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ANDES: an Underground Laboratory in South America

Claudio O. Dib

Centro Científico Tecnológico de Valparaíso and Department of Physics, Universidad Técnica Federico Santa María, Valparaíso, Chile,

On behalf of the ANDES Organizing Committee.

Abstract

ANDES (Agua Negra Deep Experiment Site) is an underground laboratory, proposed to be built inside the Agua Negra road tunnel that will connect Chile (IV Region) with Argentina (San Juan Province) under the Andes Mountains. The Laboratory will be 1750 meters under the rock, becoming the 3rd deepest underground laboratory of this kind in the world, and the first in the Southern Hemisphere. ANDES will be an international Laboratory, managed by a Latin American consortium. The laboratory will host experiments in Particle and Astroparticle Physics, such as Neutrino and Dark Matter searches, Seismology, Geology, Geophysics and Biology. It will also be used for the development of low background instrumentation and related services. Here we present the general features of the proposed laboratory, the current status of the proposal and some of its opportunities for science.

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Keywords:

1. Introduction

ANDES (Agua Negra Deep Underground Site) [1] is an underground laboratory proposed to be built in the interior of the Agua Negra tunnel, which is a road tunnel planned to be built across the Andes mountains between Argentina and Chile. The ANDES laboratory proposal takes advantage of the unique opportunity provided by the construction of the Agua Negra tunnel, as it will be the first underground laboratory of its kind in the Southern Hemisphere. Today, a dozen similar laboratories are in operation in North America, Europe and Asia, all in the Northern Hemisphere.

ANDES will be located in the deepest part of the Agua Negra tunnel, about 1750 m under the mountain rock, thus shielding the experiments from the cosmic radiation by an attenuation factor near 10^{-7}. Being protected from this radiation, the lab will have the sensitivity required for unique experiments on different subjects: Dark matter searches, Neutrino physics, Geophysical and seismic studies, Environment studies and services, impact studies of cosmic radiation on instrumentation and microchips, Biology and more.

The laboratory will be managed by a Latin American consortium, CLES (Consorcio Latinoamericano de Estudios Subterráneos), formed by representatives of the participating Latinamerican countries. The current participants leading this proposal are Argentina, Brazil, Chile and Mexico. It is expected that further nations will join in.

ANDES will receive numerous experiments from collaborations worldwide, to be installed in the caverns of the underground facilities. The selection of experiments will be made based on their scientific impact and their relevance to CLES member nations. Experiments should be presented to an evaluation committee that shall ensure in particular the aspects of safety and environmental impact. The laboratory will be accompanied by two research centers or *Support Laboratories* on the surface, near the tunnel. Given the high altitude of the tunnel (near 4000 m a.s.l.) and the distance to populated areas, one of the support labs is expected to be located near the city of La Serena (Chile) and the other in the town of Rodeo (Argentina).

In Section 2 we briefly describe the Agua Negra tunnel, in Section 3 we describe the current Laboratory design, in Section 4 we state the current preliminary ideas of the required organisation, and we conclude with a summary in Section 5.

2. The Agua Negra Tunnel

The Agua Negra tunnel is a road tunnel to be built under the Andes mountains, as part of an international road that will connect the Province of San Juan, Argentina and the Region of Coquimbo, Chile, providing a year-long access between the countries. The current Agua Negra pass is at 4780 m a.s.l. and it is closed most of the year due to bad weather conditions. The Agua Negra tunnel is part of the *bi-oceanic corridor* that will improve trading between Brazil, Argentina and Chile with Asia through ports on the Pacific coast.

The Agua Negra tunnel will actually be a system of two tunnels, two lanes each, the east bound tunnel (from Chile to Argentina) running parallel to the west bound tunnel, 60 to 100 m apart. The two tunnels are connected every 500 m with galleries for pedestrians and every 1500 m for emergency vehicles. The coordinate location of the tunnel is approximately 30.19 degrees South, 69.82 degrees West. The tunnels are 14 km in length, with the Chilean entrance at an altitude around 3600 m a.s.l. and the Argentinian entrance at 4080 m a.s.l., thus providing an average 3.2% slope for ventilation and drainage (see Fig. 1). The total power consumption for the tunnel, including emergency ventilation, is estimated to be near 15 MW.

