STATUS OF THE NEMO PROJECT

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ABSTRACT

The activities towards the realization of a km^3 Cherenkov underwater neutrino detector, carried out by the NEMO collaboration are described. Long term exploration of a 3500 m deep site close to the Sicilian coast has shown that it is optimal for the detector installation. A complete feasibility study, including all the critical components of the detector as well as its deployment, has been carried out showing that technological solutions exist for the realization of a Cherenkov underwater km^3 detector. The validation of the proposed technical solutions and a detailed study of the italian candidate site have been undertaken (NEMO Phase-1 and NEMO Phase-2).

1. Introduction

The construction of a km^3-scale underwater telescope for high energy neutrinos is a fundamental task for the development of the high energy neutrino astronomy. High energy neutrinos are expected to be very promising probes for the investigation of the far Universe and of acceleration processes occurring in galactic and extragalactic sources. Due to the fact that neutrinos are not deflected by magnetic field neither absorbed travelling through the Universe, they can allow to trace back towards the emitting source. Moreover, the detection of high energy neutrinos in the TeV-PeV range would clarify the role of the hadronic processes in the most violent events occuring in the Universe. Due to the expectations on neutrino fluxes, mainly based on the measured cosmic ray fluxes and the estimated fluxes from theoretical models for several high energy sources (GRB, AGN, GZK, ...) [1)], the "opening" of the high energy neutrino astronomy era can be only afforded with detector in the km^3 scale. The neutrino fluxes from astrophysical beam dump scenarios are expected to have a flavor ratio of $\phi_{\nu e} : \phi_{\nu\mu} : \phi_{\nu\tau} \approx$ 1:1:1 due to the flavor mixing occurring in the propagation from the source to the Earth. A km^3 neutrino telescope should be able to detect neutrinos of all flavors and, for the most energetic ones, both horizontal and down-going neutrinos have to be efficiently detected with the best possible angular accuracy. A first generation of small scale detectors has been realized (AMANDA [5)] in the South Pole and BAIKAL [6)] in the Baikal lake) and have start to set limits on neutrino fluxes. Following the success of AMANDA, which is presently the largest detector operating in the field of high energy neutrino astronomy, the km^3 detector ICECUBE [7)] is under construction at the South Pole. On the other hand, many arguments, as the full sky coverage, with particular reference to the Galactic Center (as demanded by the impressive HESS results on the detection of TeV gamma rays from the region of the Galactic Center[8]), and the better angular resolution, strongly support the construction of a km^3-scale detector in Mediterranean Sea at large depth. The three collaborations operating in the Mediterranean Sea are ANTARES[2], NEMO and NESTOR[4]). The ANTARES Collaboration, which is building an under-water detector demonstrator of about 0.1 km^2 to be installed at about 2400 m depth 40 km off-shore Toulon. The NESTOR collaboration aims at the deployment of the first NESTOR tower with 10^4 m^2 effective area for $E_\mu \geq 10$ TeV.

The NEMO Collaboration [3] activity has been mainly focused on the search and characterization of an optimal site for the detector installation and on the development of key technologies for the km^3 underwater telescope. After 30 sea campaigns carried out during 7 years, a deep sea site with optimal features in terms of depth and water optical properties has been identified by the NEMO collaboration at a depth of 3400 m about 80 km off-shore Capo Passero and a long term monitoring of the site will be carried out (NEMO Phase-2). The feasibility study of the km^3 detector includes the system analysis of all the construction and installation issues, the optimization of the detector geometry by means of numerical simulations and the validation of the proposed technologies via an advanced R&D activity and the prototyping of the proposed technical solutions and their relative validation in deep sea enviroment (NEMO Phase-1 and Phase-2). The realization of this technological demonstrator will allow to face the most critical items such as mechanics, deployment and sea operations, power distribution, electronics, data acquisition, calibration, etc.

