Institute of Physics Publishing Journal of Physics: Conference Series **39** (2006) 490–496
doi:10.1088/1742-6596/39/1/133 TAUP 2005: Proc. Ninth Int. Conf. on Topics in Astroparticle and Underground Physics

Underground laboratories in Japan and North America

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Abstract. There is a blossoming demand for deep underground laboratory space to satisfy the expanding interest in experiments that require significant cosmic-ray shielding. I'll briefly describe the existing deep facilities and their plans for expansion. I will also discuss the planning for a new major underground facility in the U.S.

1. Facilities in Japan

1.1. The Kamioka Observatory

The main facility in Japan is the Kamioka Observatory. It is located in the Gifu prefecture and conveniently reached by way of the Toyama airport. It is about a 40 minute drive from the airport to the observatory. The research buildings and dormitory of the observatory are located in the small village of Mozumi. The observatory is an inter-university facility where scientists from 17 Japanese institutions conduct research. The large Super-Kamiokande experiment is an international collaboration where about half of the 140 collaborators come from foreign countries. Most belong to US institutions, but some from European, Korean and Chinese institutions.

The Underground observatory is located in the lead and zinc mine of the Kamioka Mining and Smelting Company. The mine entrance is a short distance from the laboratory building. There, the 1.8 km horizontal Atotsu tunnel enables you to drive from the mine entrance to the experimental area, at a depth of 1000 m underground (2700 meters of water equivalent (mwe)) below the peak of Mt. Ikeyoyama. The cosmic-ray attenuation at this depth is approximately a factor of 10^5. The underground environment is also particularly free of surface vibrations and thus is an attractive place for gravitational wave antennas and laser strain meters.

The present facility contains the Super-Kamiokande experiment, KamLAND, a XMASS prototype, the dark matter experiments LiF, NaF and the gravitational wave experiments LISM and CLIO. A new $9\text{x}10^3$ m^3 facility for XMASS is planned. The next phase of the gravitational wave program is also planned to be installed in the mine. The LCGT (Large Scale Cryogenic Gravitational Wave Telescope) will be a 3 km baseline detector which takes advantage of the quiet and stable underground environment.

The Super-Kamiokande detector was the far detector for the long baseline K2K experiment. The new J-Parc accelerator is currently being constructed and a new neutrino beam from the accelerator will be operational in 2009 and once again directed towards Super-Kamiokande. The initial stage of the experiment will have a 0.75 MW beam power and is aimed towards the observation of θ_{13}. The second stage of the experiment will have 4 MW of beam power and a new much larger far detector, Hyper-Kamiokande. Some preliminary R&D has already been done for the Hyper-K detector. One of the major studies was the site selection. The Mozumi mine is unable to accommodate this large detector as there is no region of stable hard rock large enough. A candidate site has been located in the Tochibora mine about 8 km south of the

Mozumi mine. Geological surveys and core studies have already been done. The depth at this site is unfortunately only about 1400 -1900 mwe. While this will be perfectly sufficient for the long baseline experiment and nucleon decay searches, solar neutrino observations will not be possible.

1.2. The Oto Cosmo Observatory
Osaka University maintains the Oto Observatory about 100 km south of the university. It is located in the unused Tentsuji tunnel at a depth of 1400 mwe. A number of dark matter/solar neutrino detectors have been built and operated in this laboratory. ELEGANT V, searching for the double beta decay of ^{100}Mo was recently finished and ELEGANT VI, searching for the double beta decay of ^{48}Ca has begun. A scintillator-based double beta decay tracking calorimeter using 0.8 kg of ^{100}Mo is the prototype for a future 200 kg – 1 ton detector using ^{100}Mo or ^{82}Se. Another detector concept using undoped CaF_2 crystals immersed in a liquid scintillator spectrometer is being developed at Osaka. A 60 crystal version called CANDLES III is under construction and a 1000 crystal, 3.2 ton version, is being planned.

