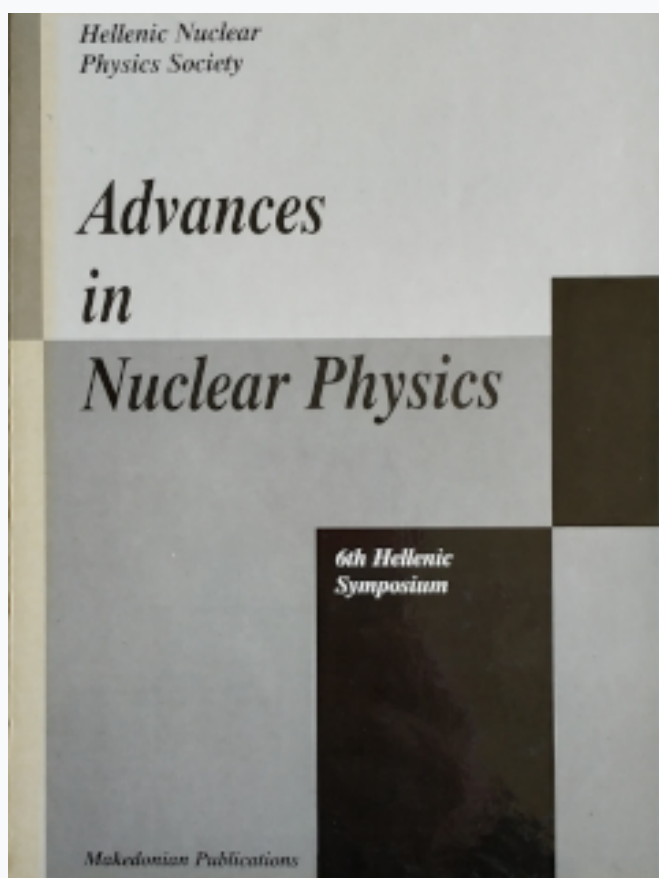


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Environmental study of natural radioactivity regime of the Ikaria island and the radiological impact

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Abstract

This is a preliminary study on the natural radioactivity of the spas in the Ikaria island and the consequent impact to the public health. In order to carry out this research : a) Car-borne radiometry has been applied in the areas around the spas as well as in some reference areas in the island b) The activity concentrations of the natural radionuclides of the ^{238}U , ^{226}Ra and ^{232}Th decay series, as well as ^{40}K , in spa water, soil, sediment, surface sea water and marine flora samples in the areas of the spas were measured. From the results derived one notes that elevated concentrations of the environmental abiotic materials are presented, which are reflected to the concentrations observed in marine flora. Consequently, higher population doses in comparison with other Greek regions are resulted.

1 Introduction

Ikaria island, an area of 267 Km^2 , is located in the eastern Aegean Sea, Greece. The island which is inhabited by a population of 7500 is mainly characterized by a mountain area. In the littoral zone of the areas of interest in the island there are several spas and in the sublittoral zone some springs bubble up from the bottom as well. These are located in Therma, Agios Kirikos, Lefkada and Xilosirtis (Fig. 1). They are divided into thermal bath spas of $45\text{-}65^\circ\text{C}$ observed temperatures and potable spa water of 20°C . The spas in Therma, Agios Kirikos and Lefkada are used for balneotherapy. Xilosirtis spa water, called locally "immortal water", is used as a potable source.

2 Methods and techniques

a) In order to determine the natural gamma-radiation status in the areas of interest, as well as in some reference areas in Ikaria, gamma-radiometry has been applied in a network of 70 km (mean value recorded every km). For the radiometry a car-borne scintillometer with a 2" x 2" NaI(Tl) cylindrical detector (sensitivity $3.5 \times 10^{-3} \mu\text{R h}^{-1} \text{cpm}^{-1}$ for ^{226}Ra at 1m) was used.

b) In order to evaluate the inventory of the environmental radiation levels of the areas around the springs, samples of spa water, soil, sea water, sediment and alga were also analyzed by gamma spectrometry. The above samples were analyzed by using a high resolution gamma spectrometry system with a HpGe detector of 20% relative efficiency to 3" x 3" NaI detector. The sampling stations are given in Fig.1. Activity concentrations in spa water, sea water, soil, sediment and alga samples of the natural radionuclides ^{226}Ra , ^{228}Ra , ^{232}Th , ^{228}Th , ^{222}Rn and ^{40}K were determined in Bq l^{-1} and Bq kg^{-1} respectively.

c) In order to estimate the population dose rate from external and internal radiation:

i) The results obtained from soil and sediment sample measurements were used for the theoretical evaluation of the external dose rate on the basis of the following relation [1]:

$$H = 3.10 A(^{226}\text{Ra}) + 2.58 A(^{228}\text{Th}) + 0.276 A(^{40}\text{K})$$

where:

H: The exposure dose rate for terrestrial gamma radiation in $\mu\text{Sv y}^{-1}$.

