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Underground laboratories

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Abstract. Underground laboratories provide the low radioactive background environment necessary to explore the highest energy scales that cannot be reached with accelerators, by searching for extremely rare phenomena. To advance the effective-high-energy frontier we need to struggle for background control and reduction. After having discussed the most important characteristics of an underground laboratory, all of the world facilities that are presently operational or in an advanced status of approval are briefly described. None of the projects for very large facilities are described.

1. Introduction. Characteristics of the underground laboratories

The only known phenomena beyond the Standard Model are in neutrino physics: neutrinos are massive and flavour lepton numbers are not conserved. This was discovered in underground laboratories with natural sources (Sun and cosmic rays). In general, underground experiments provide an indirect reach to the highest energy scales. For example, a 50 meV neutrino mass corresponds, via seesaw mechanism, to a 10^{16} GeV energy scale. The higher is the energy the more rare are the corresponding phenomena. Consequently, pushing forward the high-energy frontier requires every backgrounds to be reduced. There are important physical and practical differences between the existing facilities. These range from fully developed laboratories to simple underground sites.

The muon flux decreases with the thickness of the rock overburden, roughly, but not exactly, exponentially. Under a flat surface the flux is 10^{-3} $m^{-2}s^{-1}$ at a depth of 2.3 km w.e. (1 km water equivalent is about 300 m of rock), 10^{-4} $m^{-2}s^{-1}$ at 3.7 km w.e. and 10^{-5} $m^{-2}s^{-1}$ at 5.3 km w.e. Under a mountain, like at Kamioka or Gran Sasso, the angular dependence of the muon flux is complicated, due to the shape of the surface. It must be measured to provide the input to the background simulations needed by the most delicate experiments. The flux is time dependent with seasonal variations of several percent.

Neutrons originate mainly from (α,n) and fission processes (U and Th) in the rocks. The energies range from thermal to several MeV, and consequently are not difficult to shield. The neutron flux is substantially independent of the depth (if >100 m or so). It depends on the local geology. However, in practice the n flux is around a few 10^{-2} $m^{-2}s^{-1}$ in all laboratories.

Muons interactions in the rocks produce dangerous neutrons at a depth-dependent rate. The fluxes are typically 3-4 orders of magnitude smaller than the main n flux. The energies are large, up to several GeV, demanding thicker shields. Even more dangerous are the neutrons produced in the shields, in the detector and in the materials around it. In the case of fast reactions, namely if a neutron immediately follows the muon, the background can be reduced by anticoincidence. Neutrons from metastable nuclides can be eliminated by working at a larger depth. Their effect depends on the details of the experiment, and is generally more severe for high-*Z* materials.

Radon (^{222}Rn) is a radioactive, volatile gas that is always present in the atmosphere, being continuously produced by the decay of ^{226}Ra present in the rocks. An important source of Rn is ground water. The Rn activity, which is typically 10 – 20 Bq/m^3 in the open air, is larger by two orders of magnitude or more in closed underground cavities. It is reduced by ventilation. The equilibrium activity depends on the emanation rate and on the ventilation speed. The input air duct, which may be a few km long, should be made of SS or similar materials to avoid Rn collection input.

All experiments need to be shielded. Indeed, the shield thickness determines the physical size of the most sensitive experiments. For example, the frontier double beta decay experiments presently under construction, CUORE and GERDA, have diameters of about 15 m. The next generation may need halls 20-30 m in diameter and height. Please note that the maximum safe diameter decreases while the costs increase with depth.

Laboratories differ in many other important aspects: horizontal or vertical access, interference with nearby activities (mine work, road traffic, etc.), quality of the support infrastructures (laboratories, office space, assembly halls, etc.) and personnel on the surface, degree of internationality of the user community and programme of the advisory committee, policy of space and time allocation.

Scientific sectors different from astro-particle physics, such as biology, geology and engineering can profit of the very special underground environment provided by the laboratories and their facilities. Space does not allow these important issues to be discussed here.

