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Ecological Standartization of Dangerous Environmental Factors and Radiocapacity of Ecosystems

Запропоновано використовувати зміни параметрів радіоємності як випереджаючих показників її стану та реакцій. Радіоємність визначається як гранична кількість радіонуклідів, котра може депонуватися у біоті екосистеми без шкоди для неї. У моделях було показано, що суттєвий вплив на екосистему супроводжується оберненими або необерненими змінами параметрів – факторів радіоємності біотичних та абіотичних компонентів екосистеми. Було показано, що фактори радіоємності можна використовувати як показники стану і благополуччя екосистем при різних хімічних (важкі метали) та фізичних (гама-радіація) впливах.

It is offered to use change of parameters of radiocapacity of an ecosystem as an advanced parameter of its condition and reactings. The radiocapacity is determined, as the limited number of radionuclides, which one can be deposited by a biota of an ecosystem without a harm for itself. In models was rotined, that the essential effect on an ecosystem is accompanied by reversible or irreciprocal changes of parameters - factors of radiocapacity biotic and abiotic of components of an ecosystem. Was rotined, that the factors of radiocapacity can be used as parameters of a condition and health of ecosystems at different chemical (hard metals) and physical (gamma-radiation) effects.

1. Introduction

In the case of radionuclides releases and disposal into the environment it is important to assess the maximum admissible values of input of radionuclides into an ecosystem, where there are not yet noticeable biological changes as the result of ionising radiation. The natural boundary for the estimation of maximum permissible disposal of radionuclides into ecosystems is the dose commitment or the annual absorbed dose rate. G. Polikarpov and V. Tsytsugina [1] have proposed a scale of dose commitments on ecosystems consisting of four basic dose limits. From the given scale it follows that the real dose limit for release and accidental "disposal" of radionuclides in ecosystems and their components is the dose rate that exceeds 0.4 Gy y^{-1} for terrestrial animals and 4 Gy y^{-1} for hydrobionts and terrestrial plants. At such values of dose rates it is possible to expect the beginning of the development of evident ecological effects. Dose commitments from α-, β-, γ-radiation are not difficult to assess for the radionuclides composition of the Kyshtym and the Chernobyl releases. According to our assessments the calculated total dose (estimation by B. Amiro [2]) equalling from 0.4 Gy y^{-1} to 4 Gy y^{-1} corresponds to a concentration of ^{137}Cs of about 100-1000 kBq l^{-1} (kg^{-1}) in the ecosystem or in its elements (terrestrial plants and hydrobionts). The total dose 4 Gy y^{-1} corresponds to a ^{137}Cs concentration of about 1000 kBq l^{-1} (kg^{-1}) for the fresh water ecosystem. The maximum permissible releases of radionuclides into the ecosystems could be assessed on the basis of the above-mentioned models and equations, using an assessment of maximum permissible concentration of radionuclides in the components of the ecosystem.

2.Theory of Radiocapacity of Ecosystems

2.1. Definition and models of radiocapacity

Radiocapacity is the maximum amount of radionuclides, which can be contained, in a given ecosystem, without damaging the main trophic properties, i.e. productivity, conditioning and reliability. Special attention will be given to the concept of the radiocapacity factor. Methods of calculation of the radiocapacity of water and overland ecosystems, and also agrocenoses and factors stipulating these magnitudes will be considered.

The measure of radiocapacity and also of the radiocapacity factor is convenient and universal, and reflects the main properties of ecosystems. Using mathematical means of stationary and dynamic models is quite simple and is suitable for ecosystems of any complexity. This approach allows acceptance of the important prognostic evaluations of the quality and condition of ecosystems .

The fundamental property of ecosystems is their ability to accumulate and to keep radionuclides inside themselves. The radiocapacity factor could serve as the measure of this property. This measure is most conveniently characterized by the ratio of the amount of radioactivity strongly sorbed by components of the ecosystem, to the whole radioactivity, which is contained in the given ecosystem.

2.2. Model of radiocapacity of nonflow freshwater reservoir [3]

A conclusion that could be drawn from equation (1) is very important for the calculation of the radiocapacity factor of a reservoir (F).

$$F = \frac{kh}{H + kh} \qquad (1)$$

The ratio (1) shows which amount of radionuclides contained in the reservoir is the part of bottom sedimentations (F), and which is the part of water (1-F). F can be defined as the radiocapacity factor of a reservoir.

