Status of the Nucifer Experiment

Andi S. Cucoanes for the Nucifer Collaboration

SUBATECH Ecole des Mines de Nantes, Universit de Nantes, CNRS/IN2P3, Nantes, France
E-mail: cucoanes@subatech.in2p3.fr

Abstract. Large fluxes of electron antineutrinos are generated by nuclear reactors, carrying information related to the composition and the thermal power of the cores. This application attracted the IAEA’s attention, indeed antineutrino detectors could constitute potential safeguard tools. Here we present the Nucifer experiment, under development at CEA Saclay and SUBATECH Nantes. Nucifer is currently being installed at 7 m away from the Osiris-Saclay research reactor core and it will start to take data by January 2012.

1. Introduction

Nuclear reactors are not only important sources of energy but also very powerful sources of antineutrinos. In fact these two features are correlated, since antineutrinos are produced in beta decays of the fission products. A typical pressurised water reactor (PWR) produces \( \sim 6 \bar{\nu}_e/\text{fission} \) from which about \( 2 \bar{\nu}_e/\text{fission} \) above the inverse beta decay (IBD) threshold, 1.8 MeV. Overall the reactor flux is about \( 10^{21} \bar{\nu}_e/\text{s GW}_{\text{th}} \) with a mean energy of \( \sim 1.45 \text{ MeV} \). Such a large flux is extremely important since the detection of antineutrino is disfavoured by tiny cross sections, about \( 10^{-43} \text{ cm}^2 \) for IBD. Assuming a cubic-meter-sized detector having 50% efficiency, a rough estimate yields \( \sim 1500 \text{ events/day} \) at 25 meters from a 1 GW reactor.

During a typical fuel cycle, the core composition is changing, as uranium is burnt into plutonium (see Figure 1). Since each of the main fissile isotopes presented in the core are associated with a specific contribution to the antineutrino rate and energy, a survey of the antineutrino flux reflects the thermal power and the composition of the core. As shown in Figure 2, the overall effect is a decrease of \( \bar{\nu}_e \) rate during a reactor cycle with about 10%. As the reactor power and the core composition are correlated, they cannot be determined simultaneously from the detected antineutrino spectrum, one of them must be estimated by other means.

Any method able to provide information related to the core composition becomes important in the non-proliferation context as the plutonium produced in nuclear reactors might be used in the fabrication of nuclear weapons. Presently, the worldwide effort of non-proliferation with antineutrinos is coordinated in the framework of the International Atomic Energy Agency (IAEA) through its Division of Safeguards Technical Support (SGTS) [1].

The considerations related to the antineutrino production discussed above remain valid if the knowledge on the neutrino propagation is complete. Recent works [2] predict a possible oscillation of reactor antineutrinos into a sterile flavor at short distances. This interesting hypothesis can be tested by the Nucifer experiment for an excellent knowledge of the reactor
parameters associated to the neutrino production. In this case, any deviation from the predicted antineutrino rate is an indication of oscillation.

2. Nucifer Experiment

Having a target of about one cubic meter, Nucifer might be considered small for the neutrino physics "standards" (from 0.01 to 50 kilotons). Nevertheless, the compactness of the detector is one of the constrains included in the IAEA's program for safeguard activities, other constrains are related to the cost of production, easy operation and remote control. The simplification of design is correlated in Nucifer with a strong background rejection and relatively high detection efficiency, \~50% for 2 MeV threshold.

Nucifer detects antineutrinos via IBD, the signature of an event is a delayed (\~30 \mu s) coincidence between a positron annihilation and a neutron capture. As the target is a stainless steel cylindrical tank, filled with Gd-doped liquid scintillator, in most of the cases the neutron captures are performed on Gd nuclei which subsequently decay by a gamma-cascade of 8 MeV total energy, far above the radioactive background. IBD also acts as a powerful background rejection tool, based on the delayed time coincidence.

The light produced by antineutrino interactions and background events is detected by 16 ten inch photomultiplier tubes optically coupled with the target by an acrylic buffer region. Having a thickness of 25 cm this region increases the uniformity of the detector and decreases the influence of radioactivity events generated inside the PMT glass. The uniformity of the detector’s response is also increased by the Teflon coating of the target which reflects the optical photons. In order to satisfy the asked fire safety requirements, the target is maintained under 5 mbar nitrogen atmosphere.

Cosmogenic muon events are expected to dominate the deadtime of the experiment for Reactor OFF periods since the closeness to the reactor’s core implies shallow depth (about 5 m.w.e. for the site at Osiris). Moreover secondary products of the cosmic rays such as spallation neutrons or beta-decaying elements are difficult to be detected since they might mimic IBD events. During the reactor cycles, a major contribution to the deadtime is expected from the gamma rays produced by fission reactions in the core or after beta decays of the fission products.