The facilities are now reviewed in geographical order, from W to E. For details see “The world underground science facilities. A compendium”, available at arXiv:0712.1051. The, more relevant, historical order of the starting dates of the oldest projects is the following. 1966 BNO, 1979 LNGS and LSM, 1983 KAMIOKA, 1984-85 Slovotvina and LSC (the elder).

2. **BUL. Boulby Palmer Laboratory (UK**). http://astro.ic.ac.uk/Research/ZEPLIN-III/boulby.htm
The site was developed starting in 1988 by N. Spooner and collaborators initially from RAL. An active potash mine at 1000 m depth under a flat surface hosts it. The access is through a shaft. The salt environment limits the cavities width to about 5 m. A clean area of approximately 1500 m^2 is available to experiments. The neutron flux with E>0.5 MeV is 1.7×10^{-2} s^{-1}m^{-2} and the muon flux is 4.5×10^{-4} m^{-2} s^{-1}. A building on the surface (200 m^2) hosts laboratories for computing, electronics and chemistry, offices, a conference room, changing rooms, mess rooms, a mechanical workshop, storage and construction rooms. The scientific programme is focused on dark matter search with ZEPLIN II, to be completed by 2008, ZEPLIN III, to be completed by 2010 and DRIFT II, in the R&D phase. There are low radioactivity measurements and geophysics research. About 30 scientists work at the laboratory.

3. LSC. Laboratorio Subterráneo de Canfranc (Spain). http://ezpc00.unizar.es/lsc/index2.html
The first underground facility located under the Pyrenees, close to a dismissed railway tunnel, was created in the 1980s by A. Morales and the Nuclear and High-Energy Physics Department of the Saragossa University. Taking advantage of the excavation of a parallel road tunnel, the new laboratory was built later. The underground structures have been completed in 2005. However, more recently several design and construction defects have emerged and necessary reparation work is under way. LSC is managed by a Consortium between the Spanish Ministry for Education and Science, the Government of Aragon and the University of Saragossa. The surface building has been funded and is presently being designed. It will contain headquarters, administration, a library, a meeting room, offices, laboratories, storage areas and a mechanical workshop, safety structures and management, for a total of approximately 1500 m^2. A dozen of employees are being hired.

The access is horizontal, via one of the tunnels. The entrance must be communicated to the freeway tunnel control. The spaces available underground are: Hall A, measuring 40×15×12(h) m^3, Hall B of 15×10×8(h) m^3, Clean room of 45 m^2 and Services for 215 m^2. The old lab area is 100 m^2. The maximum rock coverage is 850 m. The muon flux is between 2×10^{-3} and 4×10^{-3} m^{-2} s^{-1}, depending on the location; the *n* flux is 2×10^{-2} m^{-2} s^{-1}. The Rn activity in the air is 50-80 Bq/m^3 with a ventilation of 11 000 m^3/h, i.e. one lab volume in 40'.

The scientific programme is presently being defined now. A provisional Scientific Policy Committee has collected expressions of Interest. After the appointment of the first director, a new International Scientific Committee has been appointed. A call for proposals will be launched soon.

4. LSM. Laboratoire Subterrain de Modane (France). http://www-lsm.in2p3.fr/

The Laboratory is operated jointly by CNRS/IN2P3 and CEA/DSM. Excavation of the Laboratory started in 1979, and was completed by 1982, to host a 900 t iron tracking calorimeter to search for proton decay. The "Frejus" experiment was finished in 1988.

The access is horizontal through the Frejus roadway tunnel. Intervention of the tunnel control is needed to stop traffic at the entrance or exit of a vehicle from the lab. The Main Hall is 30×10×11(h) m^3, the Gamma Hall has an area of 70 m^2, two smaller halls have 18 m^2 and 21 m^2 areas, for a total of 400 m^2. The surface building includes offices (100 m^2), a warehouse and workshop (150 m^2) and a flat. The personnel include 8 technicians and engineers and one post doc.

