December 2009 (Revised)

India-based Neutrino Observatory INO

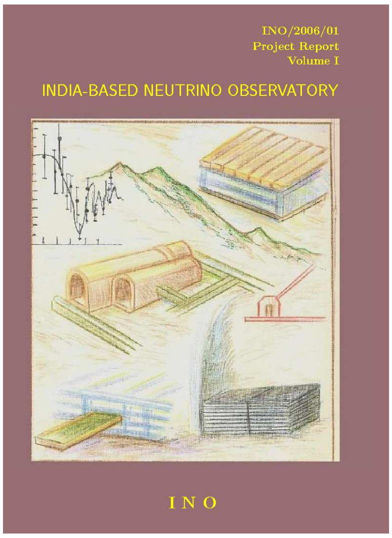
- **The India-based Neutrino Observatory (INO) is an effort aimed at building a world-class underground laboratory to study fundamental issues in physics. It is a mega-science project under the XI five-year plan with an investment of nearly 900 crores, jointly funded by the Department of Atomic Energy (DAE) and the Department of Science and Technology (DST).**
- **The ambitious INO proposal has already drawn the worldwide attention of international scientists. Once completed it will be the largest basic sciences facility in India.**
- **Nearly 25 institutions and about 90 scientists are involved in the INO collaboration with Tata Institute of Fundamental Research, Mumbai, being the host institution. This large collaboration is the first of its kind in the country.**
- **The laboratory is to be located in Tamilnadu as the steep slopes of the western ghats provide ideal and stable rock conditions for building a large underground cavern, safely, for long-term use.**
- **The primary goal of the laboratory is the study of neutrinos from various natural and laboratory sources using an iron calorimeter (ICAL) detector. It is envisaged that such an underground facility will develop into a centre for other studies as well, in physics, biology, geology, etc., all of which will make use of the special conditions that exist deep underground.**
- **The ICAL detector that will be installed in the INO laboratory will be the world's most massive detector. Such an effort will involve INO–Industry interface in a big way; hence the construction phase itself will draw heavily on available industrial infrastructure, in issues related to mechanical structure, electronics and detector-related technology.**

  Apart from the scientific goals of INO, therefore, the laboratory itself will greatly enhance the development of detector technology and its varied applications (which have earlier mostly been in the areas of medical imaging).
- **Students of science and technology in the state as well as in the country will benefit by doing research in cutting edge science and technology.**
- **INO has no strategic or defence applications. Its operation involves no radioactivity release or toxic emissions.**

1 Some frequently asked questions about INO

Over the last few years many questions have been asked about the proposed underground laboratory, INO. Below we list some of these questions and our response:

1. **What is INO?**



The India-based Neutrino Observatory (INO) is a proposed pure-Science underground laboratory. Its primary goal is to study the properties and interactions of weakly interacting, naturally occurring particles, called *neutrinos*. The objectives of the study are appended in simple layman's language at the end of this FAQ. There is world-wide interest in this field due to its implications for several diverse and allied fields such as particle physics, cosmology and the origin of the Universe, energy production mechanisms in the Sun and other stars, etc.

Several groups belonging to different Universities and research Institutes in India are part of the collaboration working on the details of INO. The current proposal focusses on neutrino detection with static detectors, to be placed deep underground at a suitable site. A short account of the physics goals and implications is appended at the end of this FAQ.