2. North American Facilities

2.1. The Soudan Mine[1]
The Soudan mine is Minnesota's oldest and deepest mine. Until active mining was completed in 1962 it was also Minnesota's richest iron mine. The mine is now a Minnesota state historical park, open to the public. In the summer, there are tours of the mine where visitors can explore down to the mine's lowest level at 713 meters or 2090 mwe. The mine originally housed the Soudan and its successor, the Soudan-II nucleon decay experiments. Soudan-II has been recently removed and the facility has been expanded by constructing a new hall to accommodate MINOS, the far detector of the Fermilab long baseline experiment. The CDMS-II, Cryogenic Dark Matter Search, experiment has been installed in a portion of the old Soudan-II hall. The remaining space in that hall, a 12x11x35m volume is available for new use. This space is surrounded by a refurbished 99% efficient active muon veto shield. One proposed use of this space is a new low background counting facility. A proposal to construct this facility has been submitted to the NSF.

The general area is accessible through airports at Minneapolis-St. Paul, Duluth and Hibbing. A long experience with this facility indicates that the area access is adequate. The rock type is enerally metamorphic, with basalts, greenstone, iron-formation, schist, sulfide-rich zones, as well as diorites, dacite, gabbro. Soudan has an attractive campus setting near lakes in a tourist/vacation-home region, existing surface and underground office and lab space, an existing neutrino beam, existing utilities and communications, experience with cleanliness and cryogens, a shaft and a Low Background Counting Facility.

2.2. SNOLAB[2]
The Sudbury Neutrino Observatory (SNO) at the Creighton Mine near Sudbury in Canada. Sudbury is located about 400 km north of Toronto and is accessible by regular flights from Toronto, Ottawa, or Sault Ste. Marie, or by major highways from any of these locations. The mine is about 25 km west of the city. The Creighton Mine is an active nickel and copper mine owned and operated by Inco. At the start of the SNO project the Creighton Mine boasted the deepest continuous shaft in the western world. The currently active shaft runs from surface to a depth of 7000 feet and mining is progressing below this level. The SNO detector is located 2000 m below ground in a 22-m-diameter 35-m-high cavern. This is the world's largest cavern at this depth designed for human occupancy. The laboratory housing this cavern and the required infrastructure is established as a deep clean room so that radioactivity in dust would not contaminate the results. The construction of the detector was completed in 1999.

The SNOLAB now under construction is an international facility for underground science at a depth of 6000 meters of water equivalent (approximately 6800 feet). SNOLAB will provide an additional 36,000 square feet of new excavations for a total of 45,000 square feet of clean underground space. The concept of a SNOLAB facility was originally focused on the extensions of the SNO work into low-energy solar neutrinos, dark matter and neutrinoless double beta decay. Each of these requires the deep, clean environment that has uniquely been established at SNO. None are expected to require a cavern larger than that created for SNO. The laboratory is now intended to be open to proposals for any form of research that can benefit from the infrastructure being established. Investigations have begun into research areas outside of particle/astrophysics. Following an enthusiastic response from the international scientific community to a call for Letters of Interest in staging experiments at SNOLAB, they are now engaged in an exercise to define an initial suite of experiments and the longer term scientific roadmap for this new facility. The scientific program under development is focused upon next generation of particle-astrophysics experiments aiming to measure low-energy solar neutrinos, neutrinoless double beta decay, and cosmological dark matter.

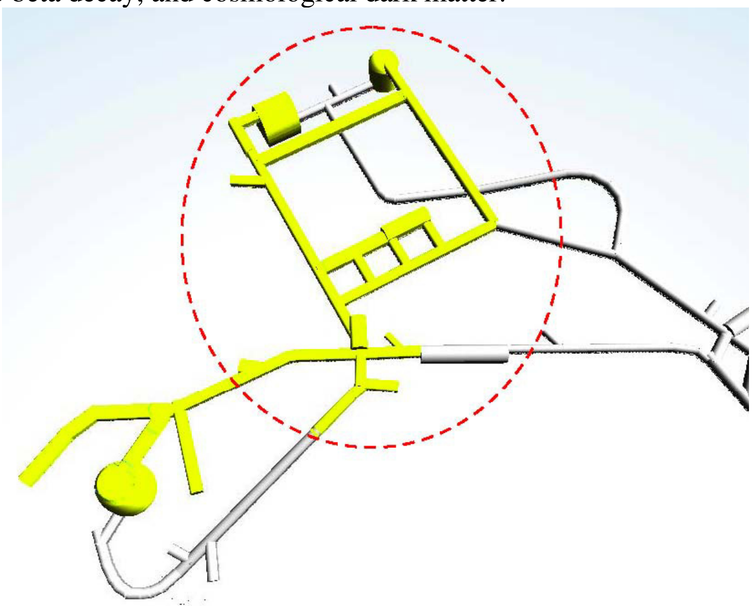

Figure 1. The SNOLAB underground configuration with the new experimental areas shown inside the red dashed region.