The rock overburden is 1700 m. The muon flux is 4.7×10^{-5} $m^{-2}s^{-1}$. The *n* flux is 5.6×10^{-2} $m^{-2}s^{-1}$. A low Radon activity in the air, 15 Bq/m^3, is obtained by in taking fresh air at the rate of 1.5 lab volumes/hour. An "antiradon factory" produces 150 m^3/hr of air with 10 mBq/m^3. The laboratory is almost full with NEMO 3 (double beta decay), EDELWEISS (dark matter), which should run at least up to 2010, and a low-radioactivity counting facility. About 100 scientists work at the lab.

The Ulisse project profits by a unique opportunity given by the construction of a new tunnel approved by the French and Italian Governments to increase the safety conditions of the traffic. Two large halls are foreseen: A of 100×24 m^2 and B of 18×50 m^2. An extremely low-background environment will be obtained in Hall B by surrounding its central volume with a water shield and by artificially producing a very low Rn content atmosphere (0.1 mBq/m^3).

5. LNGS. Laboratorio Nazionale del Gran Sasso (Italy). http://www.lngs.infn.it/

LNGS is a national laboratory of the INFN. It is the largest in the world, serving the largest and most international scientific community. In 1979 the President of the INFN A. Zichichi proposed to the Parliament to build a large underground laboratory close to the Gran Sasso freeway tunnel then under construction (an opportunity that substantially reduced the cost). In 1982 the Parliament approved the construction, which was completed by 1987.

Access is horizontal, through the freeway. The underground laboratories consist of three main halls (called A, B and C), about 100×20×18(h) m^3 plus ancillary tunnels, providing space for services and small-scale experiments. Two 90 m long tunnels were built for two Michelson interferometers to be used for geology studies. The total area is 17 300 m^2, the total volume 180 000 m^3.

Services hosted on the surface campus include offices, a mechanical workshop, storage facilities, a chemical lab, an electronic workshop, an assembly hall, computers and networking, a library, a canteen, sleeping rooms, conference rooms, headquarters, administration. Special care has been given to the development of structures, procedures and training activities in matter of safety, of the users and of citizens, as well as environmental impact. A number of outreach activities and visits to the lab are systematically organised by a dedicated Service. Personnel (physicists, engineers, technicians, administration) include a permanent staff of 64 and 23 non-permanent positions.

The rock overburden is 1400 m. The muon flux is 3×10^{-4} m^{-2} s^{-1}. *n* flux is 3.78×10^{-2} $s^{-1}m^{-2}$. Radon in the air is 50-120 Bq/m^3 with a ventilation system providing one lab volume of fresh air in 3.5 hr. Major civil engineering work has been performed in 2004-7 to upgrade the safety conditions of the interacting structures of the free-way, the water-collection systems and the laboratory.

LNGS is operated as an international laboratory. In the process of approval of the proposals, an international Scientific Committee, appointed by INFN, advises the Director. Underground space and other resources are allocated to experiments for a definite amount of time, in order to guarantee turnover. The rich experimental programme includes dark matter searches, with LIBRA, CRESST2, XENON10, WARP; Double Beta Decay with COBRA, CUORICINO, GERDA; Solar neutrinos (geo-neutrinos) with BOREXINO; Supernova neutrinos with LVD; Nuclear astrophysics with LUNA2; CNGS with OPERA and ICARUS; a test of the Equivalence principle, VIP. A special facility is dedicated to low-radioactivity measurements. The laboratory also supports several experiments on geology, biology and environmental issues. Almost all of the experiments are second-generation ones and have been approved for several years of data taking. The scientific user community is 752 strong, involving scientists from 26 countries.

6. CUPP. Centre for Underground Physics in Pyhäsalmi (Finland). http://cupp.oulu.fi/
The Centre is hosted in a working mine. Several cavities, dismissed by the mine, are available at different depths down to 980 m, for a total area of more than 1000 m^2. Presently, the mine works at between 1000 m and 1400 m depth. Access is both via a shaft and an inclined tunnel. The EMMA experiment is being installed. Small lab and office space is available in a surface building. A guest-house is also available. The personnel consist of about 3 people on site and 3 at Oulu University.

