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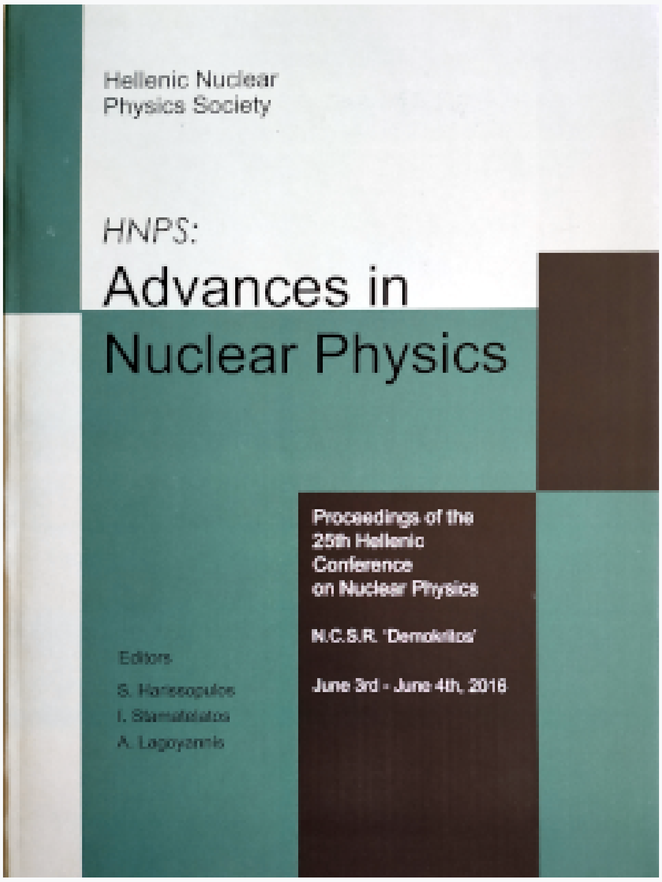

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M. Sotiropoulou, H. Florou, G. Kitis

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Radiological impact assessment in the terrestrial environment of Greece using innovative tools – Adaptation of ERICA Tool to actual measurements

Maria Sotiropoulou[*1,,2], Heleny Florou[1], Georgios Kitis[2]
[1]*Environmental Radioactivity Laboratory, Institute of Nuclear and Radiological Sciences & Technology, Energy & Safety, NCSR "Demokritos", 15310 Agia Paraskevi, Athens, Greece*
[2]*Atomic and Nuclear Physics Laboratory, School of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
msotirop@ipta.demokritos.gr

Abstract
In the present study, the radioactivity levels in terrestrial non-human biota and the transfer pathways in the ecosystem are examined. Grass of Poaceae family and herbivore mammals (ruminants) of Bovidae family and soil samples were collected during the period of 2010 to 2014, from grasslands of the Greek rural territory where sheep and goats were free-range grazing. Natural background radionuclides (^{226}Ra, ^{228}Ra, ^{228}Th) and artificial radionuclides (^{137}Cs, ^{134}Cs, ^{131}I) were detected in the collected samples using gamma spectrometry. The actual measured activity concentrations and site-specific data of the studied organisms were imported in ERICA Assessment Tool (Version 1.2.1, February 2016) in order to provide an insight of the radiological dose rates [3-6]. Natural radionuclides exhibited significantly higher contribution to the total dose rate than the artificial ones. The radiological exposure to Fukushima-derived radionuclides was quite low and owed to internal exposure, mainly derived through the ingestion pathway. According to the screening levels, the calculated dose rate to the studied non-human biota was below the threshold levels. However, the obtained results may be proved useful in further research regarding the possible impact of protracted low level ionising radiation to non-human biota on the various levels of life's organization.

Keywords
Natural and artificial radionuclides, gamma spectrometry, radiological dose rates.

