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APPLICATION OF THE G. G. POLIKARPOV CONCEPTUAL MODEL OF CHRONIC ACTION ZONALITY OF IONIZING IRRADIATION DOZE RATES TO BIOSPHERE OBJECTS IN APPLIED HYDROBIOLOGY*

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Evolution of the approach to assessing ionizing radiation effects on living organisms is briefly discussed in this paper. Using the example of Black Sea hydrobionts, possibility of applying the G. G. Polikarpov conceptual radiochemoecological model of chronic action zonality of ionizing irradiation dose rates in nature to assess ecological exposure of technogenic radioisotopes ionizing radiation on aquatic biota was shown. In applied hydrobiology, this model can serve as the basis for a complex approach in assessing aquatic biota ecological state and its prediction for a wide range of ^{239,240}Pu activity concentration in seawater. The necessity of combined use of biogeochemical and equidosimetric indicators of radionuclide behavior in a water area is emphasized. In particular, for predictive dosimetric assessments, it is important to take into account quantitative characteristics of accumulative ability of Black Sea hydrobionts and a type of radioelement biogeochemical behavior, reflecting peculiarities of plutonium biogeochemical migration in a marine ecosystem.

Keywords: assessment of aquatic biota ecological state, Black Sea, biogeochemical migration, redistribution of ^{239,240}Pu radioisotopes, dose commitments, hydrobionts, G. G. Polikarpov conceptual model

Applied hydrobiology is designed to study consequences of water bodies pollution by technogenic substances and processes of water quality formation as a result of the influence of ecosystem abiogenic and biogenic components on redistribution of technogenic substances in water bodies, as well as to offer scientifically based criteria and approaches for assessing hydrobionts ecological state. This is necessary for rational use and management of aquatic ecosystems while maintaining environmentally acceptable water quality, as well as for development of scientific basis for rationing supply of technogenic substances to water bodies and their separate water areas.

These questions are especially relevant for the Black Sea as an inland sea, anthropogenic impact on which is great, in particular in coastal areas. The area of the Black Sea drainage basin is more than 2.3 million km^2, and both biogenic and toxic substances come from it, including plutonium technogenic radioactive isotopes [13 ; 43 ; 44]. The main sources of ^{239,240}Pu in the Black Sea include global radioactive fallout and emissions after the Chernobyl Nuclear Power Plant (hereinafter NPP)

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disaster [13 ; 23 ; 44]. As a result of the functioning of nuclear facilities, as well as after accidents, high activity concentration levels of anthropogenic radioisotopes have already been formed in some marine areas (the Irish Sea and some Arctic seas) and in freshwater bodies in various regions, including Eurasia territory (in the Southern Ural and Siberia, in 30-km zone around the Chernobyl NPP, etc.) [3 ; 8 ; 13 ; 24 ; 25]. In the Black Sea, plutonium activity concentration levels are quite low, but widespread use of these isotopes in nuclear technologies increases possibility of further radioactive contamination of marine areas with Pu.

This makes it necessary and urgent to develop approaches for assessing biota ecological state in water bodies and separate water areas, based on established patterns of plutonium behavior in aquatic ecosystems. Such studies are particularly relevant in the post-Chernobyl period, since technogenic radioisotopes, coming to the Black Sea in low concentrations not causing negative changes in its ecosystems, can be measured using physical methods of research and serve as radioactive tracers of natural processes [13]. This is a unique opportunity for studying processes and their quantitative characteristics in natural conditions (without violating ecosystems integrity) including migration and redistribution of technogenic radioisotopes in natural Black Sea ecosystems. Long ^{239,240}Pu half-life periods give reason to consider plutonium radioactive radiation a component of chronic anthropogenic factor, which is being formed in the present period because of technogenic human activity. The results obtained will allow not only assessing current environmental conditions of water areas and consequences of chronic exposure, but also predicting their possible change in case of an extreme increase in ^{239,240}Pu activity concentration levels in aquatic environment because of accidents or other unplanned or planned events.