7. SUL. Solotvina Underground Laboratory (Ukraine). http://lpd.kinr.kiev.ua/LPD_SUL.htm
The Laboratory was constructed in 1984 under the leadership of Yuri Georgievich Zdesenko by the Lepton Physics Department of the Institute for Nuclear Research (Ukrainian National Academy of Sciences) in a salt mine. The laboratory space is divided into a Main Hall: 25×18×8(h) m^3 and four chambers 6×6×3(h) m^3. The total is area about 1000 m^2. On the surface, three living rooms are available. Staff members consist of 14 technicians and engineers. Access is vertical by the mine cage, taking into account the time-table of the mine.

The lab is 430 m deep in salt (≈1 km w.e.). The muon flux is 1.7×10^{-2} m^{-2} s^{-1}. The n flux is 2.7×10^{-2} m^{-2} s^{-1}. The radon concentration in air is 33 Bq m^{-3}. Eleven researchers and PhD students of the LPD work at SUL mainly on double beta decay, preparing a new ^{116}Cd experiment using 1-2 kg $^{116}CdWO_4$ higher quality crystal scintillators and developing R&D projects on scintillators and for SuperNEMO.

8. BNO. Baksan Neutrino Observatory (Russia). http://www.inr.ac.ru/INR/
The Laboratory is operated by the INR of the Russian Academy of Sciences. It is managed as an observatory, with very long-duration experiments. It is the oldest facility in the world built specifically for scientific research. M. Markov, the Head of Nuclear Physics Division of the Academy of Sciences of the USSR, obtained in 1966 a special Decree of the Soviet Government, and construction of the Baksan Neutrino Observatory started under Mount Andyrchi in the Caucasus. A new village, called 'Neutrino', was built as a part of the original project in a previously empty space with personnel providing the necessary services (heating station, water-supply system, first medical help, transportation, safety, etc.). The staff directly related to science is 50-60. The scientific activity started under the leadership of Alexander Chudakov and George Zatsepin. The access is horizontal via two dedicated tunnels, with train transportation

A large hall, 24×24×16 m^3 in volume, 300 m deep, hosts the Baksan Underground Scintillation Telescope. BUST has been ready to observe neutrinos from galactic supernovae since 1978. The Laboratory of the Gallium Germanium Neutrino Telescope hosting SAGE, has a volume of 60×10×12 m^3 at a vertical depth of 2 100 m. In this lab the muon flux is $3.03\pm0.19\times10^{-5}$ m^{-2}s^{-1}. The neutron flux (E>1 MeV) is 1.4×10^{-3} m^{-2}s^{-1}. The Rn activity is 40 Bq/m^3 with a fresh air input of 60 000 m^3/h.

The construction of a larger and deeper hall, about 40 000 m^3 in volume, was started in 1990, and stopped in 1992, when the Soviet Union collapsed. Further fate of this not finished construction is presently under discussion. Low-background Chambers with a volume from 100 to 300 m^3 are used for the R&D of dark matter and double beta decay search as well as for gravitational wave search and for some geophysics measurements. The number of users is 30-35.

9. Y2L. YangYang Laboratory (Korea). http://dmrc.snu.ac.kr/
The lab is operated by the Dark Matter Research Centre (DMRC) of Seoul National University. The presently available area is 100 m^2. Expansion to 800 m^2 is planned, but is not yet funded. 100 m^2 space for office space, computing and detector test facility is available on surface. Access is horizontal by car. The lab utilizes the space in the tunnel of the host YangYang Pumped Storage Power Plant. Researchers are requested to obey the safety and security regulation of the Plant.

