The Angra Neutrino Project: precise measurement of θ_{13} and safeguards applications of neutrino detectors

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Abstract. We present an introduction to the Angra Neutrino Project. The goal of the project is to explore the use of neutrino detectors to monitor the reactor activity. The Angra Project, willl employ as neutrino sources the reactors of the nuclear power complex in Brazil, located in Angra dos Reis, some 150 Km south from the city of Rio de Janeiro. The Angra collaboration will develop and operate a low-mass neutrino detector to monitor the nuclear reactor activity, in particular to measure the reactor thermal power and the reactor fuel isotopic composition.

The experimental initiative can turn out to be the very first stage of a much larger project (set up in a time scale that goes well until 2015), to address the study of neutrino oscillations, and particularly the precise determination of the mixing angle θ_{13}, the last still not well measured mixing parameter in the neutrino sector.

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INTRODUCTION

The Angra Neutrino Project is an experimental initiative to explore the issue of the use of neutrino detectors to remotely monitor the operation of nuclear reactors. The Angra Project will employ as neutrino sources the reactors of the nuclear power complex in Brazil, located in Angra dos Reis, some 150 Km south from the city of Rio de Janeiro. The Angra Collaboration will build one or several low-mass neutrino detectors located at short distances from the reactor cores of the Angra complex. These neutrino detectors are intended to monitor the nuclear reactor activity, in particular to measure the reactor thermal power and the reactor fuel isotopic composition.

This experimental initiative can as well turn out to be a very first stage of a much larger project (set up in a time scale that goes well until 2015), to address the study of neutrino oscillations in Brazil, particularly the precise determination of the mixing angle θ_{13}, the last still not well measured mixing parameter in the neutrino sector.

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[1] On behalf of the Angra Collaboration

MEASUREMENT OF THE THERMAL POWER AND NUCLEAR FUEL COMPOSITION

The Angra II reactor at the Brazilian nuclear power plant located in Angra dos Reis will be the main reactor for the studies. That is, it will be the main source of neutrinos for the experiment, and the main reactor to monitor. It has a nominal thermal power of 4.0 GW.[2]

We expect[3] to detect several hundred neutrino events per day. This can be achieved by constructing and efficiently operating a 1-ton target mass detector located at some 60 m from the reactor core. This detected neutrino rate will permit us to monitor the reactor thermal power with an accuracy of a few units per cent. With the additional precise measurement of the neutrino energy spectrum we will be able to investigate and trace in time the reactor fuel isotopic composition, and thus we will be able to study the use of neutrino detectors as nuclear safeguards devices in the context of the IAEA non-proliferation policies.

In the fission reactions that take place in nuclear reactors neutrinos (actually antineutrinos) are produced in enormous quantities.[4] Now, in the nuclear reactions taking place in the reactor core there are several isotopes involved, and their relative amounts change over time, as the reactor goes through the operation cycle. And the number of neutrinos emitted from the reactor associated with a particular isotope is different from isotope to isotope. Furthermore, neutrinos emitted by each isotope have a different characteristic energy spectrum. Because of these facts, the precise measurement of the neutrino flux and energy spectrum in the proximity of the nuclear reactor can reveal the fissile composition of the nuclear fuel. In particular, it can provide an indication of the fissile plutonium relative contents of the fuel, at a given time along the reactor cycle. This is the reason why neutrino detectors have the potential to be employed as nuclear safeguards tools, in the context of the IAEA non-proliferation treaty for instance.

In other hand, the neutrino flux emanating from a reactor is directly dependent on the reactor thermal power delivered, and therefore the measurement of the neutrino flux at close distances from the core will provide a measurement of the reactor thermal power: a measurement additional and independent to the one obtained by other more traditional methods. Performing this additional measurement can result in an important improvement of the global measurement, and therefore in a better optimization of the reactor operation and in the reducing of costs.

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[2] A new similar reactor may become operative in the coming years. That new reactor will be of benefit for these neutrino studies, because it will increase the total amount of neutrinos produced in the power plant.

[3] based on calculations and simulations

[4] Because of the well-known extreme penetrating capacity neutrinos have, these produced neutrinos basically can not be blocked (shielded) from escaping from the reactor in all directions, isotropically.

FIGURE 1. Photograph of the Angra II reactor and of the experimental shack (circled) presently being used by the Angra Collaboration for preliminary tests.

THE NEUTRINO DETECTOR

The principle on which the detector operation is based is the inverse beta decay process.[5] For a 1-ton detector located at a distance of 200 m from the reactor core we have estimated expected rates of the order of 60 events/day. The rate can go up to about 3,600 events/day if the detector is located at only 25 m away from the core. These rates are sufficiently high to enable investigations on the potential use of neutrino detectors for nuclear safeguards.

