parameters. If the as yet unmeasured mixing angle θ_{13} is larger than about 0.03 - 0.05 ($\sin^2 2\theta_{13} > .004 - .010$), it could be determined. In addition, the neutrino mass hierarchy (ordering of masses) and value of the CP violating phase could be unambiguously determined using an intense wideband neutrino beam with appropriate detector. Knowing this phase could shed light on the observed matter-antimatter asymmetry of the universe. It can be shown that determining well the size of CP violation in the neutrino sector requires a water detector of several hundred kton (or about 1/4 that size liquid Argon detector, due to its better acceptance and background rejection) along with a megawatt class proton accelerator for generating the wide band neutrino beam. Those requirements are a natural match with next generation proton decay experiment and possible proton beam upgrade capabilities at Fermilab or Brookhaven. With such a powerful robust neutrino program, one could also search for effects of sterile neutrino mixing, exotic interaction phenomena in matter and possible extra dimensions. If observed, such discoveries would be revolutionary in their implications.

If a very large multipurpose water Cherenkov or liquid Argon detector were built at DUSEL and an intense neutrino beam were provided by Fermilab or Brookhaven, they would together constitute a major physics program with outstanding discovery potential. Its combined capabilities would establish DUSEL as the premier underground laboratory in the world, significantly advancing elementary particle physics research and the leadership role of the USA. Presence of the very large detector facility in DUSEL would provide a stimulating and technologically advanced environment where other experiments could also flourish. Furthermore, it would be a major educational attraction for students and the general public. Neutrinos are particularly fascinating particles even for non-scientists.

2.3.2 Letters of Interest

LOI 8: 3M - A Large Water Cherenkov 100-1000 kton Detector

LOI 52: Drift Electrons in 100 kton Liquid Argon

These LOIs propose very large multipurpose underground detectors at Homestake, which would cost several hundred million dollars and, if constructed, would provide a cornerstone for the DUSEL physics program. The two LOIs emphasize the two major detector types presently considered for the science described above.

2.3.3 Recommendation

The Committee agrees that that the case for a very large multi-purpose underground detector at DUSEL is extremely compelling. If built, it would provide a broad physics program with major discovery potential ranging from proton decay and neutrino astrophysics to CP violation in very long baseline neutrino oscillations. It would truly be the flagship facility at DUSEL. In addition, such a large detector would form a foundation for future experiments and lab infrastructure as well as education and outreach programs.

The two very large detector technologies being considered are Water Cherenkov and liquid Argon. Either could be located at 4800ft. Each has promising advantages and present disadvantages that need to be addressed. Several generations of Water Cherenkov detectors have been successfully constructed and used to make important discoveries in neutrino physics while advancing significantly the search for proton decay. Extending that technology to multi-hundred kilotons is rather straightforward but expensive and requires engineering studies because of the size of the required excavation cavities. Also, rejection of pion backgrounds in neutrino oscillation experiments and compromised recognition of many modes of proton decay limits the water detector at present. Liquid Argon offers opportunities for better background rejection, as well as event recognition, resolution, and acceptance. However, liquid Argon technology is still under development and locating such a large quantity of liquid Argon (100kton) deep underground entails significant engineering and safety challenges. Further studies of both options are needed.

The Committee believes that the physics program of the very large detector would be very important for DUSEL in the long term and represents considerable motivation for the lab's existence. Such a project is, however, much too large to be part of the first two year physics program. Nevertheless, the likelihood of it being realized in the long term depends on decisions made relatively soon. Its key component, very long baseline accelerator neutrino oscillations, requires a neutrino beam from Fermilab or Brookhaven directed to DUSEL. Such a beam is currently not part of the neutrino long term program envisioned by the particle physics community. However, that situation could change relatively soon. DOE and NSF have charged NUSAG with charting a course for future accelerator-based neutrino oscillation experiments and facilities in the USA. They will consider the advantages and opportunities of sending a neutrino beam to a very massive detector at DUSEL as compared with the currently envisioned program at Fermilab and future options for its upgrade. They are expected to report their findings and recommendations later this year. Concurrently, a Fermilab-BNL task force is studying the feasibility and cost of directing an appropriate wide band neutrino beam to DUSEL.

If NUSAG recommends sending a neutrino beam to DUSEL or at least strongly recommends further study, the Homestake Lab should be prepared to respond by facilitating engineering studies, detector R&D (for both Water Cherenkov and Liquid Argon) and collaboration formation. If NUSAG does not endorse the very long baseline neutrino oscillation program at DUSEL, the stand-alone program of the very large detector (proton decay, neutrino astrophysics etc.) will need to compete with very large detectors that could be built in other parts of the world without a long baseline component.

The Homestake lab should try to contribute as much as possible to the NUSAG study and be prepared to respond to its final recommendations.

2.4 Solar Neutrinos

2.4.1 Science

Though the study of solar neutrinos began as an effort to directly verify calculations indicating that nuclear reactions powered the sun, it evolved into historic discoveries about the basic properties of neutrinos. Considering the advanced state of neutrino research by the GNO, SAGE, Super-Kamiokande, SNO, and KamLAND experiments, not to mention a proposed new generation of precision reactor experiments, it is fair to scrutinize the incremental science derivable from further solar neutrino experimentation. In a review performed for the 2004 APS Multidivisional Neutrino Study [APS], the Solar and Atmospheric Neutrino Working Group focused on three physics questions related to solar neutrinos:

- Is our model of neutrino mixing and oscillation complete?
- Is nuclear fusion the only source of the Sun's energy?
- What is the correct hierarchical ordering of the neutrino masses?

Their highest priority recommendation was the development of real-time, precision experiments that measure the spectrum of solar neutrinos down to the earliest and lowest energy part of the chain, from proton-proton (pp) fusion. Such new experiments address the first two questions. The third question has already been partially answered by current solar experiments, which observe normal hierarchy in solar neutrino mixing via matter effects in the Sun. The remaining hierarchy question will probably be answered by long baseline experiments, or perhaps by enormous samples of atmospheric neutrinos.

Since pp solar neutrinos are responsible for 98.5% of the Sun's power, new precision real-time solar spectrum experiments, constrained by measurements of luminosity, directly test solar models. Interestingly, this combination also studies temporal stability. Neutrinos generated in the core can be detected promptly, whereas electromagnetic energy requires about 10^4 years to travel to the surface of the Sun.

Another attractive feature of measuring pp solar neutrinos connecting to fundamental particle physics arises from the accurate (~1%) prediction of the neutrino flux. Experiments could exploit the precise prediction of the pp flux to extract new information about the neutrino, potentially improved determination of θ_{12}, study of the transition between vacuum-dominated and matter-dominated mixing in the Sun's interior, and sensitivity to possible admixtures of sterile neutrinos. Precision solar spectrum experiments would overconstrain parameters of neutrino mixing and potentially reveal unexpected new physics.

2.4.2 Letters of Interest

Four letters of interest address this physics.

LOI 64 proposes a high-current ion accelerator relevant to measurements of small cross sections important in the fusion reactions that take place in the Sun; this is discussed separately below in section E.

LOI 58 proposes to explore development of a large gaseous Time Projection Chamber, which would have directional sensitivity to neutrino electron elastic scattering (as well as for dark matter, closely related to LOI 63, DRIFT, discussed in section B).

LOI 56 (mini-CLEAN) proposes to develop a 100-kg prototype detector that may eventually be expanded into a 10-100 ton major experiment; the initial goals of mini-CLEAN also include detection of dark matter, as discussed in section B. Neon simulations of the CLEAN detector imply 1% precision in pp solar neutrino detection in addition to 10^{-46} cm^2 sensitivity to WIMPS. In the WIMP search mode, solar neutrinos are one of the backgrounds which must be identified with the pulse shape discrimination.

Finally, **LOI 69** (LENS, Low Energy Neutrino Spectrometer) proposes to directly measure the ν_e component of the solar neutrino flux by inverse beta decay of ^{115}In. This experiment seems to be the last remaining idea for measuring the pure ν_e flux, as it is sensitive only to the charged current reaction (unlike the neutrino electron scattering experiments discussed above). The full experiment would be comprised of 125-190 tons of liquid scintillator doped with 10-15 tons of Indium. The inverse beta decay is distinguished from ordinary ^{115}In beta decay by a delayed tag with a characteristic time of 4.76 microseconds. The detector is configured as a novel "scintillation lattice chamber", where semi-transparent foils segment the detector into an array of cells that are used to reject random coincidence background. The detector would be instrumented with 6500-13000 small PMTs. The proponents wish to develop a 100-liter prototype (mini-LENS) to test the technology of the scintillation lattice detector.

2.4.3 Recommendations

The committee finds that developing a gaseous TPC could make valuable contributions to both solar neutrinos as well as for dark matter issues. For solar neutrinos, directionality is a required feature for measuring the spectrum, as it is needed to suppress internal backgrounds. For dark matter, it is a confirming signature of the dark matter wind. Although the ideas have been discussed (*e.g.* HELLAZ) previously, the detailed detector design is not yet mature. The committee recommends submission of a technical proposal for underground background studies when they become feasible; in the meantime the committee endorses the research and development of this detector technology.

The committee finds the potential for a full-sized CLEAN detector of 10-100 tons to be a promising component of the long range DUSEL program. The committee encourages research aspects of the mini-CLEAN research program that directly address the potential for a future solar neutrino experiment.

The committee endorses research and development towards a full scale LENS experiment. The committee also notes that operation underground would likely be a valuable learning experience for eventually operating a full-sized experiment underground, and so encourages the group to consider such operation at Homestake under the Early Implementation Program should the proponents succeed in constructing their prototype detector.

2.5 High Current Ion Accelerator

2.5.1 Science of LOI 64

The principal goal of an underground High Current Ion Accelerator (HCIA) is to empirically quantify the cross sections for nuclear fusion reactions that are important for energy production in stars, with particular emphasis on those reactions that are responsible for the flux of neutrinos with energies above those from the pp fusion in the Sun. To make such measurements in the relevant energy range is a formidable challenge, primarily because reaction rates are so small that the signals are normally swamped by background. Locating the HCIA underground can greatly suppress interfering background rates, while very high currents will produce the strongest signal possible.

At the present time, the error on the predicted flux of high-energy neutrinos from ^{8}B is substantially greater than the error on the measured flux. A prominent contribution to the error on the prediction arises from the uncertainty of the measured ^{3}He(α,γ)^{7}Be fusion cross section. Precise measurements of this cross section have been impeded because the energy of the final state photon is so low as to be indistinguishable from backgrounds due to cosmic rays and environmental radioactive isotopes. By going underground and utilizing shielding and detector techniques developed for double β-decay and dark matter searches, the ^{3}He(α,γ)^{7}Be cross section and similar cross sections can be precisely measured.

The ultimate goal of the research from a HCIA is to permit combining terrestrial measurements of the solar neutrino flux with precision fusion cross section results to quantify the paths of energy production in the Sun. LOI 64 was submitted by a group at LBNL who propose eventual construction and operation of an HCIA with beam currents up to 100 mA. For comparison, the accelerator at the LUNA project, a similar accelerator at the Gran Sasso underground lab, achieves typical currents of 0.3 mA. The advocates of LOI 64 are performing design studies, and plan to build and operate the accelerator first at LBNL. They anticipate moving underground around 2010. A design report will be available in June 2006.

For this project to succeed, new personnel and funding resources need to become available. An HCIA is not among the nuclear physics community's high priorities at the moment, but the physics objectives of an HCIA are highly ranked. The currently favored route to the physics objectives is to build and utilize the Rare Isotope Accelerator (RIA); an underground HCIA appears to present a complementary and more economical route to similar physics. The LUNA project at Gran Sasso has completed some widely appreciated measurements, which validates the HCIA approach. Such measurements are extremely difficult and time consuming, so a strong case can be made for another facility to complement, cross-check, and surpass the capabilities of the LUNA project.