The rock overburden is 700 m with a μ flux of 2.7×10^{-3} $m^{-2}s^{-1}$. The neutron flux is 8×10^{-3} $m^{-2}s^{-1}$ for 1.5 MeV $< E_n <$ 6.0 MeV. The radon activity is 40-80 Bq/m^3. The underground space is mostly occupied by the Korea Invisible Mass Search (KIMS) experiment, currently taking data for a WIMP search with 100 kg CsI(Tl) crystal detectors. Other activities include R&D for double beta decay and background measurements with a HPGe counter. The scientific users are about 30.

10. **Oto Cosmo Observatory (Japan).** http://wwwkm.phys.sci.osaka-u.ac.jp/info/syoukai/oto-e.html
The laboratory has been developed by H. Ejri of the Osaka University and collaborators. Its area of consists of Lab. 2 (50 m^2) hosting ELEGANT V and MOON-1 on dark matter search with NaI and $0\nu2\beta$ decay of ^{100}Mo. Lab. 1 (33 m^2) hosts ELEGANT VI on $0\nu2\beta$ decay of ^{48}Ca and dark matter search with CaF_2. The rock coverage is 470 m, with a muon flux of 4×10^{-3} $m^{-2}s^{-1}$. The neutron flux is 4×10^{-2} $m^{-2}s^{-1}$. The radon inside "radon free" containers is 10 Bq m^{-3}. The access is horizontal through a non-used railway tunnel, which also provides the non-forced ventilation.

11. Kamioka Observatory (Japan). http://www-sk.icrr.u-tokyo.ac.jp/index_e.html
The Kamioka Observatory is operated by the Institute for Cosmic Ray Research, University of Tokyo. It was established in 1983 by M. Koshiba as Kamioka Underground Observatory. The original purpose of this observatory was to conduct the KamiokaNDE experiment, to which Super-Kamionkande followed. The present facilities have been designed for Super-K, the largest existing underground experiment. Recently, an enlargement has started, in order to accommodate more experiments. The KamLAND experiment is operated by the Neutrino Centre, Tohoku University. Buildings for offices and computer facilities are available on the surface. The staff members are 13 scientists, 2 technical support units, one for administration.

The coverage is 1000 m and the muon flux is 3×10^{-3} $m^{-2}s^{-1}$. The thermal neutron flux is $8.25\pm0.58\times10^{-2}$ $m^{-2}s^{-1}$, the non-thermal is $11.5\pm1.2\times10^{-2}$ $m^{-2}s^{-1}$. The ventilation is 3000 m^3/h. The access is horizontal by car, with no interference with the mining activity. The underground structures are as follows: Hall SK (50 m diameter) hosting Super-Kamiokande, to be continued for 15 years, at least. Clean room (10×5 m^2) with XMASS prototype. Hall 40 (L-shape, 40 m×4 m arm) hosting the purification tower for XMASS and the NEWAGE experiment on dark matter. Hall 100 (L-shape, 100 m×4 m arm) with CLIO, a prototype of Gravitational Antenna (to be terminated in 2013) and a Laser displacement detector. The new Hall A (15×21 m^2) hosting XMASS 800 kg (untill 2012) with space available for another experiment. The new Hall B (6×11 m^2) hosting CANDLE on double beta decay, to be occupied untill 2012. Small areas are available in the dismissed mine. The scientific users are more than 200 in number. A budget request for the underground large cryogenic gravitational antenna LCGT has been submitted.

12. INO. India based Neutrino Observatory (India). http://www.imsc.res.in/~ino/
One of the two experiments that first observed atmospheric neutrinos in 1964 was located at 2700 m depth in the Kolar Gold Mine in India. The India based Neutrino Observatory is the project to create an underground laboratory in southern India. It will be located near the PUSHEP hydroelectric pumping station, under a 1300 m rock overburden.
The lab will be organized with international laboratory standards with a Scientific Advisory Committee, services to the users, environmental, safety, security and outreach activities. Two main underground cavities are foreseen: Lab1 with a volume of 26× 135× 25(h) m^3 and Lab 2 with 53.4× 12.5× 8.6(h) m^3 plus connection tunnels and services. Access will be horizontal through a dedicated 2 km tunnel. On the surface it is planned to have: a 1400 m^2 building for administration,

offices, shops, etc., a 2750 m^2 building with a lecture hall and a guest house and a residential complex with 20 quarters. Personnel will be 50 to 100.