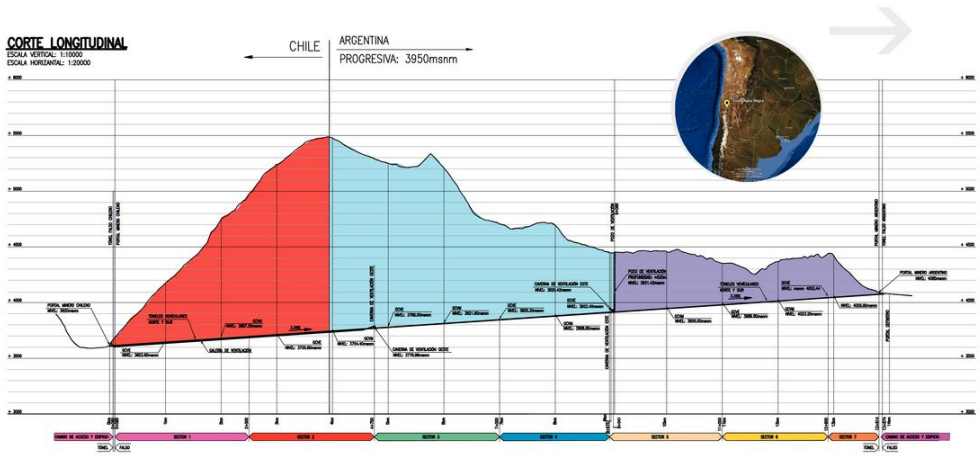


Fig. 1: Mountain profile along the tunnel. The slopes appear exaggerated due to compression of the horizontal scale.

3. The Laboratory

The underground laboratory will be located inside the eastbound tunnel (from Chile to Argentina), on its south side, which is where the mountain gets higher above, about 3.5 to 4.5 km from the Chilean entrance. At this point, a vertical maximum coverage of rock around 1750 m is reached, with an omnidirectional shield not less than 1670 m (Fig. 2). The exact location will depend mainly on the following factors:

- the geomechanical characteristics of the rock, concerning the stability of the caverns;
- the depth of the site, essential for protecting the laboratory from the cosmic radiation;
- the natural radioactivity of the rock in site, as it contributes to the undesired background radiation.

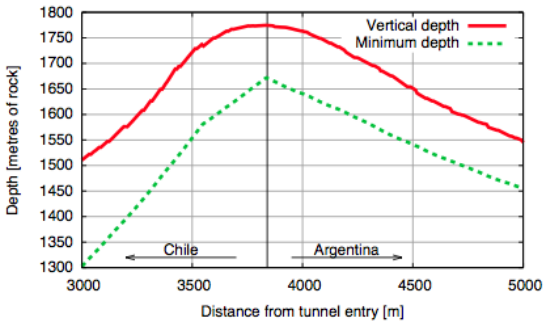


Fig. 2: Vertical and omnidirectional rock coverage as a function of the laboratory location measured from the Chilean entrance.

To date there are no rock samples at the expected depth, but 9 samples from 8 perforations done at 600 m deep were analyzed. The samples show the activities listed in Table 1.

(Bq/kg):	**Andesite**	**Basalt**	**Rhyolite 1**	**Rhyolite 2**	**Canfranc**
U-238	9.2 ± 0.9	2.6 ± 0.5	14.7 ± 2.0	11.5 ± 1.3	4.5 – 30
Th-232	5.2 ± 0.5	0.94 ± 0.09	4.5 ± 0.4	4.8 ± 0.5	8.5 – 76
K-40	47 ± 3	50 ± 3	57 ± 3	52 ± 3	4.5 – 30

Table 1: Activity from rock samples taken at 600 m depth from surface on the estimated site of the laboratory. For comparison, the activities at the Canfranc underground laboratory, Spain, are included. Measurements provided by the *Neutron Activation Laboratory*, Bariloche, Argentina.