A(i): Activity concentration of the radionuclide i considered in soil and sediment in Bq.kg^{-1} .

ii) Regarding potable water, effective dose equivalents are calculated on the basis of Rn^{222} and Ra^{226} ingestion, on the assumption that the water consumption is 0.5 l per day, per person, considering the conversion factors as:

$1 \mu\text{Sv y}^{-1} \text{Bq}^{-1} \text{l}$ for ^{222}Rn [2] and $250 \mu\text{Sv y}^{-1} \text{Bq.l}^{-1}$ for ^{226}Ra [3].

3 Results and Discussion

The exposure dose rate values resulting from gamma radiometry measurements are shown in Fig (1). They are in the range of 0.05 - 0.21 $\mu\text{Gy h}^{-1}$ with

an average value $0.14 \mu\text{Gy h}^{-1}$ in the vicinity of the areas of interest. One can note that the highest of the measured exposure dose rates are observed in the vicinity of the spas. The exposure rates in other regions of Ikaria are comparable with the reported mean value for other Greek regions [4], $0.08 \mu\text{Gy h}^{-1}$. The derived annual equivalent dose rate is in the range of $307\text{--}1226 \mu\text{Sv y}^{-1}$, whereas the annual average for other regions is $491 \mu\text{Sv y}^{-1}$.

The results obtained from gamma spectrometry measurements in water, soil, sediment and alga samples are summarized as mean values of the concentration activities of principal natural radionuclides in Tables 1, 2, 3, 4. Minimum and maximum values are also reported.

These results show that elevated values of ^{226}Ra and ^{222}Rn are detected in spa water in comparison with respective values from spas in other Greek areas as well as from areas referred in the international literature (Table 1). The concentrations of ^{222}Rn in bath spa water (Table 1) are higher than those of its parent ^{226}Ra . Apparently there is a high disequilibrium between ^{222}Rn and ^{226}Ra because of the high diffusion coefficient of ^{222}Rn in comparison with the low solubility of ^{226}Ra compounds in water. Thus, ^{222}Rn occurrence is due to its release to the water by surrounding bedrocks, enriched in uraniferous minerals, whereas only a low percentage is due to the decay of its parent ^{226}Ra . Concerning the drinking spa water (Table 1), high concentrations of ^{222}Rn , ^{226}Ra and ^{228}Ra are present. The concentrations of natural radionuclides in sea water are higher than those observed in other Greek areas (Table 2) and areas referred in the international literature [5]. The measured coastal soil and sediment samples are characterized by higher values of ^{226}Ra , ^{232}Th and ^{40}K in comparison with the respective background levels in Greece, which are referred to a wide sampling network in the Greek territory (Table 3). The elevated concentrations of natural radionuclides in the abiotic environmental materials of Ikaria spas are reflected to the concentrations of natural radionuclides in the examined alga samples, as we can conclude from the observed elevated values in comparison with the respective typical values of the Greek environment (Table 4) and other Mediterranean areas [6] as well.

3.1 Dosimetry calculations

Based on gamma spectrometry measurements in coastal soil and sediment samples, the calculated dose rates for total gamma radiation are in the range $71\text{--}358 \text{ nSv h}^{-1}$ in Lefkada, which results in an annual average rate $1522 \mu\text{Sv y}^{-1}$ and a maximum $3133 \mu\text{Sv y}^{-1}$. The respective range in Therma is $20\text{--}33 \text{ nSv h}^{-1}$ and the corresponding annual average and maximum dose rates $284 \mu\text{Sv y}^{-1}$ and $289 \mu\text{Sv y}^{-1}$. Compared with the reported average and regional maximum for Greek island areas of $430 \mu\text{Sv y}^{-1}$ and $740 \mu\text{Sv y}^{-1}$

the values in Lefkada are relatively high [7]. Also in relation with the values resulting from gamma radiometry the values in Therma are in accordance, whereas the values in Lefkada differ significantly. The spas in Lefkada are out of use and the water is flowing freely in the areas of the springs. This results a continuous deposition of radioactive elements in soil and sediments in the adjacent areas and consequently in higher dose rates compared with rates resulting from gamma radiometry in the wide vicinity. Nevertheless, in the international literature maxima exceeding $5000 \mu\text{Sv y}^{-1}$ have been reported for other regions in the world [8].