Because the current timescales are long, there is little chance that an underground HCIA itself would be part of an early implementation program at Homestake. However, to succeed in a 2010 deployment, infrastructure planning would have to commence soon. The facility would include a platform for the 300 kV portion of the accelerator, low-conductivity water for cooling, pumping and gas recirculation systems, and liquid nitrogen availability. This facility would resemble accelerator labs that have existed at university sites throughout the world.

In addition to the need for early planning, it is likely that the group will need to perform underground screening of low background components over the next two years.

2.5.2 Recommendations

In conclusion, an underground HCIA could form one of the high-profile activities at DUSEL, providing first-rate scientific advances. We encourage the proponents and Homestake to work together to develop a plan for deployment of an HCIA. Though it is unlikely that the main portions of an underground heavy ion project would begin during the Early Implementation Program, certain elements of substantial utility to a HCIA project are desirable early,, particularly screening of low-background construction materials.

2.6 Neutron-Antineutron Conversion

2.6.1 Science of LOI 7

Neutron-antineutron oscillation ($n \to \overline{n}$) is a key test of an unexplained but fundamental symmetry, baryon number conservation. Baryon number violation ($|\Delta B| \neq 0$) is a common prediction of Grand Unified Theories, with extensive references in past and current literature. It is usually argued that the best tests of baryon number symmetry come from proton decay $|\Delta B| = 1$. However, $n \to \overline{n}$ oscillation, involving $|\Delta B| = 2$ is highly complementary. Proton decay searches are sensitive to very high mass scales of order 10^{16} GeV and thus probe grand unified theories. Neutron-antineutron oscillations, by contrast, are sensitive to physics well below the GUT scale motivated by a variety of models including those that accommodate neutrino mass by the seesaw mechanism as well as large extra dimensions. The discovery of neutrino oscillations, involving two units change of lepton number, also motivates searches for baryonic processes with $|\Delta B| = 2$. A well-designed experiment will make tremendous gains over the previous best experiment. Neutron-antineutron oscillation could be connected to the baryon asymmetry of the universe.

Neutron-antineutron oscillation may also occur for neutrons bound in nuclei. Large proton decay detectors could observe bound $n \to \bar{n}$ transitions, since the antineutron would then annihilate producing a two GeV spray of pions, but the relative sensitivity must be understood. If we define the oscillation time of free neutrons as τ, the oscillation time for neutrons bound in nuclear matter must be corrected for the potential difference inside the nucleus. After such correction, the current best limit (from Soudan2, $\tau > 1.3\ 10^8$ s) is comparably sensitive to the current best limit from the best free neutron oscillation search at Grenoble ($\tau > 0.9x10^8$ s). Although not discussed in detail in any LOI, future large proton decay detectors will extend the sensitivity to bound $n \to \bar{n}$ oscillations, subject to possible limitations from atmospheric neutrino backgrounds.

LOI 7 is from an initial collaboration of about 23 scientists, representing the conceptual stages of a proposed free $n \to \bar{n}$ transition experiment. The basic proposal is to allow free neutron transition in flight down a vertical shaft one km in length. The vertical layout is key to achieving increased sensitivity over the previous measurement that used a 76-m horizontal shaft directed away from a 57MW nuclear reactor (Grenoble). For the slow neutrons involved, the deflection due to gravity was a considerable limitation. By allowing the neutrons to fall vertically, the time allowed for transition is greatly increased, directly increasing the sensitivity by the square of the relative time-of-flight. Additional gains in sensitivity come from implementing a focusing reflector. The proponents estimate an increase in sensitivity by three to four orders of magnitude, obviously a tremendous result if achieved.

2.6.2 Recommendation

The Program Advisory Committee finds this proposal of significant scientific merit, and endorses consideration as a long-range possibility for DUSEL. For the Early Implementation Program, the PAC recommends the engineering and feasibility studies needed to develop a full proposal and technical design in approximately 5 years. In particular, the PAC agrees with the proponents that serious infrastructure questions must be addressed: identifying a suitable vertical shaft (or costing the construction of a new one), engineering km-long magnetic shielding to the level of nanotesla, vacuum to 10^{-4} Pa, and numerous additional considerations related to locating a 3MW research reactor on the surface at Homestake. Issues like safety, licensing, security, and backgrounds to other experiments need to be considered.

3 EARTH SCIENCE, GEOBIOLOGY & ENGINEERING

This report discusses proposed experiments related to Earth science, to geobiology, and to engineering. Such experiments range from the earliest recovery of perishable data, include run-of-mine exploration of engineering and biological attributes of the Homestake site, and extend to long-term campaigns using multi-investigator teams. The following groups LOIs separately into the categories of Perishable Data, Geobiology, Hydrology, and Rock Mechanics. Within these categories, the principal science questions are identified, and a coherent science plan proposed which gives the best fit of science with the Homestake facility. The infrastructure needs are correspondingly identified.

3.1 Perishable Data

3.1.1 Scientific Objectives

The principal goals are to: preserve existing information related to the geology, hydrology, rock core archive, 3-dimensional layout of the mine, and other related data; take advantage of a one-time opportunity to gather geologic, hydrologic, engineering, and biologic information that will occur as the mine is reopened, and, gather new information which can be used for planning and design of later experiments and underground laboratory space.

3.1.2 Approaches and Integrated Experiment Plan

Significant archival data are available to the proposed Homestake DUSEL in the form of mine records and the core archive. The Homestake mine records fall into three general categories: rock core, paper files, and information within a Vulcan mining software database. The rock core belongs to the South Dakota Science and Technology Authority (SDSTA). Certain paper files selected by Homestake Mining Company from their archives will be donated to the Adams Museum in Deadwood, South Dakota. Two copies of the Vulcan database are available; one at the South Dakota School of Mines and Technology and the other at the SDSTA. Paper records and the Vulcan database are expected to contain critical information that will be associated with the rock core such as 3-dimensional location and lithologic descriptions, and perhaps geochemical analyses. Paper files may also contain maps of surface and subsurface geology, fractures, and faults and water inflow locations, as well as geochemical information.

Proposed Approach for Compilation of Information: The approximately 20,000 boxes of core are being inventoried (March 2006) by the South Dakota Geological Survey and the information is being entered into an electronic database. The paper files must be accessed and pertinent information must be electronically scanned while working with the Adams Museum in Deadwood, South Dakota. Information must be extracted from the Vulcan database using personnel well versed in using the Vulcan software. Information relevant to the rock core will be combined with the core inventory to create a searchable, online database. Other Homestake mine records will be made available in PDF, GIS, and other appropriate formats. This other information will also be disseminated via the internet in searchable and downloadable formats. Beyond the core inventory being performed and funded by the South Dakota Geological Survey, the rest of the aforementioned information must also be compiled and put into database-ready format for linking with related information and dissemination via the Internet **[LOI 11 and 11 addendum]**. Because of the nearly universal relevance of the Homestake mine records and core archive to any future research at the mine, serious consideration should be given to direct and immediate funding of these activities, other than the inventorying of the core, by the SDSTA.

Other Geologic, Hydrologic, Engineering, and Biologic Information: Collection of certain information related to the mine geology, mine hydrology, engineering properties of the rock, and biologic properties of media such as mine water must be initiated immediately upon reopening of the mine or the opportunity to gather such information will be lost **[LOIs 1, 6, 12, 36, 37]**. Other proposals to gather similar information require early and ongoing, but not immediate, access to the mine. Among the types of information to be gathered are stress-strain and geophysical characterization of the rock, measurement of water levels in the mine, water inflow rates to the mine, occurrence and orientation of fractures, biological signature of the stagnant and incoming mine water, and 3-dimensional mapping of fractures **[3, 40, 43, 65; possibly 39 and 55]**. Several of the Letters of Interest regarding these subjects have common or related themes and could mutually benefit from combining research efforts resulting in the most comprehensive and best information. If available records, either in hard copy or in Vulcan database format, do not provide a sufficient 3-dimensional geologic understanding of the mine or of the surface geology on and near the mine property, then work should be undertaken to create a 3-dimensional geologic database **[45, 46]**. Additionally, the use of micro technology **[13]** should be considered wherever possible for purposes of subsurface monitoring or data gathering. Subsurface data collection might also benefit from the development of robotic technology for remote collection of data **[25]**. Such technology could prove valuable by reducing the requirements for ventilation in remote areas of the mine and minimizing risks to personnel. Geologic, hydrologic, and engineering information to be gathered through implementation of activities proposed in, or similar to, several submitted Letters of Interest will be of immediate use in the design of experiments and construction of new underground laboratory space. Therefore, the most relevant of the proposed activities should be determined in consultation with the mining and design engineers responsible for creation of the underground space. Those activities deemed to be the best and most relevant should be considered for funding by the SDSTA, in addition to the activities which propose to document baseline biologic parameters of the mine environment.

Petrogenesis of Homestake Ore Bodies and Economic Geology: There are several Letters of Interest related to the petrogenesis of the ore bodies and economic geology **[10, 18, 20, 21, 44, 84]**. The activities proposed in these letters of interest do not require early access to the underground portion of the mine, but are very well suited for the opportunities presented by the Homestake mine and associated mine records.

The Homestake mine was continuously operational for more than 125 years and was closed in 2001 due to low gold prices. Although the occurrence of gold at the Homestake mine was studied extensively as part of the exploration and mining process, significant information about the gold and its host rocks remains to be discovered. Industrial and other uses of gold throughout the world are not diminishing and gold will continue to be in demand in the foreseeable future. By any standard, the gold at Homestake is a world class deposit and an improved understanding of the genesis of gold deposits at Homestake has direct and immediate relevance to mineral development elsewhere in the U.S. and the world.

3.1.3 Recommendations and Infrastructure Requirements

The PAC strongly supports these data gathering, assimilation and packaging activities and encourages SDSTA to initiate them as soon as is feasible. The provision of accurate mine, geological, and related datasets are of fundamental interest to the broad community of potential geoscience and engineering users of the facility. Care should be taken to ensure that important suites of data are not lost, that the inventorying of core recovers all measurements of likely relevance to the broad suite of users, and that the ultimate mine/laboratory model be easily accessible to the community via electronic open-source access.

These data will support varied scientific and engineering studies proposed in the various letters of interest, for which the proponents are encouraged to seek support, via the peer review process, from their various funding organizations.

Dealing with the Homestake mine records and core archive requires little to no additional space immediately. Long-term core storage and laboratory facilities for examining the core will have to be constructed or existing buildings will have to be remodeled. Many of the Letters of Interest indicated a requirement for access to only existing underground workings or underground workings newly created for other purposes; little new excavation or acquisition of new core would be required specifically for many of the early-entry activities to the mine. Many of the proposed activities would also require only very minimal office-type space underground and above ground for data analysis.

Costs: Costs will be modest for most of the proposed early-entry activities in that little new underground space or drilling/coring will be required. Most of the proposed early-entry activities require only use of existing data or existing underground workings of the mine. Dewatering of the mine, electricity, ventilation, and mine access are primary requirements. Specific costs related to the various proposed research efforts are generally lacking at this point, but the fast-track addendum to the proposal designed to make the Homestake mine records and core archive data available as soon as possible, is estimated to cost about $127,000.

3.2 Geobiology

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

3.2.1 Scientific Objectives

Geomicrobiology [LOIs: 15, 28, 29, 32, 38, 53, 70, 75, 76, 77, 78, 79, 80, 81]. In general, microbial studies proposed for the Homestake DUSEL cover the essential areas of the subsurface microbial ecosystem. Given the considerable overlap amongst multiple LOIs, the following synthesizes the proposed research activities and prioritizes the experimental timetable in geomicrobiological research at a potential Homestake DUSEL.