2. Site Properties

The Mediterranean Sea offers optimal conditions, on a worldwide scale, to locate the km^3 Telescope. The seabed along the Italian coast can reach depths beyond 3000 m, even at distances less than a hundred kilometers from the shore. These characteristics are very important, since deep water helps to filter out the bulk of the low energy component of down going atmospheric muons, and the relative closeness to the coast allows the data transfer between the shore and the detector by means of standard commercial electro-optical cables. After 30 sea campaigns since July 1998, a site located in the Ionian Sea (36° 19' N, 16° 05' E), close to Capo Passero in the South-East part of Sicily Fig. 1, was identified as the best candidate. The site is a wide abyssal plateau with an average depth of about 3500 m, located at less than 80 km from the shore and about 50 km far from the shelf break. A geological survey of the area verified the flatness and the absence of any evidence of recent turbidity events, which occur when sediments of the continental shelf slide down the continental slope and can be of potential danger for the detector. The nature and structure of the seabed was studied in detail in order to design the mooring structures of the neutrino detector.

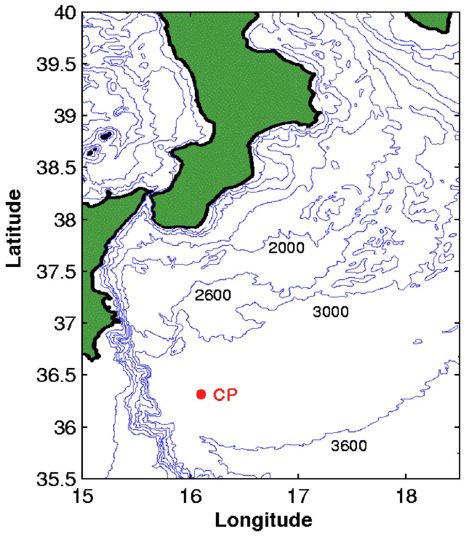

Figure 1: The south Ionian sea, showing the location of the site selected and characterized by the NEMO collaboration.

In order to describe the transparency of natural waters as a function of photon wavelength, it is necessary to measure in situ the so called Inherent Optical Properties of the water, such as the absorption, scattering and attenuation lengths. The coefficients were measured independently with the AC9 transmissometer, which used two different light paths and spanned the light spectrum over nine different wavelengths, ranging from 412 nm to 715 nm. In Fig. 2 are reported the absorption and attenuation lengths measured at 440 nm in five different sea campaigns. The measured values of the absorption length are close to the one of optically pure sea salt water (about 70 m at λ = 440 nm) [13]. Seasonal variations are negligible and compatible with the instrument experimental error.

Another characteristic of the deep sea water that can have severe impact on the detector performance is the optical background. This background comes from two natural causes: the decay of ^{40}K, which is present in seawater, and the so called bioluminescence that is the light produced by biological entities. Of these two effects the first one shows up as a constant rate background noise on the optical modules, while the second one, when present, may induce large fluctuations in the noise rate (both in the baseline and as presence of high rate spikes). In Capo Passero an average rate of 28 kHz of optical noise (fig. 3), compatible with what expected from pure ^{40}K background, with rare high rate spikes due to bioluminescence (dead time $\leq$ 1%has been measured at a depth of 3000 m in several sea campaigns.

This result is in agreement with the vertical distribution of bioluminescent bacteria

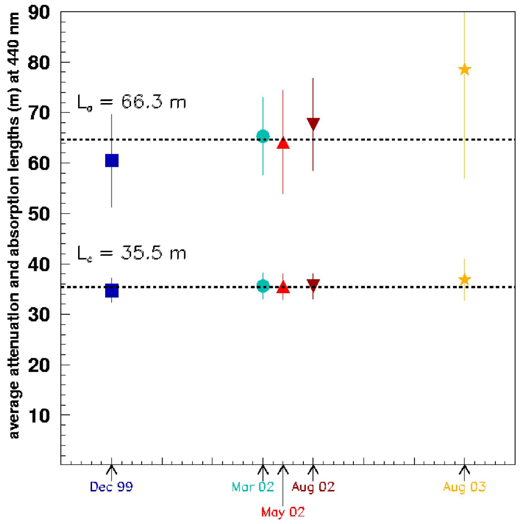

Figure 2: Values of the absorption and attenuation lenghts at 440 nm measured during five different campaigns. The reported values are the average at the depth region 2850-3250 m. Dashed lines are the average over the five campaigns.

