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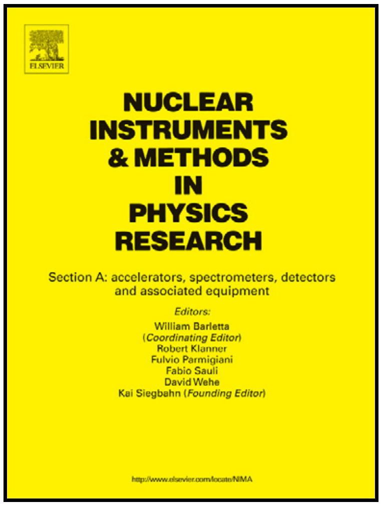
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH

Section A: accelerators, spectrometers, detectors and associated equipment

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GEMS:underwater spectrometer for long-term radioactivity measurements

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Abstract

GEMS (Gamma Energy Marine Spectrometer)is a prototype of an autonomous radioactivity sensor for underwater measurements, developed in the framework for a development of a submarine telescope for neutrino detection (KM3NeT Design Study Project). The spectrometer is highly sensitive to gamma rays produced by ^{40}K decays but it can detect other natural (e.g.,^{238}U,^{232}Th) and anthropogenic radio-nuclides (e.g., ^{137}Cs). GEMS was firstly tested and calibrated in the laboratory using known sources and it was successfully deployed for a long-term (6 months) monitoring at a depth of 3200 m in the Ionian Sea (Capo Passero, offshore Eastern Sicily). The instrument recorded data for the whole deployment period within the expected specifications. This monitoring provided, for the first time, a continuous time-series of radioactivity in deep-sea.

Key words: NaI(Tl) sensor, underwater spectrometer, marine radioactivity

1. Introduction

The GEMS (Gamma Energy Marine Spectrometer) is a prototype underwater gamma-spectrometer, developed in the framework of the KM3NeT Design Study Project, intended for monitoring the radioactivity in sea water, in particular of ^{40}K. The KM3NeT consortium has as its aim the construction an underwater neutrino telescope of cubic kilometer scale, composed of an array of photomultipliers (PMTs) used to measure the light induced by muons originating from neutrino interactions in water. The decay of ^{40}K, contained in sea salt, particulate and sediments, is one of the main sources of photon background in the underwater environment [1, 2]. So, it is very important to monitor possible variations over time of this background, which may occur because of benthic sediment mobilization or water currents [3, 4]. In the KM3NeT Project there was the need for a direct, in-situ, detection of the activity and the variation of radio-nuclides, especially ^{40}K, which generates a background noise for the detection of the Cherenkov light.

The instrument was designed by INGV (Sezione Roma 2) and commissioned for building to the Institute of Nuclear Problem (University of Minsk), which developed the detector and the related electronics. A scintillation detector with NaI(Tl) cylindrical crystal with dimensions of 150×100 mm was used in the spectrometer for the detection of gamma-rays, assembled to a PMT. The PMT is connected to a microprocessor which manages the conversion of the analog signal to a digital one through the use of an Analogue to Digital Converter (ADC). The basic functions of the ad-hoc internal code of the microprocessor include the acquisition, saving and transfer of gamma-spectra to a peripheral facility (PC or DACS, Data Acquisition and Control System), the selection of the operational mode (real-time monitoring or stand alone mode), the automatic correction of the spectrometer energy scale using physical reference (^{40}K gamma-line with energy of 1461 KeV) and the calculation of the ^{40}K specific activity in seawater using every successive spectrum acquired during 1 hour, in case of measurement times longer than one hour [5]. An auto gain-stabilized system (e.g., using the position of ^{40}K peak) does not assure the exact repositioning of the measured photopeaks, because the energy drift is not a linear function of measured energy [6].

The spectrometer was designed to measure specific activity of natural radio-nuclides occurring in seawater, with particular reference to ^{40}K, which is a possible noise source for neutrino detection. Consequently, because of the automatic correction of the spectrometer gain, the correct behaviour of GEMS requires the presence of an amount of ^{40}K in the measurement environment at least equal to the standard seawater one.

The spectrometer was designed to detect standard activity in ocean seawater of ^{40}K (10 Bq/kg), ^{238}U (0.04 Bq/kg), ^{232}Th ($4\text{x}10^{-7}$ Bq/kg), and their variations of about 10%.

Upper limit of the detectable gamma-energy range is equal to 3000 KeV and the nominal lower limit of bare crystal is 50 KeV. However, this lower limit strongly depends on the applied waterproof case where the spectrometer is assembled before its immersion to seawater. The construction of a version capable of operation in deep-sea conditions, integrated in a seafloor observatory or in a multisensor probe, was performed by Tecnomare S.p.A and included design and manufacturing of a pressure compensated housing to host the sensor and the electronic

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boards, that must work in air and at atmospheric pressure, the interface, and the power electronics.

After a series of laboratory tests, in November 2008 GEMS was deployed in an oceanographic mooring in the Ionian Sea at 3200 m w.d. for 6 months. In this paper we describe the basic results of the laboratory calibration and the long-term monitoring.

