



Monitoring natural and artificial radioactivity enhancement in the Aegean Sea using floating measuring systems

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ABSTRACT

In the present work, the enhancement of radioactivity due to rainfall in the Aegean Sea using floating measuring systems was observed and quantified. The data were acquired with a NaI underwater detection system, which was installed on a floating measuring system at a depth of 3 m. The results of natural and artificial radioactivity are discussed taking into account the rainfall intensity and wind direction. The activity concentration of ^{214}Bi increased up to $(991 \pm 102) \text{ Bq/m}^3$ after strong rainfall in the North Aegean Sea in winter (humid period) with east wind direction. On other hand, the maximum activity concentration reached the level of $(110 \pm 10) \text{ Bq/m}^3$ in summer (dry period) during south winds.

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1. Introduction

Monitoring of the seas is a major concern for the marine scientific community and the need for good and calibrated measurements at sea is obvious. In the marine environment, natural radionuclides mainly result from the weathering and recycling of terrestrial mineral and rocks, where their distributions depend on their physical, chemical and geological properties (Satyajit et al., 2000). The artificial radioactivity is extremely low compared to the concentration of natural radionuclides, so that, neither poses a risk to marine flora nor a health hazard to the population consuming seafood. However, radioactivity monitoring of the marine environment based on a continuously operating network could offer very important information on the concentrations of specific radionuclides (natural and anthropogenic) for other applications (like rainfall, submarine groundwater discharge and submarine faults) (Wedekind et al., 1999; Tsabaris and Ballas, 2005), improving the methodologies for quantifying marine radioactivity with the in situ gamma-ray spectrometry technique.

^{137}Cs is of special interest among the artificial radionuclides, because it is a long-lived radionuclide (30.05 years); it is used as a radionuclide tracer in seawater and constitutes the artificial radionuclide of greatest radiological significance in the marine environment (Papucci and Delfanti, 1999; Volpe et al., 2002; Delfanti et al., 2004). It persists in the environment from fallout from Chernobyl, weapon tests and nuclear power and processing facility discharge; it is transported over long distances by water

currents and contributes towards radioactive contamination of the marine food chain.

^{222}Rn (half life 3.823 d) is a noble gas, and its progeny (^{214}Pb and ^{214}Bi) are found in aerosol particles in accumulation-mode. Rainfall brings atmospheric ^{222}Rn progeny to the marine environment by its scavenging effect (within and below the cloud). Rainfall increases temporarily the radon progeny activity concentrations from several percent to several tens of percent of intensity compared to dry conditions with no rain (Nishikawa et al., 1995). However, the variation of radon progeny activity is not constant mainly due to rainfall intensity, rainfall type and humidity (Yoshioka, 1992). It has been measured (laboratory conditions) that the activity concentration of radon progeny in rainwater in Finland amounts up to 10^5 Bq/L (Paatero, 2000).

The continuous monitoring of ^{222}Rn progeny, which are transported by rainfall to the seawater, is necessary to assess properly the cause of any variation in the marine environmental gamma-ray dose rate. For instance, ^{222}Rn progeny variation is a serious problem for the monitoring of any release in the air of radionuclide gas from a nuclear facility. In addition, the rainfall concentration ratio of ^{214}Bi to ^{214}Pb can give significant information on the type of cloud (Takeyasu et al., 2006), where the rainfall is produced.

The quantitative information on activity concentrations using on line networks is very scarce because a lot of preparation is needed before the deployment of the system, and careful adjustments are needed for power consumption, stability conditions and data transmission. Using newly developed methods for the application and data analysis of the system, the present work tries to overcome the above problems. Many applications have been done in the past with similar systems (Aakenes, 1995a; Povinec et al., 1996; Wedekind et al., 1999; Van Put et al., 2004).

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The problem of the quantitative estimation of the detected activities as well as the reduction of the lower level of detection demands many improvements, although a lot of progress has been made by developing software for simulating underwater NaI detection systems (Vojtyla, 2001; Vlachos and Tsabaris, 2005; Ntziou, 2004).

The continuous gamma ray monitoring in the Aegean Sea has been carried out to demonstrate the enhancement of natural and anthropogenic radioactivity due to rainfall. The measurements have been performed by an underwater NaI(Tl) system RADAM (Aakenes, 1995b) with high efficiency (100%) and low power consumption (2W). The measured data were provided by the POSEIDON network (Soukissian et al., 1999) and analyzed for separating the artificial from the natural part of radioactivity. The results of the artificial and natural radioactivity due to rainout in the Aegean Sea are correlated with the season, the rain intensity (from model prediction) and the wind direction.

2. Material and methods

The setup and application of the stationary monitoring network POSEIDON (Soukissian et al., 1999) has been in continuous mode in the Aegean Sea since 1998. The POSEIDON network comprises now nine (9) stations and the measured data are transmitted every 3 or 6 h to the operational center (HCMR). The network consists of stationary gamma ray underwater spectrometers operating at open sea with satellite data transmission for long term monitoring. A description of the floating measuring system together with the underwater detector has been published recently elsewhere (Tsabaris and Ballas, 2005). The study area was focused mainly at the North Aegean Sea, named Athos (A), at the North-East, named Lesvos (L) and close to Athens, named Saronikos Gulf (S) (see Fig. 1). The LAT and LON coordinates are 39 57.932, 24 43.230 for Athos (A), 39 09.410, 25 48.515 for Lesvos (L) and 37 51.151, 23 42.370 for Saronikos Gulf (S).