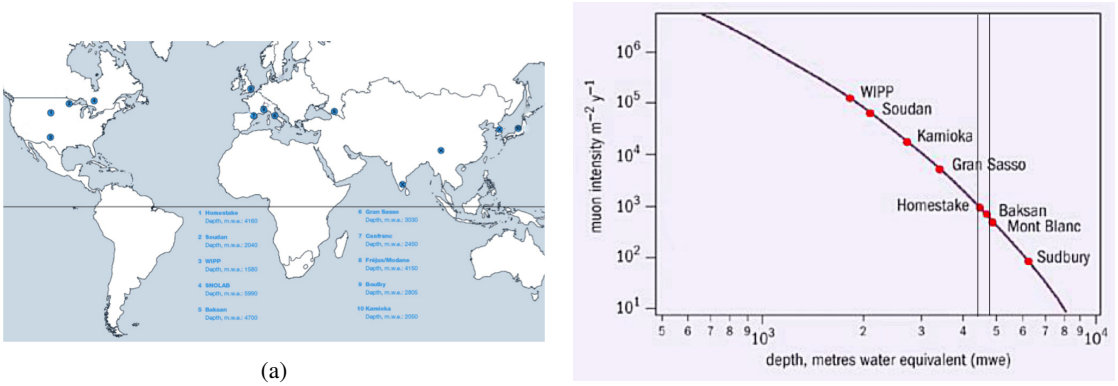
The ANDES underground laboratory will be the first of its kind in the Southern Hemisphere. To date, there are about a dozen deep underground laboratories in the world: in North America, Europe and Asia, all of them in the Northern Hemisphere (Fig. 3a). The southern location is valuable for several reasons. Currently the main scientific value of this location is to provide a southern site for Dark Matter searches that could help eliminate possible weather or other season-induced backgrounds on the observed yearly modulations of experiments located in the Northern Hemisphere [2, 3].

In terms of depth, with 1750 m of vertical rock overburden, it will be one of the deepest laboratories in the world, after Jin Ping in China (2400 m) [4] and SNOLAB in Canada (2070 m) [5]. The 1750 m depth will provide an overburden of 4500 m water equivalent, shielding the cosmic radiation by an attenuation factor near 10^{-7}. (Fig. 3b).

Other special features of the ANDES site are related to the low neutrino background from nuclear reactors and the particular location on the earth's crust, near the subduction of the Pacific and Continental tectonic plates, an issue that could be relevant for geoneutrino studies. Fig. 4 shows the signal-to-noise ratio for geoneutrinos. The nearest nuclear reactors are in Argentina: one CANDU reactor of 2.1 GWth at Embalse (560 km), and at two other reactors, Atucha I (1.2 GWth) and Atucha II (2.1 GWth) at 1080 km. The next nearest reactors are in Angra dos Reis, Brazil, about 2660 km away.

3.1. Science at ANDES

Experiments at ANDES are expected to be at the frontier in the fields of astro and particle physics in the next decade. In addition it should host experiments in other sciences, such as Geology, Geophysics and Biology, as it is the case in other deep underground laboratories around the world. The southern Andes



(a) (b)

Fig. 3: (a) World map showing the current deep underground laboratories, all of them in the Northern Hemisphere. (b) Total muon flux crossing a horizontal area as a function of depth, normalised to meters water equivalent, showing several existing underground laboratories. The vertical band shows the expected ANDES site. As a reference, the flux on the surface at sea level is near 100 [$1/m^2 s$].

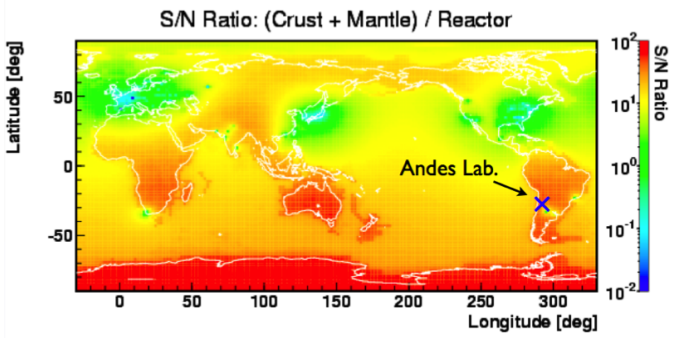


Fig. 4: Map of the signal-to-noise ratio for geoneutrino detection around the world [6], where background is mainly due to neutrinos from nuclear reactors.

mountain range is also one of the most active seismic regions in the world, and an underground facility like ANDES will provide a valuable site for seismological studies and monitoring. Finally as a low-background facility it should be able to provide services for high sensitivity measurements related to environmental sciences and for the development of state-of-the art instrumentation and electronics.

The preliminary scientific program at ANDES is as follows:

- Neutrino Physics. These experiments are flagship in many underground laboratories. At ANDES there is a proposal to install a 3 kton liquid scintillator neutrino detector, for studies of geoneutrinos and neutrinos from supernovae, among other sources [7]. This detector is of a major size, to be located inside the large pit. In addition, there are proposals for installing neutrinoless double beta nuclear decay experiments, most of which are of considerably smaller size, to be located in some of the other caverns. Neutrinoless double beta decay currently is the only type of experiment that can test the possible Majorana character of neutrino masses.