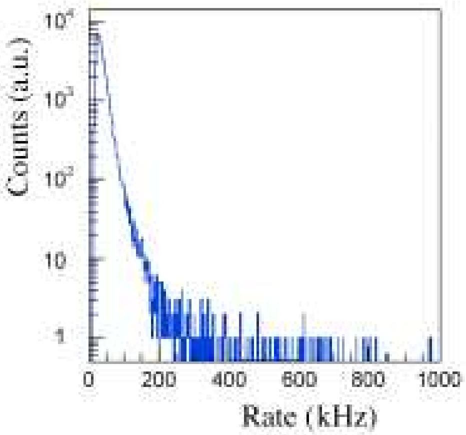

Figure 3: Instantaneous rate of optical background in Capo Passero at 3000 m depth.

measured in Capo Passero, that shows an absence of these bacteria at depths greater than 2500 m.

Current meter chains were moored in the region of Capo Passero since July 1998, to measure the water current intensity and direction in a range of 500 m above the seabed. Over more than 7 years of data taking the currents at a depth of about 3000 m appear to be low and regular (2-3 cm/s average; 12 cm/s maximum). The downward flux of sediments has also been analysed. The annual average value of material sedimenting at large depth in Capo Passero is about 60 mg m^{-2} day^{-1}, a rather small value consistentely an oligotrophic environment such as the Ionian Plateau.

3. Detector lay-out and performance

The design of an underwater km^3 neutrino telescope represents a challenging task and has to match many requirements concerning the detector performance, the technical feasibility and the project budget. In general, a km^3 detector is an array of structures (≤ 100) each one hosting several tens of optical modules (OM) arranged with a non homogenous distribution.

A proposed NEMO lay-out is shown in Fig. 4. Preliminary feasibility studies suggested some constraints on parameters such as the structure height (≤ 1km) and distance (≥ 100m). Moreover, it is important to limit the total number of structures in order to reduce the number of underwater connections.

The detector performances were evaluated by means of numerical simulations, carried out using the software developed by the ANTARES collaboration [11] adapted to km^3-scale detectors [9,10] with several thousands of OMs.

The proposed NEMO architecture is a 9×9 square lattice of towers. Details on the tower will be given in section 4.3, here we will just mention that in the simulations a configuration with 18 floors, each one hosting four OMs with 10" PMTs, was used for a total of 5832 PMTs. The proposed architecture is "modular" and the lay-out can be configured to match different detector specifications. Several configurations with different tower spacing were considered. The one studied in more detail is the so-called NEMO140dh with tower distance of 140 m. Site properties such as depth, optical background, absorption and scattering length, can have a severe impact on the detector response [12]. In this work these parameters have been set accordingly with the value measured in Capo Passero. A water depth of 3400 m has been used. The attenuation length was set at 70 m for $\lambda = 440$ nm. A rate of 30 kHz was considered as optical background.

3.1. Sensitivity to a generic point-like source

The sensitivity of an experiment is defined as the average upper limit that would

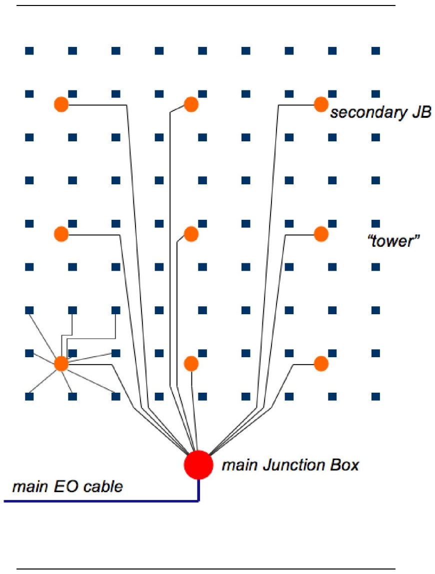

Figure 4: Schematic lay-out of junction-boxes and structures for a km^3 detecor.