The radioactivity detectors were installed for 80% of the monitoring time in the location (A), due to the strong events of water mass transfer in the specific region. The marine efficiency calibration was performed at the National Technical University of Athens in a tank of 2 m diameter and 2 m height by diluting three reference radioactive sources: ^{137}Cs , ^{40}K and $^{99\text{m}}\text{Tc}$ (Tsabaris et al., 2005). These values were used to estimate the efficiency curve in the whole energy interval (0–2000 keV) in order to quantify the activity concentration (in Bq/m³) of the detected photopeaks.

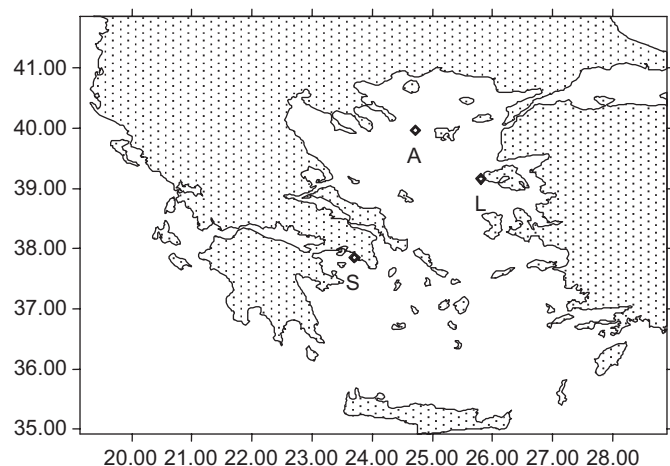


Fig. 1. The location of the floating measuring systems at the Aegean Sea.

3. Results and discussion

The data were sorted for a period of one day and stored for further analysis. During the periods of 1999–2005 a lot of data transmitted to operational center of HCMR for long periods (more than six months per year). The detector drifts were eliminated by saving the energy spectrum every 6 h and performing the energy calibration using two energy peaks which are always present: energy threshold in seawater (55 keV when the salinity value is 38 psu) and natural radiation of ^{40}K (1461 keV). The data analysis for the net area and other useful parameters was performed with the software package “SPECTRG” (Kalfas, 1991). The deconvolution procedure of the measured spectra for resolving the energy gamma ray peaks, has been published elsewhere (Tsabaris and Ballas, 2005).

The NaI underwater detector was placed in a monitoring floating buoy at 3 m depth under the sea level. The measurements of special interest concern data with rainfall, since rainwater enhances the artificial and natural radioactivity level. Typical spectra are shown in Fig. 2. The dashed line represents data before rainfall and the solid line the spectrum immediately after a rainfall event. The acquired spectrum without rainfall (dashed line) is defined as a baseline spectrum (background) for measuring radioactivity in the sea at 3 m depth, where the cosmic radiation is attenuated, and it does not interfere in the measurement. The background spectrum can be subtracted from the foreground spectrum (spectrum after rainfall), in order to resolve the fallout contributions from any other potential radioactivity enhancement in the region. This spectrum is salinity dependent and is stable for each season. A better approach of the background

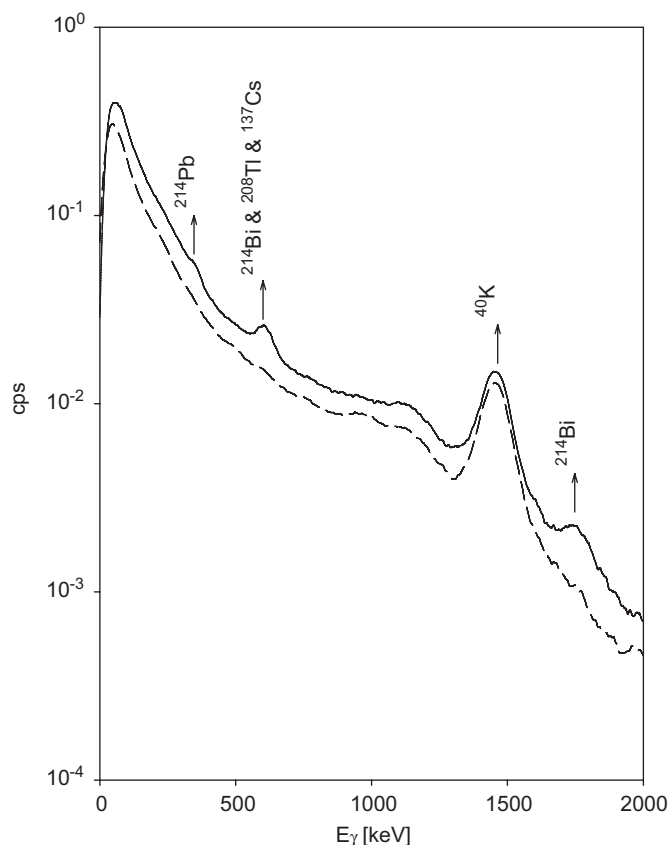


Fig. 2. The in situ spectrum of the NaI underwater detection system. The dashed line depicts background data and the solid line the foreground spectrum due to rainfall.

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