2. Experimental calibration of the NaI Spectrometer

GEMS was calibrated and characterized through the analysis of its response to some reference sources, like ^{137}Cs, ^{133}Ba, ^{60}Co and ^{22}Na [7]. During the calibration we acquired a set of data for each reference source and an measurement of the environmental background. Each spectrum, included the background one, was acquired in presence of a ^{40}K source, since the instrument uses it as a reference for an autocalibration process. The background spectrum was then subtracted from each other set of data in order to perform spectral analysis and obtain, for each source,, the mean value of photon energy in ADC channels, namely the photopeak. In this way we obtained the conversion function of instrumental response (in ADC channels) into energy of the photon that impinged on the crystal (in MeV). A small non linearity of the crystal response was accounted by a second order polynomial function. The parameters of the calibration function ($y = ax^2 + bx + c$) are the following:

$$a = (3.80 \pm 0.16) \cdot 10^{-7} [\text{MeV Channels}^{-2}]$$

$$b = (2.670 \pm 0.012) \cdot 10^{-3} [\text{MeV Channels}^{-1}]$$

$$c = (-4.2 \pm 1.7) \cdot 10^{-3} [\text{MeV}]$$

A further characterization of GEMS's properties is the analysis of the instrument's energy resolution, which provides an estimate of GEMS's ability of resolving photons, which means sources, of similar energies. The resolution is described by:

$$R_E = \frac{FWHM}{E} = \sqrt{\left(\frac{0.1053}{\sqrt{E(MeV)}}\right)^2 + (0.023)^2} \quad (1)$$

which provides 12% of energy resolution at 661 KeV (^{137}Cs).

3. Long-term monitoring of seawater radioactivity

The first long-term test of GEMS was performed in the Ionian Sea, Capo Passero site, offshore Eastern Sicily (3618.915'N, 1665.531'E), at 3200 m w.d. [8]. The GEMS was mounted in a mooring chain 3400 m long and set-up in a stand-alone mode with a 6 hours sampling rate, for a 6 months autonomous data acquisition. Figure 1 shows an example of gamma spectrum (measuring time 6 hours) obtained. The dominant peak in spectrum is due to ^{40}K. The peak from ^{137}Cs (usually the most searched-for-gamma emitter) is not easily visible because it is masked by natural ^{214}Bi [9, 10].

A Monte Carlo simulation was used to perform an activity calibration of the instrument. This simulation combines both gamma-ray transport processes in seawater and detector characteristics, accounting for the propagation and interactions of the photons with seawater, and effects due to the housing and crystal. The result of this simulation is a measure of the detection efficiency for photons as a function of their energy (Figure 2).

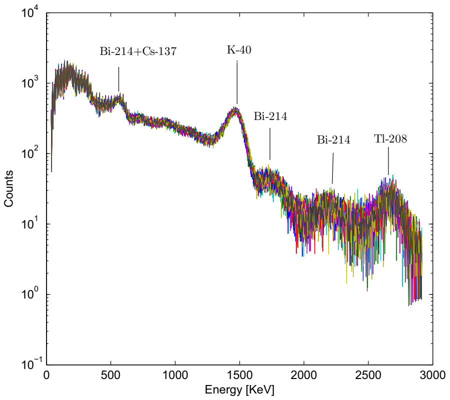

Figure 1: Underwater gamma-spectrum measured in Capo Passero site (measuring time 6 hours

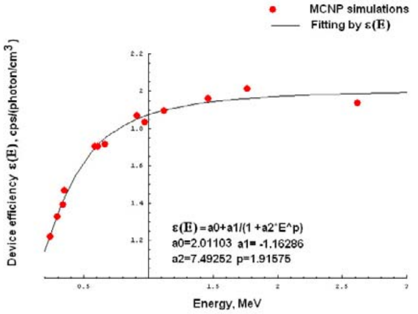

Figure 2: Efficiency of photon detection as a function of energy

Calibration in energy was made assuming that the isotropic gamma-ray source is homogenous. Through this calibration and the knowledge of the series decay of the nucleus under consideration, it is possible to evaluate the activity from the counts measured in specific energy ranges.

First of all, the Code calculates counts rate in counts pre second (CPS) for gamma-lines of some radio-nuclides including ^{40}K, ^{238}U, ^{232}Th and ^{137}Cs. Using the CPS data, the code calculates a specific activity in Bq/l. The calculated average value of ^{40}K specific activity is about 11.7 Bq/l (σ= 0.1 Bq/l), while the activity values recorded for ^{238}U and ^{232}Th are respectively 0.43

and 0.28 Bq/l, as expected [11]. The temporal series show very stable values; so activity due to ^{40}K can be considered constant in the Capo Passero area, during the time window of the experiment.

4. Conclusions

A new underwater radiometer-spectrometer GEMS was developed and successfully tested, both in laboratory and deep-sea conditions. GEMS performed the first long-term continuous monitoring of radioactivity, with special reference of ^{40}K, never done before in deep-sea (>3000 m). The instrument showed a very stable behaviour, robust electronics without any loss of data during the deployment. A detailed analysis of the acquired data will be discussed elsewhere. The sensor can be used for other scientific and environmental applications such as for monitoring natural radioactivity in correspondence with submarine petroleum or geothermal seepage sites or man-made radioactivity in contaminated areas.

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