2. **Where can one find detailed information about INO?**

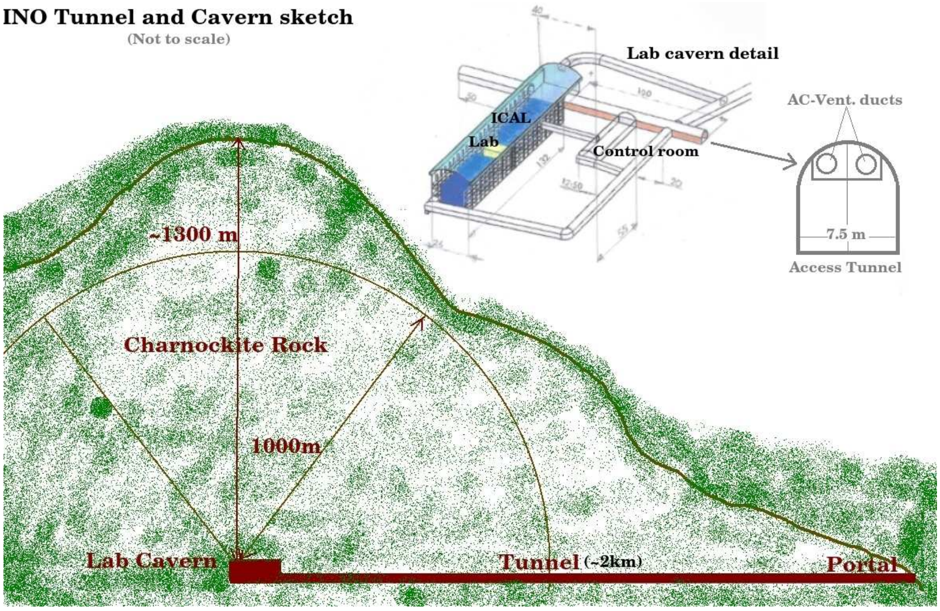
Many articles, talks and reports about INO are available from the following websites:

URL: http://www.ino.tifr.res.in/

URL: http://www.imsc.res.in/∼ino

The websites provides the current status and is continuously updated. We appreciate inputs from our scientific colleagues. It also contains information for students and non-technical material accessible to the general public.

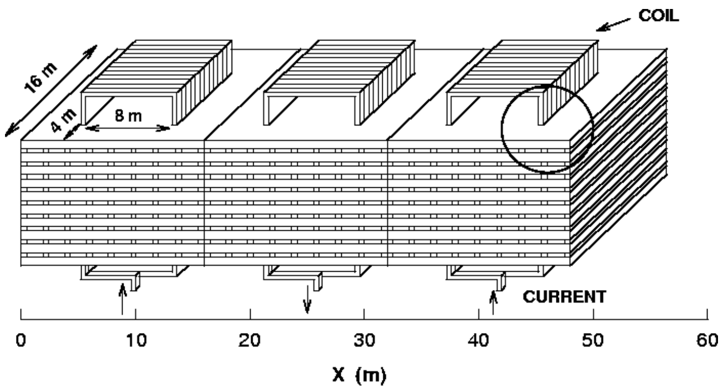
3. **What are the highlights of the proposal?**



The INO proposal consists of creating two underground laboratory caverns with a rock cover of more than 1000 metres all around to house detectors and control equipments. An access tunnel to reach the underground laboratory of length 2 km (approximate) will be driven under a mountain to reach the laboratory caverns. The surface facilities near the portal will consist of a laboratory and some housing for the scientists, engineers and operating staff.

4. **What will be the detector that will be housed at INO?**

The detector housed in the INO underground laboratory initially will be a magnetised iron calorimeter detector (ICAL). It is a static device without moving parts. Just as a telescope observes the sky through visible light, the ICAL will observe the sky through neutrinos.



Charged particles produced in the rare interactions of neutrinos with the iron (constituting the 50 kton, 1.3 Tesla magnet) will be detected in glass based detectors sandwiched between successive iron layers. The penetrating ones, such as muons, will be tracked in space and time to identify their charge (+/-) and momentum.

5. **What about radioactivity?**

The main reason for locating the laboratory underground is to create an environment free of the radiation that abounds on the Earth's surface. This radiation is due to cosmic rays and natural radiation of the materials around us. Hence the experiment will neither produce any radioactivity nor can it function well where this is radiation (at the surface).

