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ON THE POSSIBILITY OF DETERMINING ENVIRONMENTALLY SAFE NPP EMISSIONS USING THE RADIATION CAPACITY OF LANDSCAPE COMPONENTS

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Using the radiation capacity model of landscape components located in the zone of influence of the NPP and the results of the calculation of the radiation risk from human and terrestrial biota exposure, an approach was developed to determine the amount of radionuclide emission from the NPP that ensures the safe existence of terrestrial biota (ecological regulation) and humans (hygienic rationing). A conservative calculation performed for the actual emission of ^{137}Cs from the Zaporizhzhya NPP showed that an ecologically safe level of exposure to biota organisms (mammals) located in the studied territory of the plant's monitoring zone will be ensured with an emission from the NPP almost an order of magnitude greater than for humans.

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INTRODUCTION

The main trend in the relationship between man and the natural environment at the current stage is to create conditions that limit the anthropogenic impact on the components of both natural and artificial, for example, agricultural ecosystems in order to support their sustainable functioning.

To a large extent, this refers to the situation of exposure of humans and the natural environment to ionizing radiation, the sources of which are nuclear installations, in particular nuclear power plants (NPP).

Until now, systems of radiation protection of a person and the surrounding natural environment are built on the anthropocentric principle, the meaning of which is that if a person is protected from the action of ionizing radiation, then the surrounding natural environment is also protected (ICRP Publication 60, 1990) [1].

ICRP Publication 60 deals with the situation of planned exposure. It is believed that radiation protection of people is ensured in this case, and the regulations necessary for the protection of the population should ensure the protection of the biota and the natural environment as a whole.

In 2007, ICRP Publication 103 [2] was published, which already deals with all possible exposure situations: planned, emergency, existing. In these situations, to ensure a sufficient level of radiation protection of the environment, it is suggested to apply the concept of "conditional" (reference) animals and plants. It is assumed that a set of reference biological species should play the same role in the biota radiation protection system as the concept of "reference (standard) human" in the human radiation protection system. Thus, in recent years there has been a change in views on the strategy of ensuring radiation safety of humans and the natural environment in the direction of strengthening ecocentric principles [3, 4].

If the correctness of the application of radiation-hygienic rationing is not in doubt among specialists and its results have long been used in practice, then approaches to radiation-ecological (hereinafter simply "ecological") rationing began to be discussed relatively recently.

There are different approaches to environmental regulation of the radiation impact of radiation-hazardous objects, in particular NPP, on the natural environment. For example, as a quantitative criterion, with the help of which such standardization can be carried out, it is proposed to determine the concentration of a pollutant of the natural environment, at which changes are manifested in the vital activity of the biogeocenosis or in its critical elements, that is, the state of ecosystem homeostasis is disturbed [5], or the model of radiation capacity (radiocapacity) components of the natural environment, which acts as a measure of dangerous accumulation of radioactive pollution in them [6-11].

The model of radiocapacity proposed by the authors of the above-mentioned works solves the task of environmental regulation by determining the response of biota to dose loads on the ecosystem.

In our opinion, the radiocapacity model can be equally applied to both hygienic and environmental regulation.

The authors of this article believe that the radioactivity is an objective characteristic of the ecosystem or its components, regardless of the subjectively applied estimates, which act as a measure of the accumulation of radionuclides in the biota. In contrast to radiocapacity, which, for example, in works [6, 11], is considered as a function of the concentration of a radioactive pollutant in a specific place ("point") of an ecosystem, the radiocapacity of an ecosystem in our understanding should take into account its dimensions and allow describing the migration of a radionuclide from the emission source (discharge) into the ecosystem and between its components.

This article proposes a model of the radiation capacity of the landscape and its components.

The authors interpret the concept of radiation capacity of the landscape as follows [13]:

The capacity of the landscape is the activity of radionuclides (RNs) accumulated during the time during which the content of RNs in it will reach equilibrium with their content in the combined components that make up this landscape, with the

migration parameters of RNs characteristic of the landscape components.

In practice, it is convenient to represent the radiation capacity of the landscape (R_{ki}, Bq) as a sum of integrals:

$$R_{ki} = \sum_{j} \int_{S} K_{ij}\, q_{ij}\, dS,$$

where the summation is carried out over all j-th ways of the entry of RN into the k-th landscape component, and the integration is taken over the entire territory (**S**, m^2) affected by the i-th source; $\mathbf{K_{ij}}$, m/year – the coefficient that determines the rate of migration of RN in the landscape component; $\mathbf{q_{ij}}$ is the volumetric activity of RN formed in the landscape component from the i-th source along the j-th path (Bq/m^3) during the time during which equilibrium occurs.