2.2.1. Modelling of the role of biota as repository of radionuclide accumulation

Radionuclides concentration reaches a maximum value within a few minutes in zooplankton, a few days in multicellular algae, and a few months in fishes. An average total accumulation factor of radionuclides by these organisms is a constant magnitude and equals to about 10^3 [4].

Which is the role of flora and fauna of reservoirs in radionuclides distribution?

We should consider a role of biota as repository of radionuclides in water-cooling pond at a significant concentration of biota. It is possible to do this as follows.

Let the concentration of biota in a unit of reservoir water volume be P (g m^{-3}), and let the average accumulation factor of radionuclides by biota be K. Then the combined content of radionuclides in the biota of a reservoir will be:

$$A_b = P \cdot C \cdot K \cdot S \cdot H \qquad (2)$$

(A_b = Accumulation in biota).

The radiocapacity factor for the biotic component of a reservoir can be evaluated by using the following equation [5].

$$F_b = \frac{PKH}{(H + kh + PKH)}. \qquad (3)$$

Let us for an example calculate Fb for a real situation, when P makes 10 g m^{-3} of water with an average accumulation factor K = 10^4, an average depth of reservoir H = 6 m, h = 0.1 m, k = 800. We shall obtain a radiocapacity value Fb close to 0.9, when 90% of radionuclides arriving into the reservoir reach the biomass of the biota. It is necessary to take this into consideration, in a range of real situations in reservoirs or in separate rising zones of reservoirs where high concentration of biota are recorded.

3. Ecological Standardization of Permissible Radionuclide Pollutions of Ecosystems on the Basis of Theory of Radiocapacity

3.1. Problems of ecosystem ecological standardization [6]

In the case of radionuclide releases and disposal into the environment it is important to assess the maximum admissible values of income of radionuclides into an ecosystem, where there are not yet noticeable biological changes as the result of ionizing radiation.

The natural boundary for the estimation of maximum permissible disposal of radionuclides into ecosystems is the dose commitment or the annual absorbed dose rate. G. Polikarpov and

V. Tsytsugina have proposed a scale of dose commitments on ecosystems consisting of four basic dose limits [1], which is presented in Table 1.

Table 1

The scale of dose commitments onto ecosystems [1]

ZONE	ABSORBED DOSE RATE ($Gy\ y^{-1}$)
Zone of radiation well-being*	< 0.001-0.005
Zone of physiological masking**	0.005-0.05
Zone of ecological masking:	
for terrestrial animals	0.05-0.4
for hydrobionts and terrestrial land plants	0.05-4
Zone of evident ecological changes:	
Dramatic:	
for terrestrial animals	>> 0,4
for hydrobionts and terrestrial plants	>> 4
Catastrophic:	
animals and plants	>> 100

* - 0.001 $Gy\ y^{-1}$ is the dose limit for human population;
** - 0.020 $Gy\ y^{-1}$ is the dose limit of professional irradiation during normal practical work.

From the given scale follows that the real dose limit for release and accidental "disposal" of radionuclides in ecosystems and their components is the dose rate that exceeds 0.4 $Gy\ y^{-1}$ for terrestrial animals and 4 $Gy\ y^{-1}$ for hydrobionts and terrestrial plants. At those dose rates values it is possible to anticipate the beginning of development of visible ecological effects in ecosystems. Dose commitments from α, β-, γ-radiation are not difficult to assess for the radionuclides composition of the Kyshtym and the Chernobyl releases. According to our assessments the calculated total dose (estimation by B. Amiro [2]) being between 0.4 $Gy\ y^{-1}$ to 4 $Gy\ y^{-1}$ corresponds to a concentration of ^{137}Cs of about 64-640 $kBq\ l^{-1}$ (kg^{-1}) in the ecosystem or in its elements (terrestrial plants and hydrobionts). The total dose 0.4 $Gy\ y^{-1}$ corresponds to a ^{137}Cs concentration of about 64 $kBq\ l^{-1}$ (kg^{-1}) for an ecosystem with terrestrial animals.

3.2. Assessment of permissible dumping and self-disposal of radionuclides in a freshwater reservoir

For a freshwater reservoir the equation for the evaluation of the biocenosis radiocapacity factor in the water column is represented by formula (3).