Common research thrusts are gathered under the rubric proposed in “Ecology/geomicrobiology collaboration for microbe evolution” envisioned by T. Hazen. This vision accommodates almost all proposals related to geomicro-related research. Roden et al. **[LOI 70]** also proposes a comprehensive research scheme, integrating geomicrobiology with geochemistry and geophysics. The geomicrobiology proposals can be further grouped into three major areas based on the scope of the proposed studies: (i) Evolutionary/phylogenetic diversity **[LOIs: 15, 29, 38, 53, 81]**; (ii) metabolic diversity **[LOIs: 28, 32, 38, 79]**, and; (iii) ecological diversity – interactions between microbes and deep underground environments **[LOIs: 38, 70, 75, 76, 77, 78, 79, 80]**. In particular, **LOIs 78** and **80** address the importance of interactive studies in geosciences and propose multidisciplinary, long-term research plans to characterize coupled processes of Bio-Geo-Hydro-Chem- and Engineering and further to understand the limits of life on Earth.

Geochemistry [LOIs: 20, 21, 37, 44, 68]: The chemical attributes of the rock and fluids adjacent to the proposed DUSEL dictate the characteristics of the deep underground environment. Abundant information is available on the geological properties of the Homestake mine, however, it is important to examine in detail the evolution of gases, the composition of rocks, and the inclusion fluid which will affect the biological systems directly or indirectly. **LOI 37** proposes a comprehensive step-wise collaborative research on the chemical evolution of fluids in the Homestake hydrological system. In particular, outcomes of the studies on thermal history, fluid flow and inclusion, and fracture-matrix interaction in rocks may provide important clues on life history and microbial evolution in the Homestake DUSEL.

Biological Effects [LOIs: 14, 30]: The DUSEL environment is substantially shielded from cosmic rays that can cause negative impacts on human health at the genetic and behavioral levels. Two LOIs hypothesize that ultra-low-level radiation can improve biological properties of the human cells, although potential adverse impacts may still exist.

3.2.2 *Approaches and Integrated Experiment Plan*

Geomicrobiology: The majority of LOIs propose step-wise, phased approaches to research. As the 4850 ft. level becomes available, research foci are on the migration of surface microbes into the DUSEL environments. These emphasize evolutionary trends, adaptation in deep environments, and the identification of novel microorganisms. At the 8000 ft. level, the research foci are further expanded and shifted to examine microbial activities in deep and extreme environments: Metabolic uniqueness and divergence, novel metabolic pathways and biochemical components (membrane lipids), and the impacts of underground geochemical properties on microbial communities, are all proposed for investigation. However, all LOIs except **78** and **80** are ready to implement their experiments immediately after the mine reentry is allowed. The mainstream approaches are identified as: molecular studies for genomics and metagenomics of unculturables using PCR-based DNA cloning and sequencing, DGGE, DNA microarray, etc.; visualization of biofilms with fluorescence dye stain using FISH; characterization of hydrocarbon containing fluids with stable isotopes; selection of autotrophs and organotrophs; and identification of novel microbial metabolites.

<u>Timeline for the majority of the proposed research</u>: 2006 – 2007, field surveys, identification of sampling sites, and sampling (from near-surface to the 4850 ft. level); 2008 – 2009, characterization of samples for genomics, microbial ecology, bioprospecting, and corrosion effects; 2010 – 2012, deeper level – characterization of metabolic properties of anaerobes and extremophiles; and 2013 -, coupled processes in broad areas of geosciences.

Geochemistry: Various experimental approaches are proposed to determine and refine: the partitioning effects of gaseous and liquid CO_2 and other elementals; elements of litho-stratigraphy and thermal history; the role of iron formation; lithostatic pressure/fluid inclusion; crustal assimilation using isotopes; volatile evolution; and fluid flow and fracture-matrix interaction in the fractured rock system using conservative and reactive tracers.

<u>Timeline for the majority of the proposed research</u>: 2006 – 2007, study of mine database, field surveys, and sample collection (rock, fluid, and gas); 2008 – 2009, upper test block instrumentation, characterization of samples, and dewatering studies; 2010 – 2012, lower block instrumentation, characterization, and geochemical testing; and 2013 -, coupled process testing at selected blocks.

Biological Effects: Proposed studies are intended to measure (1) the effects of low-level radiation on human cells, invertebrates, and small mammals and (2) the mutation rates and survival/repair of radiation (^{60}Co)-induced damage.

3.2.3 *Recommendations and Infrastructure Requirements*

The PAC enthusiastically supports the broad array of proposed activities and notes that the scientific community driving this research plan is already organizing around the noted principal themes of geomicrobiology, geochemistry, and of biological effects. This embryonic self-organization is encouraged as an effective mechanism for the proponents to effectively seek funding in support of this science. As noted later, principal themes for this work are related to studies of (1) the origins and evolution of deep life, and to (2) complex interactions of coupled geobiological, geochemical and geophysical processes. The grouping of scientific endeavors around experiments addressing these two themes is viewed as an effective method of both providing coherence to the many LOIs presented, and in optimizing the use of shared infrastructure facilities.

The provision of shared infrastructure in support of the proposed tasks will serve to further drive scientific collaborations. Onsite state-of-the-art facilities are needed to support minimum but critical laboratory experiments on samples that need immediate attention.

<u>Surface Facilities</u>: Two basic laboratory facilities - (1) one basic wet chemistry laboratory (approx. 2,500 ft^2) and (2) one BSL 1 level microbiology laboratory (approx. 3,500 ft^2), equipped with two anaerobic

chambers (one with core access lock), walk-in cold room, -80°C freezers, multi-temperature incubators, liquid nitrogen, laminar flow hoods, microscopes (brightfield, phase-contrast/inverted, confocal), scintillation counter, autoclave, working benches, incubators (water-bath shakers), PCR-thermocyclers, gel electrophoresis kits, spectrophotometer, HPLC, mass spectrometer, biosafety cabinets, and tissue-culture incubators as a minimum. Additional equipment may have to be added as needs arise in the future.

<u>Underground Facilities</u> (at 4850 ft level): (1) one combined, basic wet chemistry/BSL 1 laboratory (approx. 2,500 ft^2), which can support simple laboratory experiments for underground geosciences research activities (sample analysis and processing) and tissue-culture incubators; (2) space for underground sampling, coring, excavation, and drilling platform; and (3) space for large blocks for coupled process testing.

In summary, these proposed step-wise approaches systematically address the broad suite of needs in geomicrobiology, geochemistry, and biology, and related interactions in hydrogeology and rock mechanics. The infrastructure needs are similarly shared, with an estimated cost of these facilities of ~$2M.

3.3 Hydrogeology

The size, depth, and extent of the shafts and drifts of the Homestake Mine offer opportunities to conduct in situ fluid flow and rock deformation experiments on a number of different scales and at different depths. The large number of drifts will permit near-field characterization of various properties over a large range of depths. Perhaps more importantly, they will allow access *across* rock volumes of various sizes, permitting greater control of experimental boundary conditions than is usual. In some cases access may be available at multiple orientations across volumes of rock. Such opportunities are rare; access to the deeper subsurface is usually limited to small excavations or sparse boreholes.

3.3.1 Scientific Objectives

The types of access afforded by the mine can be used to address a number of topics of fundamental interest in hydrogeology and hydromechanics, including fracture permeability and connectivity **[36]**, solute transport and dispersion in fracture networks **[36]**, and the effect of stress state on hydraulic and transport properties **[65]**. Examples of specific questions that might be addressed include the following:

Hydraulics and hydromechanics: (1). Is flow distributed across fractures, largely channelized within fractures, or largely along fracture intersections? **[36]**; (2). How does stress state affect permeability and permeability anisotropy, and can these properties be predicted from the stress state? **[1, 3, 65]**; (3). How do permeability and permeability anisotropy change with depth? **[65]**; (4). How does permeability change with the scale of measurement? **[2, 36, 65]**.

Solute transport: (5). What roles do intergranular porosity, dead-end pores, and velocity variation in fractures play in dispersion and tailing, and does their significance change with scale? (6). What is the source of water now entering the mine? **[37]**; (7). What is the geochemistry of subsurface waters, and how has it been altered by mine activities? **[37]**.

Although the specifics of the hydrogeology and hydromechanics of the Homestake site are of great interest, the greatest payoff scientifically is expected from results that are broadly applicable. For example, fracture permeability at depth (i.e. under high stress) and the mechanisms that control it are of interest for helping to understand the extent to which aqueous fluids can circulate in the crust, transporting energy and dissolved mass and affecting the rock's mechanical behavior.

3.3.2 Approaches and Integrated Experiment Plan

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

Access to rock volumes at various orientations via shafts, drifts, and boreholes (either existing or future and drilled from drifts or from the surface) will permit geophysical characterization (e.g. seismic) for integration with other data to provide a basis for later studies **[39, 47, 62**]. Geophysical tomography may be possible using energy sources and detectors arrayed along shafts and/or drifts.

Two approaches for experimentation with fluid flow, solute transport, and flow-deformation coupling can be contemplated: (a) passively observing the water-rock system under normal operational conditions (water-level rise, dewatering, or stable long-term), and (b) active manipulation of the system. In (a) flow will be dominated by dewatering, that is, mine workings will continue to act as fluid sinks and flow will be generally toward them. In (b), flow direction and magnitude can be changed by altering prevailing inflows or using boreholes from drifts to capture additional inflow or to inject water. Stress measurements will require boreholes drilled from the drifts if stresses are to be determined by either hydraulic fracturing or overcoring.

Both permeability and solute transport behavior may be scale-dependent, making it desirable to conduct these experiments in volumes of rock of different sizes. Ideally, different scale experiments would be nested, that is, rock volumes in the smaller-scale tests would be part of the rock volumes in the larger-scale tests. Research on different hydrogeologic problems therefore should be coordinated so that data collected at a variety of scales will be most useful when integrated.

To the extent that mine workings continue to be permitted to collect inflows (that is, they are not closed-off or their surfaces sealed), characterizing the flow regime around the mine will require measuring fluid pressures away from the drifts using boreholes with packers. Boreholes can be drilled from drifts or from the surface. Such boreholes could also be used to manipulate the flow regime by selectively injecting/withdrawing fluid. Boreholes can also serve to inject tracers for solute transport studies and fracture flow pathway delineation. Alternatively, flow and transport studies can be conducted using the drifts alone, but this will complicate certain analysis; the flow field away from the drifts will be undefined and certain behavioral artifacts may be expected, such as the excavation-disturbed zone.

Mining and dewatering have complicated fluid flow and fluid-rock interactions. Blasting and excavation have probably altered existing fractures, created new ones, and altered stresses near shafts and drifts. Dewatering has introduced air into the system, probably allowing fractures to desaturate near the drifts. Once desaturated, the permeability of a fracture can decrease dramatically and flow may even be diverted from drifts by capillarity. Experimental designs must mitigate these artifacts.

3.3.3 Recommendations and Infrastructure Requirements

The PAC supports the varied range of activities proposed in the LOIs, and the scientific questions which they propose to address. In particular, they enthusiastically endorse those which address issues of scaling in space and time, afforded by the large size and extended occupancy of the proposed laboratory, examine perplexing issues the hydrogeology of fractured rock, and address the roles of coupling between geobiological, geochemical and geophysical processes. Again, the PAC proposes that activities be grouped in support of central themes which examine both the origins and evolution of deep life, and in characterizing the complex coupled processes which control the transformation of the shallow crust.

Access will be needed to certain drifts for short-term cross-drift geophysical characterization and longer-term collection/monitoring of water inflows. Drifts probably will be chosen to provide access to inter-drift rock volumes at different scales and various orientations. Experiment locations will also be influenced by basic data on lithology, geologic structure, major fractures

A capability to drill 100 m or more at various angles from the drifts will be highly desirable for many experiments and related activities. The ability to deploy and set strings of inflatable packers in the boreholes, or to otherwise selectively seal portions along boreholes (e.g. by cementing) will be required to (1) measure fluid pressure and monitor changes in fluid pressure in the surrounding rock, (2) collect water samples without desaturating the fractures, (3) introduce tracers, and (4) inject water to modify the flow system. For example, this would allow the "forced" rather than "natural" gradient tracer tests in order to maximize recovery of the tracer and to accelerate the test. An alternative to drilling boreholes outward from drifts is to use the drifts themselves for hydrogeology experiments. This presents difficulties, noted above, related to drift-local disturbance effects.