As it is shown in Figure 3, the main detector module is surrounded by layers of polyethylene...
(15 cm) and low activity lead (10 cm), aiming to decrease the contribution of external neutrons and gammas to the total background rate.

![Figure 3](image.png)

**Figure 3.** The layout of the Nucifer detector. The main module (left) is surrounded by layers of polyethylene and lead respective by an active muon veto (right). The overall footprint including shielding is 3x3 m.

Covered by the shielding layers, the active muon veto will tag the passage of cosmic ray muons close to the detector and will suspend data acquisition in order to suppress induced neutron background. The muon veto modules are made with 5 cm thick plastic scintillator panels, having a high muon detection efficiency, about 95%.

Nevertheless, further background rejection is mandatory as the signal over noise ratio has still a poor value, about 0.25. The neutron background is identified using pulse shape discrimination (PSD). Preliminary PSD studies indicate a rejection power of 90% for neutron background, when signal rejection rests under 1%.

2.1. Current Status

Starting with April 2010, the (unshielded) detector has been taking calibration data for 6 months in order to fully commission the data acquisition system. Since April 2011 until November 2011 the support structure and the shielding have been installed at Osiris. In November 2011, 4/5th of the muon veto modules have been installed and commissioned. After this phase the target will be mounted and the detector will be closed with the rest of veto modules and the remaining shielding layers. The experiment will start to take data by January 2012.

After the data taking period at Osiris which will last one year, the collaboration foresees future deployments at ILL Grenoble and at a commercial reactor in France.

3. Nucifer and the Reactor Antineutrino Anomaly

A recent recalculation of antineutrino flux generated by nuclear reactors [3] predicts an increase of about 3% with respect to previous estimations [4][5]. Following this new flux evaluation, in Reference [2] is presented a reanalysis of the published reactor antineutrino experiments which have reactor-detector distances less than 100 m. In this case, the averaged observed to predicted event rate was found to be 0.937(0.027), meaning a deviation from unity at 98.4% C.L. This interesting result, might be interpreted as the presence of $\bar{\nu}_e$ oscillation into one or more sterile flavors and represents the so called "reactor antineutrino anomaly".

The Nucifer experiment has a non-negligible potential to test this presumptive oscillation channel. For the deployment at Osiris research reactor, the oscillation distance is about 7 meters
and it can be accurately determined based on the compactness of both: the reactor core (approx. 57x57x60 cm) and the Nucifer target. Figure 4 shows the expected spectral distortion of the oscillation hypothesis for Nucifer at Osiris, after one year of data taking.

Preliminary simulation studies based on Geant 4 and the anomaly best fit indicate a discovery potential for Nucifer as:

\[ \sin^2(2\theta) = 0.15 \quad \text{for} \quad \Delta m^2 = 2.4 \text{ eV}^2. \]

Figure 4. The simulated measured-to-expected ratio corresponding to e+ energy spectra for Nucifer at Osiris. The systematical errors and the influence of the background events are not considered.

4. Conclusions
The Nucifer experiment, aiming to demonstrate the possibility of an accurate monitoring of the reactor core composition and thermal power has an important potential for safeguards activities. In addition, the exploration of the sterile neutrino oscillation at short distances is taken into account. The detector is currently being installed at Osiris-Saclay research reactor and it will start to take antineutrino data by January 2012.

References
[1] IAEA 2008 Final Report: Focused Workshop on Antineutrino Detection for Safeguards Applications IAEA Report STR-361.
[2] Mention G., Fechner M., Lasserre Th., Mueller Th., A. Lhuillier D., Cribier M., Letourneau A. 2011 The Reactor Antineutrino Anomaly Phys. Rev. D 83 073006
[3] Lhuillier D., Fallot M., Letourneau A., Cormon S., Fechner M., Giot L., Lasserre T., Martino J., Mention G., Porta A., Yermia F. 2011 Improved Predictions of Reactor Antineutrino Spectra Phys. Rev. C 83 054615
[4] Schreckenbach K. 1985 Determination of the antineutrino spectrum from \(^{235}\text{U}\) thermal neutron fission products up to 9.5 MeV Phys. Lett. B 160 325
[5] Hahn A.A., Schreckenbach K., Gelletly W., Feilitzsch F. von, Colvin G., Krusche B. 1989 Antineutrino spectra from \(^{241}\text{Pu}\) and \(^{239}\text{Pu}\) thermal neutron fission products Phys. Lett. B 218 365