

DUSEL Program Advisory Committee Report

August 17, 2010

The DUSEL Program Advisory Committee met for the first time on July 27 and 28, 2010 in Berkeley. The Committee heard presentations on the progress towards the Preliminary Design Report to be submitted to the National Science Board. We thank Kevin Lesko, the Principal Investigator for the DUSEL project, and his team for informative presentations on the tasks that have been accomplished and those that are in progress. The Preliminary Design Report is due by the end of the year. We find that the overall progress has been excellent. It will be the basis for an MREFC proposal to start construction of the DUSEL facilities in FY2014. The proposal will include a suite of experiments to be built using a "stewardship" model that details how the responsibilities will be shared by the National Science Foundation and the Department of Energy's Office of Science. In this model, one of the two agencies is assigned as the primary steward of each major experimental program or system within the DUSEL project.

We are impressed by the breadth and depth of the DUSEL science. The envisioned program in physics and astrophysics will address fundamental questions about the Universe and its fundamental laws, such as the question of why the universe contains matter but no antimatter, the nature of dark matter, the origin of neutrino mass, and the genesis of the chemical elements. The biology program will study life in extreme conditions underground to shed light on the origin and evolution of life. The geosciences program will have opportunities to study directly at depth variety of the thermal, hydrologic, mechanical, chemical, biological-mass, and energy-transport phenomena on a scale not done before. The engineering program will study rock properties *in situ* to enable better design and use of underground space. In addition, the Committee felt that the interdisciplinary laboratory, with sustained support, will provide unique scientific opportunities that engage and educate the next generation of scientists and engineers.

The accomplishments of the Sanford Underground Laboratory have been impressive, and without them it would be impossible to consider starting a DUSEL construction project at this point. It is important for DUSEL and the Sanford Laboratory to execute the merger that they have been planning as quickly and seamlessly as possible. In particular, it is critical that the ongoing operations be supported continuously at an appropriate level. We hope that everything will be done to make it possible for that merger to proceed.

DUSEL represents a superb opportunity for education and outreach about science and technology. As the Sanford Laboratory website says, "The location of DUSEL in an economically disadvantaged region with an American Indian population of 8-10% gives the Sanford Center for Science Education a unique opportunity to affect change in this area." The Sanford Center has established a

large presence in a short period of time, and we are encouraged that the DUSEL management understands the importance of the Laboratory's educational mission.

The research in deep underground biology, geology, and engineering (BGE), will be particularly important for education and outreach. Continuing the work in this area started at the Sanford Underground Laboratory and building on it should be considered an essential part of the DUSEL project. The DUSEL facility has the opportunity to be a national leader in earth science education.

We applaud the interagency collaboration in developing the plan for DUSEL, especially the progress in forming a Joint Oversight Group. Perhaps more than for any facility yet built, close coordination among the two agencies and the laboratory management will be necessary to get the optimum scientific return on the investment.

Scientific Program

The flagship scientific program for DUSEL is in the area fundamental subatomic physics, with four ambitious experimental programs:

1. Experimental detection of dark matter particles
2. Neutrinoless Double Beta Decay
3. Nuclear astrophysics
4. Long-Baseline Neutrino Experiment (LBNE) and Proton Decay

In each of these areas of science, the DUSEL experiment would represent a unique contribution to a world-wide campaign. With this scientific program, the Deep Underground Science and Engineering Laboratory will be at the forefront of fundamental subatomic physics worldwide for decades.

In addition, the facility is designed as a platform for a set of experiments investigating the biology and geology deep underground and the engineering challenges of working deep underground.

The LBNE work at DUSEL will be part of the largest project in the national particle physics program, one that will include an extremely intense neutrino beam produced at Fermilab. The Department of Energy is taking the lead role in the entire LBNE project, and that project will need separate approval to go forward. We therefore considered the DUSEL scientific program with and without its LBNE component.

We think that the program of deep underground research at DUSEL is very compelling. Even without the addition of the LBNE, the physics program addresses two of the highest-priority questions in the national program of fundamental physics research, the nature of dark matter and neutrino mass. . About 1000 physicists have been working to develop these experiments as part

of the S4 process, which gives some measure of the enthusiasm throughout the nuclear and particle physics community.

DUSEL will also open up a new set of research opportunities in deep underground biology, geology, and engineering (BGE), supported by a strong central laboratory. The BGE scientific experiments being carried out as part of the Sanford laboratory and NSF S4 efforts address a diverse suite of scientific objectives in the fields of geomicrobiology, geology, geophysics, hydrogeology and rock mass engineering. These experiments take full advantage of the opportunities made available by the DUSEL facility for three-dimensional access to a complex rock mass at considerable depth.