Boreholes are also required for stress measurements by either hydraulic fracturing or overcoring. Hydraulic fracturing will require high pressure pumps.

Safe locations will be needed for monitoring equipment such as borehole wellhead pressure transducers, flow meters, pumps, strain meters, tiltmeters, dataloggers and such. Cableways or other modes of data delivery [**13**] will be needed for data collection, as well as electrical power. Packers may be inflated using compressed gas from cylinders. Geochemical and tracer studies may need access to a basic chemistry lab facility that might be shared with microbiologists.

3.3.4 Task Priorities

Certain tasks merit high priority to capture data before they are lost (*Priority 1*), while others will serve as bases for design of other Earth Science experiments (*Priority 2*). The remainder of the hydrogeology and hydrogeology-related tasks do not have clear priorities (*Priority 3*), although a desirable prioritization may emerge as the specific approaches to be used become more clear.

A suggested prioritization by tasks, with references to LOI numbers, is presented below. Note that assignment of LOI numbers does not imply that the task is adequately addressed by those LOIs which may include only aspects of the task.

Priority 1 – Should be implemented as soon as practical to capture data before they are lost. These include: (1) Monitoring of water-level changes and accompanying deformation **[12, 6]**, and (2) Monitoring of water-levels in any surface water bodies, flows in any streams, and water-table levels in any wells above and close to mine workings.

Priority 2 – *Should be implemented in a timely manner to provide critical data for design of hydrogeology and hydromechanics experiments.* These include: (1) Detailed surface geologic map of area of mine **[46]**; (2) Three-dimensional geologic map of the mined rock mass and making data internet available **[11, 45]**; (3) Three-dimensional fracture network characterization **[34, 62]**; (4) Geophysical imaging **[39, 47, 62]**, and; (5) Geophysical tomographic imaging.

Priority 3 – Medium to long-term hydrogeologic and hydromechanical research that may best be implemented using Priority 2 results. These include: (1) Hydraulic properties and connectedness of fractures **[36, 65]**; (2) Modes of flow in fractures; (3) Effects of stress and stress orientation on fracture permeability and permeability anisotropy **[65, 41]**; (4) Changes in fracture permeability and permeability anisotropy with depth **[65, 41]**; (5) Changes in fracture permeability with scale of measurement; (6) Dispersion mechanisms in fracture flow, and transport properties as a function of scale of transport **[36]**, and; (7) Aqueous geochemistry of the Homestake rock mass and human disturbance effects **[37]**.

3.4 Rock Mechanics & Engineering

3.4.1 Scientific Objectives

LOIs relating to rock mechanics and to geohydrology **[1, 2, 3, 4, 34, 35, 36, 40, 41, 43, 60, 62, 67, and 11, 45]** focus on an improved understanding of how rock masses respond to load. The last two are database proposals, and are discussed previously. Load is understood in a broad sense and includes changes in the ambient stress field induced by excavation and loads imposed by gravity and by forces of tectonic origin in geologic time. These latter loads are responsible for the current configuration of the Homestake rock mass that is replete with fascinating folds on folds, distributed slip on foliation planes, kink bands in graphitic schists, late igneous intrusives that cross-cut relict bedding, occasional shear zones, and deep fractures bearing hot water under high pressure, and so on, including massive units that seem indurated to high strength but lack foliation. The great geologic variety and the presence of more than 300 miles of development openings make the Homestake site a most attractive candidate for the study of rock mechanics over scales ranging form micro-meters to several kilometers. Most importantly, these scales can be related in a sound scientific manner at Homestake.

Over a shorter time scale of a decade, there are data that can be updated and used to good advantage in engineering research concerning time-dependent deformation mechanisms of Homestake Precambrian meta-sedimentary rock formations (Poorman, Homestake, Ellison). The lessons learned could well have applicability to other rock masses as the underlying mechanisms are identified and quantified at various scales.

A unique opportunity exists to investigate the mechanics of rock mass deformation in the Yates formation exposed on the 4850 Level between the Ross and Yates shaft. The Yates formation is massive and strong and thus a candidate for the 100-kiloton, water-filled neutrino detector caverns (10 proposed) that are strongly supported by the physics community. Site characterization studies linked with laboratory scale (several centimeters), intermediate scale (large block, several meters), excavation scale (tens of meters), and the far field scale (hundreds of meters) would be enormously productive towards better understanding the fundamentals of rock mass mechanics when linked to laboratory testing, followed by large block testing, excavation of a pilot scale cavern, and construction of full scale detector caverns.

Having a dedicated facility where science and engineering have the first and only priority would aid considerably in advancing knowledge on a broad front of many disciplines and in achieving specific study objectives by teams of investigators who have expressed great interest in the Homestake site. There would be no surprises and delays that could be encountered if the mine were operating as a mine with business as the first priority.

There are opportunities for cross-disciplinary studies, especially with, geohydrology. Under stationary stress fields there is no rock mass motion, but fluctuating fluid flow or changing stress fields will induce coupling between fluid flows and solid deformation that is of great interest. Progressive failure of an initially intact rock mass that experiences fluid infiltration of a growing fracture network would be an experiment of considerable scientific and engineering value under the controlled conditions possible at the Homestake site.

The nesting of scales and related structural and material discontinuities over orders of magnitude and the access to a large, three-dimensional rock mass at Homestake makes for a fertile scientific field of observation using a suite of visualization and imaging techniques from x-ray micro-tomography at the grain scale in the laboratory to large arrays of passive micro-seismic monitoring and related tomography on the scale of hundreds of meters.

3.4.2 Approaches and Integrated Experiment Plan

There is a commonality of approach to the proposed studies in rock mechanics to a certain extent in related, coupled, geohydrology and geophysical studies, which is simply the use of the extensive development openings at the mine for gaining access to a large, three dimensional rock mass that has features that compel research proposals by the numerous proponents who have submitted LOI's. A companion to the approach is the availability of the databases, especially, the geologic model of the Homestake. This model would be essential to planning a research campaign. Access is needed to locate geophones, collect samples, inject and collect water and so forth.

3.4.3 Recommendations and Infrastructure Requirements

The PAC supports the broad array of LOIs which address the scientific understanding of the mechanical response of the rocks containing the proposed DUSEL. The proponents are encouraged to organize science questions around the prior themes of deep life and of complex coupled process interactions. However, in addition, the rock mechanics studies have an important contribution to make to the safe operation of the laboratory, and to the provision of early experimental data in support of the design and construction of large caverns. Some of these data may be derived from proposed large-scale coupled process testing efforts, but other data will be needed from instrumented drift structures and the measurement of conditions local to the proposed locations of the large caverns.

Requirements for a locker room, including storage for cap lamps, safety training, supervision underground (one is not free to roam) and so on are assumed, as are utilities, electrical power, water, compressed air, transportation, and other ancillary services normally available at depth. All LOIs require **access**. Access implies safety in ingress and egress, so there is a related cost to re-establish safe air and safe ground conditions. If re-scaling, bolting and strapping (and mucking) is required, then the cost will be higher. However, such costs would be far less than driving a new drift as would be needed at Henderson.

There seem to be two distinct categories of access requirements: (1) access provided by the Early Implementation Plan (EIP), mainly to the 4850 Level, and (2) access to a large, three-dimensional rock mass. These access requirements are aligned with the engineering (1) or scientific (2) nature of the proposals. This same alignment extends to time. The few engineering proposals are immediate because they are concerned with the possible design and excavation of the unprecedented 100-kiloton neutrino detectors which has strong support from the physics community. The scientific studies extend over longer time periods, although excavation would involve several years effort or so. In this regard, excavation of large detectors would provide the rock mass disturbance needed by the proposals that involve passive observational monitoring. The instrumentation for such could be used for the dual purpose of scientific study and engineering safety.

Should access beyond 4850 be developed in consequence of Homestake becoming the DUSEL, then regaining access to other mine levels would require coordination amongst investigators seeking large access, for example, those that seek to resolve issues of scale in geomechanics and coupled geohydrology.

3.5 Summary

A deep underground science and engineering laboratory would allow many significant questions in Earth science, in geobiology, and in subsurface engineering to be addressed. Although a culture of large, centrally orchestrated experimental programs in these areas of science is less well developed than in other scientific communities, the proposed endeavors remain crucial to the success of a DUSEL. A large number of the proposed individual investigations may be grouped around two central themes: deep life, and in characterizing the complex behavior of the crust. The first attempts to answer fundamental questions regarding the origins and evolution of life, at depth, in an extreme environment, where life-sustaining resources are meager. The second examines the role of the complex interactions of stress, temperature, chemistry, and biology on the response of the Earth's crust and its fluids at large spatial scales and over the long-term – both in support of science and in the safe engineering of the very large-span caverns proposed in the parallel astrophysics program.

These two areas – deep life, and coupled processes – have been enduring central themes within the deliberations of the S1 community, and have evolved naturally from the LOIs considered here. Almost all the LOIs previously identified within **Section 3** fit within either of these two unifying themes, and could be grouped by the various PIs into well-defined and holistic themes, with shared infrastructure, and using common staging areas, probing, sampling, perturbing, and observing a common physical test-block within the proposed DUSEL.

Deep Life [This theme potentially includes LOIs: 15, 28, 29, 32, 38, 53, 70, 75, 77, 79, 80, 81, 82, 83]: This grouping of experiments probe the adaptation of microbes to subsurface conditions, and the limits of life in extreme terrestrial environments. They involve programs of chemical and biological sampling and related analysis of subsurface rock and fluids, preferably at a range of locations throughout the mine. These experiments differ from those applied in the coupled processes facility, in that they require access to an array of locations, rather than observing the response to the coupled process block to applied perturbations.

Coupled Processes [This theme potentially includes LOIs: 1, 2, 3, 12, 13, 24, 34, 35, 36, 37, 39, 40, 41, 43, 47, 55, 60, 62, 65, 67, 76, 78]: This grouping of experiments address problems of acute societal interest in resource utilization, the safe sequestration of wastes, the development of underground infrastructure, as well as fundamental scientific questions about the role of coupled processes in the evolution of the crust. The ensemble group of experiments would examine complex questions of the mechanical, chemical and biological response of the Earth's crust, to anthropogenic and natural perturbations, where vexing questions remain. Foci are in developing and verifying improved methods for the characterization of rock masses, in determining structure and the properties which control the mechanical, transport, and transformation of rock masses at length scales of scientific interest. Related to this is the desire to observe the complex processes which contribute to the transformation of rock masses, in real-time, and to develop an improved and fundamental understanding of such processes. In the short term, such experiments can also contribute to the design of proposed large chambers, including the results from purpose built experiments, and the early instrumentation of excavations.

Since the overwhelming majority of proposed experiments fit within the rubric of these dual themes – deep life and coupled process interactions – common infrastructure is recommended in support of the early implementation of these collaborative endeavors. These focus on a single experimental facility for Earth science, geobiology, and subsurface engineering, initially at the 4850 level, including the provision of shared infrastructure facilities, identified in **Section 6**.

4 EXTENDED & BROADER SCIENCE

A number of LOIs do not readily fit into the main themes of Physics and of Earth Science & Engineering, prescribed in this report for the primary subdivision of activities. These extended topics include LOIs **17, 23, 26, 33, 42, 51, 57, 71,** and **73**, and are discussed, following.

4.1 Diurnal Rotation [23]

A highly resolved knowledge of the diurnal rotation of the Earth is important in a variety of cosmological observations. The ability to improve measurements of the length of day or the Earth's rotation rate over current measurements using GPS, VLBI, LLR, and SLR is feasible through the use of an evacuated drop-tube facility. A preliminary proposal for this effort is included in LOI **23**, although extensive details are not given. However, the degree of improvement over current measurements, and the need for such improvements over existing methods, e.g. that described at the website: http://hpiers.obspm.fr/eop-pc/products/combined/eopcomb.html, is not clear.