6. **Will there be hazardous chemicals and gases?**

   The detectors measuring the impact of charged particles produced in neutrino interactions with the iron consist of glass sheets kept at a precise separation and hermetically sealed to maintain the purity of a certain kind of gas mixture at about atmospheric pressure. The gas mixture used in the experiment consists of mainly argon, freon (environmentally friendly variety that is now used in all modern refrigerators) and small quantities of isobutane. These are used regularly in all laboratory environments and the mixture that will be used will conform to international standards of safety.

   The gas mixture is recycled many times before it is let out in small volumes. The ventilation system mixes the released gases with air to ensure the safety of every one. This is more a precaution to ensure the safety of the workers inside the laboratory.

7. **What is the status of the proposal?**

   The INO proposal has been approved for funding during XI five year plan of Government of India pending statutory clearances. After many discussions with the concerned agencies, the Government of Tamil Nadu gave an in-principle approval to locate the project at Singara near Masinagudi pending statutory clearances. Though the site at Singara is the best available site for locating INO, the site was not cleared by the Tamilnadu forest department and therefore by the Ministry of Environment and Forest of the Government of India. The proximity of Singara to the Mudumalai Wildlife Sanctuary which has since been declared as a part of Project Tiger and the possibility of the region being declared as the buffer zone of the tiger sanctuary were important considerations in this decision.

   The INO collaboration is now studying the potential sites in the Kambam valley region in the Theni district for locating the project. A suitable site in this region may be chosen to locate the INO project.

8. **What are the time frames for the project from time zero?**

   The present road map envisages that the first module of the detector will start taking data at the end of five years. Immediately after that the subsequent modules will be constructed. The first year of the project will be devoted to exploration, finalisation of designs, identifying the contractors etc. The next two years will involve excavation of the tunnel and laboratory cavern. During the last two years the laboratory equipment and detector construction will begin.

9. **What were the factors in deciding the location of the project?**

   Since the laboratory cavern needs to be more than 1000 m underground (so that there is at least 1000 m cover all-round to absorb/reduce natural cosmic radiation), 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, southern 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 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 towards the end of the document.

10. **How much rock will be excavated?**

    The total volume of rock to be excavated (all tunnels, laboratories, parking etc) is estimated to be about 225,000 cubic meters if the tunnel length is about 2 km. Most of this rock will be removed from the construction site and the remainder will be used as gravel in the construction of the tunnel road.

    Many steps may be taken to minimise the impact of trucking including: maintaining quiet times; caravanning trucks; using modern, quieter, low-emissions trucks.

11. **Where will the muck be stored?**

    The construction phase requires the removal of the rock excavated from the tunnel and laboratory. A muck storage yard with retention walls (to avoid seepage into local water bodies) on all sides will be created and the muck will be removed in a phased manner from the yard.

12. **What happens when there is an earthquake or rock burst?**

    Deep underground places are often one of the safest locations when an earthquake happens.

    The occupied areas underground will have a refuge area. This is a room designed to safely isolate people, who then wait for rescue.

    A tunnel failure is not expected in locations where the rock conditions are ideal. During construction weak structures will be identified and secured using many available reinforcing technologies like rock bolts, shotcreting, etc. The portal, especially, has to be designed to withstand rock falls from outside.

13. **How many people are to be located at the site?**

    During the construction phase there will be a work force numbering about 100 or so. During the heavy construction phase the personnel needed includes civil engineers, drilling crews, truck drivers and concrete workers. There will also be design, architectural, and engineering crews along with geologists. The finishing work will require electricians, ventilation engineers, and environmental engineers.

    As described in our proposal, we estimate that the project will employ a maximum of 100 permanent staff members and visiting scientists drawn from several laboratories. Only a small fraction of these will spend a substantial part of their time at the underground laboratory. About 20-30 scientists and engineers will stay permanently at the location for operational reasons apart from a floating population of students and scientists.

