Illustration: Sandbox Studio

WANTED

Scientists seek

multi-level deep underground lab
w/ rock-lined interior and spacious caverns.
Prefer charming rural setting
w/ unimpeded view of universe.
Neutrino detectors, dark-matter traps, clean
rooms, lunch hall, locker rooms a plus.

By Kurt Riesselmann

When the Homestake mine closed in 2003 after producing 42 million ounces of gold, it left a colorful gold rush history, tall steel head-frames looming over a town of 3000 people, and an enormous hole in the ground: North America's largest and deepest underground mine.

Now scientists are rushing to Lead, South Dakota, to claim the empty space the miners left behind. A meeting to discuss potential experiments, held in 2008, brought together 350 researchers from around the world. Plans are now under way to turn Homestake into the first national laboratory for underground science in the United States–and the largest and deepest facility of its kind in the world.

"The deeper the better," says Robert Svoboda, a physics professor at the University of California, Davis, who has worked on underground neutrino experiments in Japan and Europe for the last two decades. Together with 200 collaborators, he hopes to use the lab in South Dakota for an experiment to find out what role neutrinos played in the evolution of the universe. It is one of more than 40 scientific experiments scientists already have proposed for the new laboratory.

Physicists seek out deep places for their research because they offer shelter from cosmic rays, the steady rain of particles hitting Earth. We don't feel them as they pass through our bodies, but their constant background patter is enough to drown out the rare, faint signals stemming from things like the decay of an atom, particles of dark matter, or neutrinos spat out by an exploding star. The more rock that scientists put between their experiments and the sky, the greater their chance of making a discovery.

Several countries, including Canada, Italy, and Japan, already have extensive deep-science programs. But the rising worldwide interest in underground science and engineering has led to a shortage of underground lab space, especially at very great depth. In the United States, existing underground facilities, such as the Soudan Underground Laboratory operated by the University of Minnesota, have limited space and are not deep enough. Each additional 1000 feet of overlying rock reduces the number of incoming muons—cosmic-ray particles that are a major problem for ultra-sensitive physics experiments—tenfold.

STRONG SUPPORT

Over the past decade, a dozen independent reports from the National Academies and multi-agency government committees have emphasized the need for a deep underground laboratory in the United States. In 2007, the National Science Foundation selected the 8000-foot-deep Homestake mine in the Black Hills of South Dakota as its top choice for the potential site of the Deep Underground Science and Engineering Laboratory, or DUSEL. The following year, a particle physics advisory group of the Department of Energy and the National Science Foundation, known as the P5 panel, urged the funding agencies "to make this facility a reality as rapidly as possible." The panel recommended "that DOE and NSF work together to realize the experimental particle physics program at DUSEL." In response, the two agencies established a joint oversight group to help advance the DUSEL plans. The group is modeled after the successful joint oversight group for the US contributions to the Large Hadron Collider at the European Laboratory CERN.

If the DUSEL project goes forward, it would almost double the world's present underground-laboratory space, with enough floor space to cover almost two football fields and caverns large enough to hold the Mount Rushmore carvings of the heads of four US presidents. The space would house clean rooms, lab benches, cryogenic equipment, and the world's largest neutrino detectors, along with locker rooms and a lunch hall. The mine's roughly 400 miles of tunnels would give geologists, biologists, and other scientists unprecedented access to rock formations, geological processes, undisturbed groundwater, and ancient, deep-living microbes that may hold clues to the origin and evolution of life here and on other planets (see story on page 32).

