IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: G V Lavrentyeva 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **487** 012010

IOP Conf. Series: Materials Science and Engineering **487** (2019) 012010 doi:10.1088/1757-899X/487/1/012010

Assessment of radiation environmental risk for the terrestrial ecosystem

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Abstract. In this work there is a detailed methodology for the assessment of the radiological ecological risk at the ecosystem level based on critical loads. Risk assessment consists of the following stages: hazard identification, identification of reference species and indicators, determination and analysis of critical loads on the basis of the dose-effect relationship, environmental risk assessment and analysis of risk functions. The experimental site is the territory, which has been exposed to radioactive contamination as a result of depressurization of the storage capacity of radioactive waste. On the basis of long-term (2010 – 2015) monitoring works, the input parameters for risk assessment were determined: the recipient of the impact is the terrestrial ecosystem; in the study of chemical and radioactive contamination of the territory, an environmental hazard factor was identified – Sr-90; the reference species - the mollusk *Fruticola fruticum* and reference indicators – the coefficient of accumulation of the Sr-90 of shells from the nettle and catalase enzymatic activity of soils. It was determined the acceptability of radiation risk for the terrestrial ecosystem on the basis of critical loads on the catalase activity of soils and unacceptability when accounting the coefficient of accumulation of Sr-90.

1. Introduction

ICRP in its publication [1] points out the need to provide direct evidence of the protection of biota. It reflects the eco-centric principle of rationing of the radiation factor. In this regard, many recent works are devoted to the development of ecological approaches to the rationing of radiation effects on ecosystems. It should be noted that there are two approaches to the regulation of environmental pollution. On the one hand, it is possible to ration the content of pollutants in environmental objects, on the other hand, the degree of transformation of the environment as a result of its contamination. One of the indicators of sustainability of ecosystem to anthropogenic impact, including radiation, is the magnitude of critical loads. Critical load is an indicator of the sensitivity of the ecosystem, which determines the maximum acceptable of contamination. The environmental risk is the final stage in estimating critical loads for ecosystems.

The aim of this work is assessment of radiation environmental risk on the basis of critical loads for the terrestrial ecosystem in the zone of influence of the radioactive waste storage facility.

The research area is the territory, which was exposed to radioactive contamination in 1998 as a result of depressurization of the storage capacity of radioactive waste [2].

2. Materials and methods

Soil, nettle nettle (*Urtíca dióica*) and terrestrial mollusk *Fruticicola fruticum* samplings were done to determine the input parameters for risk assessment. Samples were selected at 42 local controlled sites. The soil was selected by means of a specialized sampler with a set of tame soil drills by Edelman ("Eijkelkamp", The Netherlands). Samples of mollusks were sampled from plants and from soil under plants in the amount of 25-30 individuals from one local site. From the local site, the whole nettle biomass was selected.

Measurement of specific activity with preliminary radiochemical isolation of Sr-90 in samples of soil, plant, terrestrial mollusks was carried out on the scintillation β-spectrometer BETA 01C. The determination of Cs-137 in the samples was carried out by ɣ-spectrometry on the ɣ-spectrometer Accuspec, Canberra Industries. The concentration of heavy metals was determined by the method of atomic emission with inductively coupled plasma (ICP AES Varian Liberty II). The specific activity of Sr-90, Cs-137 and the concentration of heavy metals in each sample were determined in triplicate.

The activity of catalase activity was carried out according to the amount of molecular oxygen released per gram of soil per minute.

The statistical processing of the experimental data was carried out using the program R.

3. Results and discussion

The methodology for environmental risk assessment consists of the following stages: hazard identification, identification of reference species and indicators, determination and analysis of critical loads on the basis of the dose-effect relationship, environmental risk assessment and analysis of risk functions.

3.1. Hazard identification

This stage of risk assessment is aimed at determining the recipient ecosystem, the impact indicators on the ecosystem and the assessment of their values. The aquatic and terrestrial ecosystem were considered as possible recipients. The chemical pollution of the ecosystems (K, Na, Ca, Mg, Sr, Al, Fe, Mn, Zn, Ni, Cu, Cr, Co, Cd, Pb) and radioactive contamination (Sr-90, Cs-137) were selected as impact indicators. It has been established that chemical pollution cannot be considered as indicator of impact on ecosystems, because there is no excess of standards.

