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Distribution of artificial gamma-ray emitting radionuclide activity concentration in the top soil in the vicinity of the Ignalina Nuclear Power Plant and other regions in Lithuania

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HIGHLIGHTS

► Gamma-emitters in top soil were studied during the operational period of the Ignalina NPP.
► Only ^{137}Cs was detected in each sample of the top soil in studied regions every year.
► The mean ^{137}Cs activity in the top soil of the INPP vicinity was lower than in remote regions.
► The INPP origin ^{60}Co and ^{137}Cs deposition loads were modeled.
► Theoretically obtained data were compared to experimental results.

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ABSTRACT

The impact of the operating Ignalina Nuclear Power Plant (INPP) on the contamination of top soil layer with artificial radionuclides has been studied. Results of the investigation of artificial gamma-ray emitting radionuclide distribution in soil in the vicinity of the INPP and distant regions in Lithuania in 1996–2008 (INPP operational period) show that nowadays ^{137}Cs remains the most important artificial gamma-ray emitting radionuclide in the upper soil layer. Mean ^{137}Cs activity concentrations in the top soil layer in the vicinity of the INPP were found to be significantly lower compared to those in remote regions of Varėna and Plungė (~300 km from INPP). In 1996 and 1998 mean ^{137}Cs activity concentrations were in the range of 28–45 Bq/kg in the nearest vicinity to the INPP, 103 Bq/kg in Varėna and 340 Bq/kg in Plungė region. ^{137}Cs activity concentrations were 5–20 times lower in meadow soil (4–14 Bq/kg) compared to swamp and forest soil. ^{60}Co, the INPP origin radionuclide, was detected in samples only in 1996 and 2000, and the activity concentration of ^{60}Co was found to be in the range from 0.4 to 7.0 Bq/kg at the sampling ground nearest to the INPP. Average annual activity concentrations of the INPP origin ^{137}Cs and ^{60}Co in the air and depositions in the INPP region were modeled using Pasquill–Gifford equations. The modeling results of ^{137}Cs and ^{60}Co depositional load in the INPP vicinity agree with the experimentally obtained values. Our results provide the evidence that the operation of INPP did not cause any significant contamination in soil surface.

1. Introduction

Persistent presence of artificial radionuclides in the environment is a consequence of human activity in the development of nuclear weapon technology, nuclear industry and energy production. Soil is the main terrestrial ecosystem that accumulates and detains contaminants of natural and artificial origin. In the pre-Chernobyl period, the arable soil of 0–20 cm layer in Lithuania on the average contained 10 Bq/kg of ^{137}Cs and 5.8 Bq/kg of ^{90}Sr (Lubytė et al., 1997) and the ^{137}Cs concentration in the surface soil in the majority of Lithuanian localities was between 4 and 8 Bq/kg (Butkus et al., 1994). The fallout after the Chernobyl accident provided an additional load of radioactive contamination. Based on analysis of meteorological conditions in Lithuania after the Chernobyl accident in 1986 (Galvonaitė, 1989) and on the results of distribution of radionuclides in the ecosystems in Lithuania (Butkus et al., 1994; Butkus and Konstantinova, 2003; Nedvetskaitė and Filistovičius, 1992; Lukšienė and Druteikienė, 2004), the most

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contaminated after the Chernobyl accident regions were determined. Non-uniform distribution of ^{137}Cs concentration in the soil surface was observed in the majority of contaminated Lithuanian areas due to the Chernobyl accident (Butkus et al., 1994).

The accidents at Chernobyl and Fukushima NPPs have shown that although the Nuclear Power Plants are the most highly regulated industries in the world nevertheless there is a risk of radionuclide releases from nuclear industry facilities in the environment during emergency situations. Due to the high radiotoxicity of major released radionuclides, the consequences of the nuclear accident may pose a significant hazard to both ecosystems and human health. Probably, the territory adjacent to the NPP should be considered as a problematic concerning radioactive contamination because of releases of artificial radionuclides from this local source during the normal NPP operation. The INPP in Lithuania consisted of two graphite-moderated light-water cooled channel type RBMK-1500 reactors, commissioned in December 1983 and August 1987. The first RBMK-1500 reactor unit of the INPP had been stopped in 2004 and the second one was shut down on December 31, 2009. Besides described above, the environmental ecosystems in the whole territory of Lithuania were also contaminated by global fallout due to nuclear weapon testing in 1950–1980.

At present the knowledge of background activity concentrations in Lithuanian environmental systems becomes urgent due to plans to construct three new NPPs in the Baltic region in 2020–2030. The new Lithuanian nuclear power plant will be located in the vicinity of the present Ignalina NPP. In Belarus the preparative works to build Belorussian NPP-building have already started, and the NPP to be built at a distance of about 50 km from Vilnius, the capital of Lithuania. The third one is planned to be constructed in Russia Kaliningrad region, close to the Lithuanian recreation zone at the Baltic Sea. Consequently, soil samples and different environmental samples in the INPP vicinity and the entire territory should be studied to obtain the "background" information on the current radioecological situation in the country before the construction and operation of any new NPPs.