- Dark Matter Searches. The search for the particles that compose the dark matter in the universe is one of the most outstanding problems in cosmology and astroparticle physics. There are many different experimental techniques developed so far and further techniques are being proposed. Different techniques are sensitive to different ranges of masses of the hypothetical dark matter particles, so this diversity in techniques is still necessary. Some experiments have claimed to see signals that modulate with a year period, possibly due to the variation of the dark matter ”wind” as the earth goes around

the sun [2, 3]. In order to rule out possible sources of background coming from seasonal effects, it is particularly useful to try similar detections on a site in the southern hemisphere, such as ANDES. In addition, new detector technologies should find space at ANDES as well. Dark Matter experiments are of diverse sizes, but in general are compact enough to fit in the ANDES proposed caverns.

- Geophysics/Geology/Seismology. The Andes mountain range is an active tectonic site in the planet, with plenty of volcanic and seismic activity. From one side, this is a challenging situation, as the experimental equipment should be designed to sustain the seismic motion. On the other hand it is an opportunity to do underground research on these areas of knowledge, as well as monitoring of the seismic activity. ANDES should at least be part of a seismograph network within Chile and Argentina. Moreover, taking advantage of the high sensitivity instrumentation at ANDES, several studies of correlation between seismic activity or rock burst and other signals such as radon release can be performed.

- Biology. Underground sites provide special environments for studies of biological systems in extreme media, in low radiation conditions and the like. ANDES expects to host experiments in these sciences as well.

- Nuclear Astrophysics. The low radiation environment of an underground site like ANDES also allows studies of low energy nuclear physics [8]. These experiments require low energy accelerators in low background environments to study ion collision reactions of the type that occur in stars.

- Low radiation measurements. Low background instrumentation in underground sites have been finding new applications and services for the industry and for measurements of traces of indicators and contaminants applied to environmental studies. ANDES will be a unique site in South America for these new types of measurements.

3.2. Underground caverns

Here we show the basic design of the underground site in its current status, which is still preliminary (see Fig. 5).

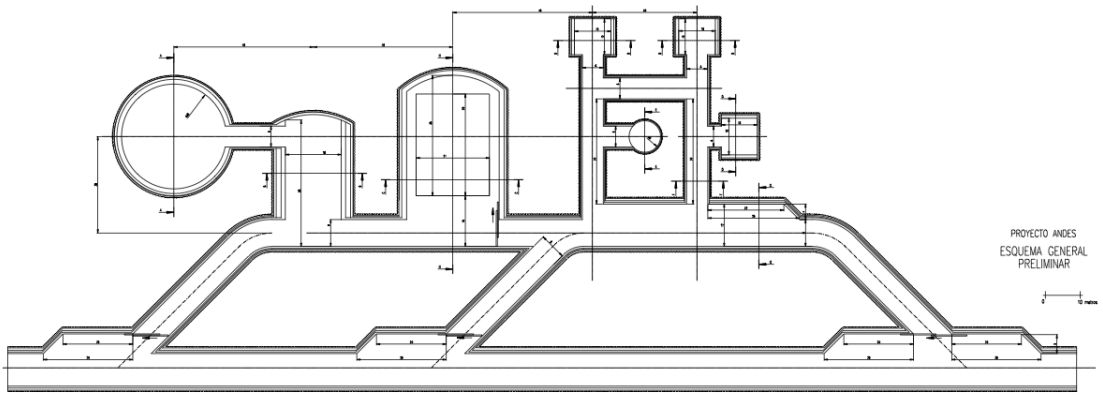


Fig. 5: Top view (not to scale) of the proposed underground site in its current preliminary status. Vehicle transit is from right to left.