NOBEL HISTORY

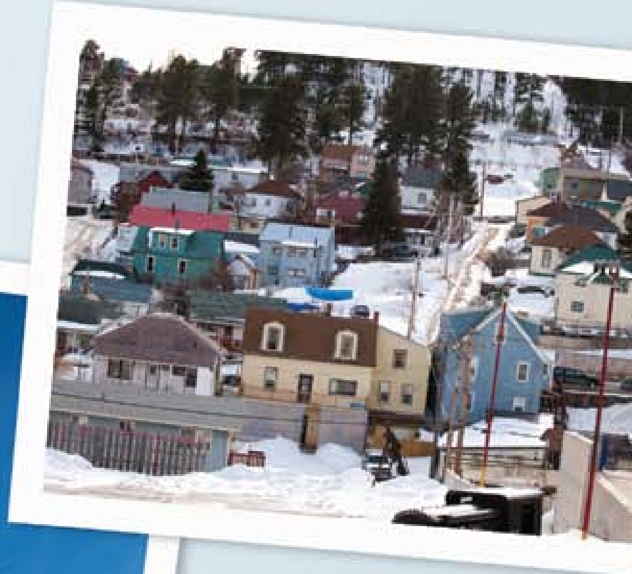
The former gold mine already has a reputation for Nobel Prize-winning research. In 1965, physicist Ray Davis started an experiment at the 4850-foot-level of Homestake to look for neutrinos emitted by the sun, using a tank filled with 600 tons of fluid to catch the invisible, ghost-like particles. Over a period of 30 years his experiment succeeded in capturing a couple of thousand solar neutrinos and proving that nuclear fusion processes account for the energy our sun and other stars radiate. In 2002, Davis and Masatoshi Koshiba, founder of the Kamioka neutrino experiment in Japan, shared half of the Nobel Prize for Physics for their pioneering contributions in astrophysics and the first observations of neutrinos from extraterrestrial sources.

"Homestake is the birthplace of neutrino astrophysics," says UC Berkeley physicist Kevin Lesko, who worked for years on an experiment to detect solar neutrinos with the Sudbury Neutrino Observatory, located more than a mile underground in a Canadian nickel mine.

The state of South Dakota has embraced the DUSEL idea and started the process of rehabilitating the Homestake mine, which had begun to fill with water. To prepare the mine for its proposed mission, the state has turned the mine into the Sanford Underground Science and Engineering Laboratory, with the help of a $70 million donation from banker and philanthropist T. Denny Sanford.

"New discoveries, new ideas, and the knowledge and education that will result from future research and experiments are more valuable than gold," Governor Michael Rounds of South Dakota said at the dedication of Sanford Lab in June 2009.

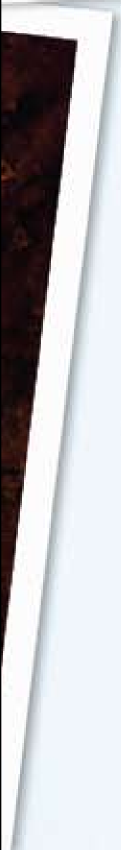
Photos: Reidar Hahn, Fermilab




WELCOME
GOLD PANNING
GUIDED 'MINE' TOURS


Lead
SOUTH
85
FITNESS COMMUNITY
Historic Lead Main Street
CANAM HIGHWAY

Photos: Bill Harlan, Sanford Lab, and Steve Babbitt, Black Hills State University



From top: Sanford Lab geologist Tom Trancynger and two scientists from the Majorana collaboration inspect the rock at the future location of the Majorana Demonstrator experiment.

Miners take core samples to determine the best place to construct large caverns for the proposed LBNE experiment.

The expanded Davis cavern, 4850 feet below ground, will house the LUX dark-matter experiment.

Scientists have set up several stations with seismic instruments to explore the possibility of creating a gravity-wave detector.

Two graduate students work in a clean room at the Sanford Lab to prepare components for the LUX dark-matter experiment.

Philanthropist T. Denny Sanford and Governor Mike Rounds celebrate the dedication of the Sanford Lab 4850 feet underground on June 22, 2009.

Cynthia Anderson of Black Hills State University takes a biological sample.

If the NSF approves the final DUSEL proposal—a decision that will be made in 2011—the new laboratory is expected to absorb Sanford Lab and greatly expand its surface campus and underground space, adding caverns and laboratories at the 4850- and 7400-foot levels of the mine.