Analysis of data from 1998 to 2014 of radioecological monitoring of contamination of Cs-137 and Sr-90 of water objects shows that the aquatic ecosystem cannot be an exposure recipient [3]. It is a local contamination of soil with the radionuclide Cs-137 and the radionuclide is mainly (50-53%) in a fixed form of location. Therefore, Cs-137 cannot be an impact indicator in assessing environmental risk. However, radioactive contamination of soil by Sr-90 was detected throughout the area with its specific activity from a control value of 19.7±11.1 to 5203±89 Bq/kg. The radionuclide is in the soil at 69-83% in its exchange form. Thus, the terrestrial ecosystem is the recipient of the impact and Sr-90 is the impact factor. The area of exposure is determined to be 0.54 hectares.

3.2. Identification of reference species and indicators

To assess the radiation environmental risk, we propose to use the term referent indicator – radiation-induced effect in biota representatives at the level of an individual, species, population or ecosystem as a whole, which can be described by a reliable model having a threshold value. The threshold value will act as a critical load in the risk assessment.

The terrestrial mollusk Fruticicola fruticum is justified as a reference species, the reference indicators are the coefficient of accumulation of the Sr-90 of shells from the nettle and catalase enzymatic activity of soils. It should be noted that mollusks have long been recognized as a convenient bioindication for environmental pollution due to high accumulation rates of heavy metals and radionuclides, widespread prevalence, ease of identification, short life cycle [4, 5]. In this case, shells of terrestrial mollusks contain about 95-99% calcium carbonate, so the shell of the mollusk is a high accumulation of strontium – as a chemical analogue of calcium.

It is known that radioactive contamination of soil can disrupt its homeostasis and lead to degradation. It causes a change in the functional and biochemical activity of soil microorganisms. At the same time, many years of research have established a high efficiency of environmental soil diagnostics through biochemical methods, among which the determination of enzyme activity is the most promising.

3.3. Determination and analysis of critical loads on the basis of the dose-effect relationship
The input parameters for the determination of critical loads are the specific activity of Sr-90 in soil (19.7±11.1 – 5203±89 Bq/kg), nettle (22.3±13.4 – 10596±195 Bq/kg), shells of mollusks (76±11 – 17640±2646 Bq/kg).

It was found that the change in catalase activity can be described by a reliable model with a threshold value of 21.3±5.9 $cm^3O_2/g*min$ [6]. The input parameter for calculating the risk is the critical load of 1858 Bq/kg of Sr-90 in the soil (figure 1).

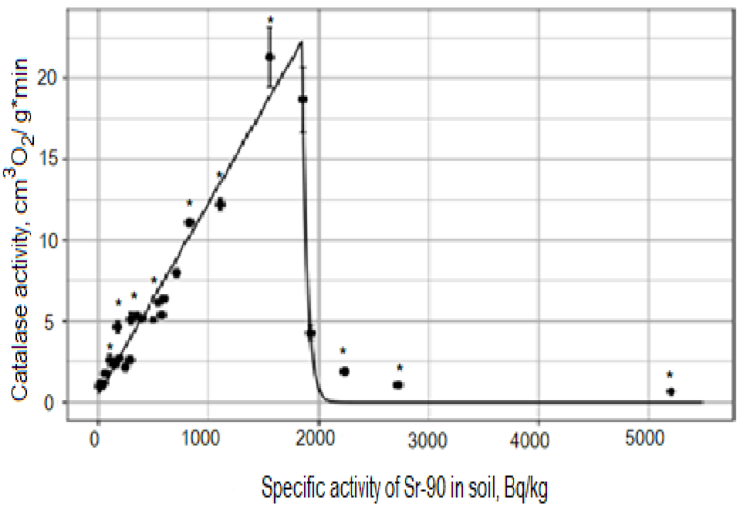

Figure 1. Change in catalase activity with increasing Sr-90 content in soil.

The analysis of the coefficient of accumulation of Sr-90 by shells of mollusks makes it possible to reveal a significant change in the indicator in the range of variation of the specific activity of Sr-90 in the nettles from 22 to 10.5 kBq/kg (figure 2). The decrease of the indicator is described by a power law dependence. The specific radionuclide activity in the nettle 2138 Bq/kg is the critical load.