INTRODUCTION

In recent years, more attention has been given to the assessment of radiological impact to non-human biota, taking into account that human protection may be inadequate to ensure environmental protection [1]. The ERICA Integrated Approach is a continuously evolving methodology for the quantification of non-human biota exposure to ionizing radiation, risk characterization and prediction of the eventual effects [2]. Natural radioactivity levels in the terrestrial environment of Greece are generally known (mainly referring to members of ^{238}U and ^{232}Th natural series) [3,4]. Artificial radionuclides have been introduced in the terrestrial environment of the country mainly from the global fallout and the Chernobyl N.P.P. accident, with ^{137}Cs still detectable in the environment [5]. Additionally, in 2011, traces of ^{137}Cs derived from the Fukushima Dai-Ichi nuclear power plant (N.P.P.) accident were also detected in environmental components [6-8] and were added to the residual ones. Traces of the Fukushima-derived ^{134}Cs and ^{131}I were also detected in the collected samples [9]. Since limited information is available concerning the internal and external exposure levels of natural organisms, the aim of the present work is to assess the radiological impact due to natural and artificial radioactivity in semi-natural areas of the Greek terrestrial environment. The objective was to perform a screening radiological impact assessment, based on the ecosystem features and the actual site-specific measurements from the rural territory of the country in order to identify the levels to which the examined organisms are exposed.

METHODOLOGY

Samples of terrestrial organisms, grass of Poaceae family and herbivore mammals of Bovidae family, and abiotic components (various types of soil) were collected during the period of 2010 to 2014, on the basis of a representative food-web of the terrestrial Eastern Mediterranean ecosystem. The sampling procedures were conducted in five semi-natural grasslands areas of the Greek rural territory, where sheep and goats were free-range grazing (Fig. 1). Natural background radionuclides (^{226}Ra, ^{228}Ra, ^{228}Th) and artificial radionuclides (^{137}Cs, ^{134}Cs, ^{131}I) were detected in the collected samples using gamma spectrometry [8]. The actual measured activity concentrations and site-specific data of the studied organisms were imported in ERICA Assessment Tool (Version 1.2.1, February 2016). The calculations of dose rates were performed on the basis of internal dose rate from the activity concentration in organisms (grass and mammals), external dose rate from activity concentration in soil and total dose rate from combination of the previous two [2].

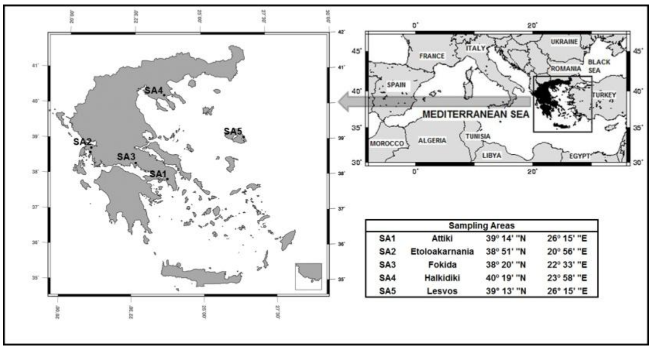

Figure 1: Map of Greece indicating the sampling areas. Sampling areas with coordinates are numbered as showed in the adjacent table

RESULTS

Activity concentration measurements

The mean measured activity concentrations of the examined samples are indicated in Fig. 2. The highest activity concentrations were detected in samples collected in Lesvos Island and the lowest in samples from Attiki and Etoloakarnania prefectures. The measured activity concentrations of naturally occurring radionuclides in soil (^{226}Ra, ^{228}Ra and ^{228}Th) exhibited some variations from region to region, which are generally correlated with the chemical composition of soils [4], however, they were in good agreement with measurements performed earlier in the country [8]. Traces of ^{137}Cs were detected in grass and mammals samples collected before and after the Fukushima-impact in Greece and it can be assumed that Fukushima-derived traces were added to the residual ones. Traces of ^{134}Cs and ^{131}I were also detected in organisms but were not detectable in soil, indicating that the uptake by grass is attributed to the radioactive deposition on foliar surfaces. As the concentration of natural and artificial radionuclides in air are generally low compared to the activity concentration in soil and the duration of the exposure is limited, the ingestion process can be considered as the main pathway for the selected accumulation of the radionuclides to the critical organs of the organism (cesium in muscle, radium in bones, iodine in thyroid, etc) [6,8,9]. The Fukushima-derived traces (^{134}Cs and ^{131}I) were detectable in organisms for a finite period after Fukushima accident, dependent on their physical, ecological and biological half-lives [8,10].