be obtained by an ensemble of experiments with the expected background and no true signal. The average upper limit represents the maximum number of events that can be excluded at a given confidence level. The NEMO140dh sensitivity, calculated following the Feldman & Cousin approach [14)] , is reported in Fig. 5 left panel as a function of the integrated data taking time. The source position was chosen at a declination δ = -60° an E^{-2} neutrino energy spectrum was considered. For a comparison the IceCube sensitivity [15)], obtained for a 1° search bin, is also reported. The NEMO140dh detector exhibits a better sensitivity to muon neutrino fluxes from point sources than IceCube and a smaller search bin (0.5° instead of 1°).

3.2. Detection of the Moon shadow

A study of the effect due to the absorption of primary cosmic rays by the Moon has also been performed with simulations. When observed in the data this Moon shadowing effect will provide a direct measure of both the detector angular resolution and pointing accuracy. Since the Moon absorbs cosmic rays, we expect a lack of atmospheric muons from the Moon direction.

Atmospheric muons are generated following the Okada parametrization and we implemented the calculation of the Moon position to simulate the muon lack. We simulated $1.25 \cdot 10^8$ events in the energy range $10^2 \div 10^6$ GeV, restricting the generation to a circular window around the Moon position with a radius of 10°. The number N_μ of muons reconstructed within a distance D from the Moon centre is plotted in Fig.

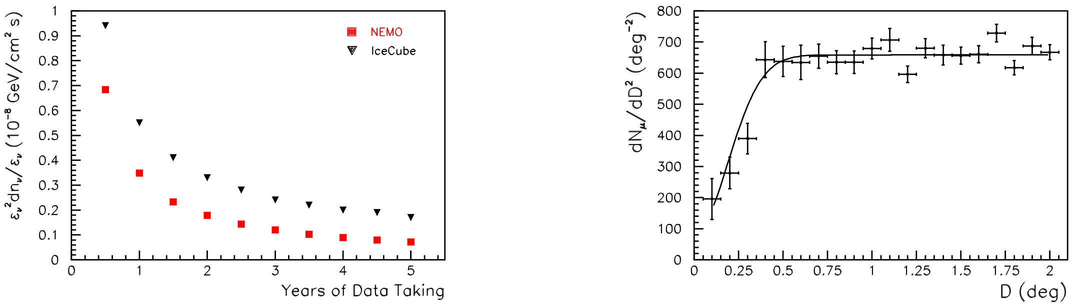

Figure 5: Left panel: sensitivity to a E^{-2} neutrino spectrum from a δ=-60° declination point-like source and comparison with the ICECUBE detector. Right panel: selected muon event density versus the angular distance fron the moon centre. The line represents the result of the fit in Eq.(1).

5 right panel. The distribution is then fitted using the function:

$$\frac{dN_\mu}{dD^2} = k\left(1 - \frac{R^2_{Moon}}{2\sigma^2}\exp\left(\frac{D^2}{2\sigma^2}\right)\right), \tag{1}$$

obtaining from the fit an angular resolution $\sigma = 0.19° \pm 0.2°$. During the fit procedure, we apply an event selection imposing suitable cut, reaching, in this way, a detection significance $S_{1\mathrm{yr}} \sim 5.3$ in 1 year of data taking. Assuming a required significance of 3, the minimum time needed to observe the shadow is therefore of the order of 100 days.

The effect of a possible error in the absolute azimuthal orientation has been simulated, introducing a rotation Ψ in the reconstructed tracks around the Z axis. For the expected accuracy $\Psi \leq 0.2°$, the shadow is still observable at the Moon position, while considering the pessimistic case $\Psi \geq 0.2°$, systematic errors should be corrected. A detailed study together with the effects of errors in the absolute zenithal orientation are still in progress.

