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India-based Neutrino Observatory project

Singara Site Report

Nilgiris District, Tamilnadu

EXECUTIVE SUMMARY

Several possible locations for the India-based Neutrino Observatory (INO) have been studied. The first round of studies were done in consultation with geologists and engineers, who narrowed down the possibilities to two locations, based primarily on the geology (which is a prime factor for the long-term safety and stability of the site) and physics requirements. These were the sites at Singara, near PUSHEP hydel project in the Nilgiris mountains of Tamil Nadu and Rammam in the Darjeeling district of West Bengal.

Subsequently, the *Environmental Management Plan* (EMP) prepared by a team of scientists coordinated by the *Care-Earth* organisation studied in detail the mitigation and management of the environmental impact at Singara. A part of their report also included a study of several other possible sites for INO. They concluded that Singara is the preferred site, provided all environmental impact management and mitigation measures are correctly and carefully implemented.

The choice of site is dictated by several factors. The main physics issue is a requirement of at least 1000 m all-round rock cover. Such a large laboratory cavern at such depths has never been constructed in India before. Hence the primary requirement of a suitable site for locating an underground laboratory is (apart from the physics and associated requirements) the safety and long-term stability of the lab. The search for a suitable site for INO is mainly guided by the rock quality; additional requirements are the availability of water and power for the project and low rainfall/humidity for the efficient functioning of the detectors, and minimal environmental impact and its management. In addition, issues such as ease of access, availability of infrastructure and length of access tunnel impacts both the physics (time taken for executing the project and hence maintaining the competing edge) and the construction.

It should be noted that peninsular India, south of 13° N latitude, offers the best possible rock medium for safe and stable cavern construction. Furthermore, the leeward side of the mountains are better suited as they are low-rainfall areas. This focuses on Tamil Nadu for a good location for INO. Among all the regions in Tamil Nadu, the best rock is in the Nilgiris where monolithic hard charnockite rock is available.

Given these criteria, several sites were considered as possible locations for INO. The study included information from geologists, engineers, ecologists and physicists. It was based on available surveys, study of topo-sheets, several site visits by different groups, and images from Google. The study included sites in the Nilgiris landscape, Anaimalai Hills, Palani Hills, Kambam-Theni landscape and Mahendragiri hills.

This report consolidates the study on the Singara site for INO, based on the initial studies on Singara, involving many site visits starting from July 2001; the EMP study; and in the light of the additional information about alternate sites. **The studies clearly show that Singara is the best available site for locating INO.**

1 Background

The site selection for locating INO project began in 2001. Initial studies involved studying the topo sheets to identify locations where the basic criterion of 1000m cover in all directions is satisfied. A set of common criteria like rock quality, safety, infrastructure, availability of power and water, dry area for operating the detectors, minimal disturbance to environment, were listed. Geologists of GSI in Chennai and Kolkata were approached for their expert opinion on the feasibility.

After an initial survey, two sites were identified as possible locations for the underground laboratory of the India-based Neutrino Observatory (INO). These were at Singara, near PUSHEP hydel project in the Nilgiris mountains of Tamil Nadu and Rammam in the Darjeeling district of West Bengal. The identification of the sites, and the eventual selection of Singara as the preferred site, was based on input from geologists, engineers and environmental scientists, keeping in mind the safety, physics and related requirements of the project.

The *Environmental Management Plan* (EMP) prepared by a team of scientists coordinated by the *Care-Earth* organisation studied in detail the mitigation and management of the environmental impact at Singara. A part of their report also included a study of several other possible sites for INO. The report concluded that Singara is the preferred site, provided all environmental impact management and mitigation measures are correctly and carefully implemented. This conclusion was reinforced by a separate, additional study of alternate sites.

2 Choice of site

Since the laboratory cavern needs to be more than 1000 m underground (so that there is at least 1000 m cover all-round), the choice of site is primarily dictated by the rock quality, in order to obtain a stable safe environment for such long-term activity.

Geologically, south Indian mountains have the most compact, dense rock (mostly gneiss) while the Himalayas are mostly metamorphic sedimentary rock with pockets of gneiss.

A considerable area of peninsular India, the Indian Shield, consists of Archean gneisses and schists which are the oldest rocks found in India. While the Karnataka region has more schistic type rocks, the Nilgiris rock is mainly Charnockite, which is the hardest rock known. Hence the mountains of Tamil Nadu are the most attractive possibility, offering stable dense compact rocks with maximum safety for locating such a laboratory. In particular, Singara in the Nilgiris is mostly Charnockite rock with very high rock density of 2.7 gm/cc and is geologically very well studied.

Apart from this, availability of water and power and easy access to the site for maximum work efficiency are other factors. These factors are listed in detail below.

2.1 Rock mechanics and stability

The cavern has to be located at a depth of over 1000 m so that it will have sufficient rock cover for the research work. At this depth, the rock would be under tremendous stress. The vertical stress is expected to be > 270 kg/cm^2. This would create problems like rock bursts, roof collapse, etc. The rock must be sufficiently strong enough to withstand the stresses. Charnockite is considered as the best performer at this depth. The rock mechanics parameters such as Compressive Strength, Modulus of Elasticity, Poisson's Ratio, Tensile Strength, Friction Angle, etc., of Charnockite are highly favourable for housing a large cavern at great depths. This rock is available in South India only, particularly south of Mangalore–Bangalore–Chennai Line. The Nilgiris mountains are formed by massive charnockite. This is the reason that geologists initially recommended the site at Singara as the best choice for INO.

The direction of principal stress and ratio between horizontal and vertical stresses play a major role in orientation of the cavern at great depths and its safety. Any new site may or may not meet the requirements. In the case of Singara near PUSHEP site, a cavern has already been excavated for the power house, at a depth of about 550 m. The insitu stress and geological setting are favourable for locating such caverns here. The location of dykes, shears, faults, weak zones, etc., and the magnitude of problems likely to arise from them are known and are manageable with preparedness.

In general, sites were considered suitable for study only if the access tunnel length could be around 3 km or less. Tunnels of longer length are avoided from considerations of time required for construction (which is non-linear in the tunnel length), maintenance and safety points of view, since single entrance, dead-end tunnels are proposed for INO due to environmental considerations.

2.2 Site selection criteria

In order to have some uniformity in selecting possible sites for INO, the recommended evaluation criteria included the following factors:

1. Long-term availability of the site (mainly due to the past experience at KGF when the lab had to be evacuated at, almost literally, a moment's notice).

2. Depth: An overburden in excess of 1000 m in all directions[1], to manage the cosmic ray background. Any site has to satisfy this minimal requirement as part of the physics considerations.

3. Risk Factors: Rock stability is an important criterion from the point of view of safety. This is the first such underground lab ever to be constructed in India at such a depth. Availability of advance geotechnical information is very important for assessing risks. Stability of rock, rock density and compactness are also crucial for managing the detector load factor. Seismic stability is yet another important criterion: it is a crucial ingredient for the design and stability of the underground detector as well as all surface facilities at the site.

4. Geotechnical/geographic information: A complete 3D topo map of the region must be available for evaluating physics backgrounds. Low rainfall area of about 75–100 cm per annum is needed for operating detectors which are sensitive to humidity. Adequate water for cooling the magnets that will provide magnetic fields in excess of 1 T is needed to be available at all times apart from the water needed for A/C for the lab.

5. Environmental impact: Given the nature of the basic requirements, the project will invariably be located in an ecologically and environmentally sensitive area. The impact will be mainly during construction period—it should be possible to minimise and manage the impact during construction.

6. Cost factors–Construction: It is important to remember that riding on an existing project is preferable to an entirely new site. This will also reduce the time gap between the start of the project and the time when the detectors are installed apart from reducing the impact on environment.

7. Operating Cost: Again this may be reduced if many aspects of the associated infrastructure are available due to the presence of another larger project at the same location.

8. Ownership and Site Sharing: Joint ownership is preferable–Governmental projects preferable to non-governmental projects.

[1]Typically, unless the cavern is under a plateau, this implies a vertical overburden in excess of 1200 m.

9. Access: It is important to have quick access to the laboratory from major cities with good industrial infrastructure.
10. Outreach: Important to convey the importance of the project and that it will not harm the environment. Hence local support and awareness are crucial.
11. Working environment: It should be comfortable from the point of view of easy access to laboratory, living comfort etc.
12. Neutrino Beam: Distances to various future possible neutrino factories and any particular advantage that may be there due to physics reasons.

We now focus on the details of the INO site at Singara.

3 INO at Singara

The proposed project site is located in the tri-junction of three major states, Tamil Nadu, Karnataka and Kerala. It is situated in the Nilgiris mountains which is a part of the southern peninsular shield, about 6.5 km from Masinagudi (100 km south of Mysore) inside the Singara camp of TNEB.

3.1 Location and Access

The site is located on the northern fringe of the Nilgiris, close to major cities (Coimbatore, Mysore, Calicut or Kozhikode and Bangalore) with excellent industrial infrastructure, see the map Fig. 1. There are many research institutions and universities within a couple of hours of driving distance. It is well connected by road network and three nearby airports with domestic and international flights with year round access to the site. The nearest railhead is at Chamarajanagar. The nearest major train stations are Calicut, Coimbatore and Mysore.

The site is located on the northern fringe of the Nilgiris mountains which is a part of the southern peninsular shield, about 6.5 km from Masinagudi (100 km south of Mysore) inside the Singara camp of TNEB. Masinagudi is at the edge of the Mudumalai wildlife sanctuary and national park, which is now a Tiger Reserve. The Singara camp is surrounded by coffee estates for up to 500 m. A panoramic view of the region is shown in Fig. 2.

Two hydro-electric power stations are located in the TNEB camp at Singara. One is the heritage Singara power-house, dating back to 1930s. The other is the fully underground Pykara Ultimate Stage Hydro-electric power project (PUSHEP), which became operational in 2005. Some relevant details are given in Appendix A.

The INO lab is proposed to be located underground under the mountain peak at 2,207m elevation. The vertical cover at this location is 1,300m. The cover is comparable to what is available at Gran Sasso Underground neutrino laboratory in Italy and better than the one at Kamioka mines in Japan. All round cover exceeds 1,000m in all directions. It is a well studied region due to the presence of the PUSHEP project. There are nearly 12,000m of tunnels in the immediate vicinity of the project site and about 60,000m of tunnels in the Nilgiris massif thus yielding valuable geo-technical data.

3.2 Climate

The project site is reachable all throughout the year as it is a low rainfall area with comfortable climate throughout the year including during summer when maximum and minimum temperatures are in mid thirty and mid twenty respectively.