The Angra Collaboration has recently (during the fall of 2008) set up a shack close to the reactor dome wall, at some 30 m from the reactor core. The shack (a container for transportation of goods by ship) will house a first laboratory. A very first prototype neutrino detector could be put at this location. It could employ a technology of plastic scintillator interleaved with Gd-contaminated foils as the target material. But a (second) prototype neutrino detector shall be located underground. [6] This detector will have to be located at more than 60 m from the rector core, farther away than the first prototype.[7]

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[5] It takes place when a neutrino (actually an antineutrino) from the reactor interacts with a proton of the detector target material. As a result of the interaction a positron will be produced as well as a neutron. The positron quickly annihilates giving off a well defined energy in the form of gammas. A few tens of microseconds later, the neutron in turn, after thermalization, will be captured by the gadolinium of the target material, giving off in turn, a well defined larger amount of energy in the form of gammas. Thus the presence of two signals of different and characteristic amplitudes, separated in time by a characteristic delay time, provides the signature of the neutrino interaction.

[6] The underground location is preferred because it provides an overburden that helps to get rid of some of the cosmic radiation (that arrives to the ground surface more abundantly than at underground locations). With a considerable overburden (several meters) the number of cosmic muons reaching the detector volume will be largely suppressed.

[7] There are several safety requirements that have to be accomplished before having the authorization to bore a shaft to set up an underground laboratory close to the reactor. The Collaboration has therefore

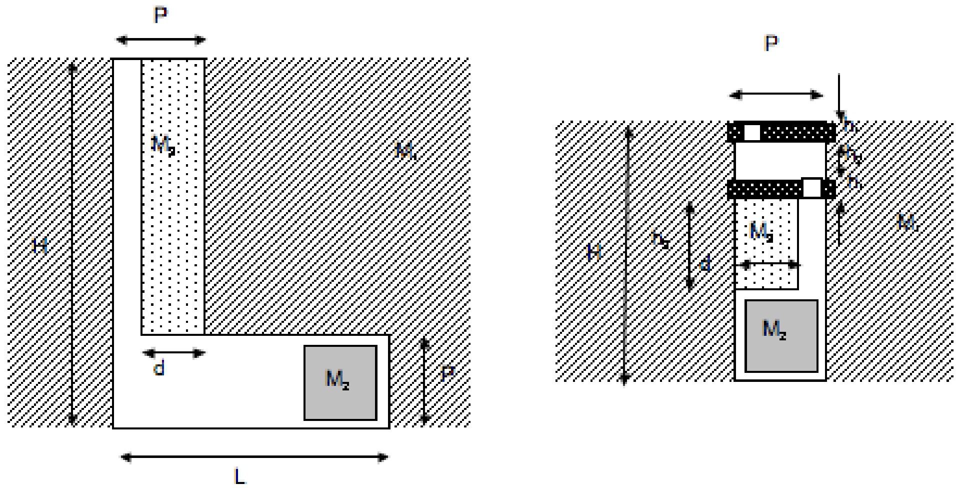

FIGURE 2. Shaft geometries presently under consideration.

We have proposed two different possible shaft configurations (Fig. 2).[8] The structure and size of the underground detector will be limited by the maximum allowed volume on the underground hall.[9] Clearly there is a compromise between the size of the detector and the sensitivity desired. A relatively small-volume detector (easier to install, less expensive, safer), but capable to operate with the desired sensitivity can do the job.

CONCLUSION

The Angra Neutrino Project constitutes an opportunity to explore the technique of using neutrino detectors for reactor monitoring in Latin America. The financial support for the execution of the project is guaranted through the Brazilian funding agencies.[10]

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submitted to the company that manages the reactor, Eletronuclear, a Cooperation Agreement and a written Request to install an underground laboratory in the proximity of the reactor.

[8] The first configuration shown (left) uses only soil as overburden (about 30 m.w.e). The second option (right) is a shallow shaft with several horizontally-placed chunks of heavy material located in the top part of the shaft, to provide a large overburden.

[9] Three possible configurations are presently under study.a) a *standard* cylindrical 3-volume configuration, b) a cylindrical 2-volume design with no gamma-catcher , and c) the *caipirinha-cup* 3-volume design, with readout photomultipliers located in the top of the detector. Computer simulation work will help us to decide on the final geometry and size of the detector. The liquid scintillator will be loaded with a small fraction, about 1g/l, of gadolinium in order to enhance neutron capture.

[10] Extra support if needed can be expected from the participating institutions.