Assessment of the Civil Plan for the Andes Lab

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February, 2014

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1) Executive Summary:

In this review I have examined the document "*Obra Civil del Laboratorio ANDES en el Túnel Agua Negra*" Provided to me by Xavier Bertou, as well as the first conceptual technical drawings of the facility. The purpose of the review was not a critical review of the correctness of the drawings … they were only first drafts meant to be used to assess the functionality of the lab, and to get early indications on the impact of that design on things like ventilation requirements, power distribution etc. Instead I considered the current design of the lab to see if there were any logistic issues that I could identify, based on my understanding of the intended functionality for those spaces. I also thought about the other infrastructure required in the outfitting of the lab, and made various recommendations based on experiences with other labs. I appreciate that many of these recommendations may be for items that have already been considered by the Andes team, but were not present in the original document. The purpose of the recommendations is only to provide constructive suggestions that might help with advancing the design.

My review considered:

- Is the laboratory going to contribute significantly to the capability of the world-wide astroparticle physics program by providing spaces that will match the needs of experiments expected in about 2020?
- The overall functionality of the laboratory. Are the spaces the right shapes and is there proper access to all halls to facilitate experimental construction and operation?
- Will the services planned for the laboratory be sufficient to meet the needs of the lab and the science program?
- Are there any other issues related to safety that ought to be considered?
- And finally, although not really the purview of this review, I made a few comments on issues surrounding jurisdiction, authority and responsibility, which are probably well understood by the Andes team, but not by me, so they raised questions as I went through the review.

My premise has been that the Andes team wishes to build a lab that will support a range of experiments, both Latin-American led and Internationally led, that will be competitive with the state-of-the-art projects expected in 2020, that it will be a highly functional laboratory, providing sufficient infrastructure support to enable the science, and that it will execute this program with safety as a top priority.

My conclusions are discussed below, along with a set of recommendations for your consideration. However, as an executive summary: I found the design to be very functional, with a few exceptions, and that the plan for the services and associated infrastructure has been well thought through for this stage of the design. I think there are a number of things you may wish to consider as the design advances, and I have added comments throughout, but I see no reason you shouldn't proceed with this general schema to the next stage of more detailed engineering design.

2) General Layout and Construction of the Laboratory:

a. Excavated volume.

As a starting point I wanted to make a rough calculation of the volume of each area, according to the default drawings and text. This I could then play with to test various arrangements, compare with experimental space requirements, etc.

In many cases the dimensions were not explicitly defined in the text, and the drawings didn't always agree with the text, or have a constant interpretation. Many of the dimensions I found in the drawings were not to scale or disagreed slightly with the text. Also, in most cases there was insufficient dimensional information, so I used my own judgement, and listed my assumptions below. For example, if a barrel shaped cavern has a width "w", is this the width at the floor, or the width at the waist, and what is the curvature of the barrel? I have not worried about these details, as I understand the drawings and the text are both evolving. In addition, the dimensions are a bit moot now, as the original drawings and text assumed the excavation would be done by boring, which would lead to circular cross sections, whereas the current plan now is for blasting. In this case the more traditional ∩ shaped tunnels were used for most spaces. The assumptions were as follows:

- The dimensions quoted were for the finished shape available to the lab. The excavated size would be larger by the anticipated shotcrete thickness.
- To get an appreciation for the costs of concrete I assumed 5 cm thick on the walls and back, 10 cm thick on the floor, and used the current commodity price of about $US 80 per m^3 of concrete … just to get a ball park figure.
- For ventilation rates I assumed one volume exchange per hour in the area of interest.
- Main Pit: Barrel shaped. 30m diameter at waist, 28m diameter at base and at shoulder, 38 m floor to shoulder, 42 m floor to back. Top section is spherical cap.
- Small Pit: Barrel shaped. 9m diameter at waist, 8m diameter at base and at shoulder, 13.5 m floor to shoulder, 15 m floor to back. Top section is spherical cap.
- Main Hall: Original design: 42 m overall length plus 8m for access tunnel. Elliptical shape (as drawn) with 14.5 m vertical major axis, 13 m horizontal minor axis, and a pit in the floor 29m long, 21 m wide, and 3m deep. Top section is cylindrical cap, end of hall is part of spherical section.
- Main Hall: Alternate design. As discussed below, I did not think the pit added to the functionality, and with blasting is not a natural consequence. In this case the shape was more traditional ∩ with dimensions: 21 m wide at base and shoulder, 42 m long separate from 8 m long access drift, 23 m high from floor to back, 20 m from floor to shoulder.
- Service hall. Also ∩ shaped with dimensions: 16 m wide at base and shoulder, 32 m long separate from 8 m wide access drift, 14 m high from floor to back, 11 m from floor to shoulder.
- Small rooms, each ∩ shaped with dimensions: 10 m wide at base and shoulder, 10 m long, 10 m high from floor to back, 9 m from floor to shoulder.
- Narrow drifts. ∩ shaped with dimensions: 5 m wide at base and shoulder, 4.5 m high from floor to back, 4 m from floor to shoulder. For the length I just scaled these from the drawings which in the main lab came to 109m. To this I added the ramp, and assuming at elevation gain of 30m and a maximum slope of 7.5%, this adds 400m to the length.
- Wide drifts. ∩ shaped with dimensions: 8 m wide at base and shoulder, 9 m high from floor to back, 8 m from floor to shoulder. For the length I just scaled these from the drawings which in the main lab came to 395m.

Obviously these are quite rough estimations, especially with blasting, but given these assumptions the results are as shown in the table below.

	Finished Volume m^3	Excavated Volume m^3	Concrete m^3	Local air flow m^3/s	Concrete cost $US
Main Hall	19500	20600	1100	5.4	$ 88,000
Main Hall Alternate	19446	19679	233	5.4	$ 18,672
Service Hall	6688	6827	139	1.9	$ 11,092
Large Pit	26970	27190	220	7.5	$ 17,600
Small Pit	840	860	20	0.2	$ 1,600
Room 1	970	995	25	0.3	$ 1,996
Room 2	970	995	25	0.3	$ 1,996
Room 3	970	995	25	0.3	$ 1,996
Small Drifts and Ramp	11198	11708	510	3.1	$ 40,812
Wide Drifts	27255	28444	1189	7.6	$ 95,088
Normal Sum	95361	98613	3252	26.6	$ 260,180
Alternate Plan Sum	95307	97693	2386	26.6	$ 190,852

b. Functionality of the design

Issues with functionality

The general design seems very sound, with a couple of notable exceptions where I think the design will limit either the functionality or the ability to access and build experiments. The main issues are:

Pit in main hall?

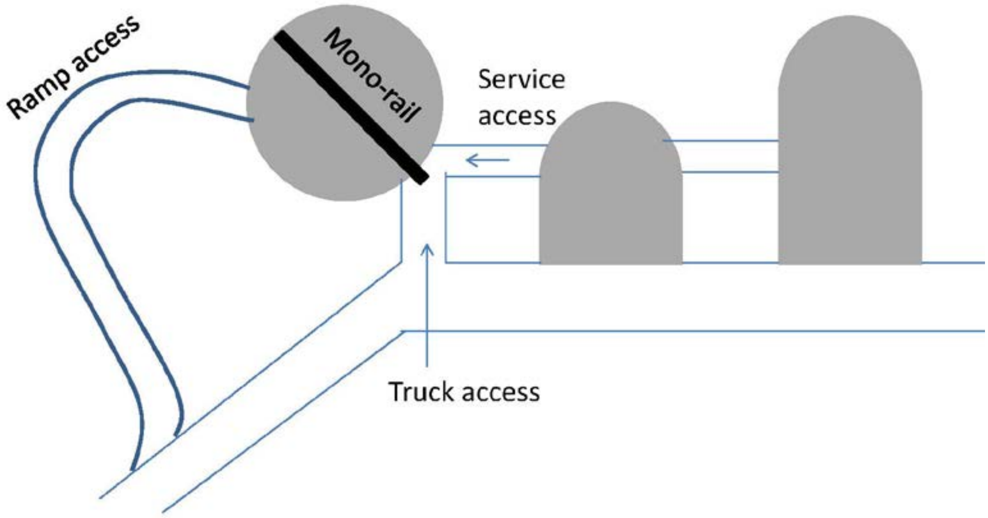
- The main hall. The original design assumed that the excavation would be done by boring, which left behind a circular section at the floor. This was taken advantage of by shaping that into a small pit. If blasting is done instead, a flat floor would be the norm. In this case, excavating the pit is more difficult or the walkways are built up by concrete. Having a pit is not ideal. You cannot access the area easily with a forklift, which is by far the easiest way to manoeuver things around in the hall. The drainage is more difficult, the floor space is not used as efficiently, you need to provide safety railing etc. If this is instead made to have a more standard ∩ shape, keeping the dimensions from the floor to the back the same, you end up with a more functional, adaptable floor space, the same volume, and potentially less cost for concrete. It is also much easier to construct, and there are no elevation changes to navigate from the access tunnel to the experimental floor.