14. **What are the benefits to local people from this project?**

    This is dependent on the location, availability of land and environmental sensitivity, to some extent. At the minimum, it is possible to foresee gainful employment for a small number of people in the region where the underground laboratory is located for maintenance and management of the facility apart from supporting staff. Since the laboratory once operational involves minimal activity, that too underground, it is not expected that it will be a major employment source.

    A major benefit will be for schools and colleges in the region as the students interested in science can benefit from the outreach activities as well as doing projects. INO is committed to create an active outreach programme for the benefit of students in and around the project location.

15. **Does INO have an outreach programme?**

    The INO collaboration is very keen on scientific outreach possibilities such as interactions with neighbourhood schools and colleges as well as with physics research and teaching groups from all over India. Small and short-term projects and other activities are envisaged to increase scientific awareness and temper and involve students from all interested Institutions. In the initial stages, the INO collaboration is also keen to inform the general public about the project and that it will not harm the environment. Hence local support and awareness are crucial.

16. **What will be the environmental impact of INO?**

    Given the nature of the basic requirements, the project location will invariably be located in an ecologically and environmentally sensitive area. The impact will be mainly during construction period; after construction ends within a few years, the lab will be maintained by a small staff with some students and scientists not exceeding about 30 persons and will have negligible environmental impact. All efforts with be made to minimise and manage the impact during construction.

17. **Does INO have an environmental policy?**

    Members of INO are acutely aware that the laboratory may be located in an environmentally and ecologically sensitive area. 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.

    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) offers immense opportunities and a challenge for realising such a model.

2 A Neutrino glossary

2.1 What are they?

Neutrinos are tiny, neutral, elementary particles which interact with matter via the weak force. The weakness of this force gives neutrinos the property that matter is almost transparent to them. The Sun, and all other stars, produce neutrinos copiously due to nuclear fusion and decay processes within their core. Since they rarely interact, these neutrinos pass through the Sun, and even the Earth, unhindered. There are many other natural sources of neutrinos including exploding stars (supernovae), relic neutrinos (from the birth of the universe), natural radioactivity, and cosmic ray interactions in the atmosphere of the Earth. For example, the Sun produces over two hundred trillion trillion trillion neutrinos every second, and a supernova blast can unleash 1000 times more neutrinos than our Sun will produce in its 10-billion year lifetime. Billions of neutrinos stream through our body every second, yet only one or two of the higher energy neutrinos will interact with you in your lifetime.

The neutrino was proposed by Wolfgang Pauli in 1930; but it took another 26 years for it to be actually detected. In 1956 Reines and Cowan found evidence of neutrino interactions by monitoring a volume of cadmium chloride with scintillating liquid near to a nuclear reactor. Reines was jointly awarded the Nobel Prize in Physics in 1995 in part for this revolutionary work. We now know that not just one but at least three types or flavours of neutrinos and their anti-particles exist in nature. They have a tiny mass whose value is still not known. Moreover, they exhibit a quantum-mechanical phenomenon in which one type of neutrino *oscillates* into another as it propagates in space; this is called neutrino oscillation and this observation has generated immense excitement in the particle physics community.

2.2 Why detect them ?

From recent experiments we know that the mass of the neutrino is non vanishing, but we are unsure how large the masses of the three individual neutrino types are because of the difficulty in detecting neutrinos. This is important because neutrinos are by far the most numerous of all the particles in the universe (other than photons of light) and so even a tiny mass for the neutrinos can enable them to have an effect on the evolution of the Universe through their gravitational effects. There are other recent astrophysical measurements that provide information on the evolution of the Universe and it is crucial to seek complementary information by direct determinations of the masses of neutrinos and their other properties. In a sense, neutrinos hold the key to several important and fundamental questions on the origin of the Universe and the energy production in stars. We have some partial answers but many details are still awaited from future experiments.

Yet another important possible application of neutrinos is in the area of neutrino tomograph of the earth, that is detailed investigation of the structure of the Earth from core on wards. This is possible with neutrinos since they are the only particles which can probe the deep interiors of the Earth.