2.3. WIPP[3]

A half-million tourists visit Carlsbad Caverns National Park each year to view the natural wonders nearly 1,000' under the surface in the Guadalupe Mountains in southeastern New Mexico. A large reef beneath an ancient ocean formed those mountains. Evaporation of this ocean during the Permian produced a thickly bedded evaporate deposit of nearly pure salt, called the Salado formation. With a thickness of 2,000' and buried 1,000' below the Chihuahuan Desert east of the Caverns, this formation is home to the 2,150 foot deep Waste Isolation Pilot Plant (WIPP), the first underground repository for disposal of transuranic material. This dry and geologically inactive site on a 16 sq. mile tract is permanently withdrawn and owned by the U.S. Department of Energy (DOE).

As it offers very low background radiation and good shielding from the cosmic radiation, in the autumn of 2000, the U.S. Secretary of Energy decided to make the underground reaches of the mine available for scientific research. Space is available underground for many new projects. By capitalizing on the investment by the government in an extensive infrastructure that will operate for at least 35 years (and will subsequently be placed under active institutional control for an additional 100 years), this site can become home to many planned US projects which do not require the much greater shielding provided by a deep site. What's more, many of the facilities needed to support a strong and vigorous science program underground are already in place at Carlsbad. These include Safety and mine rescue, training, ES&H and security.

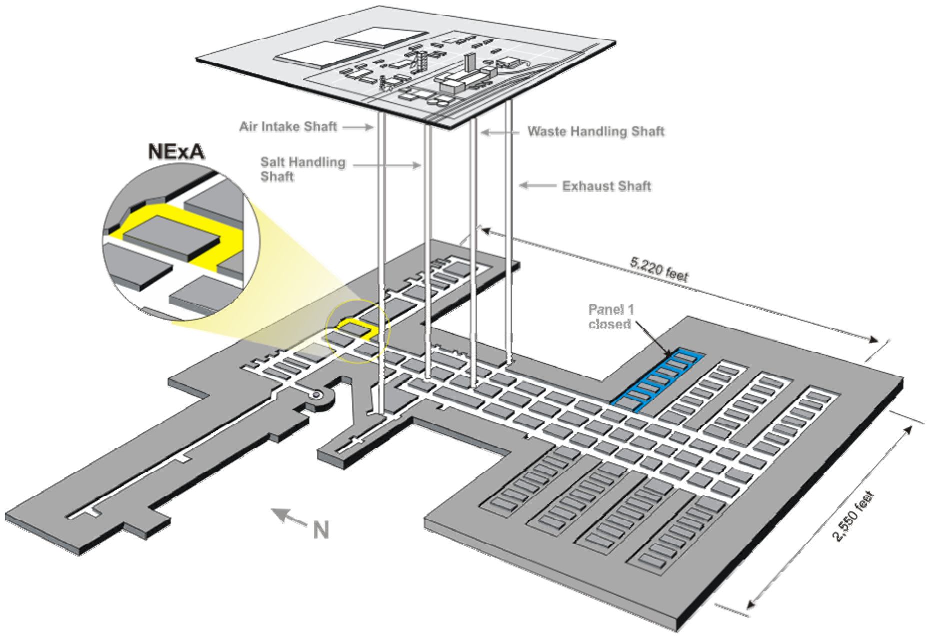

Figure 2. A schematic of the WIPP underground facility.

There has already been a significant investment to support underground science in this facility. As shown in the drawing, about 1.5 acres of space underground is completely refurbished with lighting and power installed throughout the area. This "north experimental area" is available to the science community. Much more detail about the Carlsbad facilities can be found in the document "Prospects for an Underground Laboratory in Carlsbad, NM, a Report to the Underground Laboratory Committee February 28, 2001".