Recommendation 1

If blasting is to be used for construction, change the shape of this main hall to a more standard ∩ shape, exclude the pit, keep the same volume, and increase the functionality.

Access to large pit?

- The layout of the large pit seems to have some logistics difficulties. The access could in principle come from either the top access or the ramp. However, these are both located at the rear of the main services hall. This area will be one of the first to fill up. Getting free access to the large pit at any time after the service hall is filled with equipment will be difficult, unless a large through fare is maintained. This is probably not the best use of space, and may be impossible given the equipment and tanks to be located there. There are many ways this could be resolved, and the cartoon shown below is just one example.



In this case, trucks, forklifts, etc. could easily access the main pit independently of what is in the service hall. Utilities (power, water, etc) would be installed in the small access drifts at the back of the service hall.

Recommendation 2

Reconsider the means of access to the main pit to avoid conflict with the service hall.

- Given the elevation gain of 30m from the floor of the pit to the base elevation of the lab, even with a 7.5% slope, the ramp will be 400 m long, so it will loop around in some wide arc. By locating it on this side, there is potential to use it as the starting point for future upgrades while isolating the rest of the lab. (see section on upgrading below)

- The design document calls for a short access drift from the rear of the service hall to the main cavern. This is probably valuable as it provides a good route for services, some of the air-handlers could go here, and it provides a second exit to the main cavern for safety.

Recommendation 3

Add a short service drift that connects the rear of the service hall to the main hall.

- As discussed below, a few of the services currently envisioned to go into the service hall may be better suited to be in small bays outside the main lab area. This is mainly for systems like the diesel generators, the main transformer, and the sewage treatment plant which are load, smelly and/or need external servicing.

Refuge station?

- Also as discussed below, I think there is a need for a refuge station which can protect personnel in the event of an incident in the lab or the tunnel, and this could double as a lunch and rest room area.

c. Sizes appropriate for experiments of the scale expected in 2020?

When one considers the experimental programs currently under design with a view to installation in or around 2020 one thinks of:

Direct detection of dark matter

Non-Directional Dark Matter:
There are a number of "next-generation" detectors currently under consideration world-wide. Some of these are likely to be realized on the same time scale as the Andes lab becomes available in 2020.

- Deap -50K which is envisioning 50 Tonnes LAr in a 13.4m ϕ tank.
- Eureca/SuperCDMS at SNOLAB envisioning an 8m × 8m ϕ tank.
- GEODM with interest in SNOLAB with a proposed 5.6m × 5.6m ϕ tank.
- Darwin or MAX envisioning tanks as large as 15m ϕ.
- Xenon 1 tonne, under construction with a ~ 10m × 10m ϕ tank.
- Darkside G2 with a proposed shielding tank of with a ~ 10m × 10m ϕ.
- LZD The final stage of the LUX program. 20 tonnes in a 10m × 10m ϕ tank.

Hence with the proposed dimensions of the Andes lab, one could fit several of the next generation detectors into these halls. Hence the cavern sizes should not be a limitation for this style dark matter detector. Note that once the scales reach a few 10's of tonnes of material, then one begins to reach an irreducible background rate from neutrinos. Hence significantly larger detectors in solid or liquid form are not envisioned at the moment.

Directional Experiments

Directional Dark Matter:
In the event of an observation of dark matter, or to pursue the development of directional sensitivity, or to attempt to understand the annual modulations observed in DAMA/LIBRA and CoGent, or to explore other DM scenarios (eg, inelastic DM scattering) one could imagine future dark matter experiments with directional sensitivity. These will most likely be gaseous detectors at low pressures, although some proposals have pressures up to order 10 bar. To be statistically sensitive and have good tracking resolution requires large masses and rather low gas pressures. Tracking also requires many electronic readout channels, which is likely to be the cost driver for these types of experiments. The current ideas suggest that caverns of the scale originally envisioned for DUSEL (eg 20m × 24m × 50m) or a reuse of the SuperK tank (~42m × 40m ϕ) would be about the right size for a competitive first stage experiment. Hence a first generation world leading dark matter detector with directional sensitivity could be installed in either the main hall, or the large pit. Prototyping of this technology could occur in these spaces as well, or possibly in the smaller support rooms. For a first generation detector, the caverns would be able to accommodate most conceptual designs. By first generation we mean detectors that will have real physics sensitivity, to be constructed after initial prototyping has demonstrated the feasibility to reduce the backgrounds, obtain the necessary tracking resolution, that are scalable, and not cost prohibitive.

Future $0\nu\beta\beta$ Experiments

Neutrinoless-Double Beta Decay
Current thoughts for the next generation of neutrinoless double beta decay experiments likely to be in operation near 2020 include SNO+, NEXO, SuperNemo and a combined Gerda/Majorana. SNO+ fits in the original SNO cavern, and NEXO is envisioned to be installed in the Cryopit at SNOLAB. Both of these occupy spaces that are smaller than the experimental halls envisioned for Andes. The ^{76}Ge merger of Gerda and Majorana would be a tonne scale detector, and with shielding would fit nicely into Andes. The design for SuperNemo experiment has 20 modules, each of

rectangular shape 5m wide ×3m tall × 1m deep, which would easily fit in either of the main Andes Halls.

Future Solar neutrino

Solar Neutrinos

Solar neutrino experiments tend to be big. SNO+ , Borexino, Kamland, would all fit into the Andes lab and it is reasonable to expect that the space available for a next generation solar neutrino based on scintillator would find adequate space in the lab. Some future neutrino experiments like HyperKamiokande or Laguna, are much larger than any available space in any lab foreseen at the moment. The scope of Andes does not include these mega-tonne detectors.

Supernova monitoring

Supernova Neutrino Monitoring.

Most of the experiments will be dual purpose solar neutrino experiments. Other experiments like HALO have a much smaller footprint. Hence these will fit into the lab with the same constraints as for the solar neutrino program.

The following table summarizes the potential capability of the lab for year 2020

State-of-the Art Program:	Large Cavern	Large Pit	Auxiliary Spaces
Non-Directional Dark Matter	Good	Good	Support
Directional Dark Matter	Adequate	Adequate	Prototyping
Double Beta Decay	Good	Good	Possible
Solar Neutrinos (non-cherenkov)	Good	Good	Support
Solar Neutrinos ++ megatonne	No	No	No
SuperNova Monitoring	Good	Good	Possible

Conclusion on cavern sizes.

The main conclusion here is that the cavern sizes as proposed will be suitable for all physics programs envisioned for 2020 with the only exception being the megaton experiments which will need special accommodation, or a series of huge caverns, if they are to be built. Those are beyond the scope of any current laboratory. There is a possibility that a 2nd or 3rd generation directional dark matter experiment would require a larger space, but this would be in a few decades, and dark matter would need to be discovered first before one considered such an endeavor.

d. Access to the facility.

Can vehicles enter and leave the lab safely?

Most elements for access to the lab seem just fine. The one area where the drawings probably don't reflect reality is in the design of the acceleration and deceleration lanes. Using the scale on the drawings, these are about 20 m long each in the current schematic. I expect there are local road safety rules that define these lengths, but one report I found on-line gave the minimum lengths of acceleration lanes as: 60m, 75m and 90m depending on the normal driving speed being 80 km/h, 100 km/h or 120 km/h, respectively. These calculations are based on the need to have vehicles merge into traffic within 3.5 s. Assuming the regulations for roads are similar here, much longer access approaches will be needed.

e. Auxiliary space.

