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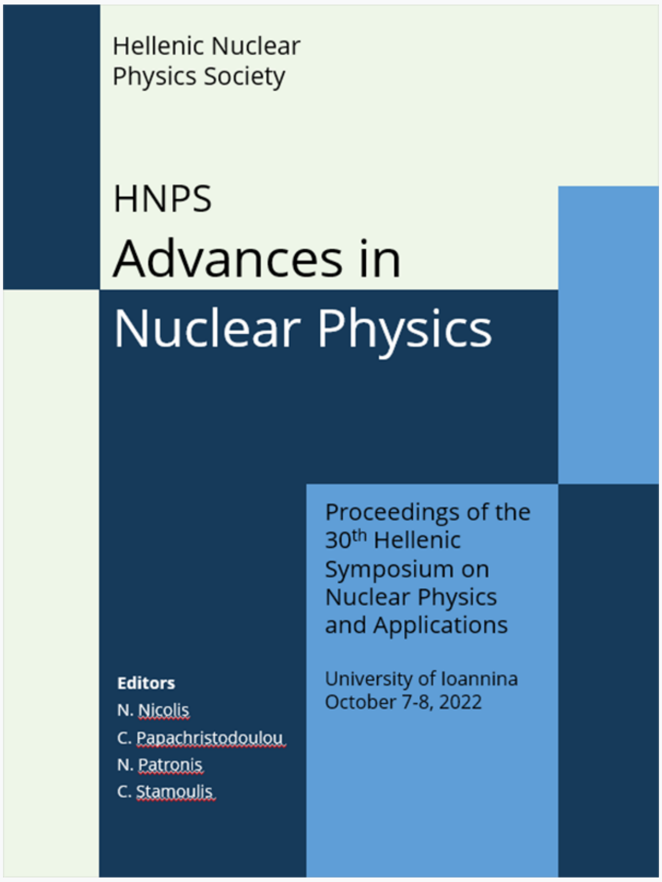

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Characterization of a Novel CdZnTe Spectrometer for Measuring Radioactivity in the Marine Environment

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Abstract The scope of this study is to characterize the response of a CdZnTe spectrometer to evaluate its performance for measuring radioactivity in the marine environment. CdZnTe semiconductor detectors have never been used before for such applications. More specifically, a spectrometer with a 4 cm^3 CZT crystal was studied under various scenarios, by means of Monte Carlo simulations and lab measurements. Using the Monte Carlo code MCNP5, the effect of the water's salinity on the detector's efficiency, as well as the ability of the sensor to localize radioactive sources in the water were examined. Futhermore, the full energy peak efficiency curve and energy resolution of the spectrometer was calculated experimentally in air. Finally, the effective volume of the CdZnTe crystal was estimated through measurements using a collimated point source of ^{137}Cs. First results are considered satisfactory, however additional scenarios should be examined in the near future to further characterize the response of the detector.

Keywords CdZnTe, marine radioactivity, characterization, Monte Carlo simulations

INTRODUCTION

Radioactivity exists in the marine environment as on land and in the atmosphere. Despite the long-term efforts by research groups and international organizations like IAEA, sample collection, measurements and studies in the ocean are considered limited both on short- and long-term scales. A serious limitation exists due to the methods and instrumentation currently being used, which have been mainly developed for studies on the land and atmosphere [1]. Consequently, a quite large gap exists between radioactivity measurements in the marine environment and air/land studies.

RAMONES (Radioactivity Monitoring in Ocean Ecosystems) is a recently funded H2020 EU Pathfinder program that sets as its main goal to close this gap. The vision is to provide *in situ*, in near real-time, high temporal and spatial resolution underwater radioactivity monitoring, by incorporating novel radiation sensors, along with low-power robotic systems and large-scale modelling.

One of the classes of radiation instruments RAMONES will provide, are the γ-sniffers. These will be mobile gamma spectrometers (inside an appropriate housing), aboard autonomous underwater gliders (AUG). Each γ-sniffer will perform surveys for long periods of time, covering large volumes of water in search of radioactivity hotspots. The spectrometers will be equipped with CdZnTe (CZT) crystals. CZT detectors have high atomic number and density, hence offering high-detection efficiency [2]. Moreover, they exhibit good energy resolution, portability, low power consumption and no intrinsic radioactivity is produced by their crystal. It is worth mentioning that this is the first time they will be used for radioactivity measurements in the marine environment. So far, their applications included studies mostly on medical imaging and radiation mapping of nuclear power plants [3,4].