Potentially such a facility could cohabit a shaft used other purposes, such as the search for the Neutron-Antineutron $(n \rightarrow \overline{n})$ transition [7], or the cloud chamber facility **[33]**, and exist as a shared facility. In common with the experimental facilities for $n \rightarrow \overline{n}$ **[7]**, an evacuated column is required in both experiments, and there may be some feasibility to combine activities.

Recommendation: The committee endorses the potential use of one of the shafts for such a purpose, identifies the potential for completing multiple experiments **[7,23]** within a shared evacuated tube within one of the shafts, and notes the need for sound engineering to minimize potential hazards from the presence of a large (and energetically-charged) evacuated tube. The proponents are encouraged to seek funding from their sponsors.

4.2 Cloud Physics [33]

Water vapor within the atmosphere exerts an important control on the energy budget of the planet, with concomitant controls on the understanding of weather, its modification, and on the evolution of climate. Necessary scales of observation range from the sub-micron to the kilometer, and present a perplexing challenge in observational science – the need for observations at fine resolution, but accommodating nucleation trajectories that sample the full scale and heterogeneity of the cloud structure. Some of these inherent difficulties may be overcome through the proposed provision of a very-large-scale cloud chamber proposed for installation within one of the available vertical shafts.

Such a facility would be unique, enabling new experiments in atmospheric science to be approached. The vertical depth (~1 km) is appropriate for the study of small cloud formation and would enable new observations that cannot be otherwise made: i.e. the Lagrangian sampling of clouds during realistic ascents, providing a history of particle growth and interactions throughout the "lifetime" of the cloud. "Benchtop" laboratory experiments can follow the evolutionary histories of particles, but only for a very small fraction of the time particles would exist in real clouds (the scales in time and in space are insufficiently extensive). Conversely, airborne measurements can sample true atmospheric clouds, but only in an Eulerian framework, giving snapshots of the cloud along pencil-like trajectories: i.e. particle histories cannot be followed. A vertical wind tunnel on the scale of DUSEL would be unique, and enable new observations and discoveries in cloud physics.

Recommendation: The committee endorses the potential use of one of the access shafts for this activity, potentially in combination with other proposed uses for the shafts **[7, 23],** and encourages the proponents to pursue funding from their sponsors.

4.3 Geoneutrinos [71]

One area where fundamental and practical sciences converge is in the understanding of how the Earth gets its energy. The major source is the Sun; a lesser but significant source is the Earth itself. Studies emphasizing the former, solar neutrinos, has been richly rewarded with understanding of energy production by solar fusion and with forefront discoveries regarding the nature of neutrinos. Energy production by the Earth is the source of geothermal energy as well as the energy driving volcanoes and earthquakes and, ultimately, the recycling of the crust through plate tectonics. The nature of energy production in the Earth is not as well understood as that in the Sun.

It is likely that nearly all of the Earth's energy production is radiogenic. It is thought that the core (out to about 3500 km) consists primarily of molten iron, and that the remainder (mantle and crust) contain heavy elements (mainly uranium and thorium) that act as the radiogenic sources for heat generation. The measured net heat flow at the surface, however, appears to be larger (by a factor of three) than the heat estimated from sources in the mantle. A limited number of possibilities exist for reconciling this conundrum.

Heat from decays of heavy elements must produce antineutrinos, with different spectra from different elements. Detecting these geoneutrinos that originate within the Earth would permit (a) measuring their total rate; (b) measuring the ratio of neutrinos from ^{238}U to ^{232}Th; and (c) testing the hypothesis of a nuclear reactor in the core that supplies a substantial fraction of the Earth's heat. Such measurements are possible; indeed, the KamLAND collaboration has recently succeeded in doing so in Japan. Unfortunately, that measurement is severely limited by antineutrino backgrounds emitted by many nearby powerful nuclear reactors.

The proponents argue that the Homestake location is much more conducive to handling backgrounds and interpreting the results. Few reactors are nearby and the near surface uranium reserves in the U.S. are well understood. They convincingly argue the feasibility of such measurements by examining the pros and cons of existing KamLAND and Palo Verde antineutrino detectors at Homestake.

Recommendation: The committee is enthusiastic about the scientific importance of making these measurements. The arguments are convincing that the Homestake mine, probably at the 4850' level, is a desirable site for a detector to carry out the research. Much remains to be done to assemble a collaboration, plan for the measurement in detail, and design a detector. Given the needed planning, as well as the size and cost of an appropriate detector, the program will not be in the time frame of the Early Implementation Program. But the committee recognizes the importance of the science and the experimental promise. We encourage the proponents to pursue this goal and we look forward to seeing positive developments.

4.4 Effects of Energetic Particles [17, 26, 42, 51, 57, 73]

A variety of LOIs propose to use the facility as a shielded environment to evaluate the impact of energetically charged particles on manufactured products **[17, 26, 51, 57],** especially electronic devices, and upon biological systems **[42, 73].** In common, these proposals uniformly require access to the underground environment, for low-background shielding and counting, and to low-background counting facilities **[19, 54**]. The idea is that variable-term-of-occupancy laboratory space be available underground, as an incubator for experiments that may not conveniently fit within the more tightly-defined physics and Earth science/engineering focus of the Lab. This incubator space would be available, via a review process, to experiments requiring access underground (for shielding). The potential availability of such space, and related shared facilities **[e.g. 19, 54]**, would be an enabling factor in allowing such projects to seek funding and the appropriate clearances from their potential sponsors and regulators.

5 EDUCATION & OUTREACH (E&O)

The South Dakota Science and Technology Authority (SDSTA) began with clear E&O objectives. After many workshops and solicited inputs, they now have a well developed plan involving broad educational goals, as well as outreach to the broader community. The invitation for letters of interest resulted in several specific responses, including **LOIs 5, 9, 16, 27, 50, 66**, and **74**. These provide specific suggestions for implementing particular E&O programs. All are worthy of further study and discussion. We concentrate here on specific interconnections with the scientific programs.

Motivation for the original South Dakota funding involved a recognized need to broaden the scientific and technical educational resources within the State, while making a broader community aware of the rich history and aesthetic beauty of the Black Hills region. In addition, the site provides great opportunities to support efforts for previously under-represented minorities in science; including Native Americans, women, and people from rural areas. All these motivations are complementary to and can be symbiotic with the goals of a national Deep Underground Laboratory for Engineering and Science (DUSEL).

The SDSTA already plans to fund and utilize renovation and construction of substantial parts of existing surface infrastructure to provide learning and museum space. Classroom and living space for summer schools - serving students, pre-college and college level teachers - would provide great educational benefit. With experimental activity at the site, enrollees could participate in hands-on research on forefront scientific operating programs. The possibilities for mutual benefit are enormous.

The Black Hills region is already host to about three million visitors a year. The Homestake mine represents an important part of the history of the area, impacting the social and economic history of the region, as well as understanding of the region's geology. The Authority plans to house a museum to educate the broader public on this history. The ground-breaking and Nobel-prize winning Davis neutrino experiment was carried out in the Homestake mine. This direct local connection to fundamental science is an obvious potential highlight for this museum, and would afford an exciting opportunity to provide a clear exposition of how the Davis experiment was pivotal in bringing new understanding about neutrino properties as well as corroborating the source of solar energy – directly or indirectly the source of nearly all the energy used on Earth.

It seems quite natural to build on this unique base with the complementary opportunities provided by a national laboratory housing underground facilities (DUSEL), housing a variety of fundamental physics experiments along with activities aimed at understanding geological principles and biological processes. Combining aspects of these activities with E&O will provide synergistic benefits that are much greater than a simple sum of parts. To derive maximum benefit, the scientific activities should dedicate some fraction of their efforts to meshing with the educational and outreach efforts of the entire enterprise.

It is also essential for the Laboratory to achieve a "critical mass" of scientific personnel in residence as early as possible. Early substantial scientific presence will make the Lab a desirable place to work, as well as provide a stimulating environment in which ideas can be exchanged among scientists while the knowledge and techniques of science are communicated to the broader community of students, teachers and general public. To quickly assemble a resident community of active scientists, to mesh with the E&O activities, needs planning.

To optimize efforts in resolving the "chicken and egg" problem of attracting a substantial number of scientific personnel early, the PAC suggests some steps that could be started soon.

1. Encourage joint scientific appointments between the Underground Laboratory and nearby universities for individuals who will further the science of the Laboratory and spend substantial time on site.
2. Establish a number of prestigious postdoctoral named fellowships endowed by SDSTA to work at Homestake in both physics and Earth science. These would attract the very

best candidates, funded to work on Homestake experimental programs (of their own choice). Individuals in such positions might be expected to spend a defined fraction (~15%) on educational and outreach activities of the Lab, perhaps communicating their own work in the schools and museum. Named positions, like “Davis Fellowships” have been suggested.

3. Encourage visitors, mostly in the summer months, to spend time at the Laboratory to work with experimenters in residence, and to contribute to the E&O activities.
4. Establish Summer Institutes of limited duration, but intensive in scope, bringing together broad groups of scientists to exchange ideas related to the science of the Laboratory.

The vitality of a national underground laboratory, both as a center for original research, as well as a communicator of the ideas of science and technology, will profit from an early presence of a substantial group of scientific personnel. This should be recognized and encouraged early.

6 SHARED INFRASTRUCTURE

For optimal operation of the underground Laboratory space, many important shared needs among experiments should be considered for shared infrastructure provided by the Laboratory. Some of these would be important in any case as part of Lab management responsibilities, like safety. Hence, the needs of experiments are worth considering before operational systems are finalized. In this regard, the more specifically the earlier (and even later) experiments can be envisaged, the better for anticipating future needs, and in reducing costs.

The Laboratory must provide the usual management oversight involving safety, space assignment, etc. To assure optimal operation, the Laboratory could broaden the scope of infrastructure assistance. The committee considered the following to be among issues worth pursuing.

General and on Surface:

1. Permanent technical and scientific staff, including liaison personnel.
2. Electronic access to mining and geologic databases, and physical access to the core archive.
3. Basic wet chemistry laboratory and BSL level 1 microbiology laboratory.
4. Receiving and shipping facilities.
5. Office space for visiting and resident scientists.
6. Telephone and high speed internet capability.
7. Global position (GPS) receiving service of appropriate precision.
8. Temporary housing and transportation provision or referral.
9. Meeting and videoconferencing facilities
10. Computer room with climate control.
11. Storage containers for transport underground

Experiments and Underground

1. Low-background counting and shielding facilities.
2. Combined basic wet chemistry/BSL level 1 laboratory (at 4850 ft level).
3. Liquid nitrogen facilities necessary to service small, and possibly larger, experiments.
4. Clean room laboratory space of a general nature that can be used temporarily for specific tests, preparations for experiments, and assembly of experimental equipment.
5. A facility for cleaning of pieces of experimental apparatus with high-purity and low-radioactivity solutions, including a mobile cart that can be moved into experimental halls.
6. Broadly available capability for drilling and the installation of equipment in boreholes, and more infrequently, excavation capability. Standardized drilling and core recovery sizes, and associated packers, injection testing, hydraulic fracturing, stress-measurement and down-hole geophysical equipment.
7. Monitoring room for data feeds from pressure transducers, stress and strain cells, multi-component geophones and displacement meters (at 4850 ft level).
8. Space for large blocks for coupled process testing (at 4850 ft level).
9. Radon free air, probably piped from above the surface, to underground locations that require it.
10. General purpose water shields that could provide neutron shielding for smaller experimental requirements, if the early experimenters find such to be useful.
11. Communications systems as required.
12. Machine shop and engineering staff for fabrication and repairs.
13. Cryogen storage, the storage of radioactive sources, and DI water supply.
14. Uninterrupted power supplies (UPS) to reduce the downtime on experiments and to retain ingress-egress capability and ventilation.