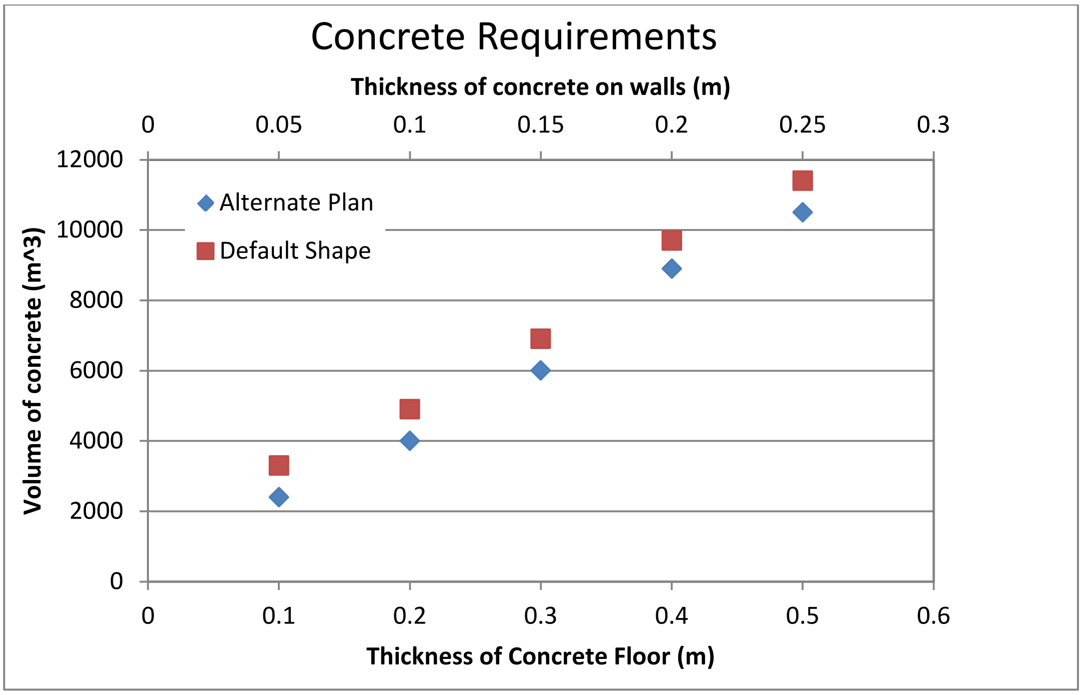
Has enough auxiliary space been allocated?

Given the expected auxiliary systems that will be installed in the service hall, including: water pre-treatment plant, ultra-pure water purification plant, 50 m^3 holding tank, Air-handling units and filters, air conditioning, power distribution/conditioning, computing, networking and fire suppression components, a rough estimate shows that these will only occupy 50% of the service hall. One could also imagine putting the machine shop and chemical handling facilities in here. It is also important to have an organized area for the storage of materials. With all of these, the service hall will be close to fully occupied in terms of floor space, while still having room to manoeuvre. Alternatively, one half of the space could be reserved for experiments which likely take better advantage of the 14m high ceiling. In this case the chemical handling and machine shop equipment are probably relegated to one of the small rooms. However it is arranged, there appears to be sufficient space, particularly if the recommendation below to move some of the services outside the lab is followed.

f. Shotcrete finishing.

How does cost scale with finishing thickness?

Although it is recognized that the thicknesses of concrete/shotcrete indicated on the drawings are just a consequence of scaling from the tunnel design, it is none-the-less useful to estimate the amount of concrete required to coat the lab under various hypothesis of thicknesses for the walls and floor. This has been calculated for thicknesses from as low as 5 cm on the walls, 10 cm on the floor, to what is likely excessive, 25 cm on the walls, 50 cm on the floor. To facilitate plotting, I kept the floor always twice as thick as the walls.



Will low background shotcrete reduce radon content of lab?

The costs for concrete, in the US, are about $80/m^3. Hence the total costs for basic concrete, for this application, will likely be in the $200k to $1.2M, so a non-negligible cost to optimize. The prices may be even higher for low background shotcrete, if a source for this is found. Some R&D would be worthwhile to understand how low a room background can be achieved using fresh outside-air and clean shotcrete. It is not obvious which will be the limiting factor, and it might be that a layer of clean shotcrete does very little to reduce the radon content … or it might be very valuable.

Install some engineered anchors at strategic locations

g. Utility anchor supports.

It is very likely that various experimental infrastructures will need to be supported from the back or the walls. For example, it is likely there will be a need for a deck structure above the water in the pits, and mezzanine structures to access the tops of experiments in the main halls. Installing an array of engineered anchors into the back and walls for future attachments may be a prudent thing to do during the dirty construction period. As their installation requires drilling deep into the rock, and high elevations, it is easier done when there is better access and no cleanliness considerations.

3) Other Infrastructure:

a. Water purification

The water for the lab will have a variety of uses, including as ultra-pure water for shielding purposes, normal clean water for laboratory services, and as potable water for drinking. The latter can be difficult as having potable water from a system means meeting various regulatory requirements for quality and testing, which introduces an overhead in operations that might be avoided by supplying bottled water fountains.

Basic water purification.

A basic purification plant will be required to produce water for the lab and as the front end to an ultra-pure water purification plant for the experiments. Such a system likely consists of a primary filtration system outside the tunnel to get rid of large particulates, and charcoal and water softening units within the lab that bring the water up to a general standard of use. With some investment into a testing program, this could be used to produce potable water.

Ultrapure water purification.

This water will then be of high enough grade to pass through a reverse osmosis system that does the bulk cleaning. At SNOLAB we also have a large degassing unit to remove radon from the water. This is only required if radon in the water is an issue, and if it is supported by emanation from tank or cavern walls. It also removes oxygen, which helps prevent biological growth in bodies of water. Passing the water through banks of ion exchange resin or a deionizer will be required to bring the water quality up to the maximum 18.3 MΩ. This can be helped by using UV light to break up complex molecules into ions in advance of the ion exchange stage. Finally it may be useful to add another bank of UV lights with a wavelength suitable to function as a biocide, to help prevent biological growth. This is one example of a working system… there are many possibilities that could accomplish the same goals. This water is not useful as potable water, as it is devoid of all ions, and hence has the effect of leaching minerals from the body.

b. Sewage treatment plant

The nature of this plant will need to be determined. There are a variety of options including:

- Transporting raw waste by container out of the lab. This is not ideal as it involves mechanical transfers that can result in leaks and spills, is messy, smelly, and requires personnel in charge of this job to take special hygienic precautions (shots for hepatitis etc)
- Chemical waste processing. This is fairly common, but not a solution I am that familiar with. I am not sure that the resulting product can be disposed of in an easy manner (down the drain as grey water).

- Biological reactor. This is used by SNOLAB and has been a huge success compared to transporting the raw sewage as was done previously. The sewage flows into a tank where microbes break it down. Once it is operational, and the biological population has been established, it works extremely well, with very little odor, very little maintenance, and the output is grey water that flows to the drain. The main maintenance activity is to supply the tank with "nutrients" in the event the lab occupancy is low … we add dog food to keep the microbes healthy in this case. Despite our good experience, this is not a facility I would install right in the lab, as undoubtedly, there will be times when an unpleasant odour is produced.

In all cases, macerating toilets will be required to process and transport the sewage from the toilets to the plant.

Recommendation 4

Install a small bioreactor or similar just outside the lab for the treatment of sewage.

c. Chemical handling.