The aim of this study was to identify the impact of the INPP operation on soil radioactive contamination with γ-emitting radionuclides. For this purpose the following tasks were set up:

- to compare a contamination of the top soil layer with artificial γ-emitting radionuclides in the vicinity of the INPP with that in other regions of Lithuania;
- to analyze results of investigations around NPPs in other countries;
- to model the distribution of ^{60}Co and ^{137}Cs activity concentrations in deposition and compare modeling results with experimental values.

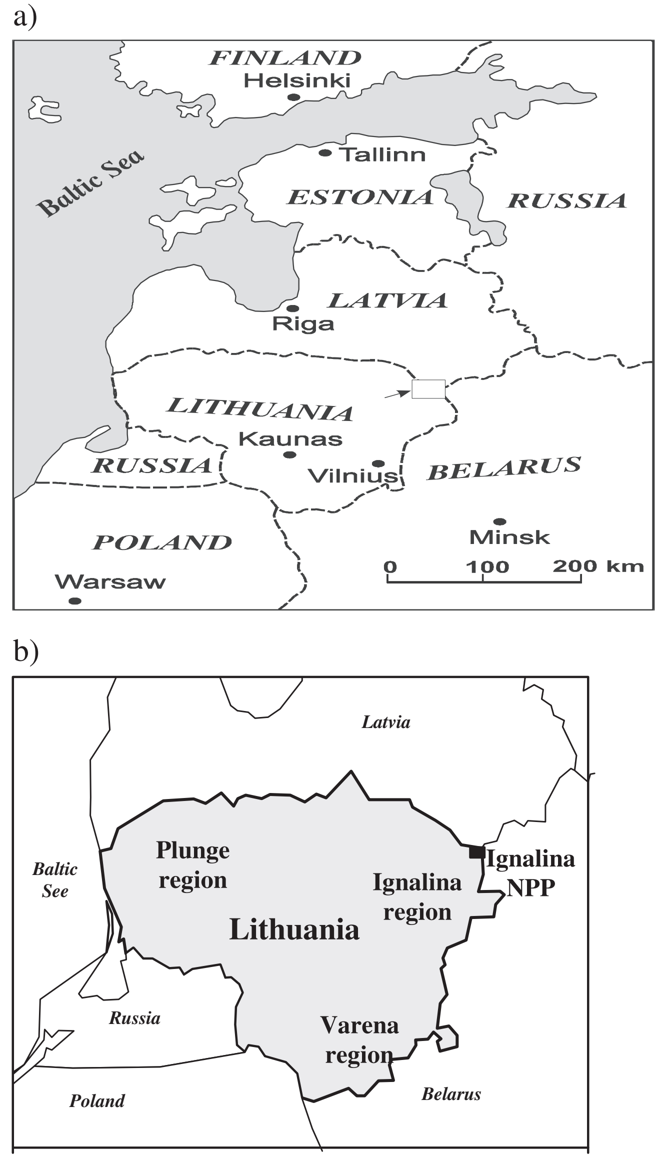

Fig. 1. The Ignalina NPP location in the Baltic region (a) and dislocation of reference grounds in Lithuania (b).

2. Materials and methods

The samples of the upper soil layer were taken and analyzed as part of the radio-ecological monitoring projects carried out in the period of 1996–2008. The start of the investigations of activity concentrations of radionuclides in surface soil in the INPP vicinity in 1996 was due to the implementation of the State Scientific Programe "Nuclear energetics and environment" (1993–1997).

2.1. Soil sampling area and γ-emitting radionuclide measurement

The reference grounds for soil sampling represent areas contaminated with artificial radionuclides from different sources due to the different human activities as explained further in the text (Fig. 1). Plungė and Varėna regions were the most contaminated regions in Lithuania after the Chernobyl accident and they are the most remote from the INPP (up to 300 km distance). Ignalina region, located at about a 30–40 km distance from the INPP, was chosen as the reference ground because according to Adliene et al. (2004), 30 km – radius area around Ignalina NPP with estimated 4.2–50.0 Bq/kg activity of ^{137}Cs in soil – belongs to the Lithuanian regions of lower contamination with ^{137}Cs from Chernobyl origin.

Based on the prevailing wind directions and difference in distance from the INPP, five reference sampling grounds of terrestrial landscape (entitled Tilžė, Grikiniškės, Vosyliškės, Šakiai–Zavisiškės, Visaginas) were chosen in the vicinity of INPP (Fig. 2).

Sampling campaigns on the top soil layer were performed using a soil sampler (inner diameter 14 cm and 5 cm height) once a year typically in June or July in 1996–2008. The top layer (0–5 cm) of forest and meadow soils (without vegetation) was sampled at the sites of habitats of specific plants (Marčiulionienė et al., 2001b); therefore, it was possible to collect soil samples in the same places with the accuracy of ±2 m. The total number of samples collected each year was approximately 48 pcs. in the basic sampling program, and 26 samples were collected additionally in 2007 and 2008. Depending on the organic matter amount that varied from 5% to 98% in samples, the weight of collected soil samples was rather different and changed from 0.268 to 1.346 kg. The soil at all sampling sites in forest showed significantly acidic reaction, pH_{KCl} values were in the range of 2.74–3.95. Collected and labeled soil samples were transported to the laboratory, then air-dried and homogenized. The weighted aliquot of the sample