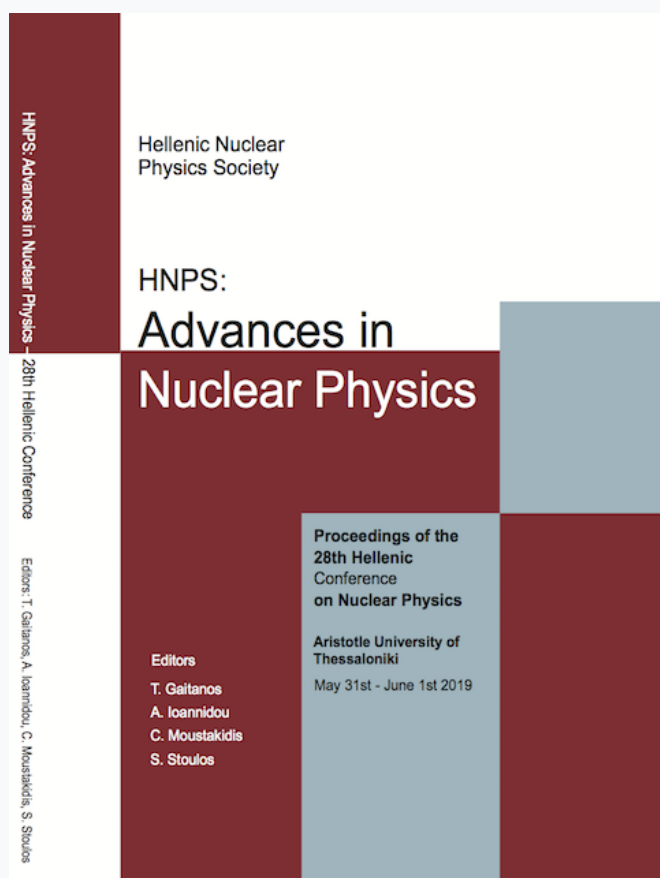


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GeoMAREA: A Gamma-ray spectrometer for in-situ marine environmental applications

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Abstract A new medium resolution (based on a 2"x2" CeBr₃ crystal) gamma-ray spectrometer named "GeoMAREA" was developed and applied for measuring radioactivity in aquatic environments. The system is capable for qualitative and quantitative measurement of radionuclides in aquatic environments with maximum depth of deployment up to 600 m. A special software is developed to fulfill different demands of the end-users in order to: a) provide real time data using the cable mode, b) perform communication tasks with a data center transferring (near) real time data, c) provide time series in sequential buffers for continuous monitoring in a stand-alone mode and d) provide profile data and subsequently maps using mobile vehicles (underway mode). The spectrometer was calibrated first using point sources for energy, energy resolution and efficiency. The system offers activity concentrations of all detected gamma-ray emitters in Bq/m³ using the marine efficiency calibration, which is reproduced via the MCNPX code [1]. Two experimental points were used for validation of the theoretical estimation obtained by two reference sources (¹³⁷Cs and ⁴⁰K) diluted in a water-filled tank. Currently, GeoMAREA is deployed in a closed aquatic system where groundwater discharges (Anavalos, Kiveri, Greece). A first estimation of the intrinsic background of the crystal at the emission energy area of ⁴⁰K is estimated. Additionally, an inter-comparison exercise with the low resolution system KATERINA II [2], is also described.

Keywords CeBr₃ crystal, in situ, sediment, aquatic environment

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INTRODUCTION

The radioactivity monitoring in the marine environment is crucial for radioprotection purposes and for healthy oceans (routine monitoring, radiological accidents, dispersion models, dose calculations). Additionally, the monitoring of certain radiotracers (e.g. radon daughters, ¹³⁷Cs) accounts many different applications (oceanography, hydrology, modelling) and the interest for such measurements continuously grows.

Nowadays, medium resolution systems are commercially available. These systems tend to replace the extensively used low resolution systems (NaI, BGO), as the number of the detected radionuclides increases (due to the improved energy resolution and the accuracy of the detection efficiency). Additionally to the technological accomplishments, an improvement of the sensors performance is also required in terms of operational oceanography. Such applications demand a smart *in-situ* sensor which will be able to a) gather data for long-term periods without maintenance (cost-effective operation), b) provide high quality information, c) operate in autonomous mode, d) identify the operation mode (sleep and awake) and e) provide high sensitivity, standardization and integration in platforms.