THE SCIENCE BEGINS

Scientists have started to scope out the mine's microbial wildlife and groundwater flow, as well as explore whether the vast mine would make for a good gravity-wave detector. Geologist William Roggenthen of the South Dakota School of Mines & Technology has installed a seismic array with sensors at several levels of the mine to measure the motions of rock. This three-dimensional view will help improve models of rock motion that were based purely on surface measurements.

"The science is beginning," says Jose Alonso, who served as director of Sanford Lab for two years until his retirement in October 2009.

Miners began excavating the new underground space for Sanford Lab last fall, blasting away the first layers of rock in September. "Rehiring the people and miners familiar with the mine has been a tremendous success," Alonso says. The construction, which includes the expansion of the Davis cavern, will add underground space equivalent to the size of three tennis courts.

SETTING UP DARK-MATTER TRAPS

Scientists will use the expanded Davis cavern to set up a dark-matter detector, the heart of the Large Underground Xenon experiment. LUX scientists will try to trap the mysterious, invisible matter that accounts for 80 percent of all matter in the universe.

Astrophysicists postulated the existence of dark matter when they discovered that the gravitational forces stemming from the ordinary matter we can see with our eyes and telescopes were not enough to explain the shapes and motions of galaxies.

But dark matter's origin and composition remain a mystery.

To detect dark-matter particles that drift through the earth, the LUX scientists will use liquid xenon, a transparent liquid that is three times denser than water. And they will use a lot of it—more than 700 pounds—to increase the chance that a dark-matter particle will collide with a xenon atom and produce a faint signal that can be picked up by photosensors in the liquid. A former Homestake warehouse, converted into a lab with clean room and cryogenic equipment, already serves as staging area for the LUX experiment and allows scientists to get ready for the underground installation of their experiment this year.

A second physics experiment in preparation at Sanford Lab, called the Majorana Demonstrator, will explore a long-standing mystery: Are neutrinos their own antiparticles?

Scientists have known for a long time that every elementary particle has a partner with the opposite electric charge—its antiparticle. For instance, the electron's antiparticle is the positron.

Since neutrinos have no electric charge, physicists face the possibility that a neutrino and its antineutrino are the same particle—or, conversely, that they are two distinct types of particles, like electrons and positrons. Theorists have developed mathematical frameworks that explain either one of these two scenarios. Once underground, the Majorana Demonstrator will help determine which theory is correct by testing several detector technologies that measure the properties of neutrinos in the decay of germanium atoms.

Eventually, the Majorana scientists hope to build at DUSEL, in collaboration with scientists from the European GERDA experiment, a one-ton germanium detector to solve this neutrino puzzle once and forever. Another experiment, called EXO, that is aimed at solving the same puzzle has been proposed for DUSEL as well; its first phase is being tested in another below-ground lab in New Mexico (see story on page 18).

PLANNING GOES FORWARD

The competition for underground lab space is fierce. Last summer, a committee winnowed the long list of proposals for underground research in physics, engineering, geosciences, and biology at DUSEL down to 16. These proposals—including the neutrino physics proposal by Svoboda and his colleagues—are now under consideration for the initial suite of experiments that DUSEL could host. Proposals for other experiments will have to wait until the laboratory is up and running.

A team at UC Berkeley, led by Lesko and South Dakota's Roggenthen, is developing the preliminary design of DUSEL's extensive surface and underground facilities and the overall plan for the scientific, engineering, and educational goals of the laboratory. The NSF will review their report before the end of the year.

Last fall, Lesko and Roggenthen invited scientists to the city of Lead for a meeting of future DUSEL users. About 150 senior scientists attended, including researchers representing more than two dozen experiments that had not been chosen for the initial round. One of the main goals of the meeting was to begin to identify the infrastructure the new facility must include to accommodate a wide range of science.

"We are pursuing some of the most exciting aspects of several different disciplines simultaneously," Lesko says. "We will exploit the synergies among those different disciplines."