The aim of our work is to consider briefly the evolution of views on the assessment of ionizing radiation effect on hydrobionts and to evaluate radiation exposure levels from technogenic alpha-emitting plutonium radioisotopes based on the use of the G. G. Polikarpov conceptual model of chronic action zonality of ionizing radiation dose rates in nature (hereinafter the G. G. Polikarpov conceptual model) as a part of a complex approach in assessing aquatic biota ecological state in a wide range of ^{239,240}Pu levels in seawater in relation to long-lived plutonium radioisotopes.

The effect of radioactive substances on living organisms is primarily due to ionizing radiation (hereinafter IR) emitted by a radioactive substance, namely quantity and quality of energy transferred to a living object from IR. Therefore, we dwell briefly on the evolution of representations in equidosimetry for the aim of assessing IR effect on living organisms.

Understanding of dosimetric criteria for assessing IR environmental effect on biota underwent a number of changes after the entry of technogenic radionuclides into the environment in the middle of the XX century. Initially, development of equidosimetry for biota was based on developments in radiation hygiene: human radiation protection. In radiobiology, the question on equidosimetry was relevant from the very beginning of studying IR effect on a living organism. This is due to the fact that ionizing radiations, having one common property (to ionize a substance), can be of different types: electromagnetic radiation, charged particles of different masses, neutral particles, etc. With the same amount of energy transferred per unit mass of living substances (absorbed dose, D, Gy = J·kg^{-1} [10]), they cause damaging effects of different levels in living organisms. Therefore, to assess the effect of different IR types on human body, a concept of an equivalent dose (H) was introduced in radiation hygiene, in which IR quality was taken into account through a radiation weighting factor (W_R) [10] (*i. e.* its relative biological effectiveness when exposed to a living organism). The radiation dose commitment to body, depending on IR type, is estimated as the equivalent dose ($H = W_R \times D$, Sv) or the equivalent dose rate (HR, $Sv \cdot day^{-1}$ or $Sv \cdot year^{-1}$) [10].

How was IR influence on biota assessed initially? In 1977, the International Commission on Radiological Protection (hereinafter ICRP) adopted a concept focusing on human protection. It stated as follows: if a human is properly protected, then, most likely, other living beings would be sufficiently protected [35]. Meanwhile, radiobiological research practice did not confirm this point of view. Often there were situations of complete people absence in a polluted environment, in which radiosensitive representatives of non-human biota could experience damaging and harmful radiation effects. This depends on intensity of organism interaction with the environment (for example, hydrobionts with aquatic environment) and on a number of other factors and conditions. Unlike biota, people can actively protect themselves from IR effect using various means and methods. These include the simplest but effective means: wearing overalls, respiratory and eye protection, vehicles use, radioprotectors taking, regulation of the time spent in radioactive pollution zone, etc. As a result, dose formation is not the same for people and biota. In many cases, biota representatives receive higher IR doses, while people receive lower and not dangerous IR doses. After all, only people are able to regulate and to actively reduce absorbed doses by special countermeasures (prevention and treatment, acceleration of radionuclides elimination from the organism, consumption of imported food and water, use of special technologies, etc.). Thus, in the same conditions, biota is exposed to a more intense impact than humans. According to a generalization of research results in the accident zone in the Southern Ural in 1957 [1], local people received doses 10–100 times less than wild vertebrates and higher plants. In the zone near the Chernobyl NPP, this difference was 30–120 times [15].

While working at the International Marine Radioactivity Laboratory of the International Atomic Energy Agency (hereinafter IAEA) in Monaco (1975–1979), G. G. Polikarpov actively studied the problem of assessing ecological IR effect on hydrobionts. In 1977, in Italy, at the XX congress devoted to radiation protection, he made a report, in which he first set out his conceptual model of the chronic zonality of IR dose rates effects on hydrobionts based on a synthesis of the results of his research and world literature on chronic irradiation effect on biota [39]. Noting the complexity of a unified assessment of IR effects on aquatic biota, due to different types of radiation, different radiosensitivity of species, ontogenetic stages of the same organism, different body tissues, and other features of radiation exposure to biota [33], G. G. Polikarpov proposed to divide the entire range of dose rates into separate zones: according to the effects (exposure level) they cause in living organisms [39] (Table 1). In this edition of the model, dose rate scale is presented in $rad \cdot year^{-1}$.