With the LBNE, the highest-priority project on the horizon for the national program for high-energy physics, the DUSEL scientific program will be broader and stronger. The additional investment of \$125 million in DUSEL will be matched by a much larger investment by the Department of Energy. We strongly support the proposed inclusion of the LBNE detector to the DUSEL project, contingent on the approval of the DOE-led project including the intense neutrino source. The scientific value of the LBNE program could receive an additional boost in the future from a proposed accelerator upgrade to the Fermilab accelerator complex. Such an upgrade would increase the intensity of the neutrino beam sent to DUSEL by a factor of three or more compared to the initial LBNE project.

Because of the importance of the four physics programs to the DUSEL project, we briefly discuss the scientific justification for each below.

Dark Matter

The direct detection of dark matter, which makes up 87% of the mass of the universe, remains one of the flagship programs for DUSEL, driven by the fact that it remains a profound mystery and that experiments in DUSEL can probe an exceptionally large part of the cross section range where it could be discovered. The importance of this effort has been highlighted in all studies that have looked broadly at the most compelling physics issues in particle or particle astrophysics over the past decade. Most recently the PASAG (Particle Astrophysics Scientific Assessment Group), reporting to the DOE and the NSF through HEPAP one year ago, looked at the full set of topics in particle astrophysics and related areas in a number of budget scenarios. In all budget scenarios, experiments aimed at the direct detection of dark matter were given high priority and recommended for a significant share of available funding for the field. It was recognized that experiments in this area are very difficult because of backgrounds of various sorts and require a phased approach where experiments of increasing scale probe ever-smaller cross sections while also providing the experience for how to improve measurements in the future.

Dark matter experiments in DUSEL will benefit from this earlier measurement campaign, allowing a significant advance in direct dark matter searches. The depth of DUSEL will be an important element in mounting an improved experiment that can probe a good fraction of the space where we expect dark matter to show up in theories such as super symmetry. It has been recognized that such experiments will ultimately be limited by an irreducible background from the interactions of neutrinos impinging on the detectors. The scale of experiment planned for DUSEL will take us all the way to this limit, if only limits are obtained. If signals are found, they will likely set the stage for future experiments seeking to identify other characteristics of the dark matter, providing a very exciting second phase for dark matter experiments in DUSEL.

There is great interest in DUSEL from the dark matter detection community. Four of the nine Stage 4 experiments seek to advance various techniques for direct dark matter detection. In addition several variants of these experiments also exist and provide additional approaches for detection. These groups have all expressed an interest to work in DUSEL. The various techniques being developed offer DUSEL the option to have an optimized program when the earlier phases of these experiments have been completed.

Neutrinoless Double Beta Decay

The search for neutrinoless double beta decay ($0\nu\beta\beta$) of heavy isotopes is a cornerstone of the worldwide program in neutrino physics. The observation of this process at any nonzero level would establish that the origin of neutrino masses includes physics that is very different from that behind the quark and charged-lepton masses. Thus, the search for this decay is a probe of the nature and origin of mass, complementing the investigation of this topic being carried out at the LHC.

The scientific importance of neutrinoless double beta decay has been strongly emphasized by both the nuclear and high energy physics communities in numerous reports. In particular, the 2007 DOE-NSF Nuclear Science Advisory Committee Long Range Plan included $0\nu\beta\beta$ in the set of the top four priorities for nuclear science for the next decade and identified the construction of DUSEL as “vital” to a nuclear physics program to “investigate neutrino properties and fundamental symmetries.” The importance of this program has been similarly underlined by the 2005 report of the NSAC-HEPAP Neutrino Scientific Assessment Group and the 2008 P5 ten-year strategic plan for high energy physics.

Currently there exists a worldwide program of $\sim 100\text{kg}$ scale $0\nu\beta\beta$ searches, with two experiments receiving significant U.S. support: the CUORE experiment at

Gran Sasso (supported in part by DOE-NP) and the EXO I experiment at WIPP (supported by DOE-OHEP). The next generation of $0\nu\beta\beta$ searches will involve detectors in the one tonne scale. Looking toward this future, the Majorana Demonstrator project at the Sanford Lab (supported by DOE-NP) aims to determine the feasibility of scaling existing germanium detector technology to a tonne-scale detector. The results of this effort, together with those from the GERDA experiment at Gran Sasso that is employing a novel germanium technology for a 100kg scale detector, will determine the path toward a tonne scale germanium detector that could be deployed at the 7400 foot level DUSEL module. A tonne scale version of the EXO experiment could also be a candidate for a $0\nu\beta\beta$ search at the 7400 foot level.

The PAC views the deployment of a tonne-scale $0\nu\beta\beta$ experiment at the 7400 foot level as an essential component of the initial DUSEL experimental program. It would capitalize on the present U.S. investment in this direction; exploit the unique opportunity for a low-background experiment at the deepest level attainable created by DUSEL; and represent a world-leading effort with high discovery potential.