2.3 Why should the laboratory be situated underground?

Neutrinos, as mentioned before, are notoriously difficult to detect in a laboratory because of their extremely weak interaction with matter. The background from cosmic rays (which interact much more readily than neutrinos) and natural radioactivity will make it almost impossible to detect them on the surface of the Earth. This is the reason most neutrino observatories are located deep inside the Earth's surface. The overburden provided by the Earth matter is transparent to neutrinos whereas most background from cosmic rays is substantially reduced depending on the depth at which the detector is located.

One of the earliest laboratories created to detect neutrinos underground in the world was located more than 2000 m deep at the Kolar Gold Field (KGF) mines in India. The first atmospheric neutrinos were detected at this laboratory in 1965. This laboratory has been closed due to the closure of the mines. Most underground laboratories around the world are located at a depth of a km or more. There are two types of underground laboratories: either located in a mine or in a road tunnel. There are now four major laboratories around the world: in Sudbury in Canada, Kamioka in Japan, under the Gran Sasso mountains in Italy and in Soudan mines in the USA. Several others are planned including INO which is an attempt to recapture the pioneering studies on neutrinos at KGF.

2.4 Criteria for locating the underground lab

1. 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.

2. Risk Factors: Rock stability is an important criterion from the point of view of safety. This is the largest ever underground lab 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.

3. 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, especially for the life span of such a laboratory (50-100 years).

4. Geotechnical/geographic information: A complete 3D topo map of the region must be available for evaluating 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 location 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.

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

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.

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. Access: It is important to have quick access to the laboratory from major cities with good industrial infrastructure.

9. Neutrino Beam: Distances to various future possible neutrino factories and any particular advantage that may be there due to physics reasons.

10. Long-term availability of the site.

3 A vision for INO and the challenge

INO has been conceived on a scale that no other basic sciences project in India has attempted. The MoU signed by seven institutions, that brought the Neutrino Collaboration Group into existence, is already the first of its kind. It is a testimony to the enthusiasm and collaborative spirit shown by the scientific community in India.

In the first phase of its operation a magnetised iron calorimeter detector, weighing about 50,000 tons, will be used for studying neutrinos produced from cosmic rays in Earth's atmosphere. The aim is to make precision measurements of the parameters related to neutrino oscillations. An exciting possibility is to determine the ordering of the neutrino masses which is not very well known at present. This is one of the fundamental open questions in neutrino physics and no other detector either existing or planned except perhaps NOνA may be able to provide an answer in the next 10 years. Because of its ability to distinguish the positive and negative muons, this detector can settle this question.

This detector can also be used as the far-detector of a long-base-line (6000 to 11500 km) neutrino experiment using the neutrino beam from a neutrino factory in Japan, Europe or USA. These are neutrinos that will be produced in a future accelerator facility which are beamed towards the detectors situated in a different part of the Earth. This is envisaged as the second phase of the INO activity, and is a long-term goal, since neutrino factories are yet to become a reality. However, there is considerable interest in this possibility not only for the rich physics potential but also because the proposed detector at INO will be capable of charge identification, which is crucial for this mode of operation.

INO will have an impact on the emerging high energy physics scenario in the country. People trained at INO will not only participate here but also have the expertise to contribute to other high energy and nuclear physics projects around the world. Over the long term INO is expected to develop into a world class underground science laboratory straddling many fields like physics, biology, geology and allied engineering fields.

Members of INO are acutely aware that the laboratory is likely to be located in an environmentally and ecologically sensitive environment. 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 is looking for scientists and engineers who will enjoy the challenge of setting up an entirely new facility to do world class research. Now is the right time to join us and make a difference!

4 Contact Information

For more information, please refer to the web-site address listed above, or contact

Prof N K Mondal (Spokesperson),
Tata Institute of Fundamental Research,
Homi Bhabha Road,
Mumbai 400 005.