3.3. Reconfigurability of the detector

The energy range of interest of high energy neutrino telescopes is very broad spanning from few hundreds of GeV to very high energies such as the GZK energies. Therefore, the detector lay-out, which defines the energy threshold and the effective area, should be optimized with respect to the physics one wants to focus on. The possibility to reconfigure the detector layout to tailor to different detection needs is a specific feature of the underwater detectors. In general, the OM density of the detector determines the energy threshold while the detector volume affects the effective area at the higher energies. Although the sensitivity is the most appropriate figure of

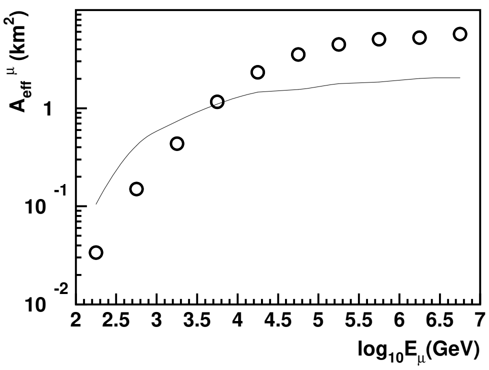

Figure 6: Muon effective areas as a function of the muon energy for square lattices of NEMO towers 140m spaced (continous line) and 300m spaced (open circles).

merit to estimate the detector efficiency of different arrangements, some hints can be gathered by looking at the effective areas. The detection of very energetic neutrino fluxes ($E_{\nu} \geq 100$ TeV) can be enhanced by increasing the distance between structures. In Fig. 6 the muon effective areas as function of the muon energy are reported for two detector configurations, with the same number of structures and OMs but two different inter-tower distances of 140 m (continuos line) and 300 m (open circles). A significant gain is observed for the more sparse array at the expenses of higher energy detection threshold.

4. The NEMO Phase-1 project

As an intermediate step towards the underwater km^3 detector and to ensure an adequate process of validation the realization of a technological demonstrator has been undertaken. This project, called NEMO Phase-1, includes prototypes of the critical elements of the proposed km^3 detector: the junction box and the tower. This will allow to validate the mechanical characteristics of both as well as the data transmission and power distribution system of the whole apparatus. The project is under realization at the Underwater Test Site of the Laboratori Nazionali del Sud in Catania and its completion is foreseen by the end of 2006.

4.1. The LNS Test Site

The Test Site of the Laboratori Nazionali del Sud consists of an electro-optical submarine cable, to connect the underwater installation at 2000 m depth to the shore, and a shore station. The cable system is composed by a 23 km main electro-optical cable, split at the end in two branches, each one 5 km long. One branch is used for the NEMO Phase-1 experiment, while the other one hosts the SN-1 underwater seismic monitoring station, realized by the Istituto Nazionale di Geofisica e Vulcanologia (INGV). The cable carries 6 electrical wires and 10 monomode optical fibres. A shore station, located inside the port of Catania, hosts the energy power system of the laboratory, the instrumentation control system, the landing station of the data transmission system and the data acquisition, as well as a mechanics and electronics workshops for the assembly of the components.

4.2. The Junction Box

The Junction Box (JB) is a key element of the detector. It must provide connection between the main electro-optical cable and the detector structures and has to be designed to host and protect from the effects of corrosion and pressure, the opto-electronic boards dedicated to the distribution and the control of the power supply and digitized signals. An alternative design to the standard titanium pressure vessels used for junction boxes operating in seawater for a long lifetime has been developed. The approach is to decouple the pressure and the corrosion problems. Therefore, the JB is made of pressure resistant steel vessels hosted in a fibreglass container to avoid direct contact between steel and sea water. In Fig. 7 the internal structure of the NEMO Phase-1 JB is reported. The fibreglass container is filled with silicone oil to compensate the external pressure. This solution should improve the reliability and also reduce costs by avoiding the use of expensive alloys.

4.3. Detector mechanical structures

The tower that will host the optical modules and the instrumentation is a three dimensional flexible structure composed by a sequence of floors (that host the instrumentation) interlinked by cables and anchored on the seabed. The structure is kept vertical by an appropriate buoyancy on the top. While the design of a complete tower foresees 16 floors, the prototype under realization for the Phase-1 project is a "mini-tower" of 4 floors, each made with a 15 m long structure hosting two optical modules (one downlooking and one looking horizontally) at each end (4 OM per storey). An additional spacing of 150 m is added at the base of the tower, between the anchor and the lowermost floor to allow for a sufficient water volume below the detector. In its working position each storey will be rotated by 90°, with respect to the up and down adjacent ones, around the vertical axis of the tower.

