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RADIOCAPACITY MODEL APPLIANCE FOR
ECOLOGICAL STANDARDIZATION OF RADIATION FACTOR IN A LAKE ECOSYSTEM

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Abstract. *In the article a new approach to creation of an ecological standardization system is offered. Such system does not coincide with the working hygienic standardization system. Basing on the radiation capacity model and theory of ecosystems reliability a method of defining of critical biota condition on an example of a lake ecosystem is offered. Through an estimation and control of a critical radiation dose on the given biota, through radiocapacity models the levels of permissible radionuclides pollution of the ecosystem's components are determined. The levels of permissible radionuclides pollution are estimated as such, at which radiation dose on the critical biota of the lake may not exceed the allowed limit — 4 Gy/year.*
Keywords: ecological norm; radiation doses on the biota; radiocapacity of ecosystems.

1. Introduction

The problem of ecological standardization of permissible waste and different radionuclides release into any ecosystems is important, because there is a current need to coordinate these processes not only with hygienic standards which dominate in modern ecology, but also with ecological standardization. The actual paradigm of modern ecology concerning absence of problems for the biota in case of observing the norms for people is not always true, is not always fulfilled, which is showed by modern researches and estimations. First of all it is connected with the facts that a man is able to avoid negative influence of pollutants, but the biota usually cannot do this.

2. The analysis of publications

The actual ecological paradigm, when the safety of ecosystems' biota is defined by norms of people's ecosystem exploitation, doesn't stand up to criticism. That's why the International Comission on Radiological Protection in publication №80 set a task to create a system of ecological standardization, based on reaction of the biota on particular radiation doses. [2, 4]. The variants are being offered in this article, when the radiological factor standardization on the biota is estimated in terms of reaction of the critical (the most radiosensitive) kinds of organisms. But it is to be noted that the critical kind for one ecosystem may not be critical for other types of ecosystems [2, 4]. Therefore it became necessary to develop other approaches. The substantiation of this need follows further in this article.

The objective of the work: to built the approaches to principles of substantiation and creation of ecological norms on permissible levels of radiative effect on the ecosystems' biota, which differs from the current hygienic rating system. The thing is that in the situations of hygienic standards adherence the dose effects on the ecosystems' biota may be critical.

3. Results of the research

In the most radiological situations the biota in the environment where it grows is exposed to external (from the exposure sources outside the biota) and internal irradiation (from incorporated in the tissues radionuclides). In the irradiation biocenosis for the experimental organisms the exposure sources may become incorporated (accumulated) radionuclides, contained in contiguous organisms. For certain organs of plants and animals external are also those sources, which are contained in other parts of this plant or animal.

In case of biocenosis contamination by artificial radionuclides initially the radioactive substances are contained on the ground and water surface contacting with plants or animals. Only after a certain time period under influence of wind, downfalls, biomass increase radionuclides are being reallocated within the abiotic constituent of the ecosystem and as result of migration processes or anthropogenic measures shift into the depth of the ground and body of water.

In case of radionuclide emissions in the environment the need arises to define the boundary values of radionuclides intake into the ecosystem,

when they haven't caused significant changes in the ecosystem itself yet.

Natural measure for evaluating the maximum permissible radionuclides release into the ecosystem is radiation dose or the annual exposure rate. In the work of G.G. Polikarpov and V.G. Tsytsuginoy [2] a scale of radiation doses on ecosystems in the form of four dose limits was introduced (Table 1).

The Table shows that the actual dose limit for radionuclides release and "storage" in ecosystems and their components may be dose rate that does not exceed 0.4–4.0 Gy/year when visible ecological effects can be expected on the scale. According to the estimations the background exposure rate of 0.4–4.0 Gy/year corresponds to the concentration of ^{137}Cs about 200–1000 kBq/kg in the ecosystem or its components (terrestrial and aquatic plants) and about 200 kBq/kg for the ecosystem including terrestrials, which makes 600 kBq/kg in average. Calculations made on the basis of dose factors developed by B. Amiro, are presented in Table 2 [1].