3. A New Deep Laboratory in the U.S. - DUSEL

In March 2004, the U.S. National Science Foundation (NSF) put a process in place for the development of a new Deep Underground Science and Engineering Laboratory (DUSEL) with a depth that is proposed to be greater than anything currently available (Fig. 3). The first step in the process, Solicitation1(S1), called for a community-wide, site-independent study to establish a cross-disciplinary scientific roadmap for such a facility and identify the generic infrastructure requirements[4]. Six PI's were chosen to head this study. The DUSEL process is multidisciplinary, as the laboratory is intended to service not only physics and astrophysics but also earth sciences, biology, and engineering. The second step in the process (S2), narrowed the field of contenders from eight initial site proposals submitted in February 2005 to the two finalists chosen by a NSF panel in July 2005, the Henderson mine in Colorado and the Homestake mine in South Dakota. NSF will make a final site selection in FY'2007 and fund a full technical design study.

3.1. Homestake [5]

The Homestake site is a vast former gold-mining facility which was owned and operated by the Homestake Mining Company for most of its 125-year history. Mining operations ended in 2001, and the mine was closed and capped in 2003 by the current owners, Barrick Gold Corp. of Canada (Barrick). When the facility closed all surface access ports to the underground structures were sealed and the airflow restricted. Although this action preserved some of the infrastructure by reducing corrosion, it also had the negative impact of halting the removal of accumulating water in the facility. (As of October 2005, the water was below the 6500 level.)

The plan to convert the Homestake site into DUSEL was formalized on January 12, 2004 when Barrick and the State of South Dakota signed an "Agreement in Principle" wherein Barrick agreed to donate the former Homestake mine to the State for the Deep Underground Science and Engineering

Laboratory. In order to fulfill the requirements of this agreement, the 2004 South Dakota Legislature passed a series of five bills. One bill created the South Dakota Science and Technology Authority (SDSTA) to oversee the conversion of the former mine and to manage this facility for the State.

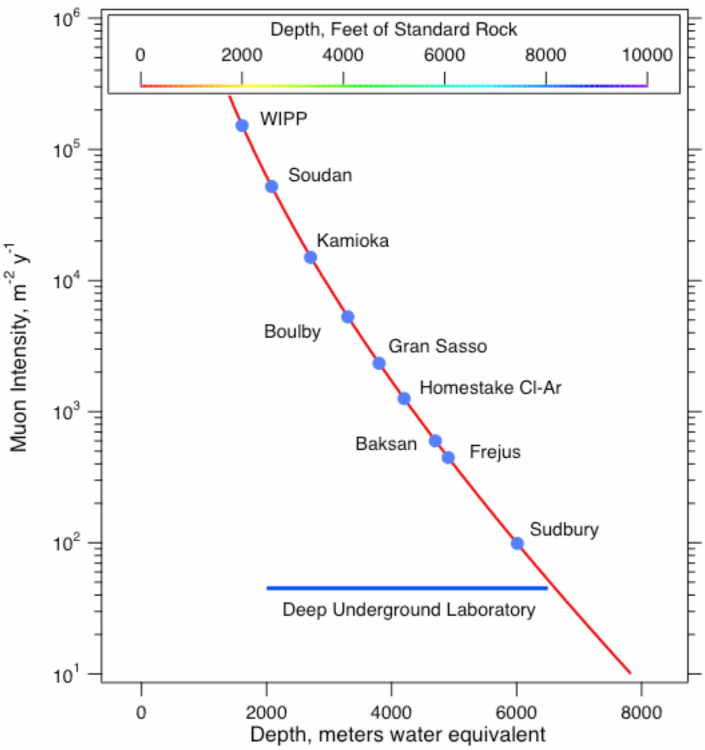

Figure 3. The muon vertical intensity versus depth curve showing existing underground labs and the proposed DUSEL site.

