A NATIONAL UNDERGROUND SCIENCE LABORATORY 
IN THE U.S.

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Recent developments in underground science are reviewed. Recent efforts to built a deep multi-purpose underground laboratory in the U.S. to explore a wide range of science are summarized.

1. Underground Science

During recent years experiments done underground have produced some of the most significant new results in physics. In addition to ongoing research at the frontiers of nuclear physics, particle physics and astrophysics, underground science also includes some very exciting work going on in geology and biology, as well as potential to impact on applied areas such as materials science and nuclear proliferation. As we illustrate below the multidisciplinary research activity of underground experiments has the potential to make a major impact in the development of modern science.

The field of underground physics has recently made fundamental discoveries that broadly impact physics, astronomy, and cosmology. Neutrinos coming from a core-collapse supernova were detected for the first time in 1987 with the observation of Supernova 1987A in the Large Magellanic Cloud. The same year, two-neutrino double beta decay was observed, which is the rarest process yet seen in Nature. In the 1990’s variations of the atmospheric neutrino flux were observed for which the simplest explanation is neutrino oscillations due to the mixing of mass eigenstates. This result was the first demonstration of existence of physics beyond the standard

*For the full list of membership of the NUSEL Collaboration see the URL “http://mocha.phys.washington.edu/NUSL/collaboration.html#membership”. 


The observation of the heavy-flavor neutrinos in the solar neutrino flux not only resolved the long-standing solar neutrino puzzle, but also provided an additional confirmation of the Standard Solar Model besides helioseismological observations. The pattern of neutrino masses emerging from these experiments implies new physics characterized by an energy scale $\sim 10^{15}$ GeV, many orders of magnitude beyond the direct reach of accelerators. The neutrino mixing angles emerging from the analysis of these experiments are close to maximal. This surprising result has consequences ranging from models of leptogenesis in the early universe to the explosion mechanism and nucleosynthesis in core-collapse supernovae.

Another interesting recent development in underground science is the discovery of novel microorganisms that live deep in the earth. These microorganisms, which show an ability to adopt to extreme environments, provide an excellent opportunity for studying evolution in isolated environments. The young field of geomicrobiology explores how microbial life can exist in dark, hot, and high-pressure environments and the implications of its findings for the early development of life. These life-forms may be the most accessible model for astrobiology, searching for evolution, adaptation, and transport of life elsewhere. Deep underground mines also provide earth scientists and engineers prospects to study stability of large caverns, and thermal properties, hydrology, and ecology of deep rock. In applied science low-background environments of deep sites provide locations for the production and storage of materials free of cosmogenic activity, for the assessment of the effects of radiation damage on the performance of chips and other electronics, and for the establishment of multi-purpose low-background counting facilities.

A recent committee of the National Research Council, Committee on the Physics of the Universe, listed eleven questions about the universe that identify most important and timely science opportunities at the intersection of physics and astronomy\textsuperscript{1}. Underground science will be crucial in answering at least six of these questions, namely i) What is dark matter? ii) How did the universe begin? iii) What are the masses of neutrinos, and how have they shaped the evolution of the universe? iv) Are protons stable? v) Are there new states of matter at exceedingly high density and temperature? vi) How are the elements from iron to uranium made? In general it is widely quoted that two great challenges of the science in the twenty-first century are exploring the nature of the dark matter/ dark energy and the origin and evolution of life. Underground science is likely to make a significant impact on both of these fields.
The next generation of underground experiments is more technically challenging than previous research requiring both significant resources and good planning and management to succeed. Establishment of a single deep multi-purpose underground laboratory will ensure that the needs of the diverse groups of physicists, earth scientists, geomicrobiologists, and others interested in underground science will be met. Such a laboratory will allow a common infrastructure (such as a facility to do low-background counting) to be shared by various research groups and provide an environment where synergistic interactions among scientists working on diverse fields is possible. An underground science laboratory will also provide a critical mass of scientists and engineers for undertaking projects on education and outreach to the general public, both locally and nationally.

2. Bahcall Committee

Current efforts to establish a deep-sited underground science laboratory in the U.S. started during the recent long-term planning exercise in nuclear science. In preparation for this planning exercise a group of neutrino physicists met in Seattle in September 2000 to discuss both the present state of the field and the new opportunities. At the same time it was announced that the Homestake mine, where the Nobel-prize winning experiment of Davis and collaborators has been located, would be closed at the end of 2001. This provided an opportunity to create a deep underground multipurpose laboratory and impetus to move rather quickly to take advantage of this opportunity. The report summarizing conclusions of this meeting rated the creation of such a laboratory as the highest priority of this community.2