Table 1. Scale of radiation doses and zones in ecosystems

Number of dose limit	Zone	Exposure rate, Gy/year
1	Zone of radiation safety	< 0,001 — 0,005
2	Zone of physiological masking	> 0,005 — 0,05
3 3.1 3.2	Zone of ecological masking: terrestrials hydrobionts and terrestrials	> 0,05 — 0,4 > 0,05 — 4
4 4.1 4.2 4.3	Zone of visible ecological effects: dramatic for terrestrials dramatic for hydrobionts and terrestrials disastrous for animals and plants	$\geq 0,4$ ≥ 4 ≥ 100

Table 2. Dose factors for the biota ecosystems on some radionuclides

Radionuclide	Internal irradiation, Gy/year/Bq/kg	External irradiation			
		Water, Gy/year/Bq/m^3	Air, Gy/year/Bq/m^3	Ground, Gy/year/Bq/kg	Vegetation, Gy/year/Bq/kg
^{137}Cs	4,1 10^{-6}	2,7 10^{-9}	1,72 10^{-6}	4,02 10^{-6}	1,72 10^{-6}
^{3}H	2, 88 10^{-8}	0	0	0	0
^{40}K	3,44 10^{-6}	1,76 10^{-9}	1,43 10^{-6}	2,64 10^{-6}	1,43 10^{-6}
^{32}P	3,52 10^{-6}	1,57 10^{-9}	1,43 10^{-6}	2,36 10^{-6}	1,43 10^{-6}
^{241}Am	2,86 10^{-5}	1,48 10^{-10}	7,73 10^{-8}	2,22 10^{-7}	7,73 10^{-8}
^{239}Pu	2,64 10^{-5}	3,72 10^{-12}	2,35 10^{-9}	5,58 10^{-9}	2,35 10^{-9}
^{90}Sr	9,92 10^{-7}	3,07 10^{-10}	2,83 10^{-7}	4,61 10^{-7}	2,83 10^{-7}
^{222}Rn	1,12 10^{-4}	8,91 10^{-9}	6 10^{-6}	1,43 10^{-5}	6 10^{-6}
^{14}C	2,5 10^{-7}	6,51 10^{-12}	6,01 10^{-9}	9,77 10^{-9}	6,01 10^{-9}

The data in Table 2 allow us to calculate the radiation doses of the wild biota in different types of ecosystems.

Ecological standardization in the lake ecosystem. The simulation results of permissible releases in lake ecosystem [3]

According to the estimation of the maximum permissible radionuclides ^{137}Cs concentration in the elements of the ecosystem the critical releases and emissions into ecosystems can be estimated (we will start with an example — the lake). Based on the model of radiocapacity of the lake ecosystem [3] we showed that for benthos of benthal deposits of a freshwater basin maximum permissible radionuclides release into the pond (N_k) shall not exceed the following value:

$$N_k < \frac{LHS}{kF},$$

where L — calculated based on the dose limit of 4 Gy/year (limit) of ^{137}Cs radionuclides concentration in aquatic biota (600 kBq/kg);

S — area of the basin;

H — the average depth of the basin;

k — coefficient of radionuclides accumulation from water by benthal deposits;

F — radiocapacity factor of benthal deposits of the basin.

For the biota, living in the water column the maximum permissible radionuclides release shall not exceed (N_b):

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

where K_b — coefficient of ^{137}Cs accumulation in the system water — biota of the water column.

For a specific freshwater basin where $S = 2$ km^2, $H = 4$ m , $K_b = 1000$, $F = 0,7$ critical value of radionuclides release according to the calculations for this model is not more than: $N_b < 10$ TBq into water of the whole basin.

At the same time, a critical value of radionuclides release into the basin for its benthos is estimated, the value $N_k < 110$ GBq.

This value is 90 times less than the permissible ^{137}Cs release into the water of this lake, which is estimated for the biota of the water column of the basin.

Further, for clarity, we give a specific example of appliance of such a model to the lake ecosystem.

Analysis and calculation of permissible radionuclides releases into the lake.