Where p is the hydrobiont a biomass in water (a value of biomass from 1 to 10 $g\ m^{-3}$ is accepted as reasonable),then K_b is the concentration factor of water body biocenosis and its components, which may reach 1000 to 100000 units.

In this case, F_b can range from the small value 0.05 up to a very large radiocapacity value 0.97, where practically all radionuclides are concentrated in the biotic component of a water body.

The maximum permissible releases of radionuclides into the ecosystems could be assessed on the basis of the above-mentioned models and equations on the basis of an appraisal of the maximum permissible concentration of radionuclides in the components of the ecosystem.

1. For benthos of bottom sediments of a freshwater water body, the maximum permissible release of radionuclides in a water body (N_k) should not exceed:

$$\frac{N_k}{N_b} = \frac{hK_b(1-F)}{HkF} \qquad N_k < \frac{LhS}{kF} \qquad (4)$$

Where L is the limit of concentration of radionuclides in the aquatic population 640 kBq kg^{-1}, S is the surface area of a water body (the remaining labels were mentioned above.).

2. For the water column population (pleuston, neuston, plankton, nekton) the maximum permissible releases of radionuclides (N_b) should not exceed:

$$N_b < \frac{LHS}{K_b(1-F)} \ , \qquad (5)$$

where the labels of equations (1, 2, 3) are used. For a specific freshwater water body, where S=2 km^2, H=4 m, K_b=1000, F=0.7, the maximum permissible release of radionuclides is N_b<17.1 TBq in the water of the whole water body. At the same time the maximum permissible release of radionuclides into a water body for its benthos was estimated using equation (4) N_k< 0,18 TBq. This magnitude is 70 times less than the permissible release of radionuclides, which was assessed for the population of the water column of a water body.

In general, the ratio of assessments of maximum permissible releases of radionuclides into a water body is determined by the following equation through two critical links (population of water column and benthos):

. (6)

3. Similar evaluations of maximum permissible releases of radionuclides can be carried out also for other types of ecosystems. Particularly, in a system of cascades of reservoirs (such as the Dnieper cascade), the first reservoir (the Kiev reservoir) is critical for the dose commitment. In bottom sediments of the upper part of Kiev reservoir, the levels of radionuclide content in bottom sediments reach about 370 kBq kg^{-1} and more. In fact, this means that at the upper part of the reservoir the level of effective release of radionuclides reaches the maximum permissible value. In the population of benthos, it is therefore possible to expect noticeable ecological consequences. The theoretical calculated maximum permissible release of radionuclides in the Kiev reservoir is estimated to be a total of 83 TBq, while the real content of ^{137}Cs in bottom sediments is estimated on location measurements at a 200 TBq. This significantly exceeds the maximum permissible concentration [7].

4. In marine ecosystems, the bioproductivity develops mainly in shallow coastal water. On an average concentration 10 g m^{-3} of biota in water forms, the radiocapacity reaches 0.9-0.99. In that case, the release of large amounts of water with radionuclide content of 1.2-12 kBq l^{-1} can result in radionuclide contamination of the community up to 115 kBq kg^{-1}. This is higher than an ecological permissible level.

3.3. Assessment of maximum permissible releases and disposal of radionuclides in slope ecosystems

The developed prime model of an evaluation of slope ecosystem radiocapacity permits assessment of dynamics, time and place of expected concentration of radionuclides in some elements of the slope ecosystem. The factor of radiocapacity of the slope ecosystem may be assessed by the equation in paper [6].

Where, P_i is the probability of a flow of radionuclides from an appropriate element of the slope ecosystem in a year. P_1 = flow from forest ecosystem. P_2 = flow from stony area. P_3 = flow from meadow ecosystem, P_4 = from terrace in a lake.

As an example of a slope ecosystem, the simplest version: Forest ⇒ Stony area ⇒ Meadow ⇒ Terrace ⇒ Lake was selected. The computing curves in dynamics of long-lived radionuclides redistribution in such a model of ecosystem are represented in Fig.1. The initial contamination of the forest was 3.7 TBq. (For the sake of simplicity radioactive decay was not taken into consideration).

