NESTOR
A DEEP SEA NEUTRINO TELESCOPE FOR THE MEDITERRANEAN

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The primary aim of the NESTOR project is the identification of point-like neutrino sources through the detection of the Cerenkov light emitted by muons produced in charged–current neutrino interactions. The detector will consist of 7 titanium towers, with a height of 220 meters and a diameter of 32 meters, immersed at a depth of 3800 meters in the Ionian sea. Each tower will have twelve hexagonal floors and each floor will contain seven pairs of photomultipliers, one pair at the center and the others at the vertices of the hexagons.

1 Introduction

The NESTOR project is described in detail in the proceedings of two NESTOR workshops [1–2] held in Pylos in 1992 and 1993. The experiment is based in the town of Pylos, in South-West Greece; the infrastructure there consists of a large workshop and of an office and laboratory building.

The coordinates of the chosen site are 36° 37.5' N, 21° 34.6' E. The extensive environmental surveys which have been performed are described in Sec. 2.

The detector, described in Sec. 3, is designed to study not only the astrophysics but also the physics of neutrinos and therefore it is rather compact and isotropic. The readout electronics aims at registering the shape of the photomultiplier pulses, in addition to the time and the total charge.

A prototype array of two floors will be deployed in 1997 and the deployment of one full tower is forseen for the following year.

2 The Site

The site selected for NESTOR is an underwater plateau, at a depth of 3.8 km and at a distance of eleven nautical miles from the town of Methoni, south of Pylos.

During the period 1989–1994 four major cruises, three with the Russian Oceanographic vessels *Mendeleev* (1989), *Vityaz* (1991) and *Keldish* (1992), and one with the Greek Oceanographic vessel *Aegaeo*

(1994), were devoted to environmental measurements. The main results obtained are described in the rest of this section.

2.1 Sea Bottom Morphology

An accurate study of the bottom of the sea was performed in November 1992. The area around the site and the access to the shore were sounded with an echo-sounder and mapped using the "Global Positioning System"(GPS). Several samples were retrieved from the surface of the underwater plain. A uniform, smooth and flat bottom surface, over a size of about 5 square nautical miles, was identified. The deposited material has a mean surface density of 1.6 g/cm^3 and indicates a low rate of accumulation (7 to 18 cm in 3000 years).

Since the access to the shore is quite steep, recently an additional hydrographic survey was carried out with the Greek Oceanographic vessel *Aegaeo*. The absolute ship position was determined to $\pm$ 1 m using the Differential Global Positioning System (DGPS). The informations obtained on the sea-bottom contour profile and on the sub-bottom structure, at the site and at the two proposed routes for the electro-optical cable have been analyzed and the route has been chosen.

2.2 Water Transmissivity, Current Velocities and Temperature

In November 1992 three sets of sea water transmissivity measurements were performed from the *Keldish*, using the ROZETTE, an automatic device to measure pressure, temperature, salinity and to retrieve water samples. All the measurements gave consistent results indicating very clear waters suitable for the detector. The absorption length at depths of more than 2000 m, in the wavelength interval between 470 and 490 nm, is in the range 45–65 m.

The underwater current velocity measurements started in October 1989: autonomous current meters were deployed at several depths and locations and for several days. The measurements were repeated with slight modifications in 1991, 1992 and 1993. In all cases the measured underwater velocities were smaller than 10 cm/sec, indicating that the deep underwater currents have low velocities, that will impose minimal mechanical stresses on the detector.

The water temperature measurements were carried out together with the current velocity measurements, by using thermometers attached to the current meters. The water temperature, below a depth of 2.5 km, is 14.0 degrees Celsius, constant in time, with a variation of less than 0.5 degrees in a year.

2.3 Optical Background

The fundamental optical background in the deep sea is due to ^{40}K decays. The ^{40}K is a natural radio nuclide with a half–life of $1.27 \cdot 10^9$ years and its abundance is 0.0118% of the potassium. The main decay mode, with a branching ratio of 89.5%, is β decay to ^{40}Ca. The maximum electron energy is 1.31MeV. The calculated background due to ^{40}K is roughly $13 \cdot 10^{-3}$ disintegrations $\mathrm{cm}^{-3}\,\mathrm{s}^{-1}$.

In May 1996, a test setup consisting of a string equipped with two photomultiplers protected by *Benthos* spheres and one titanium sphere housing the Data Acquisition and Control electronics was deployed on site, to measure the optical background from ^{40}K and bioluminescence. The rate due to ^{40}K is $\sim$55 kHz. Also some intermittent bursts of duration 3–5 seconds, with a frequency of$\sim$ 1% of the experiment live time, consistent with being bioluminescent activity, were detected.

3 The Detector

3.1 Mechanics and Optics

In order to obtain an isotropic response, the detector will consist of seven towers, with one tower at the center and six at the vertices of a hexagon. The distance between the center of the towers will be $\sim$ 150 m. This distance has been estimated on the basis of the measured water absorption length. Each tower (Fig. 1) will consist of 12 horizontal titanium floors, separated vertically by a distance of 20 m. The shape of each floor is also a hexagon.