Inevitably there will some need to work with chemicals. Having a general area where this work can be done safely, which has ventilated cabinets for the storage of acids, bases, etc. would be ideal. Also having fume hoods is essential for some work. If the fume hood is ducted, then some effort will be needed to engineer a solution for dealing with the exhaust. At low concentrations this can probably be mixed with the car exhaust ventilation system in the tunnel, but it is not obvious how this works in practise… how does one avoid blow-back into the lab from tunnel fumes, and how does one ensure nothing dangerous is introduced into the tunnel? Unless the lab ventilation has its own exhaust ducted all the way to the tunnel entrance, this might be difficult. Another option would be to use fume hoods designed to be ductless, which circulate the air in the fume hood through banks of chemical filters selected for the type of working being done. These are higher maintenance objects, and require care to ensure an appropriate filter system is in place for the work envisioned, but work well in applications where exhaust ducting is difficult or prohibitively expensive.

d. Machine shop equipment

The lab should provide space and some basic machining tools for the experimentalists to ensure that if a small modification is required, a long trip to one of the external facilities can be avoided. This is necessarily quite dirty work, so having space allocated just for this type of activity would be ideal. The basics would include a drill press, band saw, chop saw, and perhaps a milling machine and lathe. Users would need to have appropriate experience to use these machines. This activity could go into one of the 10×10×10 rooms for example, although this much overhead space is a bit excessive for a machine shop.

e. Welding equipment

Likewise, it is inevitable that some basic welding capability is required for cutting and for joining. Having this capability at the lab would be useful. Adding this capability and locating the services inside the small machine shop probably makes the most sense. This room would need to have specialized receptacles for arc welding.

Recommendation 5

Have one room set aside for machining, welding, and similar dirty activities, and outfit the room with some basic machining tools such as drill press, band saws, chop saws, …

f. Computing infrastructure

Some basic infrastructure could be provided by the lab, but I expect this would be mainly as part of the building automation controls and some local servers for the personnel in the lab. I would expect the experiments to provide their own computing infrastructure, including disk storage and data acquisition. The lab could provide a central area with racks for disk storage which would make the lab tidier that scattering these all over, and they might consider providing a cpu compute farm for use by the community. Generally, servicing things underground is much slower and more expensive in time and resources, so to the degree possible, I would move as many of the computing resources to one of the satellite support offices in Chile and/or Argentina. I would only keep essential components underground, such as are required for the primary storage of data so that the experiments continue to run even if the network is temporarily disrupted.

g. Cable trays

As a means of keeping some order in the laboratory, it would be very useful to install a series of cable trays that interconnect the relevant areas. In Canada, the regulations require that the fire/safety systems be separate from low voltages, be separate from AC power, so we generally have two tiered cable trays, one with a divider in it, to keep these three elements separate. Having the cable trays at an elevation of 2.5 m or so means they are not an obstacle when walking or maneuvering around the lab.

Recommendation 6

Plan on installing cable trays along the periphery of drifts and caverns to maintain and organize the multitude of cables that will be distributed through the lab.

h. Lifting devices.

Gantry Cranes or monorails?

Provisions have been made for cranes attached to the backs of the main halls. The current design calls for bridge cranes which have a complicated transverse motion following the arc of the back while maintaining the load at a constant elevation. This would be ideal if affordable, especially in the experimental areas where space will be at a premium, and frequent use of the cranes is expected. This is less warranted in terms of cost in the service hall. There, most of the initial installation can be done by forklift, and once installed there will be relatively few modifications to be made. In this case, options to be considered would be a gantry crane with rails running the length of the hall, or a semi-gantry crane, or a mono-rail. At SNOLAB we found the affordable option was a combination of mono-rails and gantry cranes, and this has worked well for us. If necessary with a monorail, we use engineered anchors located in the back and the walls to pull a load slightly from one side to the other. For the large pit, a bridge crane is not ideal. A better option is probably a mono-rail which extends into the access drift, so that equipment can be brought into the drift, unloaded with the crane, and lowered into the pit. This would also work well for the small pit, with a smaller beam and hoist.

Will the plan work?

i. Radon free air

The plan for radon free air is to use air from outside the tunnels which is lower in radon than the air inside the tunnels. This will certainly lower the radon levels in the lab, but I worry it will be a big expense for very little gain. The MiniClean collaboration tried something of this nature, using compressed air originating outside the lab, which they released inside a tent inside the cleanroom at SNO. It had a positive pressure so should have had a net flow of clean air outwards. None-the-less they were only able to achieve a factor of two improvement, as that air mixed with radon rich lab air. Unless something is done to limit radon emanation from the walls of the lab, I suspect you will only get a factor of two or so in reduction with this technique.

Radon from the walls.

If the coatings on the walls act as a barrier to radon, you might improve the situation dramatically. This means finding an affordable source of low background shotcrete, something we didn't do at SNOLAB, in part because we had no choice but to flow our fresh air for ventilation through the mine drifts where it became rich in radon anyway. Otherwise a polyurethane or similar liner, coupled with a radon "free" source, might work. But before I designed the lab in this way, I would see if an option like that would be feasible.

Where is LN_2 sourced?

j. Liquid nitrogen

Experiments will require liquid nitrogen and it is not obvious where the lab will get it. In the SNOLAB model, there is a large tank on surface, and we transport small 250 l dewars from surface to the lab. This works for us as the supplier has easy access to the large tank to keep it full without us having to be involved with that activity, and we look after the local delivery to the underground. We had at one time considered having a liquid nitrogen plant underground, and in the long run this might have been the better choice. The problem with this scenario is the high initial cost for the facility (although it would have paid for itself after 4 years of operation) and the fact that the air underground is high in radon. Using commercial LN_2 means that the supply is air on surface (lower radon), and the delivery mechanism ensures that the nitrogen is old by the time it is used in the experiments, ensuring that most of the radon has decayed away. One option would be to add a radon scrubbing unit to the nitrogen plant, and the feasibility for this depends on the scale of production. Or, one could have storage tanks that allowed the LN2 to sit long enough to decay.

Options to consider would be:

- to have a liquid nitrogen plant in the lab with a radon filter or holding tank,
- to have a liquid nitrogen plant outside the tunnel using cleaner air and then do local transfers to the lab in portable dewars,
- to have a "local" firm maintain a large dewar at the entrance to the tunnel, and then do local distribution with smaller dewars.

k. Cleanrooms

The lab will not be operated as a cleanroom, so individual experiments requiring this capability will provide that themselves with some local tenting structure. This is how experiments at other labs have worked successfully. However, there may be times when a small clean space is required for a particular activity … assembling some small piece of apparatus, where access to a small clean room or clean laminar flow hood would be useful. In that regard, it would be advantageous to have a small laminar flow hood available in an area like the chemistry room, where this activity could be done. Laminar flow hoods in a clean environment can produce class 100 air streams, which would be adequate for most applications.

l. General cleanliness

Minimizing migration of dirt.

Although the lab will not be operated as a cleanroom, the experiments do need clean space which they will provide locally. Cleanliness is obtained by always keeping the dirtier parts as confined as possible, thereby reducing the migration from one zone to another. The design of the lab should consider how to minimize the amount of vehicular dirt getting tracked into the lab, perhaps by having some gratings, or by asking people to at a minimum, change into clean work boots as they transition into the lab.

Net flow of air out.

Another way to help with general cleanliness is to ensure that the main experimental caverns are at a slight positive pressure so that there will be a net flow of air out of these rooms. Having some members on staff who are doing a basic cleaning of the main floors would also benefit the lab greatly.

m. Lunch room and rest area

The experimental site is a long way from "civilization" and so lab personnel and scientists will likely work fairly long shifts having made the effort to get there. Having a central area where personnel can sit down to eat, equipped with standard fridges, microwaves, tables, etc is essential. Perhaps even a coffee pot given that some people find this not only necessary, but enjoyable. This could be naturally coupled with the refuge station, as it will have most of the ingredients one would wish to find in the refuge station as well.

Recommendation 7

Provide a lunch room and rest area which serves doubly as the refuge station.

n. Washrooms

The location of the washrooms is not indicated on schematics. They would be best located inside the sealed refuge area (if that recommendation is adopted), and by the lunch and rest area in any case. Then they are available should personnel have to retreat to the refuge. In the original SNO design, this was not implemented, which meant having buckets available to personnel who drank too much coffee during fire drills or other times when staff had to retreat to the refuge station.

o. Meeting room capability

We have found it very useful to have at least one space underground where you can hold a small meeting or have a teleconference call in a somewhat quiet environment. Underground it is often quite noisy with the ventilation running, and perhaps nearby equipment. Providing a bit of space in one of the smaller rooms, either with quiet flow ventilation or some sound absorber, would make this a useful space to work and to hold meetings. Meeting underground are usually in order to review a delicate operation that is about to take place, or to go over some operational details, or to hold a safety briefing, and in all cases being able to do so in a reasonable quiet space, with some projection capability, would be useful.