Nuclear Astrophysics

Nuclear Astrophysics continues as a field of fundamental interest, addressing the combined questions of energy generation and nucleosynthesis. The nuclear physics involved in exploding stars is currently being pursued at a number of existing and planned radioactive beam facilities in the US and around the world.

In parallel, measurements of important reaction rates at the temperatures and energies involved in energy generation in the sun have begun to be pursued at underground laboratories such as LUNA at Gran Sasso, utilizing the overlying rock as cosmic ray shielding for the nuclear particle and gamma-ray detectors. In this way it has been possible to push down cross section measurements to the level of picobarns, for example, *directly* measuring cross sections for the ${}^3\text{He}({}^3\text{He},2p){}^4\text{He}$ reaction at the energies relevant to the center of the sun. These initial measurements now need to be extended to heavier nuclear systems with higher energy and more intense beams, but there is no room to expand this accelerator facility at Gran Sasso. As detailed in the White Paper "Nuclei in the Cosmos," DUSEL(4850L) provides an optimum site for such an extension via a facility such as that in the DIANA proposal. Such a facility could be made available to research proposals from outside users and visitors. Without such measurements, calculations of stellar energy generation, neutrino production, and nucleosynthesis must rely on theoretical-model calculations for extrapolations to the low energies of interest and have often been found to be uncertain by orders of magnitude. Hence these cross section measurements are vital to astrophysicists studying models of stellar evolution. One important cautionary aspect of this facility will be consideration of location and shielding to

prevent the possibility of radiation from this project interfering with other low-background experiments at this level.

Long Baseline Neutrino Experiment (LBNE)

The LBNE neutrino oscillation program, with a high intensity neutrino beam directed from Fermilab to a large underground detector at DUSEL, is a very high priority for the US high energy physics program and has been endorsed by a series of review committees, including NUSAG and the 2008 report from P5. The LBNE program will address 3-flavor mixing and CP violation in the neutrino sector. Together with the shorter baseline T2K and NOVA experiments and oscillation results from nuclear reactor experiments, LBNE will either see mass effects and CP violation in the neutrino sector or set stringent limits on the neutrino mixing matrix. Observation of CP violation among the neutrinos would be very important, establishing the first known violation of this fundamental symmetry outside the quark sector. This would increase the plausibility of scenarios in which the cosmic matter-antimatter asymmetry was generated in the decay of heavy neutrinos. This science is very complementary to the DUSEL search for neutrinoless beta decay, since the observation of that decay would be evidence in favor of the physics underlying leptogenesis.

Two promising technologies, water Cherenkov detectors and liquid argon TPC's, have been identified and considered as part of the DUSEL planning process. Final decisions about the detector technology will be made based on results from the current generation of neutrino oscillations experiments, an aggressive ongoing program of R+D and cost and schedule optimization. The Fermilab-to-DUSEL experiment will have the largest effective mass and longest baseline of any neutrino experiment using an accelerator source. This will be a unique facility in the world, with unmatched sensitivity to CP violation and mass effects.

The construction of either detector would also create new opportunities to search for the decay of the proton. A water Cherenkov detector would be sensitive to proton decay modes with much more sensitivity than the Super Kamiokande facility. A liquid argon detector would allow observation of other potentially important decay modes for which any water Cherenkov detector is much less sensitive.

The currently planned LBNE project includes a neutrino beam built at Fermilab using a 700 kW proton source with beam energy 120 GeV. The scientific reach of the program could be increased considerably by a proposed accelerator project, Project X, which would deliver 2 MW of beam at any energy from 60 GeV to 120 GeV. This upgrade would improve the sensitivity of the experiments by a factor of at least 3, without requiring significant changes in the experiments operating at DUSEL.

DOE is the steward for this project, and is expected to provide the bulk of the funding, in particular for the near detectors, beamline and civil engineering necessary at Fermilab. The far detector and associated civil engineering at DUSEL will be a shared responsibility of the two agencies, with the MREFC contribution expected to be \$125M. The LBNE project leverages substantial outside resources from HEP to enhance the neutrino physics program envisioned for DUSEL.

Planning the Experimental Program

While the general parameters of the DUSEL scientific program have been explored in sufficient detail to allow the PDR to be prepared with a reference suite of experiments, decisions on specific scientific programs have not been made. Over the next year, the PAC will work with the DUSEL management to develop a framework for solicitation and evaluation of proposals for specific experiments.