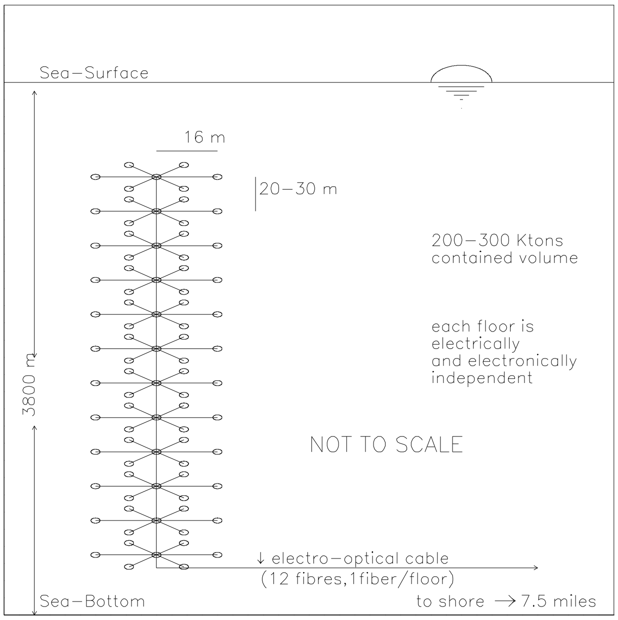

Figure 1: *A NESTOR Tower*

At the center and at the vertices of the hexagons will be placed seven pairs of Optical Modules (OM). In each pair one OM will be looking up and the other one will be looking down. One OM is formed by one hemispherical, bialkali Hamamatsu R 2018–03 15″ photomultiplier, protected by a pressure resistent 17″ diameter glass *Benthos* sphere. The photomultiplier is optically connected to one hemisphere of the Benthos sphere by a transparent silicone gel, to obtain good optical coupling and mechanical protection for the photomultiplier. The distance between OM in one floor is 16 m.

A titanium sphere containing the electronics will be placed in the center of each hexagon. The floors will be connected to each other by Kevlar cables. Each floor will be electrically and electronically independent from the other floors and will have its own optical fiber for data transmission.

The possibility to retrieve the tower for ″servicing″ by activating anchoring releases and allowing the tower to float is under study.

The whole tower will be deployed in a single operation, its sensitive area for TeV muons will be ~ 10000 m^2.

3.2 Data Acquisition

The Data Acquisition system is designed to provide the transmission to the shore laboratory, in real time, of the whole signal from all fired photomultipliers, over a distance of 30 km.

The signals from the 14 photomultipliers of each floor are sampled with a Flash ADC. One laser per floor transmits the time of threshold-crossing and the multiplexed ADC samples through a monomode optical fiber, imbedded in a submarine electrooptical cable. The data from the whole tower are transmitted on 12 fibres. The synchronization between signals of different photomultipliers is provided by the transmission of a unique Master Clock signal from the shore to the 12 floors and from a synchronous answer sent from each floor to the shore.

The data from each photomultiplier, collected in a time window of 6.1 ms periodically cleared, are memorized in a RAM on shore. The event time and the charge are extracted and used by a dedicated processor to build a first level trigger.

4 Tests

In July 1991, a detector prototype consisting of a titanium alloy hexagonal structure (7 m radius) equipped with ten 15″ Hamamatsu photomultipliers was deployed to a depth of 4.1 km. Six of the phototubes were located at the vertices of the hexagon and four 3.5 meters below the center. The sensitive area of this experiment was 373 ± 75 m^2. The vertical muon intensity and the angular distribution of downcoming muons were measured at depths of 3.3, 3.7 and 4.1 km.

In November 1992 the measurement was repeated using a linear string with five 15″ photomultipliers. Both sets of measurements are in very good agreement with previous measurements. At depths between 3.7 and 3.9 km the vertical muon flux is $(9.8 \pm 4.0) \times 10^{-9}$ cm^{-2}s^{-1}sr^{-1}.

In the Autumn 1996 two prototype aluminium floors and one titanium floor have undergone several mechanical and deployment tests.

The floors were also equipped with optical modules and electronics housed in two titanium spheres and tested, together with a 4.5 km optical link, in the laboratory. Power was supplied to the spheres by a 300 V DC system, through a conductor contained in the optical cable. Power return was through plates hanging in a tank of sea water. Both spheres contained a prototype of the Slow Control system.

Eight analog readout channels were installed, one for a compass, two for a bidimensional inclinometer and the remaining five to monitor the temperature inside the sphere in several positions, to check the heating due to the electronics. The total power consumption inside the sphere was 250 W. The conclusion from the test was that temperatures in the titanium spheres will be lower than 30 °C for all electronic components.

In May 1997 two fully equipped floors were towed, floating, at a speed of 1.5 knots, to the NESTOR site. The two floors were lowered and connected to each other at a distance of 30 m. The anchor and acoustic release were below the lower floor, again at a distance of 30 m. The whole operation of mounting and lowering the structure to a depth of 45 meter for the top floor took from morning to sunset.

The following day the structure was connected to an electrooptical cable, which was on board the *Thales*, a cable–laying boat belonging to the Greek Telephone Company. The next evening the whole system was deployed to a depth of 2400 m and recovered the following day.

In the return journey the whole structure was towed by the *Thales*, hanging at a depth of 200 m, at a speed of 2 knots relative to the water.

After the floors were pulled out of the water inspection showed that there were no damages to the structure or the optical modules or the titanium spheres. Inspection of the titanium spheres in the lab showed that no water or vapor had entered during the whole operation.

The conclusion from the test is that it is possible to tow the floors and deploy and recover, without damages, a structure consisting of more than one floor.

5 Conclusions

All the environmental measurements carried out so far have demonstrated that the site chosen for NESTOR is ideal for the deployment and proper functioning of a neutrino telescope. The read out electronics, the trigger and the slow controls system will be ready and tested by summer 1997 and the 30 km electro–optical cable will be layed, in such a way that in 1998 a structure consisting of several fully equipped floors will be deployed and will start taking data.

References

1. *Proceedings of the 2^{nd} NESTOR International Workshop*, ed. L. Resvanis (University of Athens, 1992).
2. *Proceedings of the 3^{rd} NESTOR International Workshop*, ed. L. Resvanis (University of Athens, 1993).