EXPERIMENTAL DETAILS

The ocean is considered a quite inaccessible and harsh environment, hence the performance and response of these detectors has to be studied for various scenarios. Apart from measurements in the

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lab, Monte Carlo simulations were performed for various setups and sources. The detector studied, carried a crystal with a volume of 4 cm^3.

Simulations

Using the Monte Carlo code MCNP5 [5] the geometry of the detector was simulated inside a housing composed of aluminum at its cylindrical part and acrylic as its dome. An appropriate housing is mandatory not only to ensure waterproofing for the detector, but also to provide adequate protection from the high pressure known to exist at large depths of the ocean. The electronic parts of the detector were omitted, due to lack of information regarding the precise configuration. The whole geometry was surrounded with sea water, simulated as a sphere with a radius of 20 m (see Fig. 1). Various tests were carried out to evaluate the detector's response.

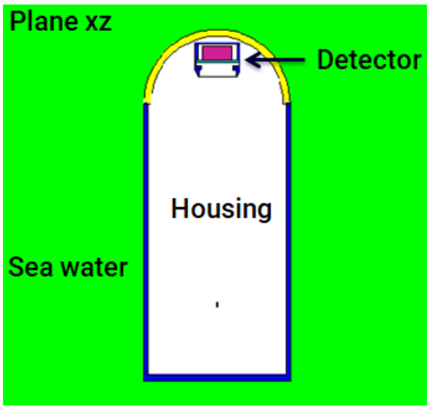

Figure 1. *Simulated geometry extracted from the MCNP5 VisEd application*

At first, the effect of seawater's salinity on the detection efficiency was investigated. By implementing a volume spherical source of ^{226}Ra (including the daughter nuclides) around the detector, simulations were performed for values of absolute salinity from 35 up to 40 g/kg. As mentioned before, each CZT spectrometer will be aboard an autonomously moving underwater glider. To examine the ability of the detector to localize radioactive sources in the ocean, specific triangulation scenarios were examined. In particular, by assuming two point sources of ^{137}Cs in the water, at a fixed distance of 100 cm between them, the detector's efficiency was calculated for various positions along a diagonal trajectory (see Fig. 2).

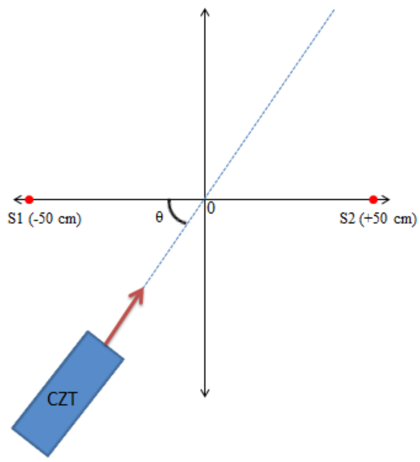

Figure 2. *Representation of the detector's trajectory simulated during the triangulation scenarios examined*

Measurements

Standard calibrated point sources were used, to evaluate different characteristics of the sensor. The full energy peak efficiency and energy resolution were calculated, in air and at a distance of 10 cm from the detector's front window.

In addition, experiments were performed to estimate the effective volume of the crystal. A ^{137}Cs point source was collimated using two 5 cm thick Pb bricks to form a narrow beam channel. The detector was then placed either alongside or perpendicularly to the beam direction. The goal was to irradiate only a thin slice of the crystal. After every measurement, the detector was moved with a small step, towards the orientation defined by the two blue arrows in Fig. 3. Then, the absolute efficiency was calculated as a function of the relative position of the crystal's slice irradiated.

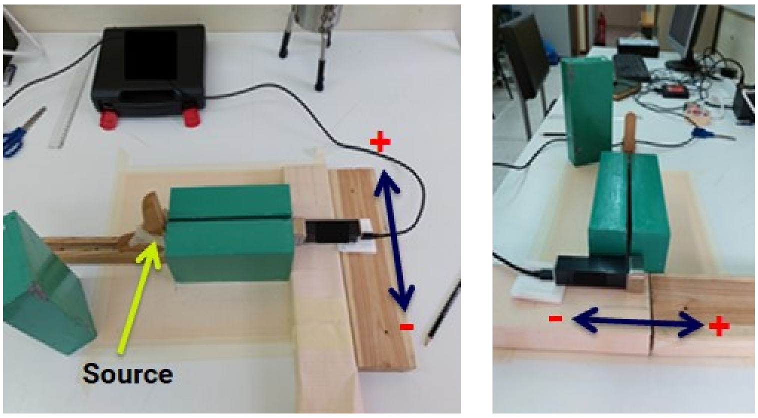

Figure 3. *Parallel positioning (left) and perpendicular positioning (right) of the detector with respect to the beam direction*