The above formula makes it possible to simplify the calculation of the radiation capacity of the landscape by presenting it in the form of a linear combination of the radiation capacities of its individual components.

The point of the above definition of radiative capacity applied to the landscape and its component is that unlike the concentration and definitions of radiative capacity, proposed by other authors, radiocapacity takes into account the size and properties of landscape components and allows taking into account the scale of RNs migration and their maximum accumulation in them, which can be compared with the level of negative impact of pollutants on the elements of the biocenosis (suppression, damage, destruction, succession).

The purpose of this work is to apply the radiation capacity model of the studied landscape component to determine the amount of environmentally safe emissions of a regularly operating nuclear power plant.

To achieve this goal, an approach has been developed to calculate the radiation capacity of the landscape component of the NPP location, which is the basis for determining the radiation risk of external exposure to humans and biota and assessing the environmentally safe emissions of the NPP.

1. DESCRIPTION OF THE BASIC MATERIAL

1.1. CALCULATION OF THE RADIATION CAPACITY OF THE LANDSCAPE COMPONENT

The main method of calculating the radiation capacity is mathematical modeling of the processes of redistribution of radionuclides, which is based on the experimental study of the migration of RNs in landscapes and the zoning of the territory, taking into account their landscape and geochemical features.

In paper [14], a simplified example showed how the proposed approach to determining the radiation capacity of the landscape component of the location of a real NPP can be implemented in practice and how to use it to determine the level of NPP radiation exposure (dose load) on the population.

The radiation capacity was determined for the site, which is located in an open area in the supervised area of the Zaporizhzhya NPP (ZNPP) (Fig.1).

The site was selected based on the results of the radio-ecological monitoring (REM) of the ZNPP, given in paper [13].

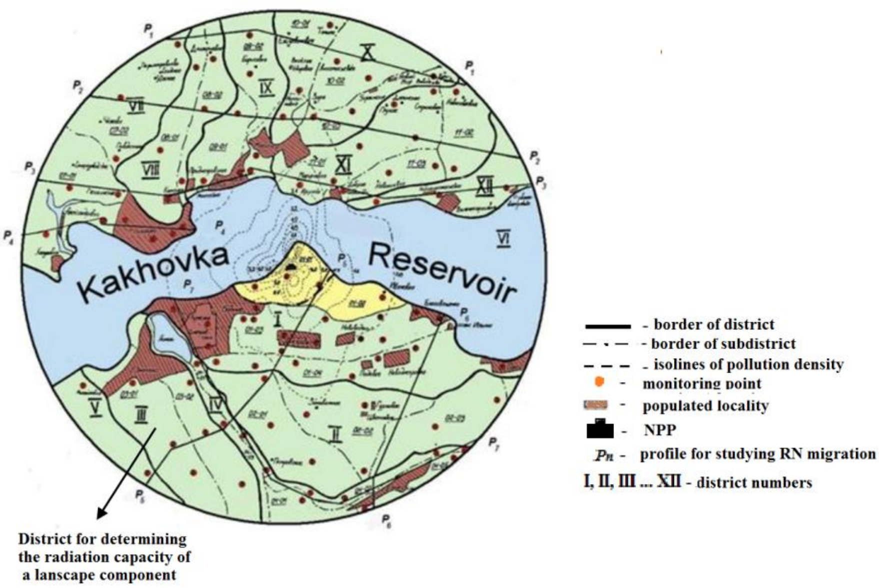

Fig. 1. Zoning map of the surveillance zone Zaporizhzhya NPP and the location of the site for determining the radiation capacity

The basic method of REM is the method of special structuring of the territory of the NPP supervised area, which is based on zoning, which consists in dividing the territory into districts that are homogeneous in terms of landscape and geochemical characteristics.

The studied area belongs to one of the districts (III), which was selected during the zoning of the supervised area of the ZNPP. It consists mainly of ordinary low-humus black soil, with a minimum of vegetation cover. Therefore, the selected soil was the landscape component for which the radiation capacity was determined.

The calculation of the radiocapacity of the site was carried out in relation to radionuclide ^{137}Cs, which is radiologically dangerous from the point of view of impact on humans and biota, which is emitted from the NPP during normal operation (planned exposure situation).