In addition to these infrastructure needs, which will serve many experiments, there are potential advantages in coordinating and co-locating certain experiments, to benefit from more specific shared infrastructure. Examples of these, considered by the committee include:

1. **Low background counting:** These capabilities will have widespread application to experiments and initial facilities on surface, and underground will be required as part of the EIP.
2. **Underground copper or germanium electroforming:** These capabilities are desired by a small subset of experiments, and could be combined at relatively low cost.
3. **Collocation of shaft experiments:** Access to a vertical shaft is required by at least three of the **LOIs [7, 23, 33]**. Collaborative use of a single shaft would significantly reduce infrastructure costs, increase viability of the individual experiments, as part of an ensemble package.
4. **Collocation of underground laboratories for Earth science and engineering:** A large proportion of the experiments related to geobiology, hydrogeology, and rock mechanics, which will examine the interaction of coupling between chemical and physical processes (coupled processes) may benefit from collocation. This would include the provision of a laboratory, central to the experimental facility (as outlined in **Section 3.2.3**), and the sequencing of multiple but coordinated experiments on a well characterized block (the coupled processes facility). This provision would at the same time allow the consolidation of infrastructure needs, and encourage collaborations not yet envisaged by the multiple proponents for the Earth Science, geobiology, and engineering experiments. This includes the ensemble set of LOIs presented in **Section 3**.

7 RECOMMENDATIONS AND CONCLUSIONS

The more than 80 letters of interest submitted to Homestake were found to represent a broad array of scientific issues. The committee identified many novel and exciting ways to investigate nature. The volume of compelling science contained therein argues eloquently for a Deep Underground Science and Engineering Laboratory (DUSEL) in the U.S. Though the consequences of not investing in a DUSEL might result in it being done a facility located in another country, it became clear that in many the instances, the science may not be done at all. The request for LOIs shook loose a plethora of experimentally accessible issues: the potential presence of a U.S. dedicated laboratory clearly stimulated the creative energies of U.S. scientists.

By and large, the letters were a pleasure to read. They contained initiatives of very different backgrounds. They varied from novel but undeveloped ideas all the way to programs that have been progressing over a long period through substantial R&D. This final chapter of the report emphasizes identifying those issues that the committee feels require early further investigation. We attempt to highlight those programs that appear now to fit into the Early Implementation Program; ie, those that would benefit substantially by being considered for incorporation into the DUSEL as early as possible

7.1 Physics Projects for the Early Implementation Program (EIP)

7.1.1 Neutrinoless Double Beta Decay

This science is crucial to our understanding of the nature of neutrinos. Experiments detecting this nuclear process may be the only way to discover and measure the Majorana nature of the neutrino particles and the absolute scale of neutrino masses. The two experiments (**LOIs 49 and 61**) represent excellent physics at the very forefront of the field. Both the EXO and Majorana experiments are outstanding opportunities for Homestake. We recommend that the Lab encourage their location there and plan on housing them as early as is feasible. Early needs -- such as the underground copper electroforming planned by Majorana for their cryostats -- should be accommodated as soon as funding and space is available.

7.1.2 Dark Matter (DM) Detectors

Dark Matter investigations seek answers to issues at the forefront of fundamental physics and cosmology. All seven experimental programs described in the Dark Matter LOIs are worthy of consideration for location at Homestake. SuperCDMS and ZEPLIN IV/MAX have accepted invitations to install their next stage detectors in SNOLAB towards the latter part of 2007. Mini-CLEAN, XENON and DRIFT-III have also been invited to locate there, but have not yet responded. The new-technology ZEPLIN and SIGN experiments are in relatively early R&D stages. The new Homestake lab could comfortably house all of the dark matter experiments, but it does not appear realistic to expect all to appear during early operation. In our judgment, the XENON100 program and the Mini-CLEAN program (**LOIs 59 and 56)** are the two most likely to require underground space during the early program. Since both groups were also invited to install their detectors in SNOLAB, collaboration decisions will be necessary. Discussions should proceed with these groups to best delineate how their needs can be met at Homestake as early as possible.

7.2 Physics Projects for the Intermediate Term

7.2.1 Other projects described in section 7.1

In all the programs described in section 7.1, the science has been judged by the community to be forefront and urgent. The LOIs specifically selected for the EIP had to do primarily with the availability to make use of a DUSEL on an early timescale, as contrasted with the others, which often represent programs already committed to other laboratories or to programs in early stages of development. The projects described here also represent forefront science; inclusions in this section are primarily consequences of the envisaged time frames. All these programs could clearly make good use of underground laboratory facilities in the intermediate and longer terms. But there may also be reasons, presently not envisaged, where R&D required to bring the project to fruition require or are greatly advanced by utilizing early space at Homestake. One great feature of the Homestake facility is the almost unlimited available space, even in early stages.

7.2.2 Long Baseline Neutrino and Proton Decay

The Committee agrees that that the case for a very large multi-purpose underground detector at DUSEL is extremely compelling. The two technologies being considered, with Water Cherenkov and liquid Argon detectors, could be located at the 4800ft level. The Committee believes that the physics program of the very large detector would be very important for DUSEL in the long term and represents considerable motivation for the Lab's existence. Such a project is, however, much too large to be part of the first two year physics program. DOE and NSF have recently charged NUSAG with charting a course for future accelerator-based neutrino oscillation experiments and facilities in the USA. They are expected to report their findings and recommendations later this year. Concurrently, a Fermilab-BNL task force is studying the feasibility and cost of directing an appropriate wide band neutrino beam to DUSEL.

If NUSAG recommends sending a neutrino beam to DUSEL or at least strongly recommends further study, the Homestake Lab should respond by facilitating engineering studies, detector R&D (for both Water Cherenkov and Liquid Argon) and collaboration formation. If NUSAG does not endorse the very long baseline neutrino oscillation program at DUSEL, it is questionable whether the stand-alone program of the very large detector (proton decay, neutrino astrophysics etc.) will be enough to justify its expense on an intermediate time scale, particularly since very large detectors proposed in other parts of the world will compete. The Homestake lab should try to contribute as much as possible to the NUSAG study and be prepared to respond to its final recommendations.

7.2.3 Solar Neutrinos

The Committee finds that developing a gaseous TPC could make valuable contributions to both solar neutrinos as well as Dark Matter issues. The committee recommends submission of a technical proposal for underground background studies when they become feasible; in the meantime the committee endorses the research and development of this detector technology, potentially culminating in a proposal for a full-sized CLEAN detector of 10-100 tons. The committee encourages research aspects of the mini-CLEAN research program that directly address the potential for a future solar neutrino experiment.

The committee endorses research and development towards a full scale LENS experiment (**LOI 4**). The committee also notes that operation underground could be a valuable learning experience for eventually operating a full-sized experiment underground, and so encourages the group to consider operation at Homestake under the Early Implementation Program should the proponents succeed in constructing their prototype detector.

7.2.4 High Current Ion Accelerator

An underground HCIA could form one of the high-profile activities at DUSEL, providing first-rate scientific advances. We encourage the proponents and Homestake to work together to develop a plan for deployment of an HCIA. Though it is unlikely that an underground heavy ion project would begin during the Early Implementation Program, certain studies are desirable early, particularly screening of low-background construction materials.

7.2.5 Neutron – Antineutron Conversion

The Program Advisory Committee finds this LOI of significant scientific merit, and endorses consideration as a long-range possibility for DUSEL. For the Early Implementation Program, the PAC recommends the engineering and feasibility studies needed to develop a full proposal and technical design in approximately 5 years. In particular, the PAC agrees with the proponents that serious infrastructure questions must be addressed, and encourages them to work with the Laboratory to do so.

7.3 Earth Science, Geobiology & Engineering Projects for the EIP

Proposed experiments in Earth science, in geobiology and in engineering range from the earliest recovery of perishable data, involve run-of-mine exploration to determine engineering, geophysical, geochemical and geobiological attributes, and extend to long term campaigns using multi-investigator teams. Although broadly defined within the disciplinary interests of geobiology, hydrology, and rock mechanics, the scientific objectives of this diverse group are better referenced relative to two main themes: deep life, and in characterizing the complex behavior of the Earth's crust. These have been persistent themes with in the community-wide S1 discussions, and encapsulate critical contemporary issues in Earth science and engineering. Experiments arrange around two main themes:

Deep Life: These experiments examine the adaptation of microbes to subsurface conditions, and the limits of life in extreme terrestrial environments where life-supporting nutrients are meager. They seek to locate and identify life, and to characterize the environment in which that life either survives of thrives. These experiments require access throughout the mine, and ultimately to reach below the open depth of the DUSEL.

Coupled Processes: These experiments use advanced methods for the characterization of rock masses to examine the complex mechanical, chemical, and biological response resulting from anthropogenic and natural forcing. The emphasis is on developing and testing improved methods for the characterization of rock masses, in determining structure and the properties which control their response and transformation at length and timescales of scientific interest. These studies can also contribute to the safe design of the proposed large caverns.

7.3.1 Perishable Data

The PAC strongly supports these data gathering, assimilation and packaging activities and encourages SDSTA to initiate them as soon as is feasible. The provision of accurate mine, geological, and related datasets are of fundamental interest to the broad community of potential geoscience and engineering users of the facility. Care should be taken to ensure that important suites of data are not lost, that the inventorying of core recovers all measurements of likely relevance to the broad suite of users, and that the ultimate mine/laboratory model be easily accessible to the community via electronic open-source access.

These data will support varied scientific and engineering studies proposed in the various letters of interest, for which the proponents are encouraged to seek support, via the peer review process, from their various funding organizations.

7.3.2 Geobiology

The PAC enthusiastically supports the broad array of proposed activities in geobiology and notes that the scientific community driving this research plan is already organizing around the noted principal themes of geomicrobiology, geochemistry, and of biological effects. This embryonic self-organization is encouraged as an effective mechanism for the proponents to successfully seek funding in support of this science. As already noted, principal themes for this work are related to studies of the origins of life, and of the complex interactions of coupled geobiological, geochemical and geophysical processes. The grouping of scientific endeavors around experiments addressing these two themes is viewed as an effective method of both providing coherence to the many LOIs presented, and in optimizing the use of shared infrastructure facilities.

The provisional scheduling of experiments on deep life is: 2006 – 2007, field surveys, identification of sampling sites, and sampling (from near-surface to the 4850 ft. level); 2008 – 2009, characterization of samples for genomics, microbial ecology, bioprospecting, and corrosion effects; 2010 – 2012, deeper level – characterization of metabolic properties of anaerobes and extremophiles; and 2013 -, coupled processes in broad areas of geosciences. These preliminary studies fit within the timeframe of the EIP, and beyond.

Coupled processes experiments relate both to geobiology, but also to hydrogeology and rock mechanics and engineering. These experiments are intrinsically multi-disciplinary, and provide a significant potential to catalyze links across disciplines.

The provisional scheduling of experiments on coupled processes is: 2006 – 2007, study of mine database, field surveys, and sample collection (rock, fluid, and gas); 2008 – 2009, upper test block instrumentation, characterization of samples, and dewatering studies; 2010 – 2012, lower block instrumentation, characterization, and geochemical testing; and 2013 -, coupled process testing at selected blocks. Again, only the preliminary experiments will be addressed in the EIP.

7.3.3 Hydrogeology

The PAC supports the varied range of activities proposed in characterizing hydrogeological processes. In particular, they enthusiastically endorse those which address issues of scaling in space and time, afforded by the large size and extended occupancy of the proposed laboratory, examine perplexing issues the hydrogeology of fractured rock, and address the roles of coupling between geobiological, geochemical and geophysical processes. Again, the PAC proposes that activities be grouped in support of central themes which examine both the origins and evolution of deep life, and in characterizing the complex coupled processes which control the transformation of the shallow crust.

The EIP should include activities related to the recovery of perishable data, and those designed to provide critical data for the design of hydrogeological and hydromechanical experiments. These include detailed geological mapping, geophysical imaging and characterization. In the longer term, experiments would include measurements of the transport characteristics of fractures, and how these characteristics scale in space and time, and with transformations of stress, temperature, chemistry, and biology.