Considering the internal dose due to the spa water consumption, the estimated annual effective dose equivalent due to radon ingestion is $67 \mu\text{Sv y}^{-1}$, whereas the respective dose equivalent due to ^{226}Ra is $100 \mu\text{Sv y}^{-1}$. The respective annual dose equivalents in Portugal are in the range of $1.8 - 1300 \mu\text{Sv y}^{-1}$ for ^{222}Rn and $0.5 - 120 \mu\text{Sv y}^{-1}$ for ^{226}Ra [9].

4 Conclusion

The environmental abiotic materials and consequently the examined marine biota in areas around Ikaria spas are characterized, in general, by elevated concentrations of natural radionuclides, compared with the respective levels from other Greek areas. This results in elevated external and internal doses to the population compared with doses to the population of other parts of Greece.

gamma dose rates at 1m above surface

($\mu\text{Sv/h}$)

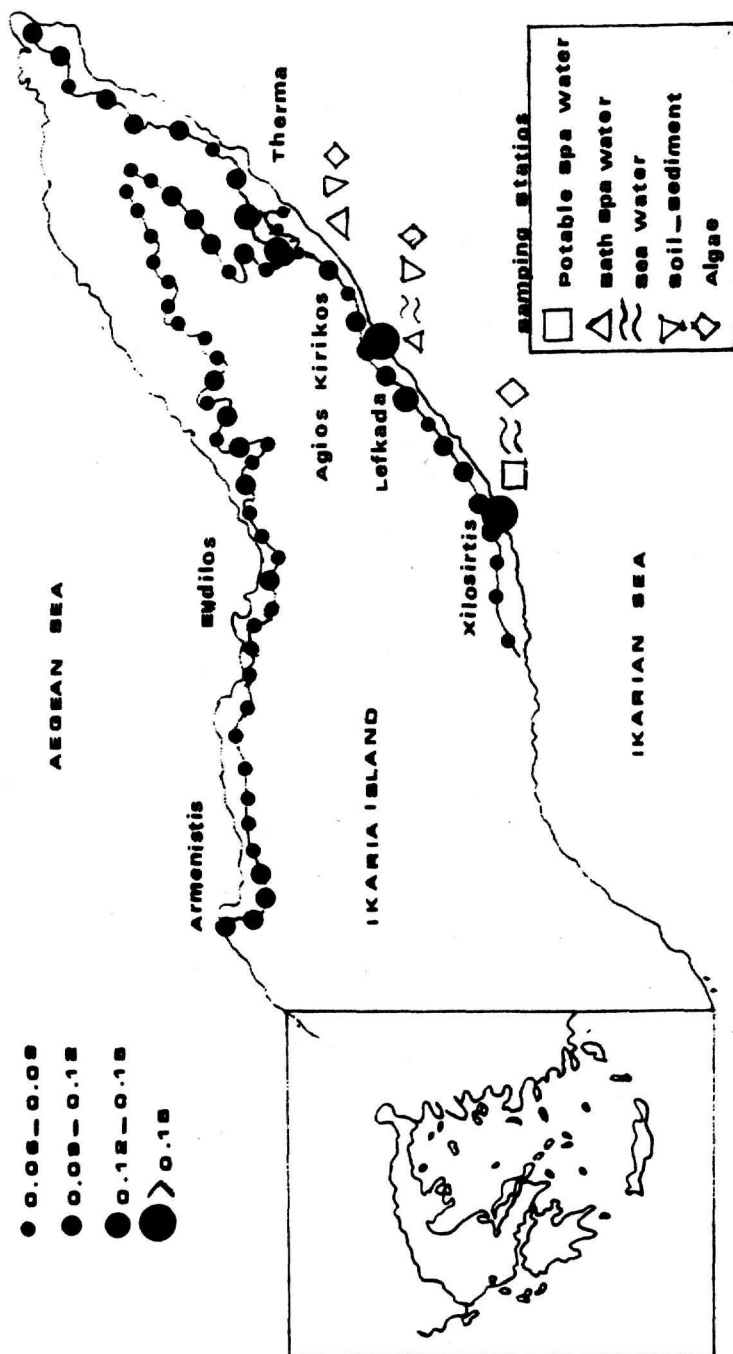
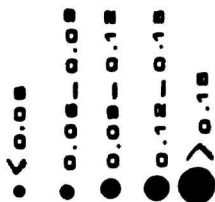


Fig.1 Map of the sampling stations and the results obtained by car-borne scintillometry.