Five zones with the lower boundary of the last one (Zone of Obvious Impact) of about 400 $rad \cdot year^{-1}$ (4 $Gy \cdot year^{-1}$) were identified (Table 1). Attention was focused on little knowledge and a need for a broader study of hydrobionts radiosensitivity to protect them adequately from IR effect.

Since the 1990s, idea of environmental criteria being necessary for sufficient biota protection has been gaining the status of the official one. In 1991, ICRP concept was supplemented by an assertion that under conditions where humans are adequately protected, certain species may be exposed to detrimental radiation effects [36]. In accordance with IAEA and ICRP recommendations [32 ; 34 ; 49], the safe dose rate limit of 0.01 $mGy \cdot day^{-1}$ (4 $Gy \cdot year^{-1}$ rounded up to whole units) has been adopted for hydrobionts. Its exceeeding leads to negative consequences for biota populations. Radioecologists started applying the concept of equivalent dose and dose rate to biota using Gy or Sv as units [11 ; 13 ; 28 ; 45]. It is significant that radiological conditions of water environment of the water body, forming a dose rate of 0.00001 Sv·year^{-1} for people drinking this water, create a dose rate of 0.03 Gy·year^{-1} in seals in the same water body [6]. In this case, the dose rate for seals is 3000 times higher than for humans. When assessing dose rate from ^{14}C being characterized by concentration factor 50,000 for freshwater fish [48], the dose rate of the internal irradiation of seals due to fish feeding can be estimated at 7.5 Gy·year^{-1}. Dose rates being even an order of magnitude lower than this (tenths of Gy·year^{-1}) cannot be considered safe for mammals [6]. The data obtained shows that when each human in a certain area receives permissible IR dose rates from drinking water, radiosensitive aquatic biota in the water body at the same time is not protected and receives unsafe IR dose rates.

Table 1. Zones of biological effect of ionizing radiation chronic irradiation in the first edition of the G. G. Polikarpov conceptual model according to [39]

Zone number	Zone name (biological exposure level)	Doze rate (rad·year^{-1}) – upper zone boundary
I	Uncertainty	$4{\times}10^{-3}$
II	Radiation Well-being	$4{\times}10^{-1}$
III	Physiological Masking	$5{\times}10^{0}$
IV	Ecological Masking	$4{\times}10^{2}$
V	Obvious Impact	$4{\times}10^{3}$

Thus, the studies led to a transition from the anthropocentric approach to biota radiation protection (there, human protection was put at the forefront as a priority task in nature conservation, considering man the most radiosensitive species and the most vulnerable one) to an ecocentric approach. It is based on an eco-ethical worldview and on results of environmental research. This approach encourages each person and the whole society to realize that human as a biological species was born and develops as a part of an integral ecosystem (from local ecosystem to biosphere as a global one) and that his future depends entirely on ecosystem health and safety [13 ; 37]. Therefore, the focus is on protection and preservation of the ecosystem: all species of living organisms. Human, being a rational species, is responsible for preserving life on the planet, ensuring safe development, and biodiversity conservation in aquatic and terrestrial ecosystems [1 ; 2 ; 13 ; 34 ; 37]. It is also important that humans are not considered the most radiosensitive and most vulnerable species; scientific data on the radiosensitivity of all species and characteristics of dose formation in relation to non-human biota are taken into account [1 ; 13 ; 16 ; 20 ; 41 ; 42 ; 49 ; etc.]. The eco-ethical approach echoes the biosphere one, in which biota and humans are considered biosphere elements. To preserve it, a unified assessment system is needed to ensure safety of humans and aquatic ecosystem inhabitants [7]. ICRP recommendations of 2007 not only contain proposals on protection of human beings, but also consider "approaches designed to create principles for proving adequate environmental protection" [14]. Section 8 on environmental protection states as follows: "A more understandable, scientifically grounded unified concept is needed to assess relationships between exposure and dose, dose and effect, and the consequences of such effects on non-human biota". An extensive research is needed "to provide pragmatic guidance in this sphere" [14].