The main foreseen experiment is ICAL, a 50 kt magnetized Fe tracking calorimeter for atmospheric and very long base-line accelerator neutrinos. It will occupy only a fraction of Lab1.

13. SNO-Lab (Canada). http://www.snolab.ca/ also http://www.sno.phy.queensu.ca/
The SNO experiment has completed its glorious life and its cavity, 200 m^2 area, is now being freed for further experimental activity. New structures are under construction: a Main hall of volume $18\times 15\times$ (15 to 19.5 height) m^3, a service hall of about 180 m^2 and a number of narrow (6-7 m) volumes, called "ladder labs". The construction of another structure, called cryopit, has been approved recently. This hall is designed to cope with the safety issues surrounding large volumes of cryogenic fluids. The total area will be 7 215 m^2, of which 3 055 m^2 is available for the experiments; the total volume will be 46 648 m^3, of which 29 555 m^3 will be available for the experiments. The access will be vertical, through the shaft of the working mine, available daily. All the laboratory will be clean, class 1500.

On the surface a 3159 m^2 building will host a clean room, laboratories, staging and assembly areas, office space (60 users), meeting rooms, control rooms, an IT server room, an emergency generator, high-speed network link off site, high-speed network link surface/underground, safety structures and management. Staff will be of 30 full-time people.

The rock coverage is 2000 m under a flat surface. The μ flux is 3×10^{-6} $m^{-2}s^{-1}$, the thermal neutron flux is 4.7×10^{-2} $m^{-2}s^{-1}$, the fast neutron flux is 4.6×10^{-2} $m^{-2}s^{-1}$. The radon in the air is high, 120 Bq/m^3. The ventilation in the smaller lab spaces provides 10 air changes per hour, in the larger ones, 5 air changers per hour.

PICASSO, searching for dark matter (2 kg) with the super-heated bubbles technique, is already running. SNO+ will be hosted in the former SNO cavity; it will be based on liquid scintillator for low energy solar neutrinos, geoneutrinos and double beta decay, by dissolving ^{150}Nd in the liquid. Dark matter search includes DEAP/CLEAN with noble liquids, which is getting ready to install prototype, and a LoI from superCDMS with bolometers. More LoIs are expected to be reviewed by the Experimental Advisory Committee.

14. SUL. Soudan Underground Laboratory (USA). http://www.soudan.umn.edu/
The underground structures include: the Soudan lab ($20\times7\times10$(h) m^3) that hosts: a) CDMSII, expected to run until 2009; b) a low-background counting facility that currently occupies $5\times5\times3$ m^3 and will expand to $25\times14\times14$(h) m^3, if funded. The MINOS lab that hosts: a) MINOS that occupies $35\times16\times14$(h) m^3 and is expected to run until 2009 or longer with a 2-year decommissioning period at the conclusion; b) the high-purity copper fabrication facility that occupies $4\times6\times3$(h) m^3 and expects to run for at least another two years. The users are 265 in number.

The access is vertical via a two-compartment slightly angled shaft. Diameters in excess of 1m and lengths in excess of 10m pose a problem. Access outside normal operating hours is possible. There is an access charge paid to our host institution, Soudan Underground Mine State Park. Normal laboratory safety requirements are in place. The laboratory coexists with an historic State Park, which offers mine tours during the summer months to the public, and winter tours to school groups. Some tours utilize a visitor's gallery available in the MINOS laboratory. There is no active mining activity.