The design of the cabling system of the structure has been made taking into account the fault tolerance and the ease of management. The goal has been the minimization of the connection interfaces. The base of the tower hosts a Tower Base Module (TBM). The TBM is connected by means of an hybrid penetrator to the

Figure 7: Internal structure of the NEMO Phase-1 Junction Box: steel pressure vessels.

backbone cabling and by means of an hybrid connector to a jumper cable terminated with a wet mateable ROV connector that allows the interconnection of the tower to the Junction box by means of an ROV. A lightweight backbone cabling system distributes the power and the data transmission signals to and from the tower floors. The splitting of the cable is performed by means of breakouts positioned at each floor level. The breakouts are realized with pressure vessels, with penetrators for the backbone cable and one hybrid connector to connect the floor cabling system. The breakout contains two passive optical devices that perform the Add&Drop functions for the optical data transmission signals of the out coming and incoming data flows. On each floor two containers are installed: a Floor Control Module (FCM) and the Floor Power Module (FPM). The FCM is the core of the system. The floor electronics is mounted inside a metallic pressure vessel placed inside an external plastic container filled with silicone oil. The FPM is a silicone oil filled plastic container since the power supply subsystem that is hosted inside has been tested to operate under pressure. The FCM is interfaced to the floor instrumentation including the Optical Modules (OM) by means of four optical penetrator and three electrical connectors. In this cabling system the connectors are positioned at the subsystems interfaces and at users interfaces, it allows to have few connectors reducing the cost of the apparatus and permits to individually test the subsystem in pressure tanks. Moreover, using penetrators instead of connectors minimizes the optical loss allowing a higher link budget for the data transmission system and permitting to test the optical links by means of OTDR since there are no refractive interfaces along the optical paths.

4.4. The Optical Module

The optical module is essentially composed by a photo-multiplier (PMT) enclosed in a pressure-tight sphere (Benthos sphere) of thick glass. The used PMT is a 10" Hamamatsu R7081Sel with 10 stages. To ensure both mechanical and optical contact, an optical silicon gel (Wacker silgel) was put inside the sphere between the PMT and the internal glass surface. A μ metal cage is used to shield the PMT from the Earths magnetic field. A LED system is used for timing calibration. In spite of its large photocathode area, the Hamamatsu PMT R8081Sel has a good time resolution of about 3 ns FWHM for single photoelectron pulses with a charge resolution of 35%. The base card circuit for the high voltage distribution (Iseg PHQ 7081SEL) requires only a low voltage supply (+5 V) and generates all necessary voltages for cathode, grid and dynodes with a power consumption of less than 150 mW. An electronic board, built with discrete components, has been designed, realized and tested as the front-end electronics for the Optical Modules. Sampling at 200 MHz is accomplished by two 100 MHz staggered Flash ADCs, whose outputs are captured by an FPGA which classifies (according to a remotely programmable threshold) the signal as valid or not, stores it with an event time stamp in an internal 12 kbit FIFO, packs OM data and local slow control information, and codes everything into a bit stream frame ready to be transmitted on a differential pair at 20 Mbit/s rate. The main features of this solution are moderate power consumption, the high resolution and the huge input dynamics obtained by a quasi-logarithmic analog compression circuit, and the fine time resolution. Through an incoming slow control channel, managed by a DSP, all the acquisition parameters can be changed, and there is the possibility to remotely re-program the FPGA downloading new codes. Moreover, the board has embedded electronics, analog and digital, in order to control the Optical Module power supply to measure temperature, humidity and electrical parameters as well as to auto calibrate the non linear response of the logarithmic compressor. As a further improvement towards the km^3 novel data readout to have an even wider input dynamic range and a simplified electronics is under development.