Following the Seattle meeting a committee chaired by John Bahcall was formed to evaluate the scientific justification for a national facility for deep underground science and evaluate the suitability of suggested sites. This committee evaluated several U.S. sites including sites at Carlsbad (WIPP Facility), Homestake mine, and San Jacinto in Southern California. For comparison it also visited all major international facilities in Europe, Japan, and Canada. The depths of options considered are shown in the Table 1. The Bahcall Committee noted that that limited depth, and thus excessive cosmogenic background, preclude WIPP and Soudan sites from being general purpose underground science facilities. (For a detailed discussion of the WIPP site see the contribution of Haines)3 The committee endorsed a single primary site as the most effective method of realizing the anticipated scientific program and identified two deep sites, Homestake and San
Table 1. Sites Considered by the Bahcall Committee

| Site                        | Depth (mwe)  |
|-----------------------------|--------------|
| Carlsbad (WIPP), NM         | 1600-2000    |
| Soudan, MN                  | about 2000   |
| Homestake, SD               | up to 7200   |
| San Jacinto, CA             | 5400-6300    |
| Greenfield sites (CA and NV)| 5000-8000    |

Jacinto, as two primary candidates. The depths of various existing underground laboratories as well as several options for the Homestake mine are shown in Figure 1.

The Homestake site has the advantages of having i) Existing access to the proposed main level at 7400 ft; ii) Permissions in place for construction, waste rock disposal and safety; iii) Multiple access routes and venting for all levels; iv) Capacity to isolate risky experiments; and v) Well-characterized and understood rock mechanics. Although vertical access is often considered inconvenient, the Homestake facility has massive shafts and tunnels allowing efficient movement of very large loads to depth. The main issue with this site is the need to transfer the ownership of a privately-owned mine to the appropriate public venue. On the other hand the San Jacinto site has the advantages of i) Construction permitting horizontal access; ii) Being in close proximity to major research centers in California; and iii) Likely lower operations cost. However it will take longer time to the placement of first experiments and permissions for mining, transporting, and disposing the waste rock have not been obtained. Another issue is the viability of the single tunnel design. In contrast to Homestake and tunnel facilities such as Gran Sasso, the integrity of the San Jacinto site cannot be established prior to construction since the necessary core studies are not permitted because of federal ownership.

3. Towards a U.S. Underground Science Laboratory

It took another year after the Seattle meeting in 2000 for the long-range planning exercise for the nuclear physics to be completed. Citing a compelling opportunity for nuclear scientists to explore fundamental questions in neutrino physics and astrophysics, nuclear science community recommended immediate construction of a deep underground science laboratory\(^4\). Subsequently such a laboratory was strongly endorsed by the High Energy Physics Advisory Panel. The Committee on the Physics of the Universe, mentioned above, also recommended in its final report that an underground
Figure 1. Muon flux versus depths of existing underground laboratories and various options for the Homestake mine.

laboratory with sufficient infrastructure and depth be built\(^1\). The elaborations of the physics community was carried through a summer study in 2001 at Snowmass; two workshops (one on physics and one on geomicrobiology and Earth sciences) in the Fall of 2001 at Lead, South Dakota; and an Aspen workshop in the summer of 2002.

Soon after the release of the report of the Bahcall commit-
eee teams representing both deep sites submitted proposals to the
Federal funding agencies in the United States. Their web sites
are http://mocha.phys.washington.edu/NUSL/ for Homestake and
http://www.ps.uci.edu/SJNUSL/ for San Jacinto. The team represent-
ing the Homestake site formed the NUSEL Collaboration. This is a group
of scientists who work on a variety of tasks important to the creation of an
underground laboratory at Homestake.

The U.S. Federal budget request for the fiscal year 2003 asked the Na-
tional Science Council (NRC) to review the merits of several U.S. neutrino
experiments in the context of the current and planned neutrino research
capabilities through the world. NRC formed a committee to answer this
charge. The experiments mentioned in this charge roughly fall into two
classes: Those experiments that study fundamental neutrino properties,
dark matter, and relatively lower energy astrophysical sources (i.e. Sun,
supernovae) require the very low-background environments of underground
laboratories. Those experiments that study very high-energy neutrinos re-
quire large volumes of neutrino telescopes. The NRC committee is expected
to address the unique capabilities of each class of new experiments and
any possible redundancy between these two types of facilities that explore
complementary, but scientifically very different questions. To help this
committee and to produce a road map that will guide investigations world-
wide over the next few years a workshop took place in September 2002 at
Washington, D.C. This workshop was designed to review and integrate the
results of recent developments in neutrino, low background and geoscience
investigations requiring great subterranean depth. With the findings of this
workshop and other results in hand the NRC committee is expected to re-
lease its final report by the end of 2002. The funding agency decisions are
expected after the release of this committee’s report.

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