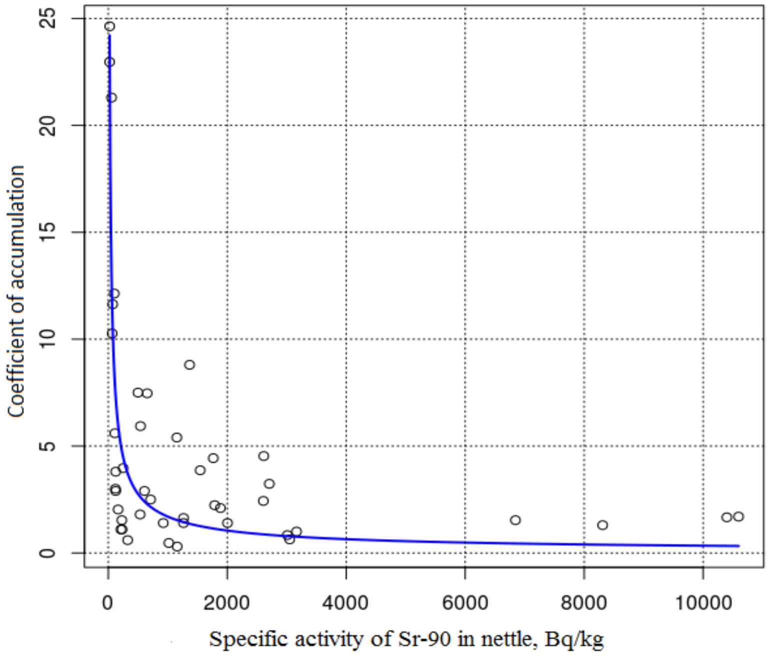

Figure 2. Change in accumulation coefficient.

3.4. Environmental risk assessment and analysis of risk functions

The environmental risk assessment was carried out through GIS-technologies. An acceptable value for the assessment of ecosystem risk is the 95% protection of the ecosystem: an acceptable risk is considered to be that the area with exceedance of critical loads does not exceed 5% of the total area [7].

The excess of the critical loads was calculated as the difference between the specific activity of Sr-90 in the soil (nettle) of the local area and the critical load. After calculating exceedances of critical loads for each local area, program R was used to determine the proportion of the area with excess of critical loads.

Analysis of calculation of exceedance of critical loads shows that the area characterized by an exceedance of the critical load for catalase activity is 0.21%, which does not exceed an acceptable value of 5% (figure 3). Environmental risk is characterized as acceptable.

The analysis the corresponding experimental data for coefficient of accumulation of Sr-90 showed an excess of an acceptable value and the share of the area exceeding the critical load was 5.75% (figure 4). Thus, the risk of the storage impact on the terrestrial ecosystem should be characterized as unacceptable.

The values of areas with exceedance of critical loads allow to proceed to determine the probability of development of negative changes in the ecosystem on the basis of analysis of risk functions. This analysis shows that the risk of exceeding the critical load taking into account the catalase activity of the soil is approaching 0, and taking into account the coefficient of accumulation Sr-90 exceeds 5%, which confirms the risk assessment through GIS mapping.