Let's assume that into the lake area of 1 km^2 was dropped just 1 MBq of ^{137}Cs.

Let the depth be 5 m, the thickness of the layer of activated sludge — 10 cm, the sludge Accumulation Factor (AC) — 200 and into account we take options when AC of the biota, living in the benthal deposits, ranges from 1 to 100000.

Let's analyze what amount of radionuclides can be released into the lake, so that the dose for the benthic biota does not exceed the critical limit **AC** of 4 Gy/year.

Using the above mentioned formula we will calculate permissible ^{137}Cs releases (Table 3).

The calculation was performed as follows.

Knowing the consistent pattern of radionuclides redistribution through the components of the lake ecosystem, you can define the radioactivity levels in all components.

Then, using a Table of dose values or coefficients (Table 2), we can calculate the partial doses on the biota from different components of the lake ecosystem for different values of **AC** for the benthos biota.

Summing up the dose of the relevant columns of Table 3, we calculate the summary dose on the benthos at the value of the initial radionuclides release only 1 MBq ^{137}Cs.

Then we take, for example, the summary dose in the last column, which is equal to $4,7 \cdot 10^{-3}$ Gy/year when the release is 1 MBq .

And if the permissible dose to the seabed biota, as we have defined, should not exceed 4 Gy/year, then dividing the value of 4 Gy/year by the estimated value of $4,7 \cdot 10^{-3}$ Gy/year we become the estimation of the quantity — Bq in permissible release, which makes — $8,5 \cdot 10^8$ Bq/year or 0,023 Cu/year.

Thus, it should be noted that at very high values of AC of the biota (100 000 units) annual permissible radionuclides release in the researched lake can make a very small value, only 0,023 Cu/year on only 1km^2 area of the lake.

A similar calculation was made for another biogenous radionuclide — ^{90}Sr.

It can be seen that, depending on the AC of the biota permissible releases into this lake make for ^{137}Cs from 0,023 to 2100 Cu per year, and for ^{90}Sr — from 0.1 to 7800 Cu per year, if releases take place for only one year, as it was after the Chernobyl disaster.

If it is a working nuclear power plant, it is clear that the permissible releases per year will be significantly less, so that they do not lead to exceeding the dose limits.

That is, for real values of AC for the seabed biota fairly strict limits on permissible levels of releases into such lake ecosystem can be applied.

In most cases the levels of water pollution, for which there are hygienic standards (2 Bq/L for ^{137}Cs), will be estimated as significantly smaller than the given hygienic standards.

Thus, the analysis shows that actually in this case of the lake ecosystem the ecological norm can be estimated as much tighter than the known hygienic standard.

4. Conclusions

Generally in ecology and radioecology in ecological standardization, environmental dominates such paradigm. If for human it is comfortable to live in the ecological situation, all the more nothing will damage the biota.

The analysis, which we conducted shows that this is not really so.

That is a safe situation for human can turn into high doses for the biota due to redistribution of radionuclides and high values of AC, which are peculiar to biota.

Table 3. Calculation of the dose on the components of the lake ecosystem and
the permissible annual ^{137}Cs release depending on the values of AC for the benthos biota

Doses from the components of the lake ecosystem, which effect the biota	$К_H$ of the biota of benthal deposits of the lake (benthos)					
	1	10	100	1000	10000	100000
Water	5,4–9	5,4 –9	5,4–9	5,4–9	5,4–9	5,4–9
Benthal deposits	3,2–8	3,2–8	3,2–8	3,2–8	3,2–8	3,2–8
Vegetative biomass of the lake	1,4–8	1,4–7	1,4–6	1,4–5	1,4–4	1,4–3
Internal dose	3,3–8	3,3–7	3,3–6	3,3–5	3,3– 4	3,3–3
Summary dose on the biota	5,2–8	4,8–7	4,7–6	4,7–5	4,7–4	4,7–3

Permissible annual release into the lake:

	1	10	100	1000	10000	100000
[137]Cs	7,7+13 Bq 2100 Cu	8,4+12 Bq 220 Cu	8,4+11 Bq 22 Cu	8,5+10 Bq 2,3 Cu	8,5+9 Bq 0,23 Cu	8,5+8 Bq 0,023 Cu
[90]Sr	2,9+14 Bq 7800 Cu	3,8+13 Bq 1020 Cu	3,9+12 Bq 105 Cu	3,9+11 Bq 10,5 Cu	3,9+10 Bq 1 Cu	3,9+9 Bq 0,1 Cu

That is, for the lake when hygienic standards for drinking water can be easily fulfilled and the limits on the dose for the biota of the lake can be unachievable.It should be emphasized that the excess of the dose limits on the biota of benthal deposits can lead to death of a part of the biota, and this in its turn will lead to acidification of the aquatic medium (pH may drop to values 5–6) , which in its turn can cause desorption of radionuclides, accumulated in the benthal deposits.

And it will mean a significant increase of water pollution that will also obviously exceed hygienic standards.

It is clear that the establishment of actually working ecological standards for Ukraine and other countries is a very complicated task.

The problem is that it is nearly impossible to establish unified ecological standards for permissible radionuclides releases in different ecosystems.

Each lake, generally any ecosystem will require the development of a specific model and evaluation of the current value of ecological standard.

But the problem remains, and it is necessary to develop it [2].

These same problems arise for other types of ecosystems as well.

References

[1] *Amiro, B.D.* Radiological Dose Conversion Factors for Generic Non-human Biota. Used for Screening Potential Ecological Impacts. J. Environ. Radioactivity. 1992. Vol. 35. N 1. P. 37–51.

[2] *Kutlakhmedov, J.A.; Matveeva, I.V.; Rodyna, V.V.* Reliability of ecological systems. Theory, models and practical results. Palmarium academic publishing. 2013. 317 p. (in Russian).

[3] *Kutlakhmedov, Yu.A.; Matveeva, I.V.; Salivon, A.G.; Rodyna, V.V.* Theory of Reliability in Radiation Ecology. Proceedings of International Symposium on Stochastic Models in Reliability Engineering, Life Science and Operations Management. Israel. 2010. 275 p.

[4] *Polikarpov, G.G.; Tsytsugina, V.G.* Hydrobionts in the zone of Kyshtym and Chernobyl disasters influence. Tsytsugina Radiation biology and radioecology. 1995. Vol. 35. N 4. P. 536–548. (in Russian).

І.В. Матвєєва. Застосування моделі радіоємності для нормування радіаційного фактора в озерній екосистемі

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Запропоновано новий підхід до створення системи екологічного нормування. Показано, що така система не збігається з діючою системою гігієнічного нормування. Спираючись на моделі радіаційної ємності і теорію надійності екосистем, запропоновано метод установлення критичного стану біоти на прикладі озерної екосистеми. Через оцінку і контроль критичного дозового навантаження на біоту досліджуваної екосистеми, через моделі радіоємності визначено рівні допустимого забруднення радіонуклідами компонентів екосистеми. Рівні допустимого радіонуклідного забруднення оцінено як такі, при яких дозове навантаження на критичну біоту озера не повинно перевищувати граничнодопустиму норму — 4 Гр / рік.

Ключові слова: дозові навантаження на біоту; екологічний норматив; радіоємність екосистем.

И.В. Матвеева. Применение модели радиоемкости для нормирования радиационного фактора в озерной экосистеме.

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Предложен новый подход к созданию системы экологического нормирования. Показано, что такая система не совпадает с действующей системой гигиенического нормирования. Опираясь на модели радиационной емкости и теорию надежности экосистем, предложен метод установления критического состояния биоты на примере озерной экосистемы. Через оценку и контроль критической дозовой нагрузки на исследуемую биоту, через модели радиоемкости определены уровни допустимого загрязнения радионуклидами компонентов экосистемы. Уровни допустимого радионуклидного загрязнения оценены как такие, при которых дозовая нагрузка на критическую биоту озера не должна превышать предельно допустимую норму — 4 Гр/год.

Ключевые слова: дозовые нагрузки на биоту; радиоемкость экосистем; экологический норматив.

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