The motivation behind this work was to exploit the technological advances for the development and construction of a smart *in-situ* sensor exhibiting advanced spectroscopy characteristics. To this end, a new underwater gamma-ray spectrometer (named GeoMAREA) is developed. The system is based on a relatively pure CeBr₃ crystal and can be integrated in fixed and mobile marine platforms for *in-situ* measurements over a wide energy range in order to provide activity concentrations for naturally occurring (²³⁸U progenies, ²³²Th progenies, ²³⁵U and ⁴⁰K, ²⁰⁷Pb, ⁷Be) and anthropogenic (¹³⁷Cs, ¹³⁴Cs, ⁹⁵Zr/⁹⁵Nb, ¹⁰⁶Ru and ⁶⁰Co) radionuclides.



In this work, the system is applied in two different aquatic environments, a thermal spring inside Geras Bay at Lesvos Island, and in a group of submarine karstic springs at Anavalos which is located near Kiveri village at the west coast of the Gulf of Argolis at the NE Peloponnese peninsula in Greece.

Although the system was primarily designed to acquire *in-situ* measurements in the aquatic environment, it is also calibrated for sediment samples measurements in the laboratory. Such measurements will be performed directly on the field, as a supplementary tool to support radioactivity mapping activities for site characterization and hot spot identification in the marine (seabed) and the terrestrial (beach sands and/or soils) environments. In this work, the system performance for sediment samples measurements is demonstrated via the activity concentration results obtained for a sediment core collected at a deep trench near Samothraki Island.

SYSTEM DESCRIPTION

The GeoMAREA system consists of a relatively radiopure 2" x 2" CeBr₃ scintillation crystal (SCIONIX model 51 B 51/2M–E2–CEBR–LB), along with the appropriate electronic modules which are designed to operate in a low power consumption (~0.8–1.0 W) and to fit inside the cylindrical Acetal enclosure. The system offers activity concentration results of the detected radionuclides in units of Bq/m³ in the energy range from 60 to 2600 keV.

Table 1. Specifications of the GeoMAREA system

Sensor type	2"x2" CeBr ₃
Detection limit for ¹³⁷ Cs	~30–40 Bq/m ³ (24-hour integration, without subtraction of Compton background)
Energy resolution	~3.7–4.0 % (at 661 keV ¹³⁷ Cs)
Efficiency calibration	Experiment and Monte Carlo simulation
Power consumption	~1.0 W (Operating mode)
Data communication protocol	RS232 and/or USB and/or Ethernet
Operating temperature	-10°C to +50°C
Maximum operational depth	600 m
Input voltage	5–18 V DC
Autonomy	Depended on battery packs (capacity of 120 Ah provides 40 d continuous operation)
Maximum input counting rate	2 · 10 ⁵ cps
Stand alone and Integration capability on floating/stationary and mobile platforms	Yes

The system's energy and resolution calibration is performed using reference point sources (¹³⁷Cs, ⁶⁰Co, ^{152,154}Eu). The full energy peak efficiency calibration is performed for two different kind of measurements, including *in-situ* measurements in the aquatic environment and stationary laboratory measurements of sediment samples. The calibrations were performed using both experimental data and Monte Carlo simulations. Details on the system calibration can be found in the literature [3,4]. Regarding measurements in the aquatic environment, the utilized enclosure offers continuous functionality up to a 600 m water depth. It is designed so that it can provide sequential continuous monitoring data, in a stand-alone mode or in stationary/mobile platforms for (near) real-time

applications. The system specifications are summarized in Table 1. More details about the system calibration and functionality can be found elsewhere [3].