To simplify the calculations, it was assumed that during the years of operation of the ZNPP (> 30 years), the flow of ^{137}Cs to the soil was approximately constant and uniform (in reality, it is approximately fulfilled), which contributed to the establishment of a balance between deposition and absorption of RN by the effective soil layer. In this case, the concentration (volumetric activity) of ^{137}Cs, which is equal to $1.25 \cdot 10^3$ Bq/m^3, is formed in the volume of the soil layer in an average year. With an area of district III of $1.2 \cdot 10^8$ m^2, the radiocapacity (activity) of its soil layer in relation to ^{137}Cs, which will be formed in a year, will be approximately 10^9 Bq, and the maximum radiocapacity of the soil layer with a thickness of ≈ 0.1 m, in which station cesium is mainly accumulated, will be equal to ≈ 10^{10} Bq.

In the same paper [14], based on data on soil radiocapacity, the dose rate of external radiation for the population living in the territory of the selected area was determined, due to γ – the activity of the radionuclide ^{137}Cs, accumulated over a year in the surface layer of the soil. The value of the power of the absorbed dose is obtained, which is equal to 40.0 μGy/year, which coincides with the RSSU-97 quota of the limit of the equivalent dose of exposure to persons of category B due to NPP emissions (40 μSv/year). **This means that the radiation hygiene standard for the group of persons of category B living in the studied territory of the ZNPP supervised area is fulfilled.**

The following general conclusion can be drawn from this: knowing the radiation capacity of all landscape components that are in the NPP supervised area, it is possible to determine the level of maximum accumulation of radionuclides that is safe for humans in each area around the NPP that is operating in normal mode that is, carrying out radiation-hygienic regulation.

1.2. DETERMINATION OF THE RADIATION RISK OF EXTERNAL IRRADIATION TO HUMANS AND BIOTA

The possibility of determining the **radiation risk of external human** exposure using the radiation capacity of landscape components is illustrated in [14].

The calculation of the lifetime individual radiation risk from external radiation from soil contaminated with stationary ^{137}Cs was performed for the population living in the territory of the ZNPP supervised area, which was considered above when determining the radiation capacity of the landscape component. The calculation showed that the individual radiation risk from external exposure for the population living on the territory of the site considered in the article is equal to $2.6 \cdot 10^{-5}$ year^{-1}. This value does not exceed the value of the individual lifetime risk for the population under the conditions of normal operation of the NPP, given in RSSU-97 ($5.0 \cdot 10^{-5}$).

Therefore, knowing the radiation capacity of the landscape component, it is possible to determine not only the level of maximum accumulation of radionuclides in the components of the natural environment, which are in the zone of influence of a regularly operating NPP, but also **makes it possible to determine the radiation risk for the population** living in the territory around the radiation-hazardous environment object.

Let's assess **the radiation risk from external irradiation of terrestrial biota** located on the territory of the studied area of the ZNPP supervised area. We will assume that such a risk is also formed due to soil contamination with ^{137}Cs. The magnitude of the risk will be assessed based on previously obtained data on radiocapacity. As a representative object of the biota, we will choose rodents (mice, moles), which belong to mammals and vertebrates.

In accordance with the recommendations of ICRP Publication 108 [15], the radiation risk to biota is estimated using the hazard ratio according to the formula:

$$R_j = D_j \,/\, RD,$$

where D_j – power of the irradiation dose of the j-th representative object of biota, Gy/day (in our case, as well as for a person, it is 40 μGy/year – the value obtained using radiocapacity data); RD is the control level of ecologically safe irradiation of biota organisms, equal to 0.001 Gy/day for mammals, vertebrates and pine.

Substituting the numerical values for the coefficients into the formula, we obtain that the radiation risk of terrestrial biota from external irradiation caused by the radionuclide ^{137}Cs contained in the soil is equal to:

$$R_j = \frac{40\ \mu\text{Gy/year}}{0.001\ \text{Gy/day}} = 1.1 \cdot 10^{-4}\ \text{1/year}.$$

Comparing the obtained value of the radiation risk for biota with the value of the individual radiation risk for a person under the conditions of normal operation of the NPP, we can see **that with the same RN emission, the value of the radiation risk for the biota is an order of magnitude higher. This in this case means that a person is more radiosensitive than the biota under study.**

1.3. ASSESSMENT OF ENVIRONMENTALLY SAFE EMISSIONS OF NPP

On the basis of data on the radiation risk of humans and biota, obtained with the help of the model of the radiation capacity of the landscape component, we will estimate the amount of ecologically safe emissions of the nuclear power plant, i.e. such emissions that do not negatively affect the vital activity of the biota as a component of the ecosystem or its landscape component.

The calculation of ecologically safe NPP emissions for terrestrial biota will be performed on the basis of the assumption that the ratio of radiation risks from exposure to humans and biota is directly proportional to the ratio of emissions that create these risks, and they are proportional to the ratio of radiosensitivity of humans and biota.