The underground laboratory will be accessed from the eastbound Agua Negra tunnel, through an exit to the right at km 4 app. from the Chilean entrance to the tunnel. The entrance will be designed for vehicles of any size to be able to enter the laboratory, and should consider an acceleration lane for a vehicle that has mistakenly taken the exit to be able to safely reenter the tunnel and merge the traffic. A main gate will be kept closed to limit access to the complex, and further along a second barrier will be closed when the main

gate is open. Vehicles will then enter a parking area. Past the parking area, after a 45 degree left turn, the access tunnel will have two entrances to the right, leading to the secondary facilities. Past that point there will be a split to the left to exit the facilities and reenter the Agua Negra tunnel, while the straight way leads to the most sensitive sectors of the lab. This sector will be protected by another gate and should allow access only to large vehicles to manoeuvre and load/unload experimental equipment. Finally, past the loading area the access tunnel will exit the facilities to join the Agua Negra tunnel with an accelerating lane to merge the traffic. In addition, a pedestrian safety connection to the westbound tunnel is considered, in case of a fire in the eastbound tunnel. We now describe the caverns shown in Fig. 5 from left to right.

The main pit: this is a large pit 30 m in diameter and 42 m deep, accessed from a point 30 m above the bottom, by a horizontal gallery coming from the back of the Service Cavern. An additional access to the bottom of the pit should also be built. The pit will host a single large size neutrino experiment of high sensitivity. As a shield from ambient radiation, the pit could be filled with water to a height of 30 m from the bottom, after the experiment is installed. A pump system for the filling and emptying of the well is therefore required. The pump system may also connect to the fire safety network, so that the pit can be used as an additional water reservoir for fire fighting. A 20 ton bridge crane should be installed in the ceiling in order to move equipment inside the pit.

The Service Cavern: This is the second cavern from left to right in Fig. 5. It will be 40 m long, 16 m wide, 14 m high, with oval profile for structural stability, and with a 20 ton bridge crane in the ceiling that slides on longitudinal rails. The main function of this cavern is to house the service equipment for the lab and the offices. In particular:

- The main ventilation equipment, able to renew the full volume of the lab air every hour and to filter the existing radon in the air. As in other clean room facilities, a slight overpressure inside the complex should be maintained. The incoming air will be transported through a sealed stainless steel pipe or similar material to prevent contamination from radon accumulated in the road tunnel.
- Air conditioning, to keep the laboratory at 21 Celsius even at the 2 MW peak consumption in the Lab. It should also control the relative humidity to guarantee operation of the equipment and human hygrothermal comfort.
- Power equipment and electrical generator. Battery bank to protect equipments against potential critical outages. The maximum total power required for the laboratory is 2 MW. In emergencies only a small fraction is needed, since most primary systems switch off. Half of the power is required for ventilation and air conditioning. The other half will be available to the experiments.
- Storage tanks, including a 50 m^3 water reserve tank, and a treatment plant for water and other effluents.
- Supply of basic services to experiments: compressed air, water, data storage and processing, communications. The computer center must have a fibre optic connection to both Argentina and Chile: redundant single-mode fibres for internet and one additional fibre for high-precision GPS-calibrated time signals. Two copper lines should be added for emergency communications in the event of fibre failure.
- Medical kit for care in case of accidents and in case of altitude sickness.
- Fire control systems, monitoring and safety systems, tightly integrated to the Agua Negra tunnel system.

The main cavern: This is the third cavern from the left in Fig. 5. It shall be 50 m long, 21 m wide and 23 m high, with oval profile for structural stability. Located in the central part of the complex, it is accessed from the front, directly from the access tunnel. An additional tunnel will connect the back of the main and service caverns. A 40 ton bridge crane on the ceiling will slide longitudinally on rails, reaching the loading area. The total use of space is achieved by making the main beams of the bridge crane having the curvature of the roof of the cavern. Lateral displacement of the load should be done by a zipper mechanism.

The site area for experimental equipment shall be rectangular 35 m long by 19 m wide. The equipment area shall have a drainage system that channels fluid leaks into lateral gutters, and a pumping system

according to the drain thereof. Collected fluid should be directed to the service cavern. It should include conveniently distributed panels for power supply, low power lines, communication networks, compressed air, water and services.

The secondary pit: this is a 9 m diameter and 15 m total depth pit, dedicated to ultra low background measurements. Just as the main pit, it is accessed by a central corridor at 10 m above the bottom. It will have a suitable vessel for low radiation measurements, properly supported to prevent flotation in the case the pit is flooded with water for further shielding. A sealed system for power lines, data, and monitoring should reach the interior of the vessel.

Secondary caverns: Three secondary 10 m x 10 m x 10 m caverns will complete the facilities. These caverns will provide space for smaller size experiments, offices, laboratories, and services for the lab personnel and visitors.