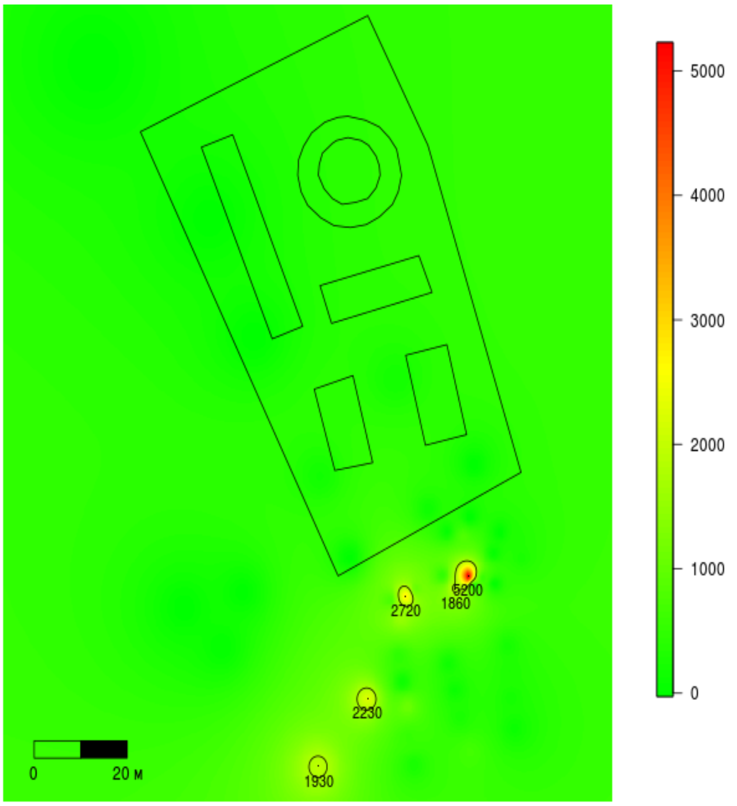

Figure 3. GIS-map for critical loads of catalase soil activity.

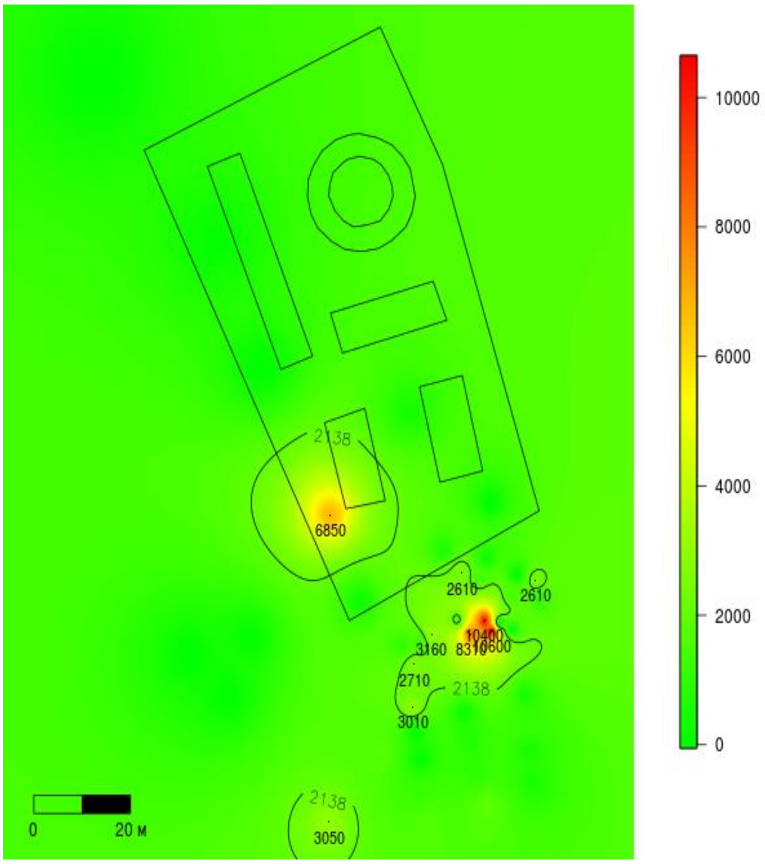

Figure 4. GIS map for critical loads on the factor of accumulation Sr-90

IOP Conf. Series: Materials Science and Engineering **487** (2019) 012010 doi:10.1088/1757-899X/487/1/012010

4. Conclusions

In this paper, it was assessed the radiation environmental risk for the terrestrial ecosystem and was considered the methodology of risk assessment based on critical loads. On the basis of an experiment in natural conditions it was determined the acceptability of radiation risk for the terrestrial ecosystem on the basis of critical loads on the catalase activity of soils. However, the risk is unacceptable when it is evaluated on the basis of an analysis of the coefficient of accumulation. It should be noted that the unacceptability of the risk in this case is characterized by exceeding the value of 5% by 0.75% from the possible 95%. It approximates the acceptability of risk, if we take into consideration uncertainty in risk assessment.

With considering the assessment of radiation environmental risk the radioactive waste storage facility can be considered an environmentally safe, even if reservoir depressurization is taken into account.

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