Thus, we assume that:

$$\frac{Rext}{Rj} \approx \frac{Aext}{Aj} \propto K_i,$$

where R_{ext} is the radiation risk of external exposure of the population. In our case, $R_{ext} \approx 10^{-5}$ 1/year;

- R_j – radiation risk (danger coefficient) of external irradiation of a representative species of biota. In our case, $R_j \approx 10^{-4}$ 1/year;
- A_j is the annual emission of ^{137}Cs from the nuclear power plant, which causes danger (risk) to biota;
- A_{ext} is the annual emission of ^{137}Cs from a nuclear power plant causing a human risk corresponding to R_{ext}. In our case, $A_{ext} \approx 10^7$ Bq/year, that is, equal to the real average emission of ^{137}Cs from the ZNPP for the years 2008–2018 [16];
- K_i is a coefficient that shows how much the radiosensitivity of a person differs from the radiosensitivity of a selected species of biota when exposed to the i-th radionuclide.

From here:

$$\frac{10^{-5}\ 1/\text{year}}{10^{-4}\ 1/\text{year}} \approx \frac{10^7\ \text{Bg/year}}{A_j} \longrightarrow A_j \approx 10^8\ \text{Bg/year}.$$

This means that the annual emission of ^{137}Cs from the NPP, which will cause a risk to biota (the level of ecologically safe exposure of biota organisms is equal to 0.001 Gy/day for mammals) is about an order of magnitude higher than the level of real emissions that cause a risk to humans.

Thus, the calculation performed for the actual emission of ^{137}Cs from the Zaporizhzhya NPP showed that the ecologically safe level of exposure of terrestrial biota organisms (mammals) located on the studied territory in the supervised area of the station will be ensured when the emission from the NPP is almost an order of magnitude greater than for a person.

If further studies for different types of biota, different radionuclides, different components of the landscape confirm the obtained result, then this can become another proof that **in the situation of planned irradiation** (full-time operation of NPP), the anthropocentric principle of anti-radiation protection can also be applied to the protection of biota, that is, testify to the absence of grounds for abandoning the hygienic principle of radiation protection in favor of the ecological one. However, in our opinion, such a conclusion is not indisputable for situations of emergency and existing exposure and needs confirmation.

The approaches to determining the radiation capacity of a landscape component, the radiation risk to humans and biota, as well as the ecologically safe emission of a NPP, and the obtained results are presented in the article and are preliminary, illustrative in nature, but, nevertheless, they are presented here to demonstrate one of the possible ways of practical implementation of the recommendations of the ICRP Publication 103 regarding the application of the ecocentric principle of ensuring radiation safety of the natural environment.

CONCLUSIONS

1. A model of the radiation capacity of a landscape component is proposed, which differs from the method of determining concentrations and models of radiation capacity of other authors in that it takes into account the dimensions and properties of the landscape component and allows taking into account the scale of migration of radionuclides between components that are components of the landscape as a whole.

2. It is shown that, knowing the radiation capacity of landscape components, it is possible to determine the level of maximum accumulation of radionuclides in the components of the ecosystem that is in the zone of influence of the nuclear power plant, and, comparing it with the existing standards of radiation exposure to these components, to draw a conclusion about the need to apply one or another anti-radiation protection measures.

3. Information on the radiation capacity also allows obtaining the value of the radiation risk from external exposure for the population and terrestrial biota located in the territory of the NPP supervised area.

4. Applying the model of the radiation capacity of the landscape components located in the zone of influence of the NPP, and the data for calculating the radiation risk from the exposure of humans and terrestrial biota, an approach was developed to determine the emission of radionuclides from the NPP, which ensures the safe existence of terrestrial biota and humans.

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ПРО МОЖЛИВІСТЬ ВИЗНАЧЕННЯ ЕКОЛОГІЧНО БЕЗПЕЧНИХ ВИКИДІВ АЕС ЗА ДОПОМОГОЮ РАДІАЦІЙНОЇ ЄМНОСТІ ЛАНДШАФТНИХ КОМПОНЕНТІВ

С.В. Барбашев

За допомогою моделі радіаційної ємності ландшафтних компонентів, що знаходяться в зоні впливу АЕС, та результатів розрахунку радіаційного ризику від опромінення людини та наземної біоти розроблено підхід до визначення величини такого викиду радіонуклідів з АЕС, який забезпечує безпечне існування наземної біоти (екологічне нормування) і людини (гігієнічне нормування). Консервативний розрахунок, виконаний для реального викиду ^{137}Cs із Запорізької АЕС, показав, що екологічно безпечний рівень опромінення організмів біоти (ссавців), які знаходяться на досліджуваній території зони спостереження станції, буде забезпечуватися при викиді з АЕС майже на порядок більший, ніж для людини.