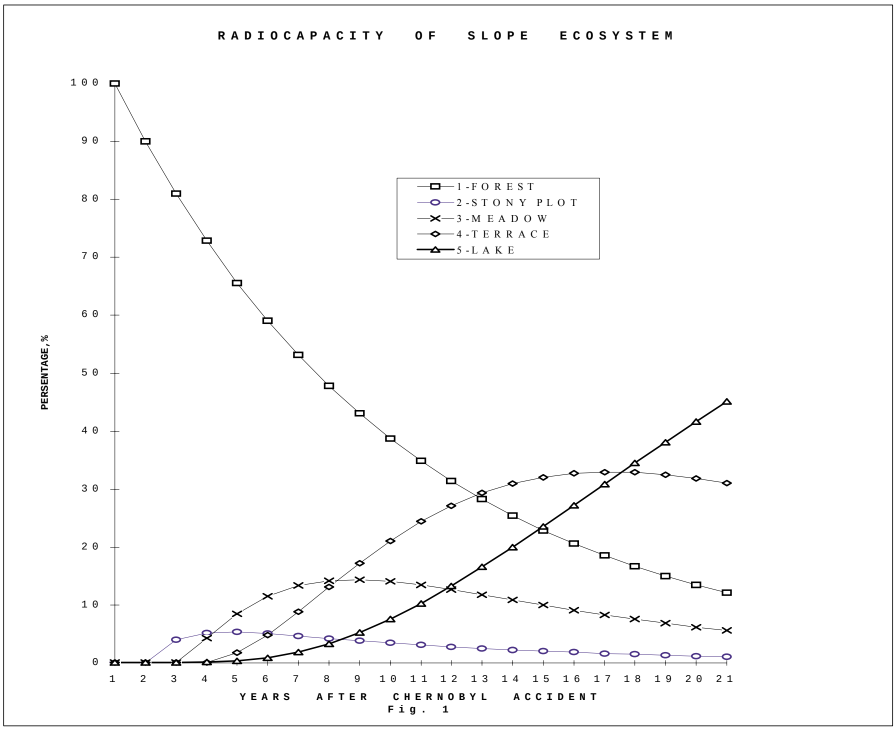

Fig 1. Radiocapacity of Slope Ecosystems

It is visible precisely, that the permissible levels of radionuclide contamination decrease noticeably in accordance with the approach of the place of contamination to a lake. Strictly speaking, the ecological norm depends on the ecosystem character. The closer to the critical unit (lake) a subsystem is situated and the higher the value of probability of drain, the lower the ecological specification of permissible contamination.

4. Assessment of Parameters of Radiocapacity as of Indexes of Stability and Reliability of Ecosystems

4.1. Introduction

Model calculations have shown, that essential effects on ecosystems are accompanied by convertible or irreversible changes of radiocapacity parameters of biotic components of the ecosystem. It depends on the intensity and duration of effect.

Changes in the radiocapacity factors for Cs^{137} under influence of external gamma-irradiations were detected in preliminary experiments on hydroponics' crop cultivation. It was manifest by a decreasing the radiocapacity factor of the plants rooted system in response to a stress-factors.

Therefore, the radiocapacity factors can be used as parameters for the condition and well-being of an ecosystem under various chemical, physical and biological influences.

The theory and the models of ecosystems radiocapacity have allowed to formulate and to define the approaches to the substantiation of ecological standards on permissible levels of ecosystems and the contamination of their components, and also on permissible releases of radionuclides [6].

The present hypothesis consists of the following elements: we presume that some rather few long-lived radionuclides have contaminated an ecosystem in its steady; the radionuclides are arranged in compartments of the ecosystem and are described by appropriate values of the radiocapacity factors; the external harmful factors (toxic, radiation and other nature) act on the ecosystem. If the effect is essential, it may affect the ecosystem and its parameters. It will bring about sharp changes of the values of the radiocapacity factors of the ecosystem components [8; 9; 10].

We assume that the noticeable radionuclide redistribution has taken place in an ecosystem with known initial distribution of radionuclide-tracer (or tracers). It signifies that values of radiocapacity factors have changed (thence values of ecosystem radiocapacity). A predicting evaluation of an ecosystem condition, its stability and reliability is supposedly to be made at measurable changes of radiocapacity parameters. The predicting evaluation can be conducted long before a response on effect of integral parameters (variety of species, biomass, number and rate of reproduction of species in the ecosystem) is noticed.

4.2. Experimental investigation

There are not many experimental data on the influence of the external factors on parameters of ecosystem radiocapacity. Some data will be given.

The researches were carried out on experimental models, such as hydroponics' cultures of peas and maize.