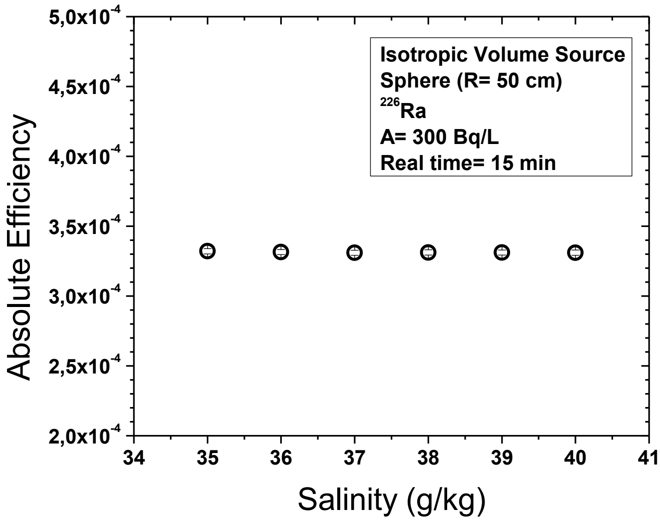

Figure 4. *Absolute efficiency calculated as a function of the seawater's absolute salinity value*

RESULTS AND DISCUSSION

Simulations

Regarding the effect of seawater's salinity on the absolute efficiency, simulation results showed a negligible effect (see Fig. 4). Compton scattering is the dominant interaction mechanism in the photon energy range studied. However, it seems that the difference in the water's density (due to change in the salinity) is insignificant, and any deviations observed between the efficiency values are within uncertainties introduced from simulations. Absolute efficiency values calculated during this test take into account the full energy spectrum and were obtained by dividing the sum of the total counts in the spectrum with the total γ-rays emitted by the ^{226}Ra source and the simulation-wise daughter products.

As described in the experimental details and depicted in Fig. 2, triangulation scenarios were applied to evaluate the detector's ability on source localization in the marine environment. An example result is presented in Fig. 5. The results can provide useful information for developing the decision algorithms responsible for managing the motion pattern of the gliders during a survey.

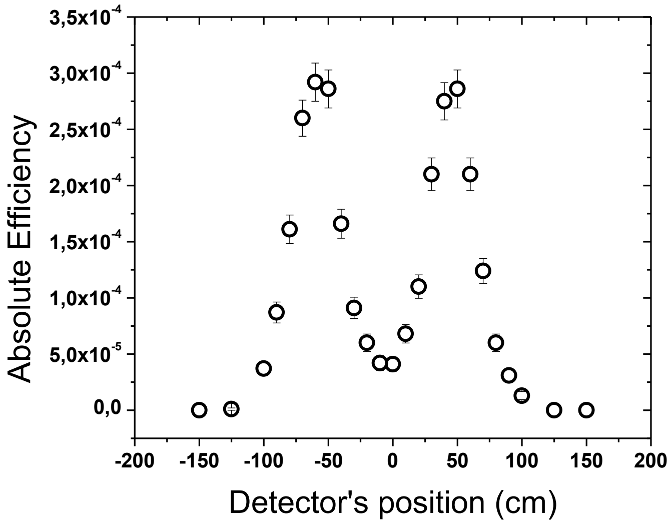

Figure 5. *Absolute efficiency calculated for an angle θ=30°, as a function of the distance between the detector's position and the center of the axes (see also Fig. 2)*

Measurements

Initially, the full energy peak efficiency (FEPE), was calculated against the γ-ray energy (see Fig. 6). Then, the energy resolution of the detector was specified in terms of FWHM and a value of 3.4% was found regarding the energy of the ^{137}Cs photopeak (661.66 keV).