7.3.4 Rock Mechanics & Engineering

The PAC supports the broad array of LOIs which address the scientific understanding of the mechanical response of the rocks containing the proposed DUSEL. The proponents are encouraged to organize science questions around the prior themes of deep life and of complex coupled process interactions. However, in addition, the rock mechanics studies have an important contribution to make to the safe operation of the laboratory, and to the provision of early experimental data in support of the design and construction of large caverns. Some of these data may be derived from proposed large-scale coupled process testing efforts, but other data will be needed from instrumented drift structures and the measurement of conditions local to the proposed locations of the large caverns.

7.4 Earth Science, Geobiology & Engineering Projects for the Intermediate Term

The broad array of candidate experiments, proposed to be initiated within the EIP, will continue into the long term. These will include the twin foci on deep life and of complex coupled process interactions within the shallow crust as enduring umbrella themes.

7.5 Extended & Broader Science

Though several of the proposed experiments do not readily fit within the framework of particle physics and Earth science and engineering, their intrinsic interests and cross disciplinary aspects make them particularly exciting. Two of these experiments, planning to examine cloud physics and variations on the diurnal rotation of the Earth, require use of one of the mine shafts. A potential synergy exists with an experiment to examine the neutron-antineutron transition ($n \rightarrow \overline{n}$), which also requires access to similar infrastructure within the shaft.

7.5.1 Geoneutrinos

The committee is particularly enthusiastic about the scientific importance of these measurements. The arguments are convincing that the Homestake mine, probably at the 4850' level, is a desirable site for a detector to carry out the research. Much remains to be done to assemble a collaboration, plan for the measurement in detail, and design a detector. Given these needs, as well as the size and cost of an appropriate detector, the program will not be in the time frame of the Early Implementation Program. But the committee recognizes the experimental promise. We encourage the proponents to pursue this goal and we look forward to seeing positive developments.

7.5.2 Diurnal Rotation

The committee endorses the potential use of one of the shafts for such a purpose, recognizes the potential for multiple experiments within a shared evacuated tube within a shaft, and notes the need for sound engineering to minimize potential hazards from the presence of an evacuated tube.

7.5.3 Cloud Physics

The committee endorses the potential use of one of the access shafts for this activity, potentially in combination with other proposed uses for the shafts and encourages the proponents to pursue funding from their sponsors.

7.6 Education and Outreach

The Homestake facility will provide important connections with the local community, with other South Dakota educational institutions, with the broader society, and with the national and international scientific communities. We discuss in section 5 various suggestions for interfacing these in an effective way. The major conclusion of the committee, from the perspective of science to be done at Homestake connecting with the broader educational role, is to make sure that the scientific presence at the Laboratory builds up to a critical mass as early as possible. Suggestions for accomplishing this include encouraging joint appointments between Homestake and South Dakota universities, providing sufficient scientific Lab staff, and sponsoring and organizing summer workshops and conferences. These should be initiated at an early stage to ensure the early scientific presence necessary to manage the arrival and installation of experimental programs, as well as to positively influence the Laboratory educational and outreach activities, so as to reflect the past, present, and future science at Homestake.

7.7 Shared Infrastucture

Many issues related to potential shared infrastructure issues are discussed in section 6. Some of these are probably obvious and essential at an early stage, such as appropriate personnel. Others should be driven by the needs at the Laboratory, as defined by the envisaged experimental program. For this reason, the dialog among the Laboratory management, the experimenters who will commit to early presence, and the relevant funding agencies should be early and in depth.

The effectiveness of the Laboratory would be enhanced with a broad suite of shared infrastructure. These resource needs include pervasive themes, such as safety, but also identify important components of necessary infrastructure, both on the surface, and below ground. These include needs for physical space (office space, environment-controlled computer space, conferencing and videoconferencing facilities, housing…..), personnel (scientific, engineering, and technical staff), services (high bandwidth internet access, radon-free ventilation, cryogen supply and storage, UPS……), and dedicated experimental support (biochemistry and chemistry laboratories, staging areas for drilling equipment, space for large block experiments….), in these various locations, both above- and below-ground. More specific recommendations relate to the provision of shared infrastructure for electroforming of necessary metals, the potential collocation of proposed shaft-based experiments, and the provision of centralized laboratory and staging facilities underground in support of the deep life and especially the coupled process experiments.

APPENDIX A

PAC Charge

1. With the information provided at this initial meeting and with subsequent discussions we request that the PAC develop of a scientific program well-suited to the Homestake Early Implementation Program (EIP). We would appreciate a first draft of the science program by late Spring to assist with the plans to rehabilitate the mine and in time for our CDR submission, June 2006.

2. The infrastructure at Homestake may be a limiting factor in hosting all of the proposed experiments and uses. From the Letters of Interest and the February meeting we will learn from the proponents their infrastructure and facility requirements. The EIP will be limited in scope, but we would like to accommodate as many experimental and educational uses as possible. This meeting will be the beginning of discussions between the South Dakota Science and Technology Authority, the Homestake PIs and the experiment's proponents concerning the infrastructure requirements. The PAC is requested to consider the infrastructure impact as well as the scientific merit when considering the experiments. Proponents have been requested to address the five criteria for evaluating the Letters of Interest.

3. We are simultaneously developing the scientific roadmaps beyond the Early Implementation Program. We are requesting the PAC to consider and advise us on longer term roadmaps for Homestake. Several of the LOIs offer staged approaches. These may require going deeper in subsequent phases, expanding efforts, etc. The PAC should take into consideration for the EIP the implications of longer term aspects of the proposals. Again an initial draft of the longer term roadmap by this summer will assist us in planning the rehabilitation of Homestake and would be helpful in our CDR.

4. There may arise situations where the PAC members are conflicted due to their involvement with particular LOIs. We suggest that the PAC adopt practices similar to the NSF and other organizations, where the conflicted members recuse themselves from the active discussion and ranking of that particular proposal.

5. The SDSTA executive director and the Homestake PI(s) will participate *ex officio* with the PAC to assist in providing information on the facility and on similar issues as appropriate.

APPENDIX B

Evaluation Criteria:

1. **Science Goals:** what are the scientific, educational, and/or applications motivations for this proposal? What are the goals for the proposal? If appropriate include as much information on experimental *reach* and parameter space to be covered by the proposal. As appropriate if this proposal is part of the phased approach, what are the subsequent steps and how will the experiment evolve in latter phases?

2. **Infrastructure Requirements and Impact on Other Users**: Using the check lists, estimate the infrastructure requirements of the proposal. You may wish to contact the SDSTA in considering space and access requirements. How will your proposal impact other users? Does it need to be isolated from other users? Will special environmental, safety or health factors need special attention or isolation? What are the plans for decontamination and decommissioning?

3. **Readiness for Deployment - technology**: As appropriate describe the state of required technology. Will additional R&D be necessary to advance the proposal to the deployment phase? What are the plans for this R&D? Describe any risks to the success of the project due to critical technology developments that are required prior to successfully advancing to the deployment phase. Will this R&D be appropriate at Homestake Lab?

4. **Readiness for Deployment - effort and funding**: Describe the collaboration or manpower required to deploy this project. Do formal collaborative agreements exist and is there a functioning management plan/program in place? Are these required for the success of the project? Who are the collaborators on the proposal and what roles do they play and what effort is committed to the program? What is the current status of funding for the proposal? Are proposals or agreements in place with funding agencies? What are the schedules and plans to securing funding?

5. **Environment, Safety and Health**: What are the environmental and safety risks for the project? How will the risks be managed and mitigated? Discussions with Homestake personnel may be warranted to complete this section in completeness.

APPENDIX C

PAC Membership

Physics

Frank Sciulli – Columbia University - Co-chair
sciulli@nevis.columbia.edu

Ed Kearns – Boston University
kearns@hep.bu.edu

Josh Klein – University of Texas, Austin
jrk@physics.utexas.edu

Bill Marciano – Brookhaven National Laboratory
marciano@bnl.gov

Harry Nelson – University of California, Santa Barbara
hnn@charm.physics.ucsb.edu

Hank Sobel – University of California, Irvine
hsobel@uci.edu

Earth Science

Derek Elsworth - Penn State University - Co-chair
elsworth@psu.edu
http://www.ems.psu.edu/~elsworth/

Sookie Bang – South Dakota School of Mines & Technology
Sookie.Bang@sdsmt.edu

Derric Iles – South Dakota Geological Survey
email: Derric.Iles@usd.edu
Internet: http://www.sdgs.usd.edu

Chris Neuzil – United States Geological Survey (USGS)
ceneuzil@usgs.gov

Bill Pariseau – University of Utah
Email: wgparis@mines.utah.edu

Education & Outreach

Charles Ruch - South Dakota School of Mines & Technology
Charles.Ruch@sdsmt.edu

Ex Officio

Kevin Lesko (LBNL); Bill Roggenthen (SDSM&T); Dave Snyder (SDSTA) and other Homestake PIs.

Relevant Resources and URLs for PAC Activities:

NSF S-2 Proposal: http://neutrino.lbl.gov/Homestake/HomestakeS2Response_final.pdf

One-page S-2 Proposal Summary: http://neutrino.lbl.gov/Homestake/ProjectSummary.pdf

Supporting documents for S-2 Proposal: http://neutrino.lbl.gov/Homestake/S2_Supporting_Documents/

Call for Letters of Interest: http://neutrino.lbl.gov/Homestake/LOI/

Agenda for Lead Meeting (February 9-11, 2006): http://neutrino.lbl.gov/Homestake/FebWS/

Written LOIs: http://ktlesko.lbl.gov/LOI-PAC/

Presented LOIs (PowerPoint): http://neutrino.lbl.gov/Homestake/FebWS/presentations/

Presented LOIs (Video): http://linnproductions.com/clients/homestake/

APPENDIX D

Schedule of PAC Meetings and Report Preparation:

2005

8 Dec	LOI provisional submission deadline

2006

27 Jan	Initiating Conference Call. KL, WR, DS, FS, DE
9-11 Feb	LOI Workshop in Lead, SD 9th – First full meeting of the PAC with Homestake PIs 10th & 11th – Presentation of LOIs
17 Feb	PAC members provide an initial evaluation of LOIs. Define short term and medium term experiments (short term ~ 2007 - 2009, mid-term ~ 2009 ~ 2012).
27 Feb	Conference calls to discuss initial impressions and to define a future plan. Separate conferences for (1) Physics, and (2) Earth science.
13 Mar	PAC members contribute initial white papers summarizing potential experiments. Separate formats for Physics and Earth science. Physics: Topics defined in Section 2. Earth science: Topics defined in Section 3.
15 Mar	White papers circulated
18-19 Mar	Consensus Meeting in Chicago.
27 Mar	PAC members contribute revised white papers, based on Consensus Meeting.
5 April	Physics and Earth Science subgroups consider their chapters
3 May	First full draft available for discussion
12 May	Final PAC report submitted

APPENDIX E

Goals and Agenda for March 18-19 Homestake PAC Deliberations

Goals of Meeting:

The first purpose of the meeting is to come to consensus for advice to provide Homestake on the choice of science directions and specific programs that emphasize the short, intermediate and long term futures. For specific science programs, it will be useful to clarify how specific programs fit

1. Essential in the short term (EIP 2 year time frame);
2. Desirable programs and their relative priority in the short, intermediate, or long term;
3. Education and outreach possibilities;
4. Possibilities for shared infrastructure.

We should identify what is expected (Homestake infrastructure, agency funding, physical presence of group at Homestake, and their time frames) that make each desirable program viable.

Areas of shared consensus by the committee should be identified as quickly as possible. Where consensus is not achieved, we should identify a plan to arrive at consensus. This could involve requesting a small group to separately come up with a proposed plan for later discussion at the meeting. For each area of agreement, a small group may be asked to separately draft a short consensus report.

In the end, either at this meeting or in the near future, the PAC must produce a document outlining its recommendations, rationale, and priorities (either specifically or in categories). This will be described at the meeting.