4.5. Data transmission system

Considering NEMO Phase-1 as a feasibility test toward the km^3 detector, its data transport system has been designed based on technical choices that allow scalability to a much bigger apparatus. Owing to synchronization purposes, a common timing must be known in the whole apparatus at the level of detection device to allow correlation in time of events. For this reason we have chosen the Synchronous Digital Hierarchy (SDH) protocol, which embeds data, synchronism and clock timing in the same serial bit stream, and allows an easy distribution of the clock signal to the whole apparatus. At the physical layer of communication the technology adopted relies on Wavelength Division Multiplex (WDM) techniques, using totally passive components with the only exception of the line termination devices, i.e. electro-optical transceivers. The great advantages in terms of power consumption, reliability, and simplicity recommend this technique as a perfect candidate for final km^3 detector. At the center of each floor of the tower electronics circuit, called Floor Control Module board (FCM), is placed. The FCM board collects data from the floor photo-multipliers (PMTs) and the floor control and auxiliary signals, creates an STM-1/SDH data stream at about 155 Mbps, and send data toward the land side laboratory. From the opposite direction, the FCM board receives slow control data, commands and auxiliary information, and the clock and synchronizations signals needed for apparatus timing. Bidirectional data transport is realized by means of a backbone optical fiber connected to each FCM module on an Add&Drop basis at different wavelength for both directions. Such backbone links each tower directly to the on shore side. Actually, in order to provide redundancy, data streams are doubled and re-directed onto two fibers using a "power splitter". The one fiber of the two used to carry the meaningful information is chosen on the on-shore station. The underwater structure has a mirrored on-shore counterpart, where all optical signals are reconverted into electrical signals. In the on-shore laboratory the Primary Reference Clock (PRC), which is used to give the same timing to all the towers of the apparatus, is also located. Assuming that the two fibers per tower maintain their integrity, the designed system provides other experiments with a further bidirectional channel. All the above mentioned electronics has been extensively tested with particular emphasis on all the power supply feeding the electronic circuits and on the photonic circuit that have to assure an adequate optical power budget for the data transport.

4.6. Electrical power system

For the Phase-1 project a three phase AC system has been chosen since it presents some advantages in terms of voltage drops and reliability. This system is used for the energy distribution up to the level of the local electronics module in each storey where a conversion to DC is made. A control system has been realized to acquire all the relevant data such as currents, voltages and environmental parameters (temperature, humidity, etc) inside the containers.

4.7. Calibration systems

The timing calibration in NEMO requires an embedded system in order to track the possible drifts of the time offsets during the operations of the apparatus underwater. The task of this embedded system is essentially to measure the offsets with which the local time counters inside the optical modules are reset on reception of the reset commands broadcasted from the shore, i.e. the time delays for such commands to reach the individual optical modules. All time measurements are in fact referred to the readout of such counters. The operation will be performed with a completely redundant system: 1) a two-step procedure for measuring the offsets in the time measurements of the NEMO optical sensors; 2) an all-optical procedure for measuring the differences in the time offsets of the different optical modules. In the first system the needed measurements are performed in two separate steps:

- with an echo timing calibration;
- with an optical timing calibration.

The former will allow us to measure the time delay for the signal propagation from the shore to the Floor Control Module (FCM) of each floor; the latter, which is based on a network of optical fibres which distributes calibration signals from fast pulsers to the optical modules, will allow us to determine the time offsets between the FCM and each optical module connected to it. The second system is an extension of the optical timing calibration system, which allows to simultaneously calibrate the optical modules of different floors of the tower.

4.8. Control system

The Slow Control Management System is composed of two high-performance servers, which act as communication managers between users and the telescope, and one or more graphical consoles. The software architecture is composed of two main modules: the data filter and console services. The data filter has the main task of receiving slow control data from off-shore boards and forwarding them to both the database, for storage, and a shared memory area, which holds the current value of all the telescope parameters. The second module (console services) is entailed with the task of offering and handling four basic service types for consoles. Command execution service can be used to perform a particular command upon off-shore equipments of the experiment, such as controlling a power switch, setting up a threshold, sending setup data to a (serial) instrument, etc. Configuration query allows a client to obtain the complete configuration of the experiment: number of towers and floors; composition of a specific floor (in terms of boards and equipments); measures sampled by a specific board; and characteristics of a specific measure (range, delta value, alarm thresholds, measurement unit, etc.). Snapshot query allows a client to obtain the current values of all the parameters and measures related to the slow control system. Finally, storage query, can be used by clients to perform queries on historical slow control data stored in the database.