THE FIRST ROUND OF PHYSICS

Nine proposals are under consideration for the initial suite of physics experiments at DUSEL, and scientists have received $21 million in NSF funding to refine them. The proposals cover four areas of research:

- What is the nature of dark matter? (Proposals for LZ3, COUPP, GEODM, and MAX)
- Are neutrinos their own antiparticles? (Majorana, EXO)
- How do stars create the heavy elements? (DIANA)
- What role did neutrinos play in the evolution of the universe? (LBNE)

In addition, scientists propose to build a generic underground facility (FAARM) that will monitor the mine's naturally occurring radioactivity, which can interfere with the search for dark matter. The facility also would measure particle emissions from various materials, and help develop and refine technologies for future underground physics experiments.

But why are there four separate proposals for how to search for dark matter? Not knowing the nature of dark-matter particles and their interactions with ordinary matter, scientists would like to use a variety of detector materials to look for the particles and study their interactions with atoms of different sizes. The use of different technologies would also provide an independent cross check of the experimental results.

"We strongly feel we need two or more experiments," says Bernard Sadoulet of UC Berkeley, an expert on dark-matter searches. "If money were not an issue, you would build at least three experiments."

The largest experiment intended for DUSEL is the Long-Baseline Neutrino Experiment (see graphic), a project that involves both the DOE and NSF. Scientists would use the LBNE to explore whether neutrinos break one of the most fundamental laws of physics: the symmetry between matter and antimatter. In 1980, James Cronin and Val Fitch received the Nobel Prize for the observation that quarks can violate this symmetry. But the effect is too small to explain the dominance of matter over antimatter in our universe. Neutrinos might be the answer.

The LBNE scientists would generate a high-intensity neutrino beam at DOE's Fermi National Accelerator Laboratory, 800 miles east of Homestake, and aim it straight through the Earth at two or more enormous neutrino detectors in the DUSEL mine, each containing the equivalent of 100,000 tons of water.

Studies have shown that the rock at the 4850-foot level of the mine would support the safe construction of these caverns. In January, the LBNE experiment received first-stage approval, also known as Mission Need, from the DOE.

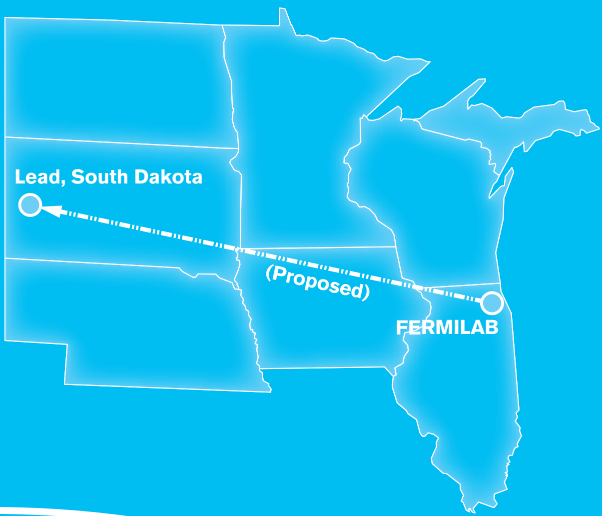
Lesko and his team now are combining all engineering studies and science proposals into an overall proposal for review.

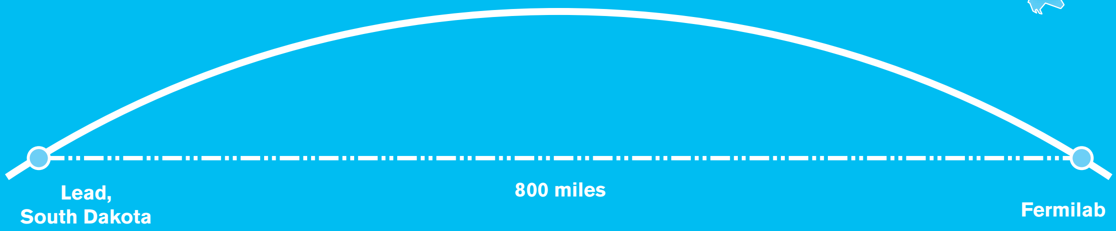
"By the end of this summer, we hope to complete a preliminary design of the DUSEL facility and then integrate it with a generic suite of experiments," Lesko says. "While formal selection of the experiments will not have been made by that time, we know enough about them now that we can move forward with the preliminary design. The experiments themselves will be selected through a peer-review process, as is common in the NSF."