The four research programs that represent the core of the DUSEL physics program have clearly identified goals and scientific collaborations that have been working on developing the experimental designs for years. That is not the case for the biological, geological, and engineering research programs. Once the DUSEL facility is approved, there is a clear need to make the broad scientific community aware of the potential of DUSEL to carry out experiments that address first-order questions. The most interesting experiments might be done by scientists who have not yet considered working at the Homestake site. The PAC stands ready to help facilitate the advertisement of this opportunity, to introduce DUSEL BGE science with appropriate programs within NSF, DOE and other agencies and to assist in the scientific review process as appropriate.

Facility planning and integration

In this section we call attention to some issues that apply to the entire facility, rather than individual experiments.

Design of laboratory facilities

The DUSEL leadership has carried out the very difficult task of drawing a set of requirements for the laboratory modules and infrastructure needed to support the initial suite of experiments. This required gaining a working knowledge of an impressively broad range of experimental designs. It also required thoughtful consideration of the projected needs of each experiment, on the one hand, and the imperative to mount an experimental program broad enough to justify the construction of the laboratory. At our first look, the laboratory has done a good job of developing a preliminary design that optimizes the initial scientific program.

Optimal use of the 7400 level

The additional shielding of cosmic muons at the 7400 level is an advantage for any experiment that needs low radioactive background. Such deep experimental facilities are very rare, and the availability of the 7400-level laboratory is a very important part of what DUSEL contributes to the science that needs low radioactive backgrounds. Such space comes at a significant premium, however since it is more expensive to create and to maintain. It should be demonstrated that an experiment is likely to be limited by muon-generated backgrounds before committing to install it at that level. The experiment may need to operate in a smaller space at that level, and that must be considered in deciding the optimal level.

Comprehensive monitoring

There is a clear need to establish comprehensive monitoring efforts, independent of individual scientific programs, to monitor changes in the facility during continued dewatering and underground excavation and construction. Particular areas that need to be addressed are:

- 1) Establishment of a permanent seismic network - A three-dimensional broadband seismic network of wide dynamic range that would be expanded in depth as the water table is drawn down. This information would contribute both to the safety of the facility (seismic hazard assessment) and to an improved understanding of the causes and effects of earthquakes induced by changes in stress and pore pressure that are, at least to some extent, known.
- 2) Comprehensive geodetic monitoring should be part of the monitoring effort for the same reasons. There will undoubtedly be both horizontal and vertical deformation. Our sense is that the current proposed geodetic experiments are not sufficient for comprehensive deformation monitoring of the facility.

Preparing for BGE Experiments

The BGE experiments undertaken to date have done a good job of helping the facility make plans for supporting BGE experiments that might be proposed once the facility is constructed. One omission from this planning process is the creation of underground work spaces where BGE experiments could be carried out. These work spaces might only be bays that open from existing or planned tunnels and shafts where power and telemetry would be available and investigators could set up their instrumentation. This would be particularly valuable for longer-term *in situ* experiments that require monitoring and repeated sampling.

The dewatering process now going on should be viewed as an experiment that could yield important insight into coupled hydrologic and geomechanical processes.

1. Pore pressure should be monitored at as many points in the rock mass as is feasible to assess its hydrologic characteristics by measuring its response to the depression of the water table by pumping. These measurements would help to define the hydrologic regime at DUSEL and how pore pressure changes couple to physical changes in the rock mass and, perhaps, induce or trigger seismicity.
2. Temperature in boreholes already drilled into the rock mass should be monitored as the facility is dewatered and then cooled by ventilation. These measurements will help document the thermo-elastic response of the rock mass and calibrate coupled thermo-poro-elastic models.
3. Gravity should be monitored at a number of sites to measure changes associated with facility development, especially as the water table is drawn down.

A comprehensive microbiological monitoring program should be developed to ensure the integrity of the planned microbiology sampling and research to be conducted at DUSEL. A primary objective is to assure that a specific regimen of coring and sampling handling will be maintained to facilitate microbiological characterization of the DUSEL site. Specific recommendations are:

1. The laboratory should consider how to take advantage of new drilling technologies now under development that minimize incursion of drilling fluid into recovered cores. Existing tracers are effective; however, newer tracers and tools should be considered to enhance quality and rigor of all microbiological analyses.
2. Archiving should become a routine aspect of the DUSEL sampling program. A dedicated (on site) technician is recommended. These samples would provide a long-term resource for culturing relevant prokaryotes and for ex-situ activity measurements. To maintain the genomic stability of cultured organisms, rapid freezing of archival samples to -80°C is required. Samples should also be archived in an appropriate fashion for subsequent molecular-level studies, such as transcriptomics, proteomics, and metabolomics.

An archive for rock and fluid samples obtained during drilling and excavation activities should be established. These samples could be of appreciable scientific value in the future as new future research projects are proposed and as novel analytical techniques become available.