Recommendation 8

Provide quiet space in one of the smaller auxiliary rooms.

p. Security

The document describes the process for entering and leaving the lab, which sounds very reasonable. In addition, there will be security personnel associated with the tunnel that will have access to security monitoring information from the lab. Other things that one might consider are:

- Some kind of tag in board to identify who is in the lab at all times. In case of an emergency you know if you have accounted for all personnel.
- One employee underground each day with a general lab coordination responsibility with the authority to stop work he/she deems unsafe or which might put other experiments at risk, and who is generally aware of what activities are underway in the lab.
- Having webcams in the main halls. This is useful for people to see remotely into the halls, (and also useful to build time lapse videos of construction progress for promotional purposes).

4) Ventilation. Fresh air and Radon suppression. Lab "sealing"

a. Fresh air requirements and air-handling units

Can volumes of air be circulated reasonably?

The total volume of the occupied space in the lab will be close to 100,000 m^3 when empty. To turn over this entire space in one hour implies a total flow of about 30 m^3/s. (I have used this value, as it was suggested in the main document. This is however quite a low value. The recommended number of **fresh** air exchanges per hour is quite variable depending on the application of the space, but the minimum is around 4, and in certain cases it can be 10 or 20, for example in chemical handling areas). Provided there are several air-handling units, each circulating to some local area, this should be manageable. Perhaps 4 units would be sufficient. One providing local circulation to the main hall, one for the large pit (while empty) and service area, one for the utility rooms, and one for the access drift. Each would be circulating at a rate of nearly 8 m^3/s. Units with this capacity are generally available for industrial purposes. At 8 m^3/s flow rate, the maximum recommended velocity in a duct is 7 m/s (to keep noise and energy consumption in a reasonable range). This implies a duct with an area of 1.1 m^2, or a diameter of 1.2 m. This is a pretty large duct, but ducts of this size are readily available, and could fit into the lab, especially if located against the back. However, having more units might be the better solution. This analysis was just to demonstrate that a feasible solution exists…the engineering team will need to develop the optimal one. The velocities expected in the laboratory are all well below the maximum recommended velocities for user work areas, which tend to be in the 10 to 16 m/s range.

Fresh air

In addition to local circulation, some fresh air should be added. (In fact as stated above, 4 fresh air exchanges per hour is normally considered the minimum). Since one of the goals for the make-up air is to reduce the radon level in the lab, the ratio of fresh air to circulating air should be as high as is practically possible. If this could be as high as 20%, then this would suggest you need to supply about 6 m^3/s of fresh air to the lab. The main supply ducts in industrial plants have velocities in the range 6 to 12 m/s. Taking the lower of these would imply a duct with an area of 1 m^2, which is an expensive prospect for a 4.5 km duct. Dropping to 10% make-up and a velocity of

12 m/s would imply a duct with an area of 0.25 m, or a diameter of 0.56m, which is quite reasonable. However, these are all providing a rather low amount of fresh air compared to general recommendations. Given the noxious fumes in the tunnel, and potential for cryogenic fluid boil off in the lab, it might be better to design for a much higher fresh air flow rate.

Recommendation 9

The default design of one volume exchange per hour may be on the low side. Check local codes and engineer the system accordingly. The design may require quite expensive (large diameter) supply and exhaust vents, or the use of high pressure ducts. As this is likely installed as the tunnel is constructed, it is a somewhat urgent engineering task.

b. Venting

Normal exhaust rate

Under normal conditions, one could consider just venting the lab to the tunnel exhaust, and this might still be the best solution. It depends on what the tunnel airflow rates are, and how quickly anything noxious from the lab would dilute. In the case of the rapid boil-off of a large cryogenic detector, one would need to have an exhaust that was completely isolated from areas of human occupancy until it reached an air volume where it could dilute safely. This is difficult to determine without input on tunnel airflow dynamics and the cryogenic quantities. At the very least one would need a laboratory exhaust duct as large as the supply duct, to exhaust air from the lab to the ventilation tunnel. In the worst case this would extend to the end of the tunnel. Again, this is design work that is fairly critical.

Emergency cryogenic boil-off

The cryogenic experiments will be responsible for engineering the safe release of cryogenic gases in the event of a total failure of an experiment. In this case asphyxiating gasses could fill the caverns. As a figure of merit, the DEAP-3600 experiment will install a 25 cm diameter steel pipe to deal with the potential boil-off of 3600 kg liquid argon. This will exhaust into the main mine exhaust which is at a very high flow rate, and personnel are never exposed to it. This will not be so easy given the length of the tunnel, so installing this as a general infrastructure is probably prudent.

c. Pressure variations.

Tiny pressure changes have large impact

If the tunnel has a high ventilation rate, and if this is driven by fans, then the sudden stoppage or starting of a fan can lead to a pressure fluctuation in the lab. Even if the ventilation is passive, fast transients due to large vehicles in the tunnel, or slow transients due to atmospheric effects will be possible. As an example, at SNO, fast pressure spikes of order 6” water (0.015 bar) were fairly common due to events in the mine. Even if the tunnel has smaller fluctuations of say 0.005 bar, if the large pit has a sealed deck, then the load on this deck would be 36 tonnes! Hence the engineering of the lab needs to take into account the large forces from tiny pressure fluctuations and develop ways of protecting equipment like decks and other “sealed” spaces. In practise it is probably not possible to seal such spaces, but rather one must design solutions that allow them to equalize pressure quickly, while still limiting radon ingress and (if PMT’s are involved), light ingress.

5) Electrical Power and Lighting.

a. Normal power distribution system.

Is sufficient power available?

The document suggests that the power available to the lab will be 2 MW. This is similar to the capacity of SNOLAB, where there have not been any issues with insufficient capacity with the current set of experiments. It might be limiting if several experiments need peak power at the same time. Upgrading the power distribution to the lab at a later date is likely to be difficult and expensive, and so you probably want to double check the requirements once the initial suite of experiments has been defined.

What is the battery limit?

I have not seen the plans for the power requirements of the road tunnel, but with mostly passive ventilation, the only electrical power requirements will be for some light ventilation fans, lighting, instrumentation, and the facilities near the tunnel openings. Hence I have assumed that the power demand for the tunnel will be less than a few MW, and that of the lab 2 MW at peak capacity. With these numbers I expect that the power transmission from the grid to the tunnel will be in the 10kV to 100 kV range (and likely the industrial standard of 13.2 kV). Presumably only specially trained high voltage power electricians are allowed to work on this system. (In Canada, a normal licenced electrician can only work with 600V and below). Since interactions with this system will be rare it is unlikely there will be somebody on staff that can deal with this system. The tunnel authority may maintain that expertise, so it might be prudent to locate the high voltage systems in an area accessible to the tunnel or power authority, and to define the battery limit such that the switchyard is part of their purview.

Where will the switch yards be?

How will power be distributed?

The location of the main power centre transformer, that will convert from say 13.2 kV to the voltage required for the lab, needs to be considered. It will need service very rarely, and not by normally available personnel. It is a dangerous unit, and often a bit on the noisy side. I would recommend it be located just outside the lab in a separate bay where it can be serviced by contract personnel, or the power authority, safely. For security it should be enclosed by a chain-link fence, which distances people, but allows for ventilation. I would recommend co-locating the backup generator near here. Having this unit readily available in the service cavern introduces a dangerous noisy unit into the lab, where it takes up space for no particular advantage. The main electric switch yard can also be located there, so in an emergency, the power to the laboratory can be isolated by throwing a single switch.