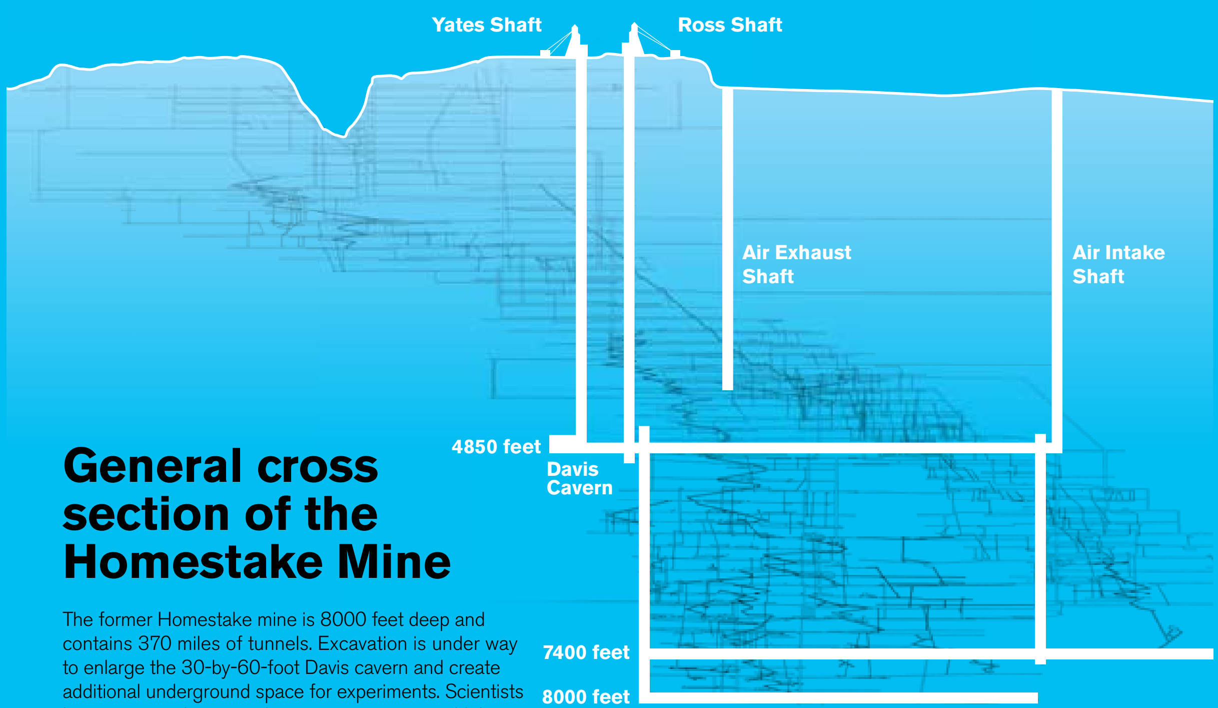
If all goes well, Lesko says, scientists and engineers could break ground on the major DUSEL excavations in 2013, marking the start of a new era for deep underground research in the United States.

Long-Baseline Neutrino Experiment

Neutrinos are among the most abundant particles in the universe, yet we know very little about these mysterious particles and their role in the evolution of the cosmos. The proposed Long-Baseline Neutrino Experiment would help determine whether neutrino interactions could explain the dominance of matter over antimatter in our universe. LBNE would generate a beam of neutrinos at Fermilab in Batavia, Illinois, and examine the behavior of those neutrinos as they traveled through the Earth to a proposed underground particle detector in the Homestake mine in Lead, South Dakota.







General cross section of the Homestake Mine

The former Homestake mine is 8000 feet deep and contains 370 miles of tunnels. Excavation is under way to enlarge the 30-by-60-foot Davis cavern and create additional underground space for experiments. Scientists have proposed turning the mine into a national laboratory for deep science and engineering research with a surface campus, several underground labs and large caverns for neutrino detectors.