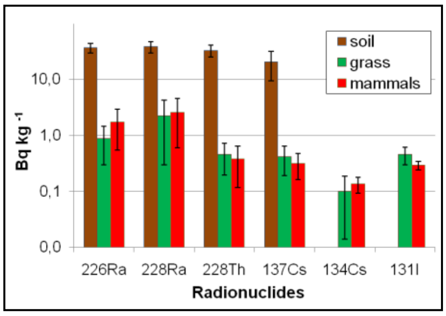

Figure 2: Mean measured activity concentration (Bq kg^{-1}) of radionuclides detected in soil, grass and mammals collected from the case study sites

Radiological impact assessment

The highest contribution to the total dose rate was clearly derived from the internal exposure, which is closely related to the exposure to alpha emitters of the natural background (^{226}Ra and ^{228}Th) (Fig. 3). Natural radionuclides exhibited significantly higher contribution to the total dose rate than artificial radionuclides to both grass and mammals (Fig. 4). The contribution of natural radionuclides (^{226}Ra, ^{228}Ra, ^{228}Th) to the total dose rate was calculated at 95%, while artificial radionuclides (^{137}Cs, ^{134}Cs, ^{131}I) contributed for about 5% for both grass and mammals. The highest contribution from artificial radionuclides derived from the residual (due to Chernobyl impact) ^{137}Cs for about 4% for grass and mammals, while the contribution of the Fukushima-derived traces of ^{134}Cs and ^{131}I was estimated close to 1%, mainly attributed to the internal exposure from the incorporated radionuclides. The highest calculated dose rates were equaled to 4·10-1 μGy h^{-1}, which is by far lower from the levels of 100 μGy h^{-1} for animals and 400 μGy h^{-1} for plants that have been proposed by UNSCEAR [11] and 10 μGy h^{-1} set by ERICA Project [2], for the assessment of the radiological impact and the prevention of effects at the population level of the generic terrestrial ecosystem. As there are limited data on the impact of the protracted ionizing radiation of non-intervention levels to the various levels of life's organization, the obtained results may be proved useful in further research.

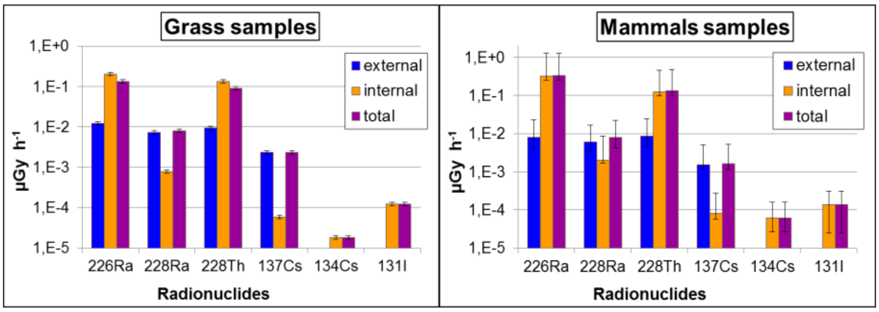

Figure 3: Mean internal, external and total dose rate calculated by the ERICA Tool for a) Grass and b) Mammals of the selected case study sites (in μGy h^{-1})

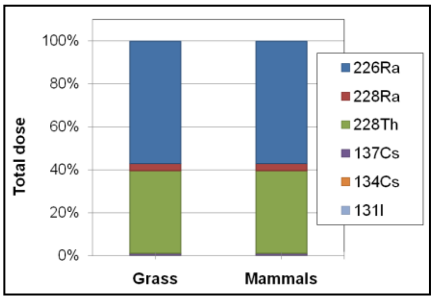

Figure 4: Relevant contribution to the total dose of the studied non-human biota

CONCLUSIONS

The studied non-human biota have been exposed to low level ionizing radiation and no significant impact can be estimated. However, the obtained results may be proved useful in further research regarding the possible impact of protracted low level ionising radiation to non-human biota and on the various levels of life's organization. Even though the ERICA Tool is mainly a generic model, when actual measurements are introduced, can result to more specific findings in terms of the radiological dose rates of the considered ecosystem. This kind of studies may provide support to the decision making, in terms of an integrated approach of the environmental impact assessment policies.

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