In September 2005 Barrick and the SDSTA announced they had reached agreement to transfer title of the facility under the conditions of an Early Implementation Program and the NSF DUSEL solicitation process. On 14 October 2005, the State of South Dakota held a special session of the state legislature and approved a bill to fund the Early Implementation Program and to fund the basic operation of the facility into 2012. This legislation provides an additional $20 M fund from South Dakota to take ownership and to reopen the former Homestake mine, provide safe, redundant access to the 4850 level and above. With this additional appropriation, a total of $45.6 million is available for the development and operation of this underground laboratory. It is anticipated that the Early Implementation Program will make space available for science and engineering experiments by early 2007. Development of deeper levels and additional major excavations are being planned as part of the DUSEL process in the coming years. These subsequent developments will not negatively impact nor interfere with on-going experiments.

There are approximately 60 existing levels spanning the rock mass from the surface to 8000 feet below ground. More than 350 miles of drifts are spaced at roughly 150-ft intervals connected by many ramps. The Homestake Lab surface facilities include 162 acres with numerous buildings that for the initial phase will be converted for use as offices, meeting rooms, warehouses, staging and assembly and laboratories. The EIP will initially focus on making the 4850 level available for fixed-location experiments.

The drifts on the 4850 level and many other levels are typically 13 by 15 feet. Existing excavations, rooms, and drifts would be made available for experimental uses. Requests for new construction, alterations to existing space, or other special requirements (environment, access, isolation, etc.) are also solicited.

The former Homestake Mine is a two-level facility: the upper levels from the surface to 4850 ft are serviced by one set of utilities, and the 4850 to 8000 levels by a second set. The SDSTA has created a comprehensive conversion plan to dewater the mine and make it available for re-entry and early access down to 4850 level. This plan forms the initial basis of the underground laboratory at Homestake.

The 4850 level will be the deepest laboratory in the United States and the second deepest laboratory in the world. Existing drifts and chambers on the 4850 level provide extensive space for early access experiments and opportunities to develop new experimental chambers. From direct rock strength measurements using the Homestake core repository, it has been established that chambers with spans of 50 meters can be readily and safely constructed at this level.

The main axis of the 4850 laboratory is the 2900 ft long, 13 ft by 15 ft cross section drift that connects the Ross and Yates shafts, the two main surface to underground access shafts. At the Yates end of this tunnel is the 2000 m^3 chamber that previously housed the chlorine solar neutrino detector. There are 30 levels between the surface and the 4850 level, providing options for labs at alternate levels, and a 3-dimensional matrix for geophysical investigation, with a cubic kilometer volume for exploration by geoscientists.

Exploratory downward and sideward drilling into virgin rock for biological and geophysical investigations can be carried out at a number of sites at the 4850 level without disturbing any of the other experiments. Rock excavation and cavity construction, necessary for the complete Deep Labs Conversion Plan for DUSEL, will not disturb existing experiments on the 4850 level or expose them to rock dust.

Services to the underground labs will include up to 8 MW of available electrical power. Permanent and supplemental spot chillers will be installed to provide sufficient air conditioning capacity for normal lab operations and for rehabilitation and construction work. Standby generator sets will provide up to 1500 kW of emergency power in the event of standard power outages in the facility. Both industrial and potable water will be available at the 4850 level. Approximately 6000 cfm compressed air will be in service for initial operations.

Existing data communication fiber optics cables are 24 pair, 62.5 micron, multi-mode, Tbase-10. These extend through the Yates Shaft to the 4850 level. As-needed, additional data communication cables and server capacity may be installed for specific lab requirements.

The South Dakota Science and Technology Authority is currently soliciting Letters of Interest for experimental uses of the Homestake Lab for underground science and engineering experiments, R&D, and education and outreach programs. These non-binding Letters will help to establish the facility requirements and enable the Authority to work proactively with the proponents to ensure that Homestake fulfills their needs and is competitive with alternative underground sites.