3.3. Support Laboratories

In addition to the underground site, ANDES, as most underground laboratories, requires infrastructure at surface level as well in order to provide all the services related to administration, reception of equipment, preparation of experiments, office and meeting space, data processing and connectivity, and outreach to the public.

Since the underground site lies at high altitude (near 3800 m a.s.l.) in a relative isolated place, two support labs are proposed. The current proposed sites are one in La Serena, a city of 230,000 inhabitants and port at the Pacific coast in Chile, 200 km from the tunnel, and one in Rodeo, a town of 2,400 inhabitants in Argentina, 90 km from the tunnel. La Serena is a city with universities and the technical infrastructure that supports major astronomy observatories in the region, so that this support laboratory is envisioned as hosting most of the administrative and long term equipment construction and assembly. The support laboratory at Rodeo, which is closer to the tunnel, should be used for more frequent installation and operations of the experiments.

An important activity of the support laboratories should be the outreach to the public. As a first estimate, a support laboratory should consider 100 to 200 m^2 for office space, 200 to 400 m^2 for equipment and laboratory space, and 100 to 200 m^2 for an adequate visitor center.

4. Organization

Since ANDES will be an international laboratory in Latin America and the first of its kind in the region, important steps at the highest political levels of the participating nations will be required. Notwithstanding the foreseen efforts, the proposal has received widespread support.

The current proposal is that ANDES will be managed by an international institution called *Consorcio Latinoamericano de Estudios Subterráneos* or CLES (Latinamerican Consortium for Underground Studies). The organization of CLES is still under discussion, but it should be responsible of the following functions:

- To conduct, through the concurrence of the interested parts, the administrative organization of ANDES and its integration to the scientific communities of the region.
- To define and coordinate the areas of scientific interest.
- To coordinate the division of the different sciences.
- To form the external scientific advisory boards, and the internal committees that oversee the operation of the experiments.
- To establish the rules and protocols for the selection and setup of the experimental proposals.
- To coordinate the academic integration with other institutions, including the participation of researchers and students.
- To identify the regular sources of financing for ANDES and to establish the financing mechanisms, define the budgets and the rules for support and overheads of the experiments.
- To organise scientific events, such as conferences and workshops.

- To promote the outreach of the laboratory activities.
- To establish the long term plans for the ANDES laboratory, including expansion and upgrades.

The initiative of the ANDES underground laboratory can be thought of as the experimental branch of a broader scientific organization, aimed at strengthening the links between the laboratory and academic communities in Latin America. CLES can be envisioned as an institution analogous to CERN in Europe, in its role as coordinator of scientific endeavours. As such, the existence of CLES should enable not only the definition of the management and organizational structures for ANDES, but also as an instrument for the creation of the appropriate environment for regional integration in science and culture.

The participating nations in the initial proposal, at the scientific level, are Argentina, Brazil, Chile and Mexico [1], and it is expected that other Latinamerican countries will soon join in. In particular, Colombia has already expressed interest in being part of the ANDES proposal.

5. Summary

ANDES (Agua Negra Deep Experiment Site) is a proposed underground laboratory to be built inside the Agua Negra tunnel, the latter a tunnel which is part of an international road that will connect Argentina and Chile, between the province of San Juan (Argentina) and the region of Coquimbo (Chile). The laboratory will be set at the deepest point, 1750 m vertical under the rock, at an altitude of approximately 3,800 m a.s.l. It will include a large cylindrical pit 42 m deep and 30 m diameter to host a large neutrino experiment, a main cavern 50 m long, 21 m wide and 23 m high for other large experiments, a service cavern of slightly smaller size, and several smaller caverns, including a ultra low background pit. Due to its location, it will be third deepest underground lab in the world and the first to be built in the Southern Hemisphere.

The scientific programme of the laboratory should include experiments in particle and astroparticle physics, in particular Neutrino and Dark Matter experiments, and other experiments in Nuclear Physics, Biology, Geophysics, Geology and Seismology. It should also provide services of ultra low background measurements and applications to instrumentation development and industry.

The underground site will be accompanied by two support laboratories at surface level at the most convenient places. One of them could be set in the city of La Serena, Chile and the other in the town of Rodeo, Argentina.

The laboratory will be managed by an international Consortium formed by scientists and representatives of the participating Latinamerican nations, called CLES (Consorcio Latinoamericno de Estudios Subterraneos). This consortium, besides managing the ANDES laboratory, should constitute a seed for further integration of the sciences and culture in the continent.

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