APPLICATIONS

In Fig. 1 the setup of the first implementation of the GeoMAREA system to perform measurements in a hot spring, inside the bay of Gera (Lesvos Island), is presented along with the obtained spectrum. A 3–hours measurement was acquired by deploying the system inside the Bay in a stand–alone mode. The system was placed close to the spring and the crystal is positioned well above the seabed surface in order to acquire events attributed to radionuclides present solely in the seawater column. As it can be seen only ^{40}K is detected in this acquisition setup, which is the most abundant radionuclide in the seawater. The detection of Radon daughters requires a larger acquisition time.

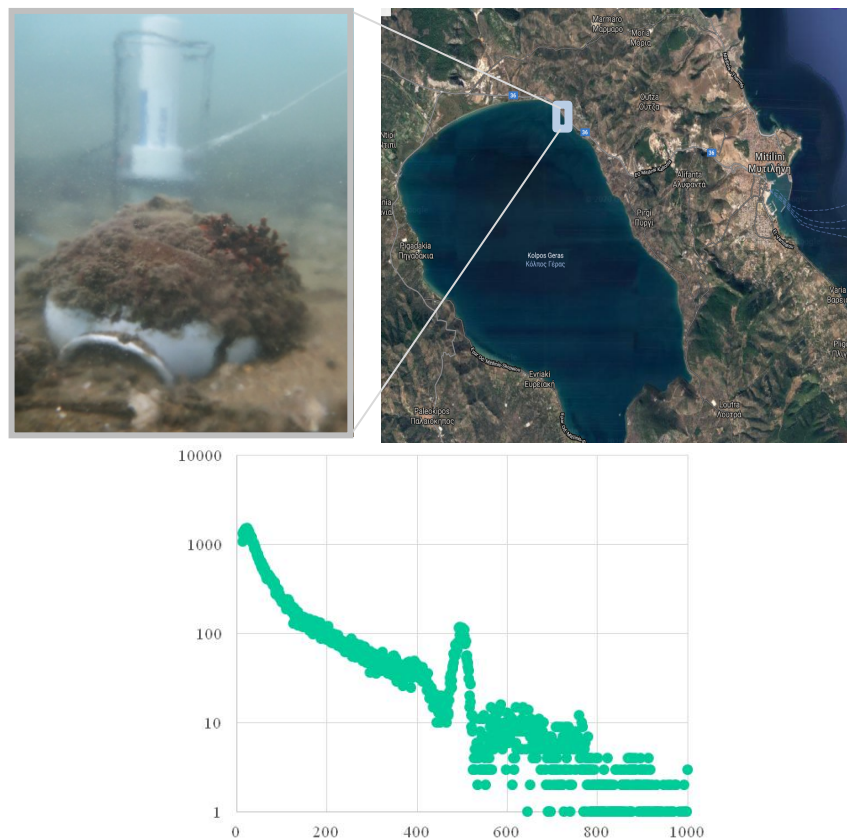


Figure 1. *In-situ measurements in a thermal spring (Bay of Gera) at Lesvos Island.*

In Fig. 2 the Anavalos dam and the system setup inside the submarine groundwater spring are presented, along with a typical acquired spectrum for a 1–hour acquisition time. The detected radionuclides are ^{40}K and Radon daughters (^{214}Pb , ^{214}Bi). The system was placed 1 m above the seabed as near as possible to the exit of the biggest submarine spring. During the 5–month monitoring period (February to July 2019) the activity concentrations of radon progenies varied between $(1.28\text{--}15.57) \cdot 10^3$ Bq m^{-3} . Details of the obtained results are presented elsewhere [5].



Figure 2. In situ measurements in Anavalos groundwater spring.

In Fig. 3 the setup for laboratory measurements of marine sediment samples is presented along with a typical acquired spectrum using the GeoMAREA system and a high resolution system (HPGe detector). The activity concentration results for the radionuclides ^{214}Pb and ^{208}Tl are presented in Fig.4. The obtained results using the GeoMAREA system are compared with corresponding high resolution measurements in order to evaluate the accuracy of the measurements using the medium resolution system. As it can be seen the two measurements are in excellent agreement within the statistical uncertainty [6].