Recommendation 10

> *Locate the main high voltage transformer and switch yard outside the lab in an area easily serviceable by the power authority and define that area as part of their responsibility. Possibly this would be the same location as the diesel generator, which would supply the low voltage side.*

The power requirements for equipment in the lab probably consist of 390V 3ϕ and below. I expect it would be useful to have a main distribution system in the service hall. This would distribute the 390V to all of the main spaces, which in turn with have a local distribution of 390V and 220V that would service the needs of the experiments, and the laboratory infrastructure.

power cleanliness?

Subatomic physics experiments usually employ sensitive electrical devices. Hence it might be worthwhile to install a power conditioner in the service hall that would help regulate and clean the power being distributed. Another issue to be thought through is the overall grounding scheme for the lab. The industrial standard tends to lead to many ground loops.

b. Back-up power.

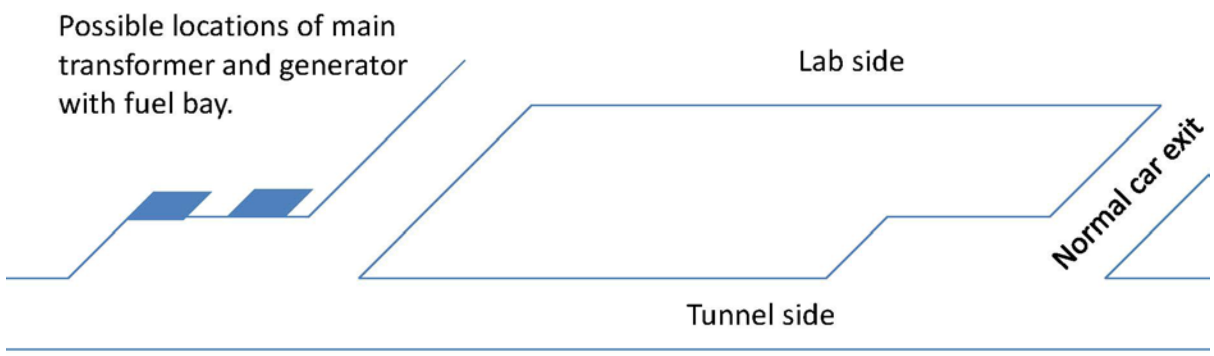
What will the emergency power distribution system look like?

It is not clear from the discussion how thorough of a backup power system is envisioned. Below are two extremes one might consider…probably the final solution is somewhere in between.

The **minimal system** would have local UPS power supplies located around the lab near critical components that should be powered, at least for a short period of time, in case of a power failure. The most obvious things to keep powered are emergency lighting systems to allow the safe passage from the lab, network gear to enable the status of the lab and the experiments to be monitored, critical control and monitoring instrumentation, and networked power switches that would allow remote personnel to stop/start equipment and control critical computers during their boot sequences. Experiments could supply their own as part of the cost of running the experiment.

The **most elaborate system** could be configured as:

- The lab provides (limited) emergency back-up power via a reasonably large UPS that would maintain the critical components during a brown out, and provide sufficient power in the period between the power failure and the time a diesel generator activates.
- A diesel generator would then provide emergency power to critical components. The location of the generator would need to be thought through. Having the generator in the lab is somewhat problematic for a number of reasons. The principle issue is that it necessarily needs a fuel storage bay, and must exhaust the diesel fumes. Having a small dedicated fuel storage bay away from the lab is probably much easier, depending on the fire codes. Normally such a bay would require secondary containment for spills, and some local automated fire suppression system. Having the generator outside, where the fumes will be mixed with the automotive exhaust, may be a simpler solution that trying to pump the noxious fumes out of the lab without leaks. Additionally, if the generator is inside it cannot be serviced (for example to refill the fuel storage tanks) if access to the lab is restricted. Finally, diesel generators are normally hot, smelly and noisy when operational. Although one cannot imagine “normal” operations in the lab during a power failure, this is not the sort of object you want in your clean environment. Having it in the lab would mean you at least have to power a subset of the ventilation system to ensure the exhaust is removed safely. Finally, having the diesel generator near the main power switch yard could reduce some of the costs. A possible lay out is:



Recommendation 11

Place the generator outside the laboratory. Perhaps the best location is in a small bay at the end of one of the access lanes where it can be reached and serviced from outside but in a safe way. For security reasons, it should be behind a locked chain-link fence or similar. The exhaust fumes should merge with the car exhaust ventilation.

- An emergency power distribution system will be required to provide power where needed. Although the capacity will be less, this probably means providing power to all the experimental areas and the service halls, and so very nearly a duplication of the regular power system. It is often difficult to retrofit a system like this after the lab is complete, so provisions for it should be included in the original design. This is a significant cost, but is a cleaner, more elegant solution. Some controls would need to be in place to ensure only critical components were plugged into this distribution system, and it should be easy to visually distinguish between regular and emergency power receptacles.
- Individual experiments may wish to have some local ups capacity.

c. Lighting system.

What is envisioned for standard and emergency lighting systems?

Some thought has to go into the lighting systems, but in any case, these are usually dictated by standard building codes. In a laboratory environment like this, having lots of clean bright light is important. This can be complicated as the lighting is normally suspended from the ceiling and in many cases this will be too far away so side lighting may be necessary. The lighting is further complicated in the service drifts, as the back is usually used to run the ventilation ducts, cable trays for electrical services, water lines, fire sensors, etc. In narrow drifts, this can become a crowded area, and getting sufficient light, although not difficult, is easier to do by design rather than retrofitting afterwards.

There are a few ways to install emergency lighting, and this is, in any case, probably dictated by building regulations. One way is to have lights with local emergency battery power located strategically throughout the lab. These are on normal power, but transfer to battery power when the power fails. These have to be part of a regular maintenance plan to know that the batteries are still functioning properly in the event of a power failure. The other alternative would be to wire a series of lamps into the distributed back up power supply, if it exists.

6) Water and Drainage.

Is there enough water?

It is understood that the water supply is to be obtained from local streams in the vicinity of the laboratory. A study should be made to ensure that this provides an adequate supply of water year round (it doesn't freeze in winter and does not have dry periods in summer…), that there are no environmental impact issues steaming from extracting water from this supply, and that there are no environmental issues with discharging grey waste water from the lab.

Flow rate?

The stated requirements for the lab are "some litres per second". At 1 litre per second, a 50 tonne shielding or storage tank could be filled in 14 hours. This seems like a sufficiently high rate, and if necessary, one could probably function well with a slightly lower flow rate. The main issue for the flow is whether or not the source is adequate, whether it will need to be pumped, or whether it will be gravity fed. With a reasonably sized pipe (say 10 cm diameter) and a flow rate of 1 lps, the pressure drop over 4.5 km is very modest, less than 1 bar assuming a straight piping path. Hence the main driver for the pressure and pump required, if at all, will be the elevation change from the source to the laboratory. If the source is at a much higher elevation, pressure regulation will be required, and this can be difficult as high pressure regulators are delicate instruments, which means the water must be quite clean before entering the pressure regulator, and the regulator must be serviced regularly.

Pipe material?

We have had poor experience underground using steel pipe. This is likely worse in the case of SNOLAB, as the long vertical drops ensured that the water was saturated in oxygen, which led to a lot of corrosion in the pipes. After switching to an all plastic pipe, bought in rolls of several hundreds of meters, we no longer had problems with rust, and we had a system that was easy to install, and has never leaked. The only drawback to plastic water piping is that if not hung properly, it will form sags between supports, and if the pressure regulation is not maintained properly, it can burst. The mine followed our example of installing plastic pipe, after our great success, but they were cheap on the number of chain supports they installed, and they did not properly maintain their pressure regulators, so it was a disaster for them.