Half litre glass vessels containing growing plants (4-5 twenty-four hours) were irradiated by external gamma-irradiation at doses of 1-2 Gy. It was shown, that this dose provokes depressing of growth of the main root and additional roots. Thus it is possible to observe decrease of volume of a rooted system and absorption surface. A small amount of ^{137}Cs (1000 Bq l^{-1}) is introduced into these culture vessels . It has been found for this experimental model that exactly the volume and surface of a rooted system determines the accumulation of the radionuclide in plants, and determines the factor of biota radiocapacity.

It was shown in the experiments (Fig 2, 3), that the external gamma-irradiation provokes a noticeable decrease of the accumulation of the tracer (^{137}Cs) in rooted and over ground biomass of plants during growth. It turns out that the larger the dose, the smaller is the biota radiocapacity factor in this experimental model. A precise relation between the degree of decline of biota and its radiocapacity factor was established.

These researches have shown, that similar effects are reached at adding heavy metals (for example Cd) in salt solutions (Fig 2, 3).

Prolongation of researches in this direction will supposedly allow extending these ideas and approaches to the most various experimental models. Study of the action of the physical, chemical and biological factors on parameters of biota radiocapacity and comparison of a level of changes of radiocapacity with an action of external gamma-irradiation doses will allow to enter an independent method of ecological dosimetry of the indicated factors.

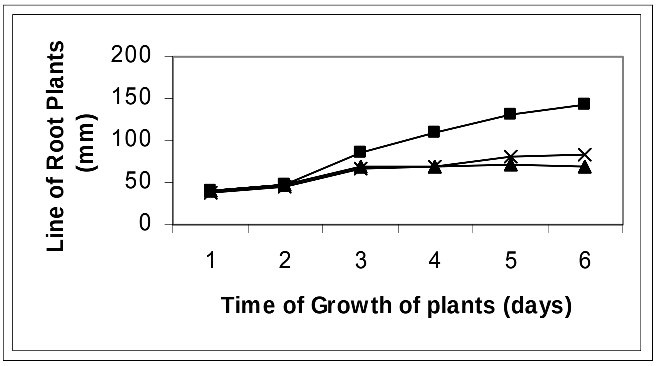

Fig 2. Dynamics of Growth of Root Plants in Control (■), under action of Cd (X) and after action of gamma-irradiation (▲)

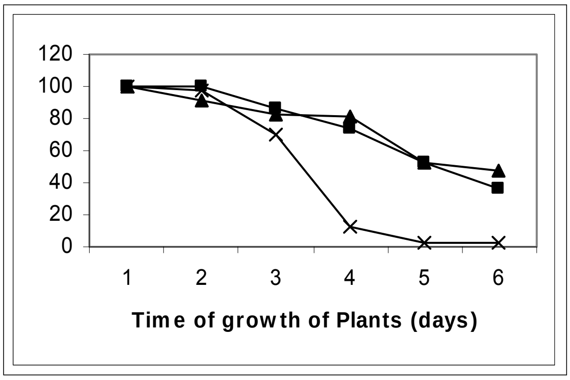

Fig 3. Dynamics of Growth of Root Plants in Control (X), under action of Cd (■) and after action of gamma-irradiation (▲)

The experiments have shown, that the external gamma-irradiation provokes a noticeable decrease of tracer (^{137}Cs) accumulation in rooted and overground biomass of plants during growth (Fig 2, 3). It turns out that the larger is the dose, the smaller is the biota radiocapacity factor in this experimental model. An exact relation was established between the degree of decline of biota and its radiocapacity factor

These researches have shown, that the similar effects are reached both by thermal stress (warming-up of plants) and by adding heavy metals (for example Cd) in salt solutions (Fig 2, 3). We suppose, that an extension of researches in this direction will allow promoting these ideas and approaches to the most various experimental models. Study of an action of the physical, chemical and biological factors on biota radiocapacity parameters and comparison of the level of changes of radiocapacity through external gamma-irradiation will allow to introduce an independent method of ecological dosimetry of the indicated factors., Application of similar simple model objects will presumably allow to substantiate and to concretise the given assumption.

The quantitative equivalents of dose loads on ecosystems for different factors can be found by constructing by means of model objects the relation between the change of the radiocapacity factors at a gamma-irradiation and the one of other harmful factors.

Such researches will allow shifting from a dead point a problem of the quantitative description of ecosystems and “dosimetry” of various effects on them.