The overburden is 700 m of rock. The muon flux is 2×10^{-3} m^{-2} s^{-1}. The neutron interaction rates are approximately 10 kg^{-1} d^{-1} (from U/TH, low energy) or 0.01 kg^{-1} d^{-1} (muon generated in the rock). The radon concentration is seasonal, varying from 300 Bq/m^3 in the winter to 700 Bq/m^3 in the summer. The mine has natural ventilation, about 550 m^3/h for the level of the laboratories. Half of this is diverted to ventilate the MINOS and Soudan spaces. This results in a complete air change every 110'.

The major facility on the surface is a building of approximately 650 m^2 with offices, a kitchen and sanitary facilities.

The laboratory has a staff of 9, including secretarial and accounting assistance and network and computer maintenance personnel. It is staffed 10 hours/day, 5 days per week, but the staff is on-call during the balance of the time and responds to requests for emergency access.

15. DUSEL. Deep Underground Science and Engineering Laboratory (USA)

Solar neutrino physics started in the Homestake mine in South Dakota with the experimental work of R. Davis and the theoretical sun model developed by J. Bahcall. After a long and complex process, in spring 2007, NSF selected amongst several proposals the Homestake mine in South Dakota as the site in which the Deep Underground Science (physics, biology, and geology) and Engineering Laboratory (DUSEL) should be designed. The project foresees a funding by NSF of about 250 M$ for the facility plus a contribution to the initial set of experiments, costing about 250 M$. In addition, to prepare the site, SD provides 46 M$ on its own and 70 M$ from a donation by T. D. Sanford. NSF is expected to fund with 15 M$ the design of the facility, which will take three years. For the time being, the facility is a SD State Laboratory, funded primarily from SD-controlled money. Water constantly flows into the mine at a rate of 1.2 Mt/yr. Pumps had stopped in spring 2003. Rehabilitation work started in January 2007, securing the level at 1450 m depth with pumps at 1600 m.

On the surface several existing buildings will be rehabilitated for about 10 000 m^2 to host offices, support structures and laboratories. A major science education centre has been funded by Sanford. The initial staff is estimated to be 30-50 strong, to increase to 100-150 when the State Lab will become DUSEL. The Scientific Committee has been established with an USA composition in 2006.

Laboratory spaces will be built separately for biology, geology and physics. Service and R&D structures (e.g. electroforming) will be available for physics at a 100 m deep level. Two main campuses are foreseen for physics at about 1450 m and 2200 m deep. Each will contain a number (4 and 3 respectively) of standard modules of $50\times20\times15$ m^3 plus service areas. A staged construction of the upper campus using SD and private funding is foreseen. For the lower campus, NSF and Congress approval will be necessary.

A site-independent study group on the science of the DUSEL has been appointed by NSF with B. Sadoulet as chair. The work has been completed at the time of writing and presented at NSF on November 2, 2007.

16. Outlook and acknowledgements

Physics beyond the Standard Model was discovery of Underground Laboratories (solar and atmospheric neutrinos). The physics programme for the next decades appears to be extremely rich and challenging. The interest of the scientific community is increasing. We have several facilities, but only a few are managed as international laboratories, with a really international Scientific Committee, full-scale services, turnover of the experiments. New laboratories and upgrades of existing facilities are being created along these lines. They will provide very good working conditions in the next decades. Existing ‘single-Institution’ facilities may still contribute with R&D activity, which however should be well focussed on frontier experiments, training of the students, and low-background measurements, which are badly needed in material screening for the experiments. However, new sub-critical facilities should not be created.

Co-ordination actions are occurring inside the European Union. In particular EU, has funded with 7.5 M€ over 5 years the ILAS project on gravitational waves, dark matter and double beta decay. The actions include: a) “networking”, in practice exchange of experience and common developments in matters of safety and public awareness; b) Joint R&D projects (low-background techniques, double beta decay, noise in gravitational wave detectors); c) international access to underground laboratories, funding per diems to foreign scientists in their work at the laboratory. These actions are useful and are having positive impacts. However, while directing LNGS I learnt that only the merging of contributions of different (scientific) cultures on a global, not only Western European, scale can create a fully developed scientific environment. Indeed, this is the case of the accelerator laboratories.

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