Drainage

Underground experiments make use of water for shielding; cooling, cleaning … and generally they will find a way to flood every space they occupy. Hence the lab floor and drainage system should anticipate there will be floods to deal with. Having open drains, as was the case at the original SNO, was not a good idea. Very soon there is all nature of biological activity growing in them which is not pleasant in the lab. Having a below grade drainage system is best. This means getting the floors properly sloped (but very nearly flat to help with the experiment installations), and draining to a sump where a pump can extract the waste liquids is what we have found to work the best. This requires some effort by the contractors. Despite our best efforts, we ended up with some floor drains at local high spots, which has not proven to be too useful. These floor sumps should report to a main sump just outside the lab, which then pumps the effluent into the tunnel drainage systems. It should be possible to quickly isolate any sump pump in the event of a spill of a substance which presents an environmental hazard.

sewage

With workers in the lab, sewage and non-dischargeable raw waste water are inevitable. These will need to be processed in some fashion, see section 11)b, and the grey waste effluent discharged from the laboratory. Perhaps these feed into the main sump as well, before being pumped out of the lab. Since on average, the flow rates into the lab should be the same as those leaving the lab, similar considerations apply. Here steel pipe is an option as corrosion in the waste water is not an issue. Where this waste water discharges will be of environmental concern. Presumably the main tunnel will have some water discharge system, and it may be possible to join into that. It would certainly be the lowest cost solution.

7) Compressed Air System

The laboratory will need a source of compressed air. This will be used to power pneumatic instruments and tools, possibly as a source of radon free air (if the source is outside the tunnel), and possibly to provide breathing air for a refuge station.

Normal use

If all that is required of the compressed air system is to provide power to tools and in pneumatically driven instruments, then a reasonably small compressor (5 to 10 kW) providing pressures of about 5 to 7 bar should be sufficient. Compressors are very noisy, and do not require much maintenance, and they run automatically. Hence such a compressor is best located outside the main lab area. For cleanliness reasons, having filters to remove oil and water from the compressed air will be essential.

Radon reduced air?

If the compressed air is to be used to provide a source of air which is lower in radon, by virtue of the source being at some elevated point outside the tunnel, then the compressor will likely need to be located outside the tunnel as well, and a steel piping system will need to transport the compressed air to the lab. As the current plans are to get lower radon content using fresh ventilation air from outside the tunnels, this is not required. However, I expect the cost of vent ducting for this purpose will be much more expensive than the small pipes required for compressed air, so it is something to consider.

Refuge air?

If the lab is to have a dedicated area where staff and scientists meet, and seal themselves into, in the event of a fire in the lab or the tunnel, then they will need a source of breathable air. This is best done by having an external compressor provide compressed air to the lab. This compressor could be located near the entrance to the tunnels. In the event of an incident in the lab or the tunnel, personnel would retreat to the refuge station, barricade the door, and open the compressed air line to provide fresh air. The compressor should be on a different electrical circuit from the lab, so that if an event in the lab or tunnel cuts off power, there is still a source of fresh air.

Recommendation 12

Install a compressor outside the tunnels. It will then be multifunctional in providing compressed air for instruments and tools, may be used to provide air low in radon, and can provide emergency fresh air to a refuge if required.

8) Fibre Optics Network.

Fibre redundancy

The plans call for redundant fibre optic connections to both Argentina and Chile. This sounds good. Redundancy can be by virtue of having extra fibres within the bundle, so that if one fibre breaks one still has full connectivity, albeit with some loss in bandwidth. Depending on where the cables run within the tunnel, you may also want to consider having two bundles physically separated from one another. This prevents a single mishap (forklift backs into the bundles for example) from taking out the entire system. Having single mode is good. Some systems are not so critical (eg VOIP) and you may find it useful to have some multimode fibres to increase capacity for these types of things. You will also want to ensure that all network switches and equipment are on good UPS systems as this is one system you do want to keep active under any circumstance.

Recommendation 13

> *If there is some potential for the fibres to be physically at risk within the tunnel, build redundancy by having separate bundles physically separated from one another.*

9) Life Safety Systems

Fire safety

In terms of life safety systems, these things appear to have been thought through carefully. In most cases there are multiple exits for emergency egress. In the text, it suggests that the main hall will be connected to the service hall, by a drift at the back of these halls. That would provide some space for utilities, and another exit means, and is worth thinking about. This idea did not appear in the drawings. In terms of fire, the document suggests that engineering the systems and choosing the materials to be fire retardant, to the degree possible, is the first line of defence, and that a variety of fire suppression tools will be available. This is good. Having fire hoses strategically placed around the lab is good. Fires often lead rather quickly to electrical power outages, either because that is where fires start or because the systems get isolated. In this case, keeping the fire suppression lines charged will be difficult unless the water is pressurized from an external source or the fire pump is on its own electrical circuit. Some thought into how this best arranged is required. It was also mentioned that the water in the pits could be used as an emergency backup fire-water source. This is a good idea, but the water will need to be pumped out, and so that pump also needs to have power in the event of a fire. Having a submersible pump in the pit would mean you wouldn't have to worry about losing prime, as would be the case for a pump above the pit but may lead to cleanliness issues for the experiments and electrical safety issues.

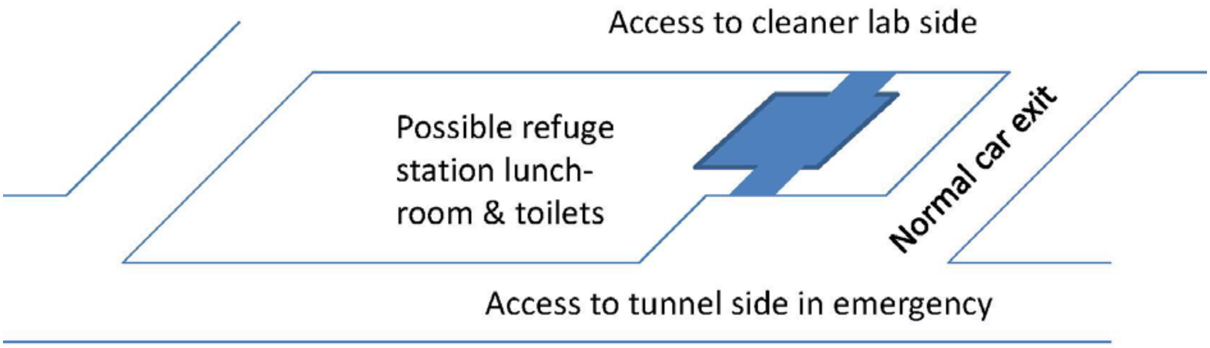
The maximum depth of water that can be extracted using a pump located at the top of the pit is 10 m, so this is not particularly useful. One option would be to place this pump at the bottom of the ramp, below the lowest point of the pit, and to have the pit drain to a controlled valve, to this pump, with the pipe passing through the sealed pit wall. In this way you have access to the pump, can drain the entire volume, never have to worry about prime, and keep the dirty pump and components outside the pit.

Recommendation 14

> *Install pump for draining the main pit and providing source water to the fire suppression system at the bottom of the ramp, outside the pit.*

Refuge Station

In the event of a fire underground, either within the lab or within the tunnel, the main risk to personnel safety is asphyxiation by the fumes. Hence it seems like dedicating one room as a refuge station is essential. This should be a room which has very little equipment within it (so it is not a potential source) and which can be sealed off from the rest of the lab with a source of fresh air. The mining standard is to use compressed air delivered by a system external to the lab. (see discussion of compressor in section 5) This room should also have access to water, food, and ideally the toilets. Hence the personnel lunch room and facilities area is likely the best choice for this. Having some general computers in this area, to communicate during a shut in, is recommended. Having a copper based phone line is essential. The location of a refuge requires some thought. Ideally it could also be used for people to retreat from the tunnel in the event of an incident there, while having its main purpose retreat from the lab. Perhaps one of the three 10×10×10 rooms was envisioned for this, but they are not the most accessible, nor is such a high back required. Having a 10×10×4 would be ample for a refuge station, and it could be located between the tunnel area and the lab to allow access from either side in an emergency. The following is one idea for a location:



Recommendation 15

Create a safety refuge area which doubles as the staff lunch room and facilities area.

Foul Air Monitors

Not really mentioned explicitly in the document, are the nature of the safety monitoring systems. The lab should be outfitted with fire and smoke detectors, as well as monitors for oxygen content and carbon monoxide (and perhaps NO_2) that generate alarms at certain thresholds. Ideally, the air quality information should be available remotely, so that in the event of an incident in an unoccupied lab, personnel could determine the air quality before entering the lab.

Recommendation 16

Install foul air and smoke/fire detectors at strategic locations within the lab.