3.2. Henderson [6]

The Henderson Mine is owned and operated by the Climax Molybdenum Company (CMC), a subsidiary of the Phelps Dodge Corporation. Using an underground mining method known as panel caving, the mine currently produces 28,000 tons of raw ore per day, with estimated reserves for about twenty more years of production. The mine site is located 50 miles west of Denver, Colorado, and lies 10,400 feet above sea level on the eastern side of the Continental Divide. It is easily reached from Denver International Airport in less than 1.5 hours by an interstate freeway, US highway, and a short distance on a paved, well maintained access road. The 2900 acre mine site is privately owned by CMC and is surrounded by the Arapaho National Forest. The site contains two mountain peaks: Red Mountain, under which the molybdenum orebody is located, and Harrison Mountain, which is believed to be barren of economically viable mineral deposits. The Henderson ore body is the second largest known molybdenum deposit in the world today. The general nature of the orebody and the surrounding host rock is that of high strength granite with compressive strengths ranging from 14,500 to 40,000 psi. The average specific gravity of this rock is about 2.5. The area under Red Mountain has been extensively explored with 606 boreholes, totaling 90 miles of core drilling. These drill holes, located both within and outside the orebody, provide detailed information about the geology as well as the geotechnical aspects of the rock mass. The Henderson orebody has been studied extensively, and numerous journal articles and reports have been published. A wealth of additional information is available within the company. One 2500 ft long drill hole, funded by the HUSEP member organizations and the State of Colorado, was drilled to an area 5500 ft directly below the summit of Harrison Mountain, the proposed DUSEL central campus location. The rock type was found to be competent Urad Porphory with a Rock Quality Designation in the range of 70 to 100. Based on this preliminary drilling, there is a strong likelihood that the area under Harrison Mountain is highly suitable for excavating the large openings required for DUSEL.

Henderson began operation in 1976 after a 10-year predevelopment program and a $500 million investment. The $150 million Henderson 2000 modernization program was completed in 1999. The mine was designed as a high capacity operation, and its infrastructure is engineered to support production in excess of 30,000 tons per day, making Henderson one of the ten largest underground mines in the world today. The mine is accessed from the surface (10,200 ft) by a 28-foot diameter shaft for personnel and material to the 7500 level An inter-level ramp extends from the 7500 level down to the 7065 truck level. Excellent rock mass conditions allowed a large underground excavation of the crusher station with dimensions of 61 ft wide × 48 ft high × 93 ft long in Vasquez Porphyry, and the ore transfer station in Silver Plume Granite. After crushing, the ore is transported to the mill site by a series of conveyor belts. Mill tailings are placed in large containment areas that will be reclaimed and re-vegetated when the mine is closed. The infrastructure available for DUSEL includes a large capacity shaft which can transport up to 200 people at a time. The trip from the surface to the 7500 level takes about five minutes. The cage can accommodate 20-ft international shipping (ISO) containers weighing up to 30 tons. Loads of up to 50 tons can be carried if a crosshead is substituted for the cage and counterweights are used. Four other shafts are used for ventilation. 150 miles of drifts provide access to various levels of the mine, some of which could be dedicated to DUSEL. Two Mine Safety and Health Administration (MSHA) approved emergency escape routes exist for the safe evacuation of personnel. The mine conveyor system for rock removal was designed for a capacity of 40,000 tons per day, but the mine currently uses about 28,000 tons per day and estimates that no more than 35,000 will be needed in the future. The excess of 5,000 tons per day far exceeds the estimated 3,000 tons per day needed during DUSEL construction. The mine ventilation system has a capacity of 2,000,000 cfm provided through four shafts and three large surface fans. Of this, at least 100,000 cfm of excess capacity is available for DUSEL, significantly more than the 50,000 cfm estimated requirement. The electrical network has a 100% redundant feed from two independent 13.8 KV power lines. Two 24 MW substations are integrated into the statewide distribution network and are located on the mine property. The mine currently uses 10 MW and reserves an additional 10 MW for backup. With the existing transformer stations, DUSEL would have 14 MW available with 14 MW for backup.

References

[1] Alec Habig, *private communication*; also: http://neutrino.d.umn.edu/~habig/soudan-dusel.pdf

[2] See: http://www.snolab.ca/ and *The SNOLAB S2 Proposal to the NSF*: http://www.snolab.ca/files/dusel/SNOLAB_DUSEL_S2_abridged.pdf

[3] See *The WIPP S2 proposal to the NSF*: http://euclid.temple.edu/~DuselWIPP/

[4] See: http://www.dusel.org/

[5] Kevin Lesko, *private communication*; see also http://neutrino.lbl.gov/Homestake/

[6] See: http://nngroup.physics.sunysb.edu/husep/ and *The Henderson S2 proposal to the NSF*: http://nngroup.physics.sunysb.edu/husep/HUSEP_Project_Description.pdf