To assess IR radiation hazard for biota, being based on the ecocentric approach, equidosimetric concepts, and generalization of long-term radiobiological and radioecological studies, G. G. Polikarpov developed the previously proposed model [11 ; 14 ; 41 ; 42] and formulated a conceptual model of zonality of chronic IR dose rates in nature: at all living organization levels from a cell to biological communities and biosphere as a whole (Fig. 1) [11 ; 13]. This model served as a basis for equidosimetric analysis of biota ecological state in relation to ^{239,240}Pu in a complex approach of hydrobionts ecological state assessment [19 ; 20], where the equivalent dose rate (Gy·year^{-1}) is used as the value of dose commitment [11 ; 13]. The use of equivalent dose rate is important in assessing IR environmental effect levels from those radiation types for which $W_R > 1$. For alpha-particles emitted by ^{239,240}Pu, $W_R = 20$ in radiation hygiene [10]. In our work, we used $W_R = 20$ for hydrobionts, since in the modern period there is no other valid accepted unified W_R value for alpha-radiation in respect to biota, although different relative biological effectiveness for different IR types was observed in animals. In addition, most of data for establishing W_R in human radiation protection have been obtained in animal studies [33]. In a review on this subject [31], researchers did not come to a final informed decision, although they recommended using an average value $W_R = 5$ for biota populations and indicated that ranges of W_R changes were 1–10 and 1–20 for deterministic and stochastic effects in biota, respectively. In the studies used in the analysis, W_R value varied in a wider range: 37–150 in publications of 1966–1995 and 1–50 in works of 1991–2003 [31]. The absence of accepted reasonable W_R value in relation to biota is also mentioned in ICRP publication No. 108, dedicated to environment protection from IR [33]. ICRP publications No. 103 and 108 [14 ; 33] indicate that in this situation, for biota, in relation to alpha-radiation, $W_R = 20$ is used, the same as in human radiation protection. Meanwhile, equivalent doses for biota are expressed in Gy (units of absorbed dose) and equivalent dose rate: in Gy·day^{-1} or Gy·year^{-1}, respectively [14 ; 33]. In this work, the equivalent dose rate for non-human biota was obtained by multiplying the dose absorbed by $W_R = 20$ and presented in Gy·year^{-1}.

In the modern period, various approaches to environmental standardization and assessment of biota ecological state in aquatic and terrestrial ecosystems are being developed. Plenty of research and generalization methods are used. Bioindication and biotesting, as well as mathematical modeling are applied; processes of migration and accumulation of anthropogenic substances are studied; effects on organisms at different biota organization levels (from genetic to biocenotic one) are investigated. An integral part is the development of approaches for assessing radiation dose commitments to biota and the equidosimetry use [3 ; 7 ; 9 ; 26 ; 27 ; 31 ; 42 ; etc.]. The ecosystem approach in assessing IR effect on biota is becoming increasingly important internationally [13 ; 29 ; 30 ; 33 ; 38 ; 40 ; 41]. The concept of using both reference biota representatives and a range of accepted reference (control) dose rates is being developed: the range of derived consideration reference levels (DCRL) in relation to representatives of different taxonomic groups of aquatic and terrestrial biota [33]. In this case, DCRL is considered Radioactive Dosage Zone, within which stochastic effects are likely to occur and which separates Background Dose Rate Ranges Zone and Deterministic Effects Zone. According to data available at the time of the problem analysis (2008), for 12 selected reference representatives of animals and plants, DCRL Zone, according to preliminary estimates, was 0.1–100 mGy·day^{-1} [33]. Therefore, the equivalent dose rate equal to 10 mGy·day^{-1} (4 mGy·year^{-1}), accepted by G. G. Polikarpov as the lower boundary of Damage to Ecosystems Zone (in accordance with previously formulated proposals of international organizations [32 ; 34 ; 49]), is still relevant,