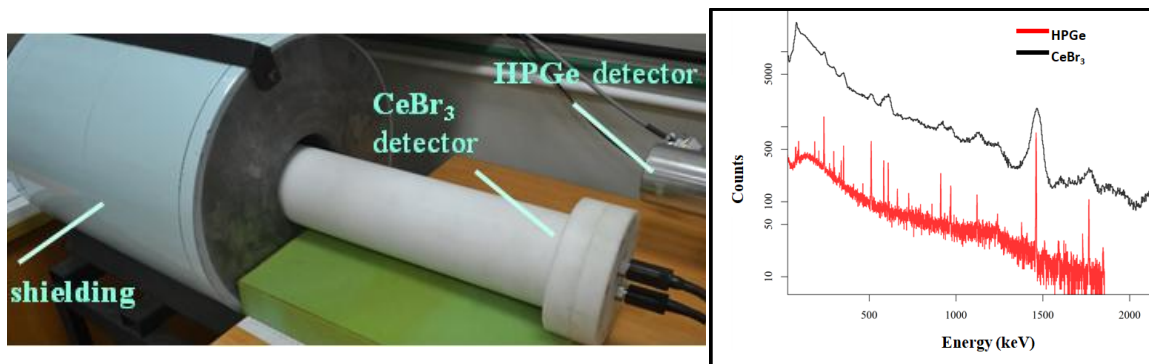


Figure 3. The experimental setup for the core sediment measurements in the laboratory using both medium and high resolution (CeBr_3 , HPGe) systems and the obtained spectra.

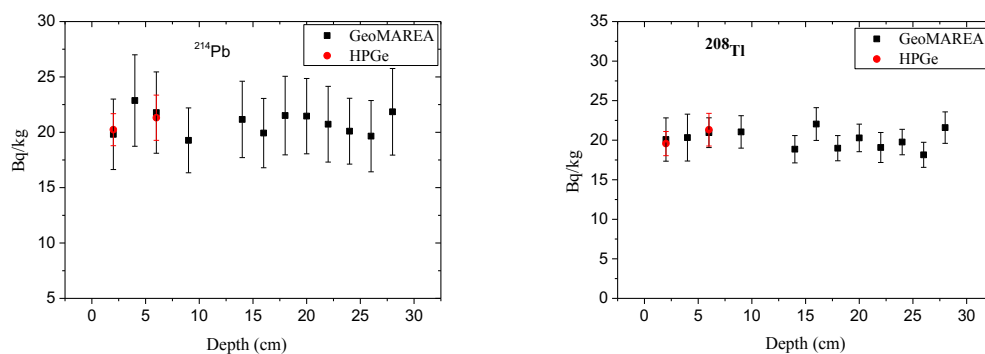


Figure 4. Activity concentration results (in Bq/kg) for ^{214}Pb and ^{208}Tl in the sediment core collected from a deep trench near Samothraki Island. The results obtained using the GeoMAREA system (black dots) are compared with corresponding high resolution measurements (red dots).

DISCUSSION – PERSPECTIVES

A preliminary study of the thermal spring in Geras Bay (Lesvos island) determined the water quality regarding the levels of activity concentration of radon daughters. The studied spring proved to

be an optimum aquatic area for further investigation of understanding the mechanisms that governs the water flow in this bay. Furthermore, the radiological study of the submarine groundwater discharge in Anavalos (Kiveri, Argolida) was performed by acquiring data in continuous mode for the radon daughters (^{214}Bi , ^{208}Tl) and ^{40}K . The GeoMAREA spectrometer was also applied for sediment samples using a quantitative method combining experimental calibration, inter-comparison exercises with high resolution spectrometers and simulation runs.

The GeoMAREA detection system provides higher performance features against the commonly low resolution underwater detection spectrometers due to the improved energy resolution and lower power consumption. The GeoMAREA system is stable during deployments and self-calibrated. The system may be pre-programmed to provide spectra in sequential mode (time series) without connection to personal computer and it is capable to operate in real-time mode by integration in fixed platforms. Regarding future applications, *in-situ* measurements in the atmosphere will provide significant results to quantify the rainwater and to estimate the cloud type using continuous monitoring of the radon daughters. The GeoMAREA upgrade should provide additional information for the directionality of radioactivity origin taking into the angular position of radioactive source and related prompt techniques for the detection of radiation.

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