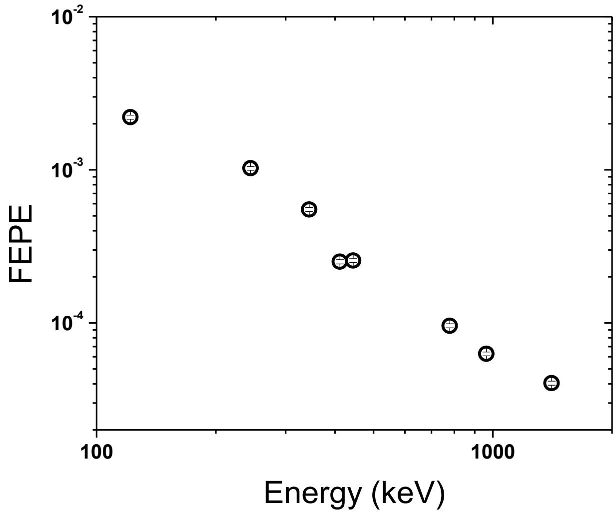

Figure 6. *Full energy peak efficiency as a function of the γ-ray energy*

The crystal's effective volume was estimated by using certain geometries including a collimated point source of ^{137}Cs. Measurements were performed, aiming to evaluate the effective dimensions of the crystal for all three orientations. During the parallel positioning of the detector, a rather symmetrical response was observed around the center of the crystal (indicated by the dashed line in Fig. 7). Same behavior was obtained after rotating the detector by 90° around its longitudinal axis (red scatter in Fig. 7). Regarding the perpendicular setup, maximum response was observed in the range of distances between 0.6 up to 1 cm.

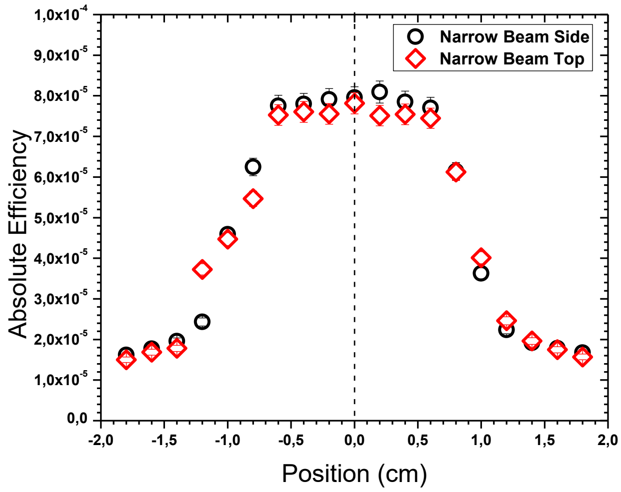

Figure 7. *Absolute efficiency as a function of the detector's position, during the parallel setup*

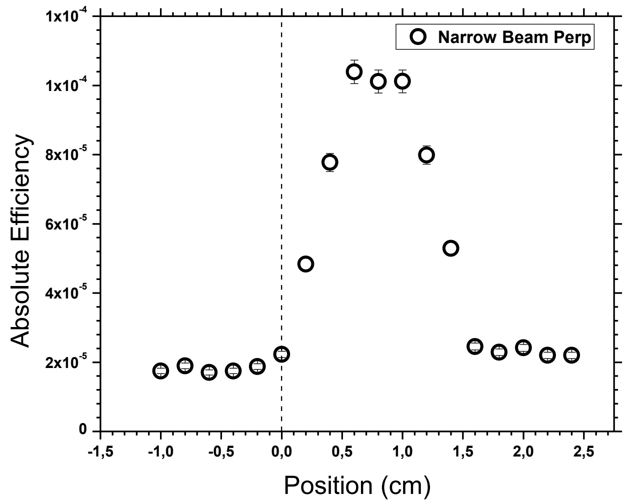

Figure 8. *Absolute efficiency as a function of the detector's position, during the perpendicular setup (x axis refers to the distance from the detector's front window up to the middle of the beam)*

CONCLUSIONS

The main objective of the current work is the characterization of a novel γ spectrometer equipped with a CZT crystal, intended for radioactivity monitoring in the marine environment. Through Monte Carlo simulations, the effect of seawater salinity on the detection ability was found to be a non-important issue for a range of typical absolute salinity values (35-40 g/kg). Also, from the triangulation scenarios the detector's ability for source localization in the water was determined to good detail. From the additional measurements the full energy peak efficiency curve was measured in air, as well as the energy resolution of the detector was determined. Finally, the effective volume of the CZT crystal was estimated by means of a simplified γ tomography method, which will serve as input for more detailed simulations in the near future for various advanced designs and measurement scenarios.

Acknowledgments

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