Additional fire suppression

Some experiments may present hazards for which additional fire suppression is required. For example a large mineral oil based scintillation detector might need a sprinkler system installed above. These will be installed on an ad hoc basis, but the design philosophy of the fire suppression system should allow for these upgrades.

First Aid

The document describes there will be adequate first aid supplies available, including provisions for treatment of altitude sickness, which could be an issue at this elevation. One should also consider having emergency showers in areas where chemicals are being used extensively, and eye wash stations located strategically throughout the lab. Defibrillators are becoming fairly standard safety equipment now, and could be useful in a remote location like this. Other than that, the standard first aid supplies and stretcher boards are likely all that can be useful.

10) Seismicity.

Seismic Risk

Although the details of the experiments are not known at this time, it is likely that they will include large water tanks, vessels on legs, steel mezzanine structures, lead shielding walls, and similar. These need to be designed to meet the expectations for local seismicity. A geo-engineer should be able to provide an upper limit for the seismicity in this area, and with this provide a forcing function that can be used to design any lab or experimental infrastructure.

Recommendation 17

> *Get a geo-engineer to assess the seismic risk and provide a forcing function for design of infrastructure.*

Seismic monitors

In addition, one should consider instrumenting the lab and exterior with free field micro-seismic instrumentation that will monitor the condition of the lab and record the history of seismic activity. This is also useful in the event of some large seismic event, in order to wait for the aftershocks to die down before sending personnel into the lab for an inspection. This instrumentation is normally inserted deep into the cavern walls, so it is best installed before the wall finishing is done.

Recommendation 18

> *Have some form of seismic monitoring instrumentation which can alert operators to raising activity or to assess the situation after any significant seismic activity.*

11) Jurisdiction and Regulations Applicable to the Site

Legal Jurisdiction

The laboratory personnel will need to ensure that work done in the lab is done safely, and with due regard to other experiments in the facility. This will inevitably lead to the generation of some general policies to guide this. The equipment will need to be built in accordance with standard regulations for electrical safety, pressure vessels, etc. Normal building codes may apply, or the lab may be governed by underground mining regulations. Since this is a new science facility, in an underground laboratory, built as a consortium of many countries, straddling the border of Argentina and Chile, it will be necessary to understand what jurisdictions have authority here. Are Argentinian standards or Chilean ones de rigour? Do mining regulations supersede standard building code, or is there a separate classification for scientific laboratories? Which institution will own the property in trust for the others? All of this needs to be determined in advance of detailed design work on the lab and the experiments, to be confident it is designed and built to the appropriate set of codes.

Recommendation 19

> *Determine which regulations and codes will apply in the design and construction of the facility, and which jurisdiction is the authority.*

12) Authority and Responsibility

Organization Chart

At the moment, the Andes project appears to be organized by a collection of like-minded scientists, with a few key people taking leadership roles. There are also some memoranda of understanding, as was recently signed at the workshop in Mexico, that define the willingness to work together on this project. There may be a lot more agreements and structures that I am unaware of. That being said, as this moves forwards with more significant expenses, and hence more significant risks, and eventually real construction, a more defined organizational chart delineating responsibility and authority will be required. Although the countries involved in this consortium are considerably less litigious than is the case in North America, you can still ask the question "if something goes wrong, who is responsible". However, the purpose of the question is not so that you can assign blame, but so that you can account for everybody's set of responsibilities and authorities, so that you are confident that for all activities, somebody is taking the responsibility, and thereby minimizing the possibility that something goes wrong. If nobody is assigned responsibility in a certain area, it is likely to lead to mishaps, delays, problems, etc.

It is not clear to me what kind of legal entity the laboratory will be, and that probably depends in the end on how the money flows and what agreements are made with the funding agencies. However, determining the legal status of the lab, appointing a Director of the Laboratory, and assigning roles to the key individuals would seem to be a prudent step to take at this time.

Recommendation 20

Define a rudimentary Organization Chart outlining key responsibilities for the design and implementation of the laboratory. Understandably it will evolve as the project does.

13) Upgrade Capability.

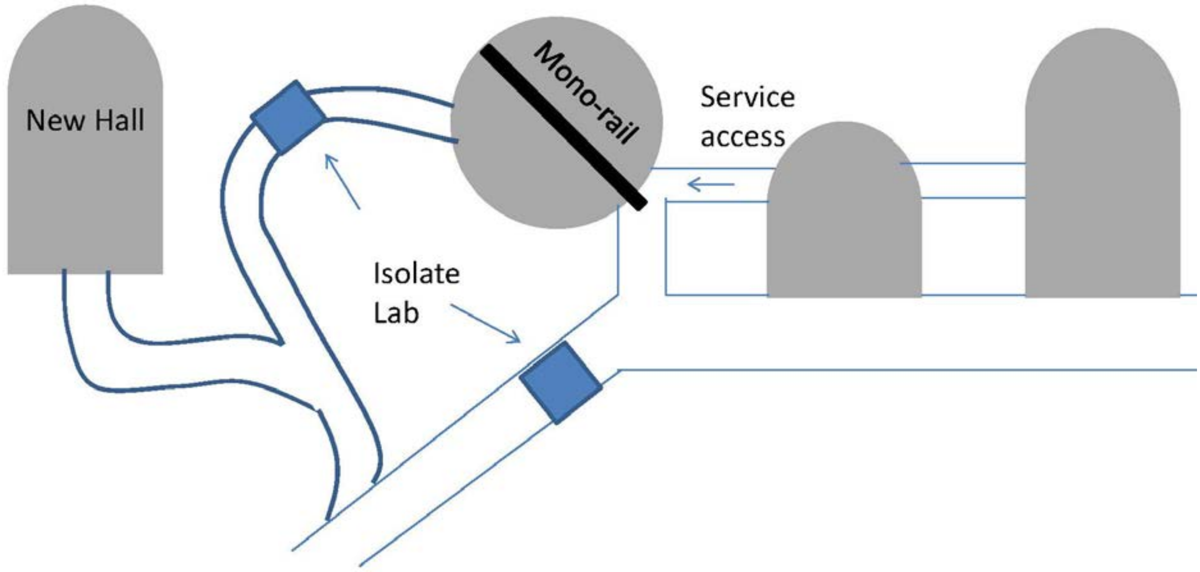
The document and the drawings do not consider the option for future expansion, and it has been said at workshops that this would be impossible. However, if a future need arises, I believe one could expand the lab without significant disruption to the running experiments or tunnel operations. The main issue for the lab would be to prevent construction blasting from creating dust, a large pressure transient, or seismic activity. The main issue for the tunnel would be to ensure vehicular traffic was not disrupted, and that the eventual transport of rock from the tunnel could be done in a way that neither damaged the road nor interfered with traffic.

Can the rock be moved from the lab?

Working through some of the numbers: If a cavern with a volume of 20,000 m^3 (similar to the main cavern) were to be excavated over a period of 100 working days (20 weeks), then each day you would need to move 200 m^3 of rock. A typical dump truck carries 10 m^3 so this would imply 20 trucks per day, or 2 per hour over the quieter part of the evening/night. This seems possible. The main issue would be to ensure they did not damage the roadway (or make a mess of it) in the process, so it would probably be necessary to clean the trucks a bit before they departed. Hence this part is doable in principle, I think, and so the lab design should be open to this possibility, just in case.

Can the lab be isolated?

If the ramp to the cavern is located as suggested above, then it would be possible to consider a new cavern being developed from there, as suggested in the cartoon below.



In this case the way to isolate the lab from harm would be to build two walls or some kind of solid pressure plugs, one at the bottom of the ramp (to protect the bottom of the pit), and one in the second exit from the lab to protect the lab from the blasting activity. Then one could blast a short drift starting in the original ramp (and sloping up if you wanted to keep the labs at the same elevation. This would allow you to develop the new hall with minimal interference to the operating lab. You could still access everything you needed to in the original lab, the only inconvenience would be that the second exit was closed, so for this period trucks would have to back up, and use the first exit. One would also want to have a blast curtain before the roadway to minimize the dust entering that way from the blast. Not easy to do after the original facility is built, but not designed out either…