5. Conclusions

1. This theory of radiocapacity of ecosystems permits description of regularities of radionuclides distribution for different types of aquatic and terrestrial ecosystems [9, 10].

2. The scale of dose commitment on ecosystems permits evaluation of the maximum permissible concentrations of radionuclides. The higher these concentrations rise, the more noticeable influence is expected on structure, on biological characteristics and on radiocapacity parameters.

3. Regularities of radionuclide redistributions in different types of ecosystems, which are described by radiocapacity models, permit the definition of maximum permissible releases of radionuclides in particular “compartments” of ecosystems on the basis of ecological standardization.

4. In selected ecosystems (e.g. pond, water-cooling pond, forest) general ecological maximum permissible releases of radionuclides into the ecosystem or its components are determined:

a) by initial radionuclide contamination of the ecosystem and its elements;

b) by dynamics of redistribution of radionuclides;

c) by radiocapacity parameters of the ecosystems.

5. The proposed method of assessment of ecological maximum permissible radionuclide contamination of ecosystems and their components may be used as a theoretical basis for the System of Ecological Standardization of radionuclide releases from NPPs in normal and accidental conditions.

6. It was shown, that in conditions of noticeable effects at a physiological level on ecosystem

by factors such as stress, suppression and/or depressing of one species, a predictable decline of ecosystem and changes in the values of the radiocapacity factors and radiocapacity of ecosystem as a whole are necessarily to be expected.

7. The following remarks are to made though: There are the essential concentrations of radionuclides in biota and in bottom sediments (roughly $3.7*10^5$ Bq l^{-1}) in the ecosystems of 10-km zone of the Chernobyl Nuclear Power Plant (NPP). Presented here are all sorts of stress-effects (chemical, biological and other nature), capable to provoking releases of radionuclides in environment (in a water, for example). Then the biota radiocapacity of the ecosystem (one or several species) will sharply decrease. It will cause in turn an increase of the content of radionuclides in water, bottom sediments and in biomass of other species of biota. Such a process is capable to continue, down to full ecosystem destruction (the lake Karachay in the Ural is an example) .

8. Thus, any effect on ecosystems affecting Tf_i and P_i and other indexes of an ecosystem condition can be reflected as a noticeable change (decreasing or possibly increasing) of F_i (radiocapacity factor) and of the value of radiocapacity. Such a situation will be reflected in a reduction of permissible releases in ecosystem, for example, in the reservoir-cooler of NPP. In this case the initial well-being in ecosystem will be quickly lost. In other words the strategy directed on preservation and/or increase the radiocapacity of ecosystem and the radiocapacity factors of composed biota species of ecosystem is an optimum method of ecological-ethical management of the ecosystems.

9. Thus well-being and viability of ecosystem bear witness of its high radiocapacity. To the contrary, high radiocapacity, and stable high values of the radiocapacity factors of ecosystem biota species bear witness of the well-being and reliability of ecosystem.

10. The control of radiocapacity and the radiocapacity factors and especially of their time changes and after-effects (gamma-radiation, hard metals –Cd) can serve as an objective predicting criterion and method of an assessment of the well-being any ecosystems (water, continental, wood and marine ecosystems).

11. The presented method of application of tracers can be successfully applied for research and characterisation of the status and well-being of ecosystems. There are some Chernobyl's tracers to be assumed in an ecosystem. The artificial introduction in natural ecosystem of the radionuclides ^{134}Cs, ^{137}Cs for example can also take place. The condition of the radiocapacity factors in the ecosystems can be assessed by estimating their dynamics over years and seasons. If after various antropogenic actions and countermeasures a noticeable reduction of the radiocapacity factors of some components of biota are observed, this condition can serve as a predicting index for a possible decrease of ecosystem viability, and of the decrease of its radiocapacity.

12. If the observation with tracers shows stability and especially increase of the radiocapacity factors of biota species, we the general well-being of ecosystem may be considered not to be uncertain, although some changes can certainly take place, especially in case of the use of countermeasures. At the same time the steady decrease in the value of the radiocapacity factor of one species only, not been compensated by the increase of the radiocapacity factors of other species, can be an sign of danger for a species and ecosystem as a whole. It is essential that the similar decrease of F_i (radiocapacity factors) has a predicting character. It is important, that there is possibility to carry out similar experiments in nature.

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