Table 1. Activity concentrations of natural radionuclides in spa water and respective summarized results from other areas in Greece and European countries (Bq l⁻¹).

| Bath water | ²²⁶ Ra | ²²⁸ Ra | ²²² Rn | ⁴⁰ K |
|---------------------|--------------------------------|--------------------------------|--------------------|-----------------|
| Ikaria (This study) | | | | |
| MV±SD | 2.6±1.7 | 1±0.9 | 888±864 | 22±1.9 |
| Min | 1.1±0.4 | <0.1 | 114±8 | 19±4.0 |
| Max | 5.0±0.4 | 2.4±3.2 | 2468±120 | 24±5.5 |
| Other areas | | | | |
| | <5 (10) | | 1-850 (10) | |
| | <0.05-6.4 (11) | 0.18±0.07-1.10±0.14 (11) | 4.5±0.2-451±5 (11) | |
| | (375-524)10 ⁻³ (12) | | 52-89 (12) | |
| Drinking water | ²²⁶ Ra | ²²⁸ Ra | ²²² Rn | ⁴⁰ K |
| Ikaria (This study) | | | | |
| MV±SD | 0.4±0.3 | 0.8±0.7 | 67±43 | 8.1±2.6 |
| Min | 0.1±0.2 | 0.1±0.9 | 30±3.0 | 5.3±1.8 |
| Max | 0.7±0.3 | 1.5±0.7 | 114±8.5 | 10.4±2.6 |
| Other areas | | | | |
| | (10-130) 10 ⁻³ (13) | (30-300) 10 ⁻³ (13) | | |
| | (4.1-89) 10 ⁻³ (14) | | 25-629 (14) | |
| | <2 (9) | | <1-814 (9) | |
| | 0.140±0.004 (15) | | 17±0.7 (15) | |
| | 1 (16) | | 600 (16) | |
| | 0.02 (16) | | 3 (16) | |
| | | | | 0.15-13 (17) |

Table 2. Activity concentrations of natural radionuclides in sea water in Ikaria and other Greek regions (Bq l⁻¹).

| | ²²⁶ Ra | ²²⁸ Ra | ²²² Rn | ⁴⁰ K |
|---------------------|-------------------|-------------------|-------------------|-----------------|
| Ikaria (This study) | | | | |
| MV±SD | 1.2±1.0 | 0.6±0.6 | 18±17 | 19±0.6 |
| Min | <0.1 | <0.1 | 1.3±2.9 | 19±7.4 |
| Max | 1.9±0.3 | 1.1±0.9 | 35±6.7 | 20±1.9 |
| Other areas (5) | | | | |
| Min | 0.00145±0.00025 | 0.00208±0.00030 | | 9.8±1.18 |
| Max | 0.00167±0.00037 | 0.00432±0.00065 | | 11.9±1.30 |

Table 3. Activity concentrations of the main natural gamma-emitters in soil and sediment in Ikaria and other Greek areas (Bq kg⁻¹).

| | ²³⁸ U | ²²⁶ Ra | ²³² Th | ⁴⁰ K |
|--------------------------|------------------|-------------------|-------------------|-----------------|
| Ikaria (This study) | | | | |
| MV±SD | 214±410 | 212±311 | 43±18 | 1130±823 |
| Min | 15±9 | 24±14 | 18±48 | 258±14 |
| Max | 1049±30 | 764±10 | 66±3 | 2464±70 |
| Other Greek areas (5,18) | | | | |
| MV±SD | | 48±14 | 45±16 | 621±225 |
| Min | 7 | 6 | 4 | 47 |
| Max | 92 | 80 | 83 | 1214 |

Table 4. Activity concentrations of the main natural gamma-emitters in alga samples in Ikaria and other Greek areas (Bq kg⁻¹).

| | ²²⁶ Ra | ²²⁸ Ra | ²²⁸ Th | ⁴⁰ K |
|-----------------------|-------------------|-------------------|-------------------|-----------------|
| Ikaria (This study) | | | | |
| MV±SD | 75±41 | 49±9 | 10±4.8 | 358±69 |
| Min | 23±6.6 | 14±9.0 | 6.1±2.8 | 258±15 |
| Max | 124±4 | 33±11 | 17±3.4 | 415±36 |
| Other Greek areas (6) | | | | |
| Min | 0.5±0.3 | 0.6±0.4 | 0.5±0.5 | 50±27 |
| Max | 2.7±1.1 | 10±2.5 | 8.5±2.5 | 183±15 |

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