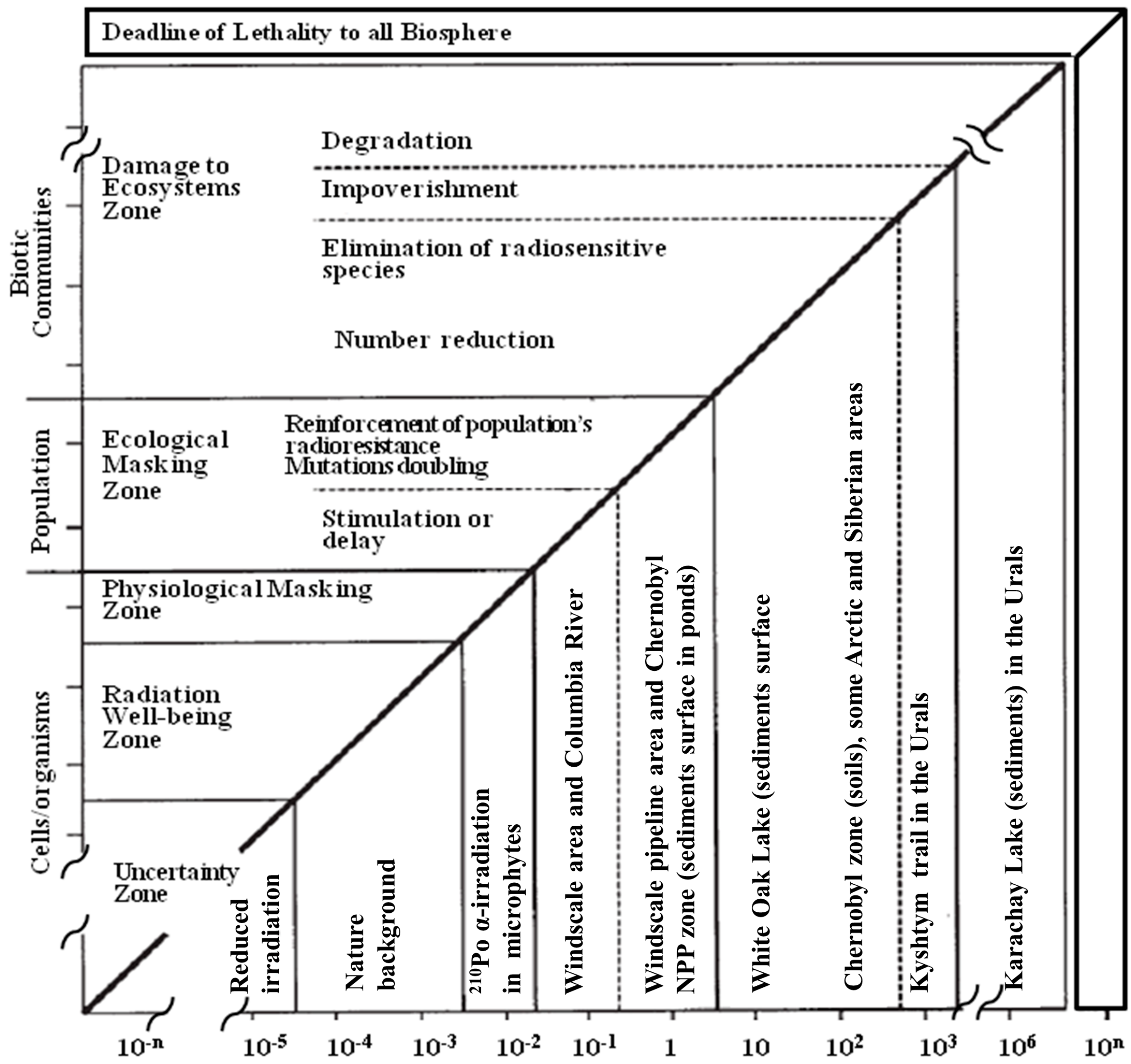

Fig. 1. Correspondence of ionizing radiation dose rate ranges and biological effect levels under chronic irradiation in the G. G. Polikapov conceptual model with examples of the state of existing contaminated aquatic biotopes, depending on dose rate level [11 ; 13]

and further research is required to clarify and revise it [33]. This was pointed out by G. G. Polikarpov paying attention to early stages of hydrobionts development, which are often more radiosensitive than adult ones [13].

As a rule, when considering the ecosystem approach, biota radiation protection focuses on the aspects of dose assessment and their effects. On the other hand, attention is paid to taking into account the diversity of structure and functions of ecosystems, their locations, and choice of reference animals and plants; this is undoubtedly necessary and important and is a very difficult task [12 ; 14 ; 29 ; 30 ; 33 ; 34 ; 38 