4.9. Acoustic position control system

The acoustic position system of the NEMO Phase-1 project has the aim to detect the position of the Optical module of the NEMO minitower (a NEMO model tower with 4 floors) with a precision of 15 cm. The system is composed by a LBL (long Base line) of 5 beacon based on the sea bed. Two beacons (one installed on the junction box, the other one installed on the base of the minitower) are power supplied by the main electro optical cable, the other beacons are supplied by long life battery pack. The long base line distributes an accurate clock signal to all the sensors (acoustic receivers) that are located on the floors of the minitower. In order to calculate each beacon time offset, two monitoring stations are installed at the base of the minitower. Each floor is equipped with two hydrophones. Beacon distances and positions will be measured during the field construction phase using a ROV equipped with a 32 kHz GPS time synchronized pinger and a high accuracy pressure sensor. The pinger and the pressure gage will be held in the ROV manipulator arm during the calibration underwater activity.

4.10. Project status

The submarine cable was deployed in 2001. In January 2005 the project has achieved a major milestone with the installation of the two cable termination frames (that host the wet mateable underwater bulkheads) and the deployment and connection of a small acoustic detection station on one branch and the SN-1 seismic and environmental observatory on the other branch. Both these stations have been operational ever since, continuously transmitting data to shore. All the components have undergone extensive laboratory tests and the integration of the junction box and the prototype tower is progressing. The project will be completed in 2006 with their deployment and connection. In its final configuration this project will not only represent a fundamental test of the technologies for the km^3 detector but it will also be a fully functioning multidisciplinary laboratory at 2000 m depth, offering the possibility of on line connection to a variety of experiments.

5. The NEMO Phase-2 project

Although the Phase-1 project will provide a fundamental test of the technologies proposed for the realization and installation of the detector, these must be finally validated at the depths needed for the km^3 detector. For these motivations the realization of an infrastructure on the site of Capo Passero has been started. This infrastructure will consist of a 100 km deep sea cable, linking the 3500 m deep sea site to the shore, a shore station, located inside the harbour area of Portopalo di Capo Passero, and the underwater infrastructures needed to connect prototypes of the km^3 detector. Due to the larger cable length with respect to the Phase-1 project, a different solution for the electro-optical cable was chosen. In this case the backbone cable will be a DC cable, manufactured by Alcatel, that will carry a single electrical conductor, that can be operated at 10 kV DC allowing a power transport greater than 50 kW, and 20 single mode optical fibres for data transmission. The completion of this project is foreseen by the end of 2007. At this time it will be possible to connect one or more prototypes of detector structures, allowing a full test at 3500 m of the deployment and connection procedures. This project will also allow a continuous long term on-line monitoring of the site properties (light transparency, optical background, water currents, ...) whose knowledge is essential for the installation of the full detector. The possibility of installing multidisciplinary observatories on the site is also foreseen.

6. Conclusions and outlook

The realization of an underwater km^3 telescope for high energy astrophysical neutrinos is a challenging task. In its seven years of activity the NEMO collaboration has contributed in this direction by performing an intense R&D activity. An extensive study on a site close to the coast of Sicily has demonstrated that it has optimal characteristics for the telescope installation. The technical and budgetary feasibility of the km^3 detector has been proven by means of a complete study carried on in cooperation with companies with great experience in underwater operations. The realization of a demonstrator of some of the technological solutions proposed for the km^3 detector is under way at the underwater Test Site of the LNS in Catania. Its completion is foreseen by the end of 2006. A further R&D program will be developed within the KM3NeT[16)] Design Study in which all the European institutes currently involved in the Mediterranean neutrino astronomy projects are participating. The project has started in February 2006 and in three years will produce a Technical Design Report for the realization of an underwater Cherenkov km^3-scale neutrino telescope.

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