Suggested Agenda

1. Discussion of goals (5 min) KL/DS
2. Description of final desired document (5 min) KL/DS
3. Summary of outcomes and remaining critical issues on white papers
    a. Physics
        i. Each rapporteur/project (5 mins each)
        ii. Suggestion for integration and way forward (5 min) FS
    b. Earth Science
        i. Each rapporteur/project (5 mins each)
        ii. Suggestion for integration and way forward (5 min) DE
4. List areas of consensus, areas still requiring consensus plan ... subgroups?
5. Come to consensus on all areas; for areas where not, identify additional information required.
6. Prepare outline of Table of Contents for final report
7. Final report

APPENDIX F

Listing of Letters of Interest

#	Date Received	Title	Discipline	Principal Investigator	Lead Institution
1	11/21/05	Time Dependent Deformation	Rock Mechanics	Dr. W.G. Pariseau	Uni. Of Utah
2	11/21/05	Scale Effects In Rock Mechanics	Rock Mechanics	Dr. W.G. Pariseau	Uni. Of Utah
3	11/21/05	Stress & Rock Properties of the Yates member of the Poorman Formation	Rock Mechanics	Dr. W.G. Pariseau	Uni. Of Utah
4	11/22/05	Mine Engineering & Management Related Activities	Mining	Dr. Gautam Pillay	SDSMT
5	11/23/05	DUSEL Education & Conference Center	Education & Outreach	Dr. Larry D. Stetler	SDSMT
6	12/2/05	Determination of Water Levels & Stress Release during Dewatering	Geology	Dr. Larry D. Stetler	SDSMT
7	12/2/05	Search for Neutron-Antineutron Transition at Homestake	Physics	Dr. Yuri Kamyshkov	Uni. Of Tennessee, Knoxville
8	12/6/05	Plan for Near Future of High Energy Neutrino Physics at Homestake	Physics	Dr. Al Mann	Uni. Of Pennsylvania
9	12/8/05	Hard Rock Underground Mine Mapping & Surveying	Geology	Dr. Diane Wolfgram	Montana Tech
10	12/8/05	Partitioning of CO_2, H_2O, gold and trace metals between synformal and antiformal fold hinges	Geology	Dr. Diane Wolfgram	Montana Tech
11	12/8/05	Developing an Internet-accessible database of 3D geologic and engineering data	Geology	Maribeth Price	SDSMT
12	12/8/05	Hydrologic Instrumentation of the Homestake DUSEL	Geology	Dr. Arden Davis	SDSMT
13	12/9/05	New Paradigms in Sensing	Engineering	Dr. Steven Glaser	Uni. Of California - Berkeley
14	12/9/05	Effects of Ultralow Radiation Levels on Human Cells	Microbiology	Dr. Betsey Sutherland	Brookhaven National Laboratory
15	12/9/05	Microbial Evolution	Microbiology	Dr. Susan M. Pfiffner	Uni. Of Tennessee, Knoxville
16	12/9/05	Workshops	Education & Outreach	Dr. Susan M. Pfiffner	Uni. Of Tennessee, Knoxville
17	12/1/05	Effects of Cosmic Rays on the Soft Error Rate of Semiconductor Memory Chips at Ground Level	Engineering	Dr. Li Chen	SDSMT
18	12/2/05	Controls on World-Class Homestake Gold Mineralization	Geology	Dr. Colin Paterson	SDSMT
19	12/8/05	Low Radioactivity Measurement Laboratory	Low Backg. Counting	Dr. Ila Pillalamarri	MIT
20	12/9/05	Role of Iron Formations in the Making of Giant Gold Deposits	Geology	Dr. Nuri Uzunlar	SDSMT
21	12/9/05	Thermal History of Homestake Mine	Geology	Dr. Nuri Uzunlar	SDSMT
22	12/9/05	Super CDMS	Physics	Dr. Dan Akerib	Case Western
23	12/9/05	Determination of Diurnal changes in the rotation rate of the earth	Physics	Dr. Gautam Pillay	SDSMT
24	12/9/05	Establishing the Physical Footprint for Future Geoscience Research at DUSEL	Geology	Dr. Larry D. Stetler	SDSMT
25	12/9/05	Developing of a robotic sampler for underground and confined environments	Engineering	Dr. Gautam Pillay	SDSMT
26	12/10/05	Homestake Electrical Engineering Laboratory (HEEL)	Physics	Dr. Robert McTaggert	SDSU
27	12/10/05	Homestake Outreach Program (HOP)	Education & Outreach	Dr. Matthew Miller	SDSU
28	12/10/05	Bioprospecting	Microbiology	Dr. Bruce Bleakley	SDSU
29	12/10/05	Analysis of soil-like materials in the mine	Geology	Dr. Bruce Bleakley	SDSU
30	12/10/05	Biological effect of low levels of radiation-Health Physics	Microbiology	Dr. Robert McTaggert	SDSU
31	12/10/05	Homestake Neutrinos	Offer to Collaborate	Dr. Robert McTaggert	SDSU
32	12/10/05	Establishing baseline data for microbial populations of the mine before and after dewatering	Microbiology	Dr. Bruce Bleakley	SDSU
33	12/12/05	Cloud physics facility and experiments for an underground laboratory	Atmospheric sciences	Dr. John Helsdon	SDSMT
34	12/11/05	Fracture network characterization at Homestake	Rock Mechanics	Dr. Matthew Mauldon	Virginia Tech
35	12/11/05	Risk Assessment of underground space modifications at Homestake	Rock Mechanics	Dr. Matthew Mauldon	Virginia Tech
36	12/11/05	Hydrogeology Collaboration on flow path delineation and modification	Earth Sciences	Dr. Joseph Wang	LBNL
37	12/11/05	Geochemistry collab. for the geochemical evolution of fluids in the Homestake hydrologic system	Earth Sciences	Dr. Joseph Wang	LBNL
38	12/11/05	Ecology/geomicrobiology collaboration for microbe evolution	Earth Sciences	Dr. Joseph Wang	LBNL
39	12/11/05	Geophysics collaboration for imaging	Earth Sciences	Dr. Joseph Wang	LBNL
40	12/11/05	Rock Mechanics and geoengineering collaboration for excavation research	Earth Sciences	Dr. Joseph Wang	LBNL
41	12/11/05	Couple process collaboration for large block experiments	Earth Sciences	Dr. Joseph Wang	LBNL
42	12/11/05	Cosmic ray studies	Earth Sciences	Dr. Joseph Wang	LBNL
43	12/12/05	Characterization and mechanics of faulting and rock fracture at homestake mine	Rock Mechanics	Dr. Stephen Martel	University of Hawaii
44	12/12/05	Breccia evolution associate with degassing of tertiary veins and dikes at Homestake	Geology	Dr. Alvis Lisenbee	SDSMT
45	12/12/05	Development of a 3D geological model of the Homestake mine area	Geology	Dr. Dean Peterson	Uni. Of Minnesota - Duluth
46	12/12/05	Detailed geological mapping of the Homestake mine area	Geology	Dr. Dean Peterson	Uni. Of Minnesota - Duluth
47	12/12/05	Close range remote sensing for mapping of rock in underground excavations	Geology	Dr. Joseph Dove	Virginia Tech
48	12/12/05	ZEPLIN - a multi ton scale liquid xenon dark matter direct search program	Physics	Dr. Hanguo Wang	UCLA
49	12/12/05	EXO - the enriched xenon observatory for neutrino-less double-beta decay	Physics	Dr. Giorgio Gratta	Stanford
50	12/12/05	Educational outreach support infrastructure	Education & Outreach	Dr. Omar El-Gayar	Dakota State University
51	12/12/05	Low-alpha lead and the cosmic-ray equivalency factor	Physics	Dr. Glenn I. Lykken	Uni. Of North Dakota
52	12/12/05	Study of a LANNDD of 100kTon at Homestake DUSEL	Physics	Dr. David B. Cline	UCLA
53	12/13/05	Investigation of microbial diversity in subsurface ecosystems	Microbiology	Dr. Sookie S. Bang	SDSMT
54	12/13/05	Initial low background counting facilities for Homestake	Physics	Dr. Kevin Lesko	LBNL
55	12/14/05	Large block (Pillar) test to study the failure of rock - rock strength and earthquake mechanics	Rock Mechanics	Dr. Derek Elsworth	Penn State
56	12/14/05	Mini-CLEAN	Physics	Dr. Daniel N. McKinsey	Yale

57	12/14/05	Understanding the complxities of long term data storage in space exploration	Data storage	Dr. William Figg	Dakota State University
58	12/14/05	R&D and physics with a 9m3 gaseous time projection chamber	Physics	Dr. Giovanni Bonvicini	Wayne State Uni., Detroit, MI
59	12/15/05	XENON100/1000	Physics	Dr. Richard Gaitskell	Brown University
60	12/16/05	Long term seismic and seismologic monitoring of stress and fluid dynamics in the upper crust	Earth Sciences	Dr. Serge A. Shapiro	Freie Universitaet Berlin
61	12/21/05	The Majorana Neutrinoless Double Beta-Decay Experiment	Physics	Dr. John Wilkerson	University of Washington
62	12/9/05	Deep fracture mapping at DUSEL using acounstic techniques	Geology	Dr. Gautam Pillay	SDSMT
63	12/16/05	Directional recoil identification from Tracks (Drift)	Physics	Dr. Dan Snowden-Ifft	Occidental College
64	12/22/05	High-current ion accelerator	Physics	Dr. Paul Vetter	LBNL
65	1/5/06	Coupled mechanical-hydrological behavior of fractured, rock mass	Geology	Dr. Herb Wang	University of Wisconsin
66	1/9/06	Center for Risk, the community and the environment	Education & Outreach	Dr. Peter Young	The RedWater Group
67	1/9/06	Rock bolt research, backfill testing,large diameter excavation research	Rock Mechanics	Dr. R. L. McNearny	Montana Tech
68	1/12/06	Crustal assimilation of volatile evolution in rhyolite and phonolite dikes	Geology	Dr. Genet Duke Dr.	Genet Duke collaboration
69	1/15/06	Low energy neutrino spectrometer	Physics	Dr. Raju Raghavan	Virginia Tech
70	1/20/06	Microbiological cultivation,community metagnomics, nanogeoscience, and stable isotope analysis	Microbiology	Dr. Eric Roden	University of Wisconsin
71	1/27/06	A Geoneutrino experiment at Homestake	Physics	Dr. Nikolai Tolich	LBNL
72	1/27/06	SIGN - A high-pressure, gaseous-neon-based Dark Matter Detector	Physics	Dr. James T. White	Texas A & M University
73	1/30/06	A longitudinal study of the health of homestke lab personnel exposed to the 4850 environment	Medicine	Dr. Jeffrey A Henderson	BH Center Amer. Indian Health
74	1/30/06	Surface facility planning and design for the Homestake Mine	Education & Outreach	Dr. Jennifer Karlin	SDSMT
75	2/10/06	Impact of subsurface microbial activity on the physical and chemical propeties of geological form.	Microbiology	Dr. T. C. Onstott	Princeton University
76	2/10/06	Large scale vs. small scale tranport of microorganisms and multi-phase CHO fluids	Microbiology	Dr. T. C. Onstott	Princeton University
77	2/10/06	Impact of subsurface microbial activity on the corrosion and deterioration of metallic infrastructure	Microbiology	Dr. T. C. Onstott	Princeton University
78	2/10/06	Deep Coupled Process Laboratory	Microbiology	Dr. Tommy Phelps	Oakridge National Laboratory
79	2/10/06	Ecosystem biochemistry transistioning from Near-Surface to Deep Earth Ecosystems	Microbiology	Dr. Tommy Phelps	Oakridge National Laboratory
80	2/10/06	Limits of life in the biosphere	Microbiology	Dr. Tom Kieft	New Mexico Tech
81	2/14/06	Evolution of Autotrophy	Microbiology	Dr. Bruce Bleakley	SDSU
82		PNNL	Offer to collaborate	Dr. Harry Miley	PNNL
83		Combining advanced microbiological cultivation, community metagenomics, nanogeoscience…	Microbiology	Dr. Brian Beard	Uni. Wisconsin
84		Precambrian research center	Geology	Dr. Dean Peterson	Uni. Of Minnesota - Duluth