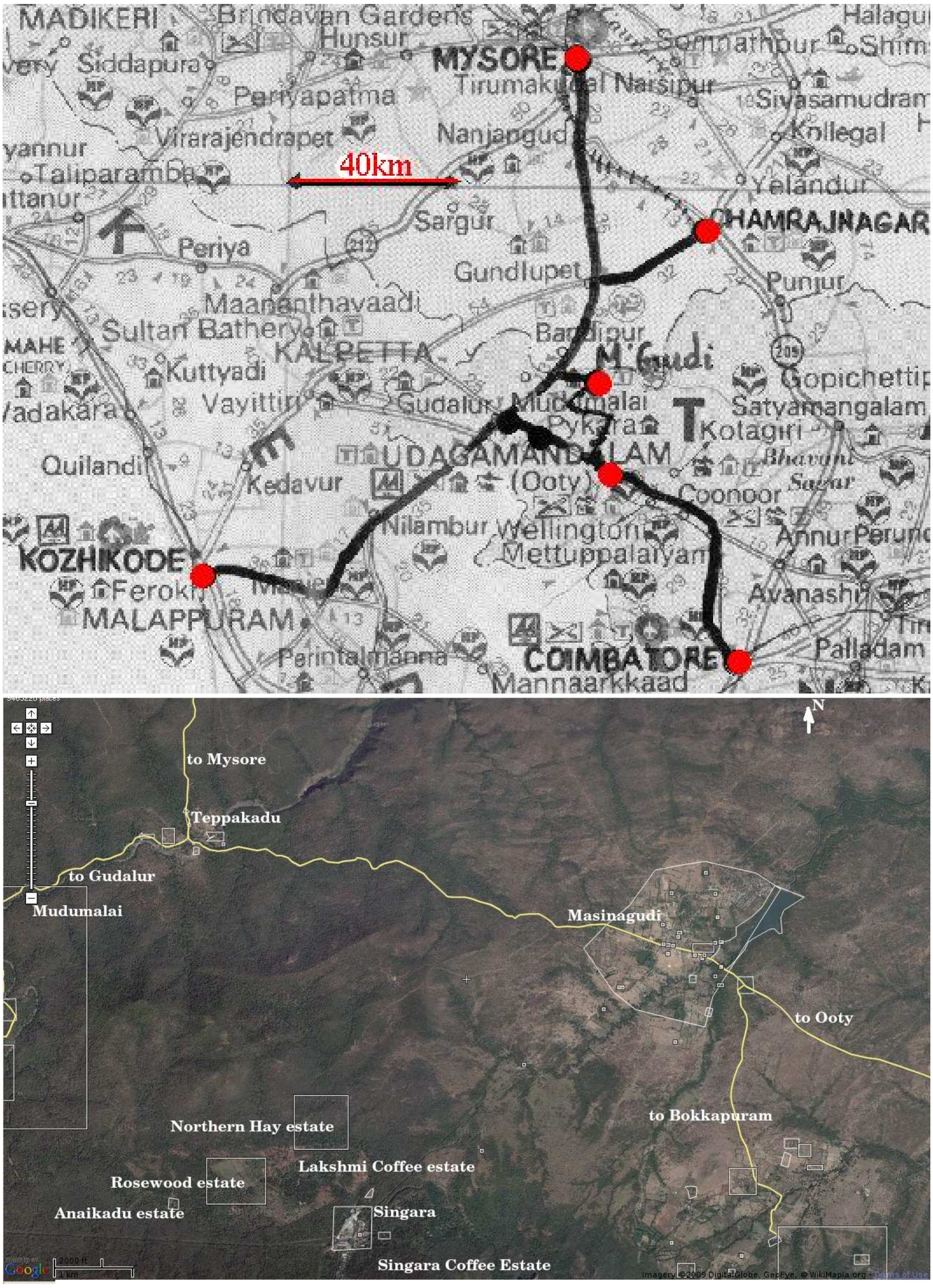

Figure 1: Map showing approaches from major cities around Masinagudi (above). The Google image below shows the local approach to Singara camp of TNEB and surrounding coffee estates (Source: Wikimapia).

Figure 2: Panoramic view of Singara with the Peak at 2207m in the background.

It will be approximately ten degrees lower in winter. The road approach from the northern side (Mysore) is almost flat without any ghat sections to negotiate. The rainfall is moderate with an annual rainfall of 50-100 cm and it is a semi-arid region.

3.3 Site specific Geology

Driving a new tunnel is always a journey into the unknown. In PUSHEP, based on geotechnical studies, lot of extrapolation has been done to map out the various shear and fracture zones in detail. The tunnels that have been already driven stand as a testimony to this knowledge. In fact there have been no surprises until now. PUSHEP has now been built to last over 120 years, a time scale that suits an underground laboratory like INO.

We mention a few important site features here. For details we refer to Appendices B and C which contain the full Geotechnical Reports.

- Geological Features: The site is an extremely stable geological region and the medium is almost uniform - Charnockite with an average density of 2.7g/cc. The portal locations and initial portions of the proposed alignments are through migmatites. Most of the access tunnel and Cavern will be set in Charnockite with density varying between 2.61 to 2.9.

  It is a well studied region both in theory (forecasting) and in practice, due to the presence of the underground PUSHEP project. Nearly 12 kms of tunnelling in the vicinity and about 60 kms of tunnelling in the region as a whole has been done and engineering solutions to all problems have been successfully found. It is well known that there are about 12 sets of joints, 20 shear zones and 19 fracture zones. These have been mapped in detail. The alignments in the section have been proposed keeping these features in mind.

  The foliation, joints, shear/fracture zones are oriented near normal to the INO alignments which is favourable for tunnelling. Most of these reaches are expected to be dry with a few showing seepages - moist to low dripping type. In any case the quantum of seepage may not exceed 5 litres/min as observed in PUSHEP tunnels.

- Seismicity: The site falls under the seismic zone 2 according to the standard seismic zoning map of India issued by the Bureau of Indian Standards in the year 2000 (see map in Fig. 3). Note that there are changes from the 1984 standards, specifically zone 1 has been eliminated and assimilated in zone 2.

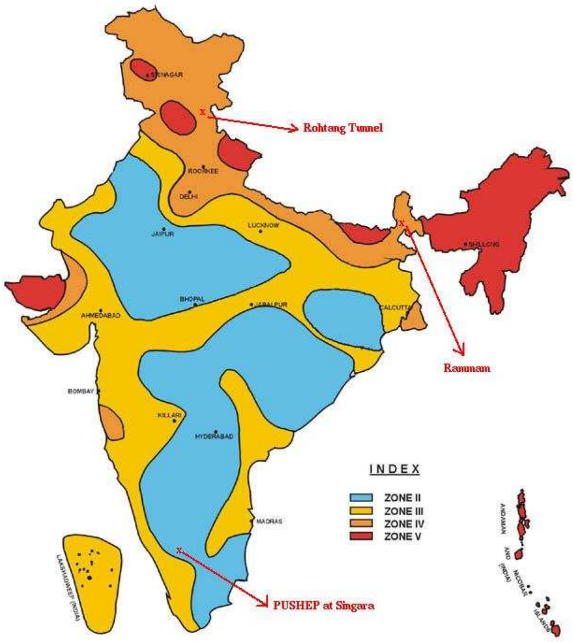

Figure 3: Seismic zoning Map of India- issued by Bureau of Indian Standards, 2000.

- Rock Radioactivity: The maximum rock radioactivity is of the order of 0.005 mR/hr or less which is considered very low. This is useful for future low energy experiments for which low backgrounds are a must.

- TCLP and Leachate Analysis: No toxic or heavy metals are found beyond acceptable limits; many are below detectable limits. See Appendix D for details.

- Rock Quality: The rock mass has a Q value[2] ranging from 4 to 45 which is considered fair to very good for tunnelling medium. The stand-up time ranges from 3 months to infinity. From this point of view the rock quality in this region is considered excellent.

- Stress Data: The ratio of horizontal to vertical stresses as measured in Adit-2 and in the powerhouse cavern is about 1.6. Typically this should not be less than 1 or greater than 2 for stability of caverns. However, a comparison of stresses in these two show a sharp rise in stresses both in horizontal and vertical directions. It would therefore be prudent to know the in-situ stress conditions at the proposed INO Cavern by drilling before a final design for the lab is done. This may be done, for example, using bore holes from adit-5 of PUSHEP for a depth of about 300 to 500 ms. The samples may be used for stress analysis.

- Cavern orientation: A preliminary assessment based on surface and subsurface geological data available indicates a North-South alignment below INO peak (2207 meters) of the proposed lab

[2]The Q value denotes the rock quality. Larger the Q-value the better it is for tunnelling

cavern. Physics requirements suggest that it should be slightly towards North-West because of the possibility of neutrino beam from CERN in stage II of INO experiment.

- Projections: Projections from PUSHEP data indicate no major geological adversities will be encountered in the lab cavern of INO. It may be necessary to have a few support measures like spot bolting, systematic rock bolting, mesh/fiber reinforced shotcreting, PCC/RCC lining. This will have to be dealt at the construction stage.

3.4 INO tunnel alignments

As a part of the feasibility study the Geologists from GSI at Chennai have proposed four possible alignments for INO access tunnel to reach the Cavern below the INO peak (elevation 2207m). These four alignments are shown in the topographic map- see Fig. 4. All the proposed alignments cross the tail race tunnel of the PUSHEP project. We first give the details of all the four alignments and focus on alignment-2 for a detailed analysis.

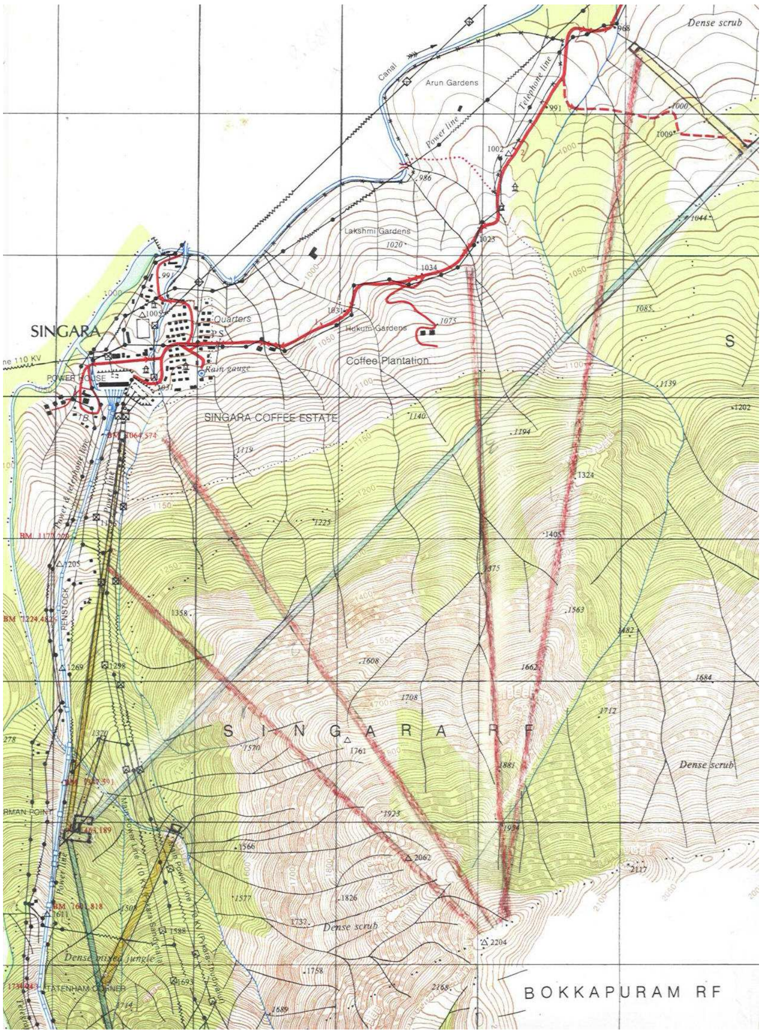

Figure 4: The four possible alignments for the INO tunnel are shown. The proposed INO cavern is at the bottom of the picture. Alignments 1–4 go from left to right, in order. Alignment 2 is considered the best option both from operational and environmental considerations.

The location of the INO laboratory cavern has now been frozen and is located below the INO-Peak whose coordinates are North 11^{o}31" and East 76^{o}36.5" (see Fig. 2). The INO peak is the highest peak on the northern slopes of the Nilgiris. South of this peak is the plateau with an average elevation of more than 2000m above sea level. It is part of the southern peninsular shield,

The details of each alignment are given in Table 1.

	Alignment location	Length	Portal level	Cavern base	Vertical Cover	Cover at TRT
1.	From access Tunnel 450m from PUSHEP portal	1867m	1019m	894m	1313m	+51m
2.	Next to access Tunnel 187m east of PUSHEP portal	2129m	1050m	908m	1299m	+63m
3.	South of Adit 4	2380m	1025m	867m	1340m	+61m
4.	Around Adit 4 inlet	3194m	966m	753.5m	1453.5m	-18.9m

Table 1: The four alignments for the INO tunnel. A reverse gradient of 1 in 15 has been assumed. The cover at TRT crossing is above for the first three and below for the fourth.

Alignment-1 starts from inside the PUSHEP access tunnel and is the easiest to execute since the tunnel portal will be in hard rock medium. There is no need for any portal formation. It also has the shortest distance to the INO cavern. The saving on time will be quite considerable. However, logistics problems during construction are quite considerable since the powerhouse is operational.

Although the geological set up and the structural fabrics are similar for all the four alignments, **the alignment 2 is considered to be the best** independent access considering various other aspects. In particular, alignment 3 and 4 are closer to the critical elephant corridor, hence not advisable.

3.4.1 Preferred tunnel Alignment-2

A detailed report on Alignment-2 by the scientists of Geological Survey of India is given in Appendix C. We recall the salient features of this preferred alignment here. Although the geological set up and structural fabrics are similar for all the four alignments, the alignment 2 is considered to be the best independent access considering all other aspects.

Geological and geotechnical evaluation was done based on the available surface and subsurface information collected from the PUSHEP project. A forecast of the geological features that may be encountered is given in Fig. 5. The main features are summarised below.

- An examination of the surrounding area indicates the availability of bedrock at a shallow depth and the tunnel inlet portal can be established after a short open cut.
- Initial 675m reach of the INO access tunnel will be driven through inter banded sequence of hornblende biotite gneiss/migmatite and charnockite. Beyond this the excavation will be in massive charnockite. The details of Joints, Shear zones, Fracture zones and sheared dyke are shown in Fig. 5 and discussed in Appendices B and C.
- The rock mass is rated as fair (30% of reaches) to very good (60% or reaches) with Q value ranging from 4 to 45.
- Negotiation of minor/small weak zones with poor rock mass may be non-problematic due to the favourable orientation and near horizontal excavation of the tunnel. Minor tunnelling problems such as formation of critical wedges at the intersections of smooth planer and filled joints are easily negotiated with suitable support intervention.
- Most reaches are dry except in the initial reaches where moist to low dripping types of seepage is anticipated.

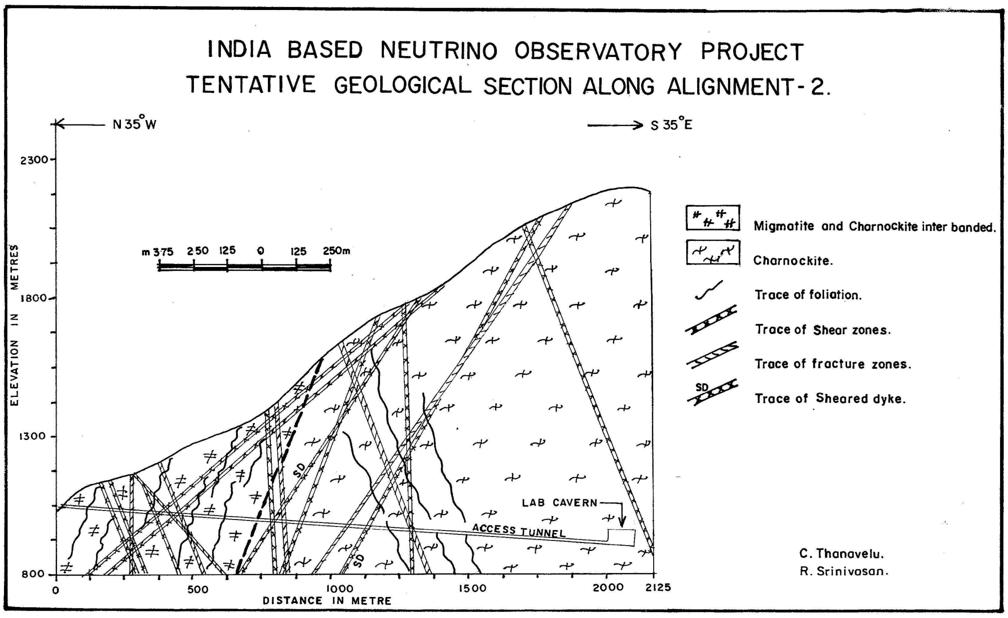

Figure 5: Plate showing the detailed cross-section and geological features along alignment-2.

GSI Recommendation: As all the geological and geotechnical data required except the information on insitu stress for the areas with more than 500m cover is readily available, the proposed site is assessed to be suitable for siting the underground laboratory. In fact as the data control is so excellent, it is strongly recommended that the project authorities to immediately commence construction activities and drive an access tunnel along alignment-2 as exploratory tunnel for a length of 300m to 500m, which can be assimilated as part of the project subsequently. This will also enable obtaining advance information on the prevailing stress condition for further planning. Other than this no further exploration is needed at the present state to initiate construction activities.

4 Atmospheric Muon background

General topographic features around the INO cavern, on a larger scale, are shown in the topographic map in Fig. 6. The Alignment 2 and the location of the INO portal and laboratory under the peak are also indicated. For maximum stability and ease of construction, the tunnel orientations should be, as far as possible, transverse to the direction of the rock folds. Beyond the INO peak to the south lies the Nilgiris Plateau with an average elevation of 2000 meters. Thus future extensions of the INO tunnel oriented along the ridge beyond 2207 peak can, in principle, provide overburden comparable to that available in SNO.

A section of the overburden viewed from different angles around the 2207m peak is shown in Fig. 7 to indicate the possible rock overburden in different directions. The cavern location is taken to be 900m. Minimum overburden of 1000m is assured from this sampling. A full three-dimensional modelling is in progress.

The atmospheric muon background flux at these depths may be gleaned from Fig. 8 where the depth is measured in MWE (depth times the density of matter).

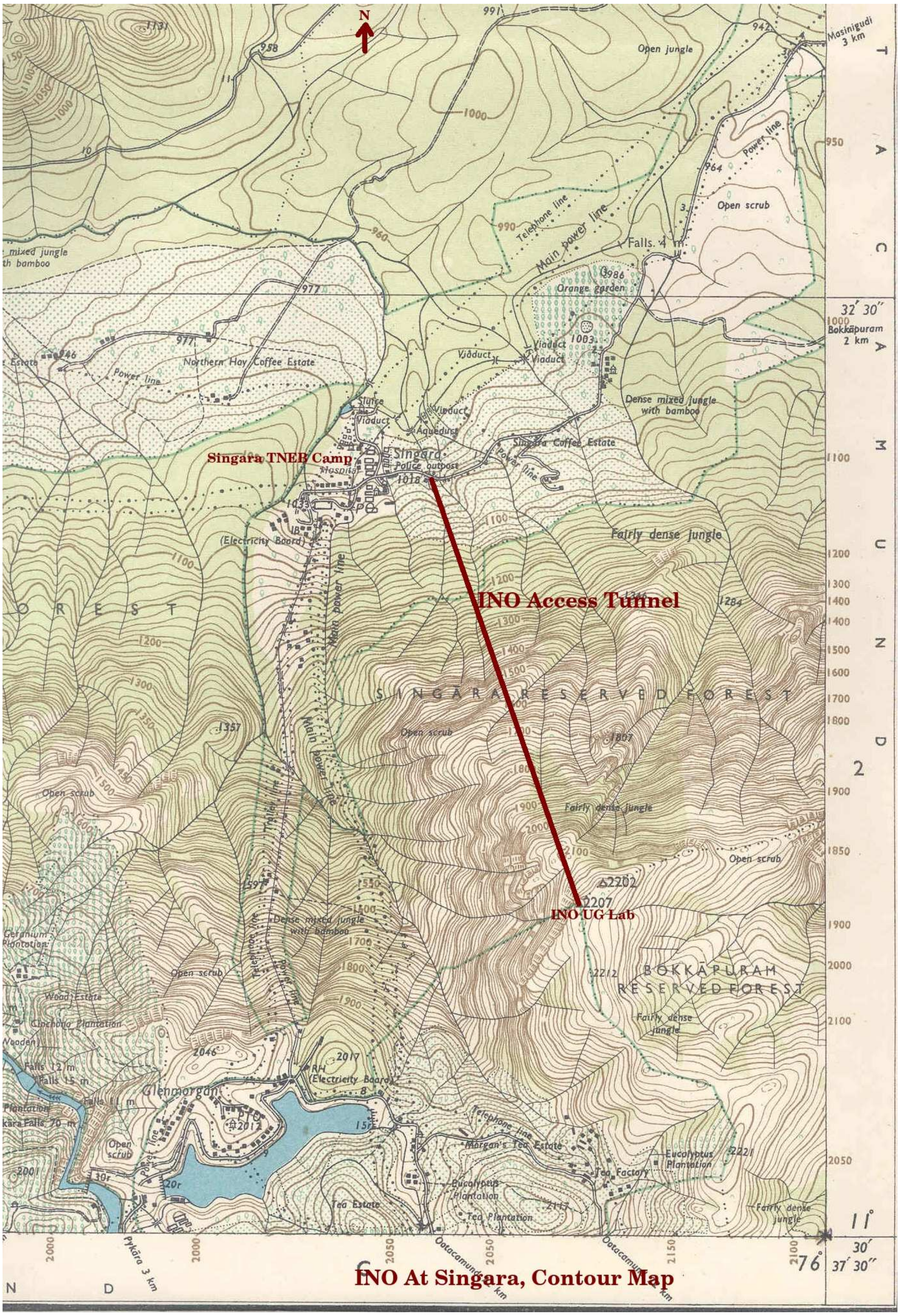

Figure 6: General topographic features around the recommended alignment. Note that the tunnel is entirely underground with portal at Singara camp as indicated. The first 500 m of tunnel runs under the coffee estate while the rest runs under the Singara Reserve Forest.

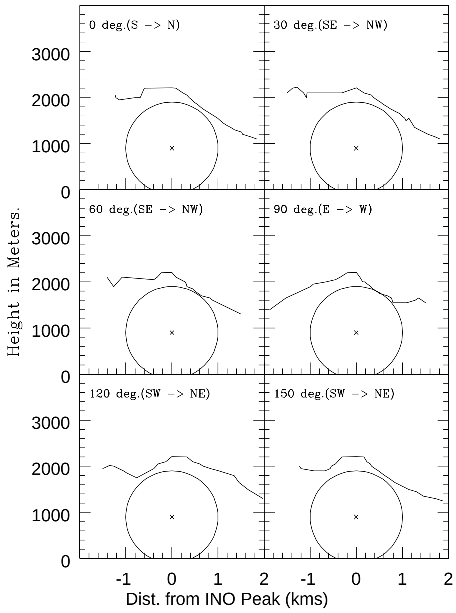

Figure 7: Around the INO Peak (2207m): The cross-section of the mountain around the peak seen from different orientations. The South to North direction corresponds to 0 degree orientation. Other orientations are indicated in the figure itself. X denotes the approximate location of the INO cavern at 900 meters elevation (in all four options the cavern is located below this level) and the circle marks out a 1000 m distance all around.

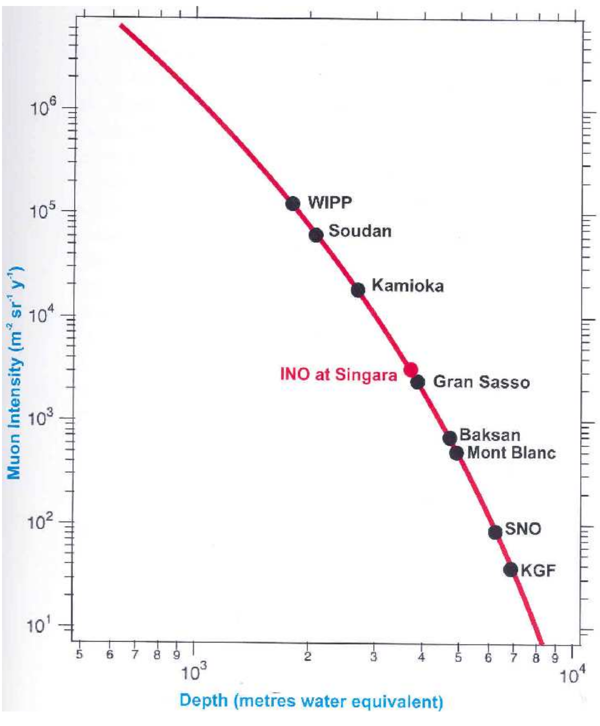

Figure 8: Atmospheric muon background as a function of depth. The best location for INO corresponds to backgrounds as in Gran Sasso Lab.

5 Overview of INO facilities at Singara

5.1 Available Infrastructural Facilities

The project has a radio-link to Ooty with high speed data connection. The Masinagudi exchange is connected by Optical Fibre by BSNL. The project staff are housed in the TNEB campus at Masinagudi. The TNEB campus has residential houses as well as offices with recreational facilities like sports complex, children's park, and three well equipped Inspection Bungalows (IB) at different locations.

Since the completion of the PUSHEP project, only operating staff of PUSHEP (in Masinagudi) and Singara Heritage project (in Singara) are resident. Surplus housing and land is presently available for INO project staff.

The tourist traffic is considerable and Masinagudi town is dotted with many resorts and hotels to accommodate the floating population.

The Radio Telescope and Cosmic Ray Laboratory at Ooty are less than an hours drive from the PUSHEP project site.

In addition, IISc has a field station in the campus for environment and ecology related studies for over a decade now.

5.2 Proposed INO Facilities

During the initial phase of planning INO facilities, it was suggested that all the facilities, including the main R& D facility, housing, guest house, hostels etc, may be located in Masinagudi while the surface facility servicing the underground laboratory be located near the portal at Singara. During a meeting with the environmental activists in the Nilgiris region it was pointed out that expansion of Masinagudi will be detrimental to the region's delicate ecology and further add to the population pressure. INO collaboration responded positively to this suggestion and it was decided, after consultations with TNEB, to locate minimal facilities at Singara itself while the main INO centre could be relocated to a nearby city. Though TNEB has earmarked 4 ha of land in Masinagudi next to IB, it will not be used.

The facilities at Singara, therefore, include:

- Underground laboratory 1300 m below the 2207 peak.

  INO underground laboratory is expected to have a large cavern of dimensions 132 m(length), 26 m (width) and 29 m (height). A smaller cavern will serve as a control room and may also house smaller experiments; see Fig. 9.

- Surface facilities to provide services to underground laboratory:

  The surface facilities include ventilation equipment to circulate fresh air into the underground laboratory through the access tunnel. A chiller plant for providing A/C to the laboratories, storage for detector gas mixture and a liquid Helium plant. A small workshop for carrying out maintenance work will also be constructed. About 0.58 ha of land around the portal is earmarked for this facility by TNEB, see Fig. 10.

- Accommodation for scientists and engineers: About 20 family accommodation will be constructed. This refers to the resident operating staff at underground laboratory in the area of about 2.92 ha allotted for the purpose in Singara camp, see Fig. 10.

- INO laboratory, at any given time, will have floating population of students and scientists. Being a multi-institutional collaboration, several scientists and students may be attached to

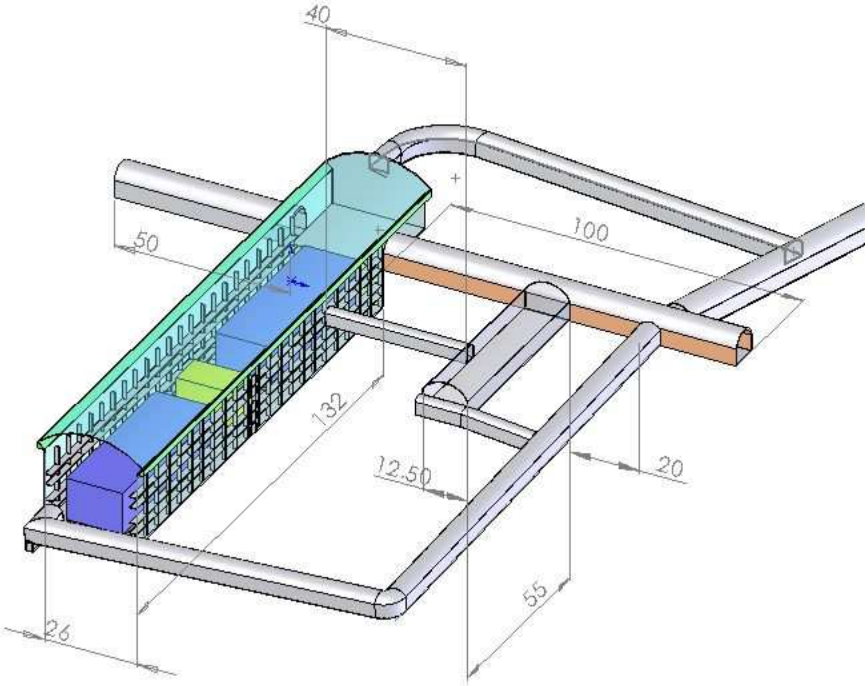

Figure 9: Schematic view of the underground laboratory caverns.

other participating institutions. In order to accommodate the floating population, a guest house and a student hostel will be built in the area allotted.

- A temporary storage yard for storing rock debris has been allotted by TNEB in the existing muck yard which is larger than that required for storing the rock debris from INO tunnel and cavern excavation. The muck will be stored in this yard for a long period of time. If necessary the muck will be stored permanently using it for levelling the uneven ground and the land returned to TNEB. An area of 2.33 ha has been allotted for this purpose.

- During the construction period about 100 labourers will be required. It is envisaged that all the available local labour will be used, to the extent possible. A temporary colony will be created in 0.42 ha of land allotted for the purpose to be dismantled after the construction period is over.

All these facilities are to be located in the land made over to TNEB when the Singara power house was built and not on any forest land or even forest leased land as the titles clearly indicate.

We would like to emphasise that all these facilities are a minimal addition to the existing facilities of Singara Power House and the PUSHEP project. To summarise the salient features are,

- All major project components are underground.

- The tunnel portal is located in TNEB land and the first five hundred metres runs under a private coffee estate and the rest is under the Singara reserve forest. The tunnel is at least 400 metres deep by the time the forest boundary is reached.

- Minimal over ground components are not on forest land, hence there will be no cutting of trees or clearing of forest.

- Existing facilities will be used where-ever possible. Crucially, power and water required for the project is available.

Figure 10: Schematic view INO facilities in Singara camp of TNEB (not to scale). Existing TNEB powerhouse and auditorium are also shown. Source–Google Maps.

6 Environmental Issues

Members of INO are acutely aware that the laboratory is proposed to be located in an environmentally and ecologically sensitive area, namely, in the Nilgiris Biosphere Reserve (NBR) in the buffer zone of the Mudumalai Wildlife Sanctuary and National Park, now demarcated as a Tiger Reserve; see Fig. 11. The challenge for INO is to build a world-class science laboratory, keeping in mind the ecological and environmental concerns, especially during the construction phase, and to actively participate in on-going conservation efforts in the region.

- During its normal operation phase, the laboratory is not expected to cause any damage to the environment. All efforts will be made to minimise the disturbance during the construction phase.
- INO will ensure that its activities are in conformity with environmental laws as are applicable.
- All members of the collaboration, executing agencies and their workers will be trained to cooperate in ensuring compliance with environmental guidelines.
- Being part of such a sensitive biosphere reserve will also bestow responsibilities on INO not only to maintain the integrity of the biosphere and but also to actively participate in on-going conservation efforts where possible.

It is imperative to recognise that the study of Nature's innermost workings need not be at loggerheads with Nature itself. Models of S & T development that are sensitive to environmental conservation thus assume importance. The proposed India-based Neutrino Observatory (INO) at Singara in the Nilgiris offers immense opportunities and a challenge for realising such a model.

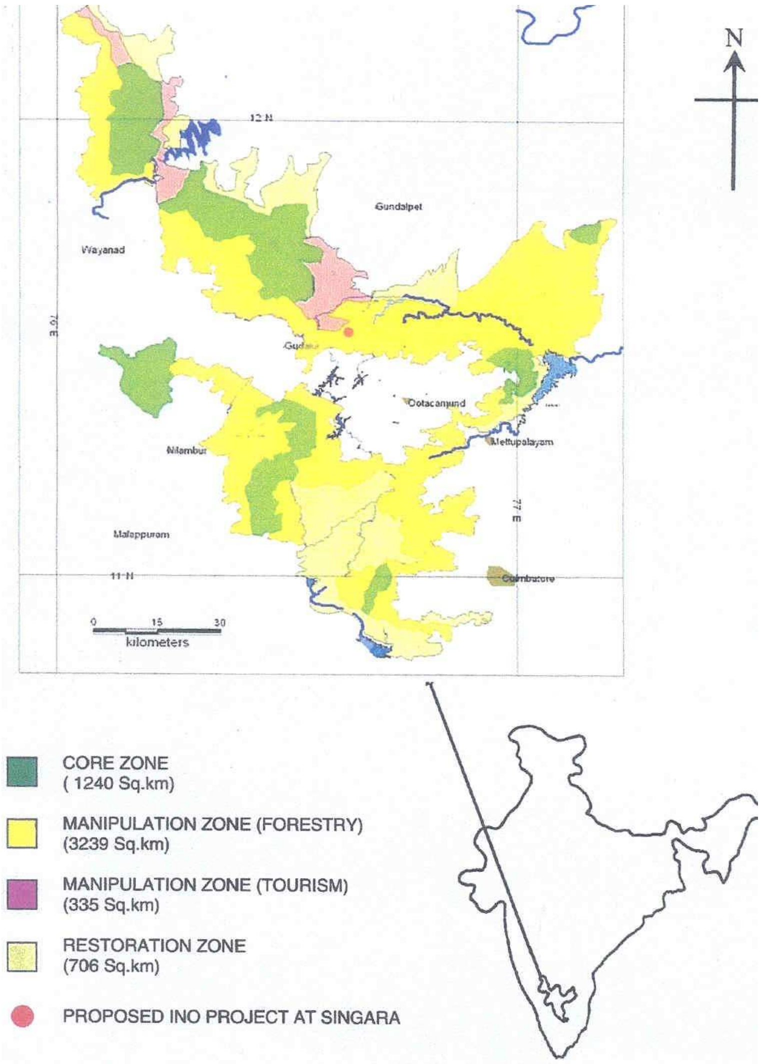

Figure 11: Map of the Nilgiris Biosphere Reserve - INO location is indicated by a pink dot which lies in the Manipulation zone (yellow) of NBR. The core zone was declared the core zone of the newly demarcated Tiger Reserve and the manipulation zones as the buffer zones of the Tiger Reserve. The entire region is now demarcated as Critical Tiger Habitat. Map courtesy: Dr. Raman Sukumar.

6.1 Environmental Impact and major mitigation measures

This section outlines the proposed measures to be taken by INO in order to comply with the recommendations of the rapid Environmental Impact Assessment (EIA) prepared by Salim Ali Centre for Ornithology and Natural History (SACON) and the Environmental Management Plan (EMP) prepared by the Care-Earth, Chennai.

In brief the highlights of EIA/EMP are:

- Location close to a critical wildlife habitat. Elephant movement corridor cuts the road from Masinagudi to Singara, about 2 km from the Singara camp; See Fig. 12.
- Impact of transportation of construction and detector material as well as the muck accumulation and disposal are serious concerns.
- Noise control is an important factor due to proximity to wild-life habitats.
- Splitting of infrastructure between Masinagudi and Singara is flawed. Places undue pressure on critical animal movement corridors.

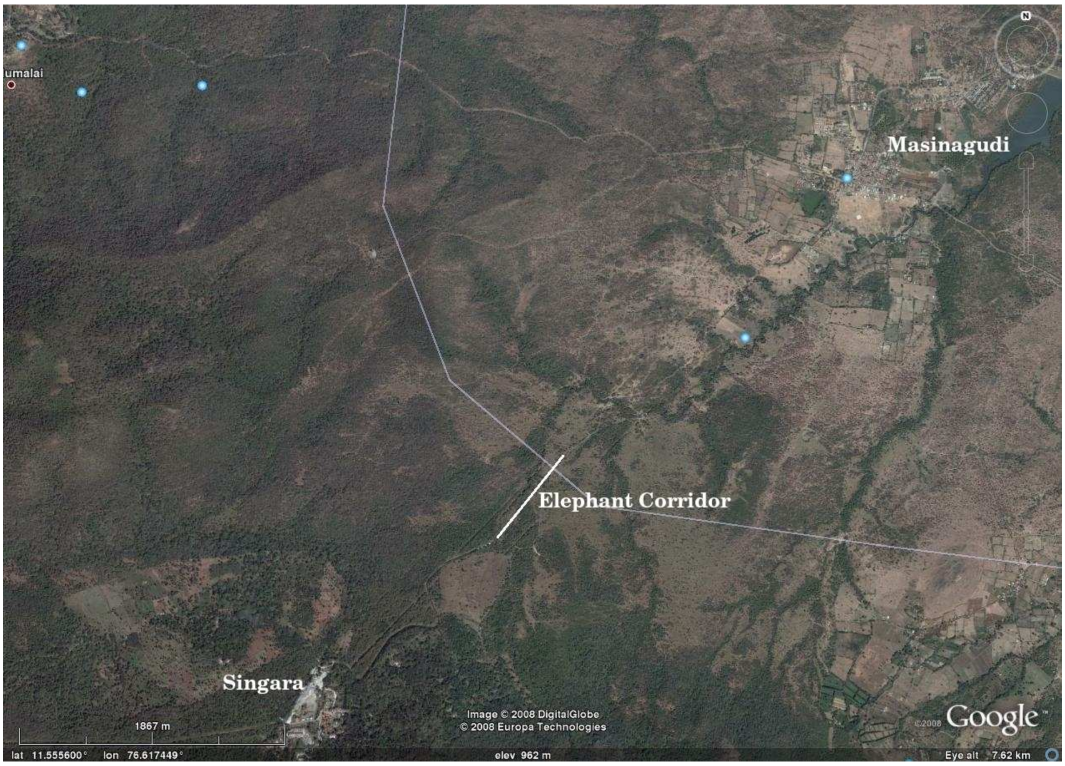

Figure 12: Location of the Elephant corridor on the Masinagudi–Singara Road. Map courtesy: Google Earth.

In response to this recommendation, INO collaboration has already made changes in the project components such that all its facilities will now be in Singara.

- Infrastructure does not involve extensive over ground construction. Offers scope for local employment generation (minimal). Does not involve materials that could lead to environmental pollution.

- INO is sensitive to environmental concerns; training of young scientific work force is a must. Resident work force is minimal.

The first two item are the most serious impact of INO during construction phase. We will consider this in some detail now.

6.1.1 Transport of construction and detector material

INO being a very large basic sciences project involves transportation of large amount of detector material into the project location from outside. The transport of the granite debris produced by tunnelling is also a crucial issue as both these involve movement along the Singara-Masinagudi road. This road crosses a critical elephant corridor—the Singara-Mavinhalla corridor—about 2 km away from the project site (in TNEB Singara camp), see Fig. 12.

The Environmental Management Plan (EMP), prepared by Care Earth for INO, places severe restrictions on the movement of vehicles on the Masinagudi–Singara road, based on studies of the current traffic pattern in the region. It recommends a complete cessation on movement of heavy vehicles during the main elephant migration period (which falls during approximately 3 months from November to February). Furthermore, it recommends that heavy vehicular movement be restricted to day-light hours, in particular, between 6.00 AM and 4.00 PM at any time of the year, in order to avoid the dawn/dusk large-animal movement and the night hours when the night-animals are abroad.

In response to this recommendation INO has agreed to restrict the number of round trips to 6 per day during the times and months stipulated in the EMP, where each round trip may consist of a single truck or a single convoy consisting of maximum three trucks. Note that the maximum load carrying capacity of a truck in the region is limited to 8 tons. Expert trackers/watchers will be engaged to monitor wild-animal movement along this road, and suitably advise on the heavy vehicle movement.

Permission will be sought to use the causeway at Theppakadu for movement of heavy vehicles for INO-related work.

We give below the material types and logistics of their transportation.

Construction material and equipment :

This includes all the material that is to be brought in to the site.

1. One-time movement of construction equipment such as drill jumbos, mobile crane, tipper trucks, jack hammers, rock bolters, excavators/loaders, etc.

2. About 12,000 tons of cement and 3,500 tons of sand for construction.

3. About 4,000 tons of structural steel and utility equipment.

4. About 53,000 tons of iron, glass RPC detectors and other detector material for neutrino ICAL detector. Of this, 1/3 will be moved in the 4th year of construction to build the first module of the detector. The second and third modules will be built over the next few years.

Tunnel/cavern excavated granite muck :

The tunnel muck generated will be 2,25,000 cubic meters. The muck to be utilised will be about 25,480 cubic meters (61,150 tons) for project construction. The muck will be stored in the TNEB muck yard, for eventual evacuation.

Abstract of material movement :

The year-wise abstract of total material movement and the number of trips required is given in Table 2. Detailed break-up of all the materials and their movement logistics is given in a separate report.

Note that the following realistic assumptions have been made in working out the details of the material transportation:

- Material will be brought it and muck moved out in separate trucks.

- Assumed maximum load capacity of 8 tons per truck.

- Assumed unit trip for transportation of steel plates as a convoy of 3 numbers of 8 ton trucks, that is 2× 4 ton plates per truck.

- Assumed unit trip for transportation of rock muck as a convoy of 3 numbers of 8 ton trucks.

- Assumed 6 tons per truck for sand transportation.

- Assumed unit trip for transportation of all other materials as a single truck of 8 ton capacity.

- In-situ long term storage of rock muck at the storage yard can be planned if necessary.

Year	Q-I (16 Feb to 15 May)		Q-II (16 May to 15 Aug)		Q-III (16 Aug to 15 Nov)		Average round trips per day			
	No. Trips In	No. Trips Out	No. Trips In	No. Trips Out	No. Trips In	No. Trips Out	Q-I	Q-II	Q-III	Q-IV
1	47	47	176	176	432	432	0.52	1.96	4.80	0
2	342	342	342	342	536	536	3.80	3.80	5.96	0
3	538	538	540	540	540	540	5.98	6.00	6.00	0
4	491	491	530	530	538	538	5.46	5.89	5.98	0
5	530	530	530	530	530	530	5.89	5.89	5.89	0
6	528	528	540	540	538	538	5.87	6.00	5.98	0
7	539	539	531	531	534	534	5.99	5.90	5.93	0
8-16.6 years	530	530	530	530	530	530	5.89	5.89	5.89	0

Table 2: Year-wise abstract of the average number of round trips per day over three quarters of the year are given. Years 8–16.6 involve only the rock muck movement as the laboratory would be complete and operating by then.

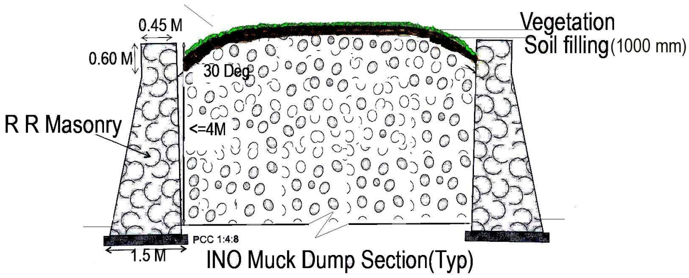

Figure 13: Existing muck storage yard is shown on the left. Sketch of muck storage yard protected by dry stone masonry wall is shown on the right.

Storage of granite debris :

The granite debris that will be excavated will be stored, a few hundred metres from the portal, within the Singara TNEB campus, away from the sensitive corridor. About 20% of this will be used by INO for construction purposes and about 50% may be lifted for use elsewhere. The debris will be moved out in a phased manner as outlined above.

- Muck yard, already existing, is within 500 m of portal location, hence the operation is completely localised.
- About 1/4 of the area will be utilised.
- The muck storage yard will be protected by dry stone masonry wall all around except for entry and exit points, to prevent contamination of any nearby water sources as shown in Fig. 13. Later it will be covered with vegetation to prevent run-off after construction.

6.1.2 Noise reduction and control

The EIA clearly recommends that care should be taken to reduce noise generated during construction. Use of well maintained machinery and vehicles could considerably help in this matter. Nevertheless driving a tunnel involves both noise and vibration.

Therefore blasting will be limited to the bare minimum, especially in the initial reaches. Controlled blasting will be adopted in the initial reaches to dampen noise and vibrations.

It has been noted in the EIA that blasting deep inside the tunnel with delayed detonation considerably dampens both noise and vibration as observed during PUSHEP excavation due to the overburden of rock and soil above. Number of blasts will be regulated and temporally spaced out to reduce the impact further. Modern tunnelling methods will be adopted where-ever possible both to reduce the impact and for faster execution.

INO will also undertake ground vibration monitoring study during actual execution of the project along with other rock mechanics and instrumentation studies as done in similar underground project already commissioned nearby. Appropriate blasting pattern and modern blasting techniques based on the actual site geology, will be adopted such that vibration due to the blasting is the minimum.

Estimated particle velocities are shown in Fig. 14. For example, at the forest boundary (500 m from the portal) it is approximately 3.4 mm/s and on the peak above cavern (2210 m from portal) it is approximately 0.5mm/s.

6.1.3 Additional measures

In addition to the above major mitigation measures, INO project will also undertake the following measures:

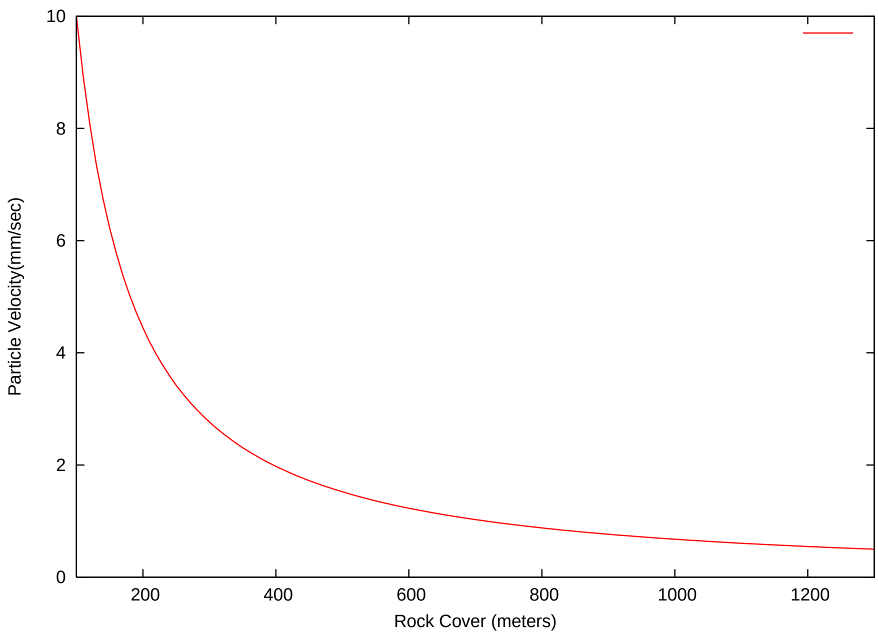

Figure 14: The particle velocity (m/s) as a function of rock cover (in m).

- Engage local labourers as much as possible to avoid migration/settling problems. Totally about 100 labourers needed during years 2-4.
- Labour colony is located on site in Singara. Strict monitoring of their movements/welfare will be in place. The labourers will be provided with LPG/stoves. No firewood will be used. In order to avoid cows grazing into the forest areas, the labourers will be supplied with milk.
- No tree cutting will be allowed. However, as a commitment to conservation, planting of trees near portal and residential areas will be undertaken in consultation with TN Forest Dept. No non-native or invasive species will be brought in.
- INO will use electrical vehicles for local people movement to reduce pollution during the operation phase.
- All INO members will be given training and awareness of environmental and wildlife issues.
- INO staff will also be trained in disaster/ fire management.

6.2 Ecological awareness and monitoring

Compliance with the environmental management plan will be monitored locally by an Environmental Monitoring Cell, to be stationed at the site, that will include INO members, members from the Forest Department, the site engineer, representative of Masinagudi panchayat, and environmental experts. INO will adopt the following measures:

- Put in place an Environment Monitoring Cell before construction begins. Adopt best-practices used world-wide during construction and operation stage.
- To create a corpus that may be used for conservation efforts.
- Construct watch tower(s) at strategic points within the project site for monitoring, especially of elephants in the vicinity.

- Employ local tribals as trackers both accompanying vehicles and at critical points.

- The INO project is committed to nature conservation and environmental protection. It plans to adopt the elephant as its nominate species. Funding to the extent permissible by governing laws will be provided for nature conservation and environmental protection. Possible tie-up with groups like CES (IISc), NCBS (TIFR) for wildlife biology program permanent wildlife research and monitoring facility being explored.

In addition, there will be an Environment Management Panel to oversee the activities of the Environmental Monitoring Cell. Members from the Tamil Nadu Forest Department, District Administration, TNPCB, TNEB, SACON, Care-Earth, and academic/research institutions, will be ex-officio members, along with INO members.

It may be noted that about 500–1000 m of land on either side of the Singara-Masinagudi road is privately owned, with some segments owned by the Tamil Nadu Electricity Board. INO will make all efforts, through appropriate negotiations with the concerned, so that additional land may be acquired and dedicated to the existing elephant corridor.

7 Disaster Management and Safety

We highlight certain important safety features that will be adopted during construction and operation phase:

Cause	Measures
1. Blasting operation	Qualified and approved blasting materials used with expert blasters Controlled blasting with mandatory warning
2. Transport/material handling	Qualified operators Well maintained/tested vehicles
3. Working environment	Proper ventilation, quick evacuation
4. Fire hazards	No smoking/fire in work environment Cables and systems adequately sized and tested. Fire extinguishers provided
5. Electrical Shock	Certified electrical devices Cables and systems sized/tested

Work will be allowed under proper supervision, with safety training, apparel, display posters, presence of qualified health and safety officers. A disaster management manual has been prepared outlining in details measures to be taken during emergencies.

During the operation phase following measures will be implemented.

- Working environment in tunnels and caverns: Proper ventilation, no blocking of passages for quick evacuation.

- No fire or smoke in confined spaces, Non-inflammable materials (oil free switch gear, fire retardant cables), Electrical systems adequately sized and tested, Oil/bitumen free cable jointing kits to be used, fire detection and protection systems provided with stops and barriers.

- Electrical shock: Protective relays and certified devices used, Earth leakage breakers provided at distribution boards, cables and systems adequately sized and maintained by qualified electricians.

- General Safety measures: Safety training for personnel with periodic updates, safety apparels, Posters displayed prominently. presence of qualified health and safety officers at site, First aid boxes in work areas.

In addition the following energy conservation measures will be adopted.

- Energy efficient Cfl lamps, Hpf discharge lamps used. LED display in switch boards.
- Variable frequency drives for large equipment.
- Electronic regulators for fans and chokes for lamps.
- Energy efficient motors, chillers/blowers.
- Solar hot water system for GH and hostel and solar lighting for small internal paths.
- Closed loop systems to conserve energy.
- AC temperature setting kept at maximum permissible limits and lighting switched off automatically beyond essential duration.
- Parallel running of transformers to reduce copper losses.
- Power factor improvement with capacitors at substation.

INO project will be continuously looking to improve the energy conservation measures and make the project as "green" and environmentally friendly as possible.

8 Outreach

It is a considered opinion among INO collaborators that they should strive to reach out to people and communities living in the vicinity of the project. The members have already met the members of the local body and people from nearby villages. Among the outreach activities planned, we mention a few below:

- INO members to contribute to the educational activties of local schools in the region.
- Support student projects both in the local schools and in the underground laboratory involving local students.
- Contribute to the improvement of laboratories in the neighbourhood schools.
- While conservation related studies and activities are not directly related to the aims of the laboratory, INO will actively collaborate with environmentalists and ecologists who work in the region and also share facilities where-ever possible.

9 Conclusion

The primary requirement of a suitable site for locating an underground laboratory is (apart from the physics and associated requirements) the safety and long-term stability of the lab. Hence the search for a suitable site for INO is mainly guided by the rock quality, availability of water and power for the project, low rainfall, ease of access and minimal environmental impact and its management. In particular, the main physics issue is a requirement of at least 1000 m all-round rock cover. In addition, issues such as availability of infrastructure and length of access tunnel impacts both the physics (time taken for executing the project and hence maintaining the competing edge) and the construction.

Given these criteria, several sites were considered as possible locations for INO. These include sites in the Nilgiris landscape, Anaimalai Hills, Palani Hills, Kambam-Theni landscape and Mahendragiri hills. The study included information from geologists, engineers, ecologists and physicists. It was based on available surveys, study of topo-sheets, several site visits by different groups, and images from Google.

It should be noted that peninsular India, south of 13° N latitude, offers the best possible rock medium for safe and stable cavern construction. Furthermore, the leeward side of the mountains are better suited as they are low-rainfall areas. This focuses on Tamil Nadu for a good location for INO. Among all the regions in Tamil Nadu, the best rock is in the Nilgiris where monolithic hard charnockite rock is available.

The study, based on factors outlined above, clearly show that Singara is the best available site for locating INO. This report thus highlights the basic features of INO at Singara.

Acknowledgements : We thank the geologists of Geological Survey of India, engineers from TNEB, environmentalists and ecologists for valuable input and information.

Appendix A: PUSHEP Site History

There exists a 70 MW power station at Singara built in 1930s, one of the oldest generating stations in the country and the first one to be built in Tamil Nadu. This powerhouse is now designated as a Heritage Power House due to its historical importance.

Singara is also the location of the PUSHEP project which is located underground. The PUSHEP project proposal was made in the late 1980s and construction took off in 1995. The project started functioning in 2005.

The PUSHEP generating station uses the same water reservoir as the existing power station at Singara. The generators for the older project are obviously at the foothills of the Nilgiris mountains. The reservoir is at the top, the Pykara fore bay in Glenmorgan village, at an elevation of 2,000 m, giving a water head of about 600 m. The water that drives the turbines is brought down by penstocks that have been laid along the mountain slopes.

In the new PUSHEP, the water from the Pykara fore bay is brought down by a pipe running underground, at an angle of 60° to the horizontal. The powerhouse is also located in a cavern underground, and the hydel power that can be generated has been increased by locating the powerhouse 500m underground (938 m elevation) so that there is a corresponding increase in the water head (to about 1 km). The underground powerhouse is accessed by a 1.5 km tunnel whose entrance is near the location of the old powerhouse and is therefore not on Forest land. It descends to the power house at a gradient of 1 in 13.11. The wide tunnel supports both incoming and outgoing traffic at the same time. The tunnel entrance can be reached by an all-weather road from Masinagudi.

About 150 MW of power is generated by 3 turbines, each generating 50 MW. Hence the cavern is large enough to house three sets of generators, while the water is fed through one pipe that divides into three just before it reaches the generators (see Fig. 15). The run-off from the turbines is carried by a tail-race tunnel (TRT) 6.8 km long (again through an underground channel) where it feeds the Maravakkandy Reservoir and finally meets the Moyar river.

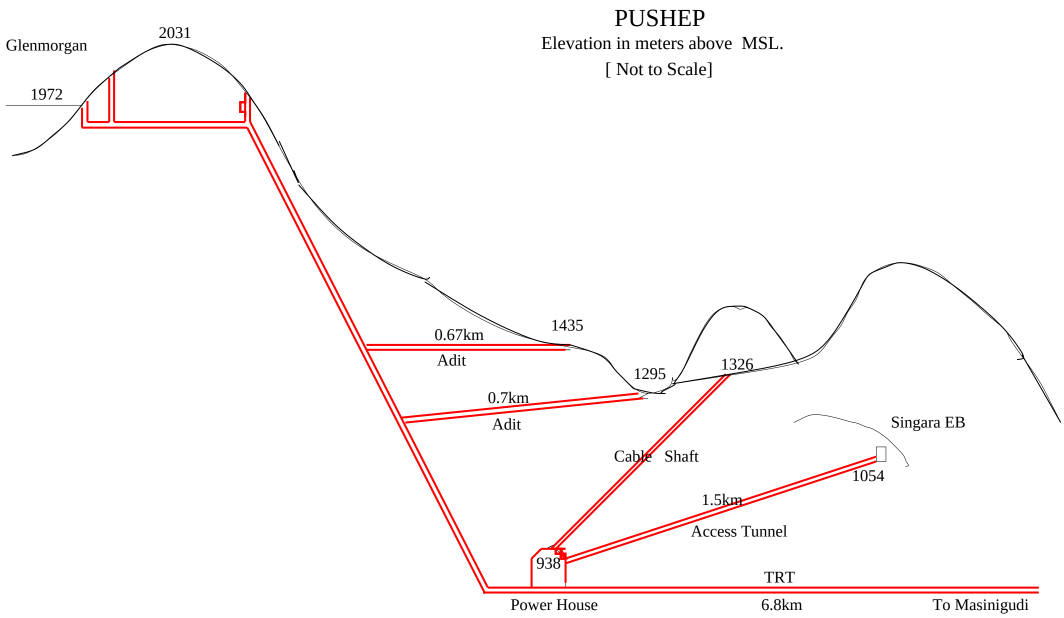

Figure 15: Vertical section of mountain in which PUSHEP is located. The double lines marked in red show the existing tunnels and their approximate lengths

The section view of PUSHEP is shown in Fig. 15. The two adits are marked at 1435m and 1295m. Elevations of different installations are marked in the figure. Fig. 2 gives a panoramic view of the PUSHEP site.

Fig. 15 also shows the outline of the mountain on top of the powerhouse and along the shaft. The power house has three generators in a cavern which is 20 meters wide, 39 meters high and 70 meters long. The power generated is taken by 3 sets of copper bus bars to the transformer that is located in the adjoining (smaller) cavern. From here it is taken out by aluminium bus-bars. The power generated is taken through cables in the cable shaft to the switch yard outside.

Engineering constraints determine that the largest width of self-supported caverns is about 20–25 ms. The roof of the powerhouse is supported by rock bolts and shot-creted; so also the walls of the powerhouse. The control room is located inside this cavern.

Appendix B: Soil and Rock Analysis

A note on the Preliminary geotechnical investigation for INO project, Masinagudi, Nilgiri District, Tamil Nadu

C. Thanavelu and R. Srinivasan
Geological Survey of India, Chennai

Introduction: Institute of Mathematical Sciences, a constituent of National Neutrino Collaboration group, engaged in feasibility studies to locate an under ground laboratory—the India-based Neutrino Observatory (INO), has approached Geological Survey of India to identify a suitable location in South India. In response, Geologists of GSI, Engineering Geology Projects, considering the technical requirements of INO and the infrastructure facilities available have suggested a site near Masinagudi, adjacent to the on going Pykara Ultimate Stage Hydroelectric Project (PUSHEP)- an under ground power house project.

After the preliminary discussion and field visit, the members of NNCG have decided to carry out feasibility studies of the proposed site. The geotechnical feasibility of the site was carried out by GSI at the request of the Scientists of IMSc. The investigations carried to arrive at the feasibility include preliminary geological studies and geotechnical features encountered in the PUSHEP and synthesis of data available besides aerial photograph/satellite imagery studies and interpretation.

Regional Geological Milieu: The proposed project is located on the northern fringe of Nilgiri massif forming part of the southern peninsular shield. The principal rock types exposed in the project area include Charnockite with bands and patches of granulite (amphibolite) and banded magnetite quartzites belonging to charnockite group of rocks andhornblende biotite gneiss with or without garnet, garnetiferous quartzo feldspathic gneiss (leptinite) fissile gneiss and trapshotten gneiss belonging to migmatites of the Archean age. Mafic and ultra mafic dykes/bodies, besides pegmatite and quartz vein are occuring as intrusives in the country rock.

The regional trend of foliation is in the ENE-WSW direction with steep dips on either side. Three generations of folding have been recognized, two are coaxial, trending in the E-W direction, and the third in the N-S direction.

The Nilgiri massif is considered to have been block faulted and lifted up between Bhavani and Moyar sheal. There is other school of thought considering it to be symotogenic upwarp due to presence of bauxite and laterite capping. As sequel to the area confined between the metga shears, sympathetic shears are common in the study area. Some of the sympathetic shears are encountered in the bores of PUSHEP project and are expected to be encountered in the INO excavations also.

Site specific geology: The portal loation and initial reaches of the four proposed alignments of access tunnel (plate) will be bored through migmatites. Part of the access tunnel and cavern will be set in charnockite. Foliation, 12 sets of joints, 20 shear zones, 19 fracture zones and 5 sets of dykes are the discontinuities present in the rock mass. Their physical attributes are presented below:

- **Foliation**: The strike of the foliation is N70E-S70W dipping 60 deg to 80 deg towards S20E. The variations in the strike direction and the azimuth of the dip is noticed owing to folding.
- **Joints:** Twelve sets of joints present in the rock mass is tabulated here under-

Joint Set No.	Strike	Dip	Spacing in cm	Nature
1.	N70^{o}E-S70^{o}W	80^o S20^{o}E to Vertical	50-200	Selectively mylonite filled
2.	N70^{o}W-S70^{o}E	50^o N20^{o}E	100-300	Tight
3.	N70^{o}W-S70^{o}E	60^o to 80S20^{o}W	widely spaced	Tight
4.	N to N10^{o}W-S to S10^{o}E	Vertical	50-400	Occasionally stained, weathered and mylonite filled
5.	N45^o to 70^{o}E-S45^o to 70^{o}W	55^o to 60^o N20^o to 45^{o}W	50-200	Tight, Mylonite filled, close to shears
6.	N40^{o}E-S40^{o}W	Vertical	widely spaced	Tight
7.	N40^{o}W-S40^{o}E	Vertical	widely spaced	Tight
8.	N30^{o}W-S30^{o}E	45^o S60^{o}W	100-300	Mylonite filled
9.	N30^{o}W-S30^{o}E	40^o N60^{o}E	100-300	Tight
10.	N10^{o}E-S10^{o}W	30^o S80^{o}E	50-300	Tight
11.	N60^o to 70^{o}E-S60^o to 70^{o}W	20^o to 30^o N20^o to 30^{o}W	100-400	tight
12.	N60^o to 70^{o}E-S60^o to 70^{o}W	30^o S20^o to 30^{o}E	widely spaced	Tight

About 20 shear zones and about 19 fracture zones with widths ranging from 30cm to 400 cm were encountered in various components of the PUSHEP. Though the sheared/fractured zones have trends parallel to all the twelve sets of joints, the most predominant weak planes are oriented ENE-WSW direction followed by WNW-ESE direction.

- **Dykes:**

The following table shows the sets of dykes present in the study area:

Serial No.	Strike	Dip	Width in cm
1.	N-S	70^{o}E	80
2.	N45^{o}E-S45^{o}W	55^o to 70^o-N45^{o}W	
3.	N25^{o}E-S25^{o}W	25^{o}N 65^{o}W	80-100
4.	N60^{o}E-S60^{o}W	55^o -70^o N30^{o}W	150-2
5.	N05^{o}W -S5^{o}E	65^{o}N 85^{o}E	30

Geotechnical Evaluation: In the process of feasibility studies four alignments were considered for the INO access tunnel to lab cavern wise 1 to 4. All the proposed alignments are to cross the

Characteristics	Alignment-1	Alignment-2	Alignment-3	Alignment-4
Location	450 m from Chainage of PUSHEP access Tunnel	Adjacent to Pushep access Tunnel (200m East)	About 1 km south of Adit-4 inlet	From Adit-4 inlet
Total Length	1867 m	2129 m 2380 m	3194 m	
Gradient proposed	1 in 15	1 in 15	1 in 15	1 in 15
Inlet sill level	1019 m	1050 m	1025 m	966 m
Sill level at Cavern	894 m	908 m	867 m	753.5 m
Height of Cavern	40 m	40 m	40 m	40 m
Cavern crown level	934 m	948 m	907 m	793.5 m
Vertical cover from sill level	1303 m	1299 m	1340 m	1453.5 m
Sill level of INO access tunnel at TRT crossing	981 m	992 m	987.5 m	903.5 m
Crown RL of TRT at crossing	929.5 m	929 m	926.5 m	922.4 m
Cover between INO access and TRT.	51 m	63 m	61 m	-18.9 m

tail race tunnel of the PUSHEP project. The alignment wise details are enumerated in the table below:

Geological set up and structural fabric being the same for all the alignments, considering the other aspects for the feasibility, the alignment from the access tunnel (alignment-1) of the PUSHEP is the best. If the project authorities intend to have independent access, the alignment-2 is considered to be more suitable.

In the absence of any exploration data the exact location for the portal of the alignment-2 and cover details could not be worked out. In order to have the exact data on portal formation, the length of soft rock/earth tunneling and to arrive at bedrock level, it is necessary to carry out exploration by drilling or geophysical profiling in the portal location and at TRT crossing.

The rock mass in general as observed in various components of PUSHEP can be rated as fair to very good with Q value ranging from 4 to 45. The rock mass in and around the shear/fracture zones/sheared dyke are rated to be very poor. The stand up time worked out and as experienced ranges from 3 months (Sheared/fractured rock) to infinity. The tunnel being near horizontal, negotiation of the shear/fracture zone and sheared dykes are easier. The rock mass is considered as good to very good tunneling media with the Specific gravity ranging from 2.61 to 2.90. The p-wave velocity (Vp) varies from 4 km/sec to 5.45 km/sec in fresh rock and varies from 2 km/sec to 3.3 km/sec in weathered rock.

In order to have an idea about background radiation radiometric survey using scintillometer has been carried out in the area both at surface and in the underground openings. The maximum rock radioactivity is of the order of 0.005 mR/hr or less. The soil cover over the rock shows 0.01 to 0.015 mR/hr, which is slightly higher than the underlying rock, and is more predominant in the lateritc capping present in the higher altitudes (near Glenmorgan reservoir or HRT areas of PUSHEP).

The chemical analysis of major rock types present in the project is given in the following table: The foliation, most of the joints sets, shear/fracture zones are oriented near normal to the INO alignments, which is favourable for tunneling. Though 12 sets of joings are presetn in the rock mass, in a given reach only two to three joints occur as predominant set. Almost all the joints are tight, fresh, rough to smooth planer and unfilled except the reaches close to shear zones where the

Constituent in %	Biotite gneiss	Charnockite	Amphibolite
SiO_2	60.44	71.54	53.09
TiO_2	00.63	00.61	00.98
Al_2O_3	16.72	13.70	14.54
Fe_2O_3	00.87	00.60	02.92
FeO	05.46	04.45	07.90
MnO	00.11	00.10	00.21
MgO	03.60	00.88	06.42
CaO	06.82	04.36	10.61
Na_2O	03.82	03.10	02.10
K_2O	01.09	00.21	00.27
P_2O_5	00.14	00.06	00.06
LOI	00.12	00.12	00.76

parallel joints are filled with gouge/Mylonite. Most of the reaches are expected to be dry with a few reaches showing seepages moist to low dripping type. The quantum of seepage may not exceep 5 lit/min as observed in the PUSHEP tunnels.

Geological projections from the components of the PUSHEP to the proposed INO access tunnel alignments indicate that allthe alignments may encounter five prominent shear zones with width ranging from 1m to 3m and a number of minor shears (width 30- 50 cm) and shear joints. Almost all the shears are either normal or askew with the proposed alignments.

To provide comparative information on the insitu stress of the area, the results of the stress measurements carried out at PUSHEP adit 2 junction with presure shaft in the pilot tunnel of the power house cavern is detailed under:

- **ADIT-2:**
- Cover: about 200 m
- Maximum Horizontal Stress (SH) - 9.79 Mpa
- Minimum Horizontal Stress (Sh) - 6.53 Mpa
- Vertical Stress (Sv) - 6.08 Mpa
- Direction Maximum Horizontal Stress - N 100^o
- K-factor = (SH)/(Sv) = 1.61
- **Power House (Sandwiched between two sheared dykes:**
- Cover: about 532 m
- Maximum Horizontal Stress (SH) - 26.59 Mpa
- Minimum Horizontal Stress (Sh) - 13.25 Mpa
- Vertical Stress (Sv) - 15.21 Mpa
- Direction Maximum Horizontal Stress - N 110^o
- K-factor = (SH)/(Sv) = 1.74

The comparison of the data in conjunction with the cover indicates a sharp rise in the stresses with the increase in cover/depth. From this it is prudent to know the insitu stress condition at the proposed lab cavern. The observations in the access tunnel/power house/busducts and cable shaft which are located at about 500 m depth indicate opening of the joints particluarly along N70E-S70E dipping 70 degrees towards S20E and at places along N20W-S20E dipping 70 degrees N70E joints indicating moderate stress conditions. To have advance information on insitu stress borehole from adit 5 of PUSHEP for a depth of about 300 to 500 m may be drilled and stress measurements may be carried out.

Most of the discontinuities are oriented in the ENE-WSW direction. Preliminary assessment based on the surface and subsurface geological data available indicate a north- south alignment of the proposed lab cavern. However a final decision on the orientaiton of the proposed lab cavern can only be taken based on the insitu stress measurement data.

The projections of the PUSHEP data also indicate that no major geological adversities are to be encountered in the lab cavern of INO. However, minor tunneling problems may be encountred due to critical wedges in the underground openings at the intersections of smooth planar, filled joints, smooth planar/filled joints, with shear/fracture zones, presence of shear/fracture zones, sheared dyke and due to anticipated moderate stress condition at cavern level. In order to overcome the above mentioned problems and smooth driving the support measure like spot bolting, systematic rock bolting, mesh/fibre reinforced shotcreting, PCC/RCC lining may be necessary for select reaches.. The location and type of support measures will be dealt during the construction stage investigation. However, to have pre-construction stage visualization of the geological condition, a tentative geological section will be provided after finalisation of the alignment.

Conclusion *The site is assessed to be geologically and geotechnically suitable for construction of an underground laboratory cavern for the following reasons:*

- *Bare minimum of exploration is needed as wealth of data is available which are collected from the ongoing PUSHEP project.*
- *The project is located in the South Indian Peninsular Shield.*
- *Low to moderate insitu stres condition prevailing in the area.*
- *The rock mass is one of the best tunneling medium, with limited geological adversities.*
- *The rock surrounding the proposed cavern is homogenous and monolithic nature.*
- *The cover requirement of more than 1000 metre all around the site is also satisfied.*

Appendix C: Geotechnical forecast along the preferred alignment

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Persuant to the request from the National Neutrino Collaboration Group member (IMSc-Chennai), geotechnical feasibility studies were carried out to locate an underground laboratory cavern in the Nilgiri hills adjacent to a on going underground power project - Pykara Ultimate Stage Hydro Electric Project near Masinagudi, Nilgiri district, Tamil Nadu. Considering technical requirements and infrastructure facilities available, a site below peak 2207, for locating the underground lab cavern, identified. For the access tunnel to the proposed cavern, four alignments were considered and geotechnical evaluation carried out. Although, the geological set up and the structural fabrics are similar for all the four alignments, the alignmnet 2 is considered to be the best independent access considering other aspects.

Geological and geotechnical evaluation was carried out based on the available surface and subsurface information collected from the PUSHEP project. Based on the exhaustive data analyses and projection of the geological features encountered in the various under ground openings of PUSHEP, a forecast geological cross section with adequate ground control was prepared along the best suitable independent access tunnel alignment 2 (See Fig. 5).

Boulders of gneiss and migmatite and soil occupy the inlet area. Examination of the surrounding area indicated availability of bedrock at shalllow depth and adequate super incumbent and lateral rock cover. The tunnel inlet portal can be established after a short open cut. Incidentally the Inlet portion can be located (till obtaining a face) falls in a private estate, which is expected to be acquired without difficulty. The prognostication indicates that the initial 675m reach of hte tunnel will be drives through interbanded sequence of hornblende biotite gneiss/migmatite and charnockite beyond which the excavation will be in massice charnockite. The ground strike of the foliation is in N 40^o to 70^oE - S40^o to 70^o W dipping 60^o to 80^o towards N20^oW up to about 1000m and beyond the dip is 60^o to 80^o towards S20^oE. The variations in the strike direction and dip owing to folding are noticed.

Apart from the rough/smooth planar joints sets to be negotiated, the discontinuities of critical importance to be negotiated include fracture zones, shear zones and sheared dykes. The details of the discontinuities are enumerated below.

Joints: Although a total of twelve sets of joints are present in the terrene, in any given tunnel reach, the likely prominent joints to be encountered will not be more than three sets. Most of the joints are fresh, tight and irregular planar. Some of the planes are stained, smooth planer and some others are filled with mylonite seams especially in the vicinity of shear/fractured zones. In the initial low cover reaches the joints are expected to be open, weathered and stained.

Shear zones: About eight numbers of shear zones are prognosticated to be encountered along this tunnel with width varying from about 30cm to 250cm. The chainages at which these shear zones expected to be met with are 197m, 235m, 338m, 412m, 450m, 587m, 925m and 1300m. Most of the shear zones manifest fracturing, brecciation, formation of mylonite/gouge and quartz feldspar permeations. Most of these chear zones are disposed near normal/considerably askew to the tunnel alignment. The experiences in the underground openings of PUSHEP show the sheared rock mass are having stand up time more than six months to a year an negotiating the same was non-problematic even with full section excavation of size 6.5m X 6.5m with routine DBM.

Fracture zones: About six fracture zones are to be met along this tunnel alignment at chainages 287m, 412m, 450m, 839m, 1090m and 1300m. The width of the fracture zones varies from 50cm to 400cm. Only fracturing/close spaced jointing are manifested along these zones. As experienced the stand up time is considerable and hese zones may not pose any problem during excavation and may warrant only ultimate support measures.

Sheared dyke: Two sheared dykes of width 1.5 to 2m will be met in this tunnel at chainages about 800m and 1140m. The contacts of these dykes are highly sheared with clay gouge. Islands of good rocks with slickensides are observed at the Centre. The material is soft and so fragile that it can be excavated with crow bar. In act these two zones need careful excavation and concurrent support.

The rock mass in general can be rated as fair(30% of reaches) to very good(60% of reaches) with Q vaue ranging from 4 to 45. Even in the case of minor/small weak zones with very poor rock masss their favourable orientation and excavation of the tunnel being near horizontal renders negotiation of these weak zones non-problematic, as experienced. Minor tunneling problems such as formation of critical wedges at the intersections of smooth planer and filled joints is a routine tunneling problem, which can easily be negotiated with suitable support intervention. Most of the reaches in the tunnel are expected to be dry except in the initial reaches with weathered/open joints and in shear/fracture/sheared dyke reaches where moist to low dripping types of seepage is anticipated.

Post excavation distress inthe form of opening up/widening of joints noticed in the underground openings of PUSHEP in the areas proximus to Access tunnel/Cable shaft/TRT sheared dyke (the one forecast at Ch.800m). In view of hte above and the mandatory practice for the high cover projects to assess the stress related tunneling problems and for preparedness to tackle, it is essential to have advance information on insitu stress conditions for the proposed under ground openings for the reaches with rock cover more than 500m. In addition it is also necessary to find out the maximum principle stress direction to decide upon the orientation of the cavern. Therefore it is recommended that concurrent with access tunnel excavation of this project, advance microseismic surveys can be carried out to determine the stress field and for advance planning of excavation and support intervention which will also decipher the orientation of the lab cavern.

As all the geological and geotechnical data required except the information on insitu stress for the areas with more than 500m cover is readily available, the proposed site is assessed to be suitable for siting of the under ground laboratory. In fact as the data control is so excellent, it is strongly recommended to the project authorities to immediately commence construction activities and drive an access tunnel along alignmnet-2 as exploratory tunnel for a length of 300m to 500m, which can be assimilated as part of the project subsequently. This will also enable obtaining advance information on the prevailing stess condition for further planning. Other than this no further exploration is needed at the present stage to initiate construction activities.

Appendix D: TCLP and Leachate Analysis

Heavy Metals	Water Leachate Values (mg/L)	TCLP Values	TCLP regulatory limit (mg/l)
Arsenic	BDL	BDL	5.0
Cadmium	BDL	0.4326	1.0
Chromium	0.0239	0.1270	5.0
Copper	0.0010	0.3240	–
Mercury	BDL	BDL	–
Nickel	BDL	0.1186	–
Lead	BDL	0.0616	5.0
Selenium	BDL	0.0966	1.0
Zinc	BDL	BDL	–

TCLP: Toxicity Characteristic Leaching Procedure; BDL: Below determination Limit. Limit values: Arsenic=0.01, Cadmium=0.03, Mercury=0.06, Nickel=0.05, Lead=0.05, Selenium=0.05, Zinc=0.05 (mg/L). Tests carried out at CES, Anna University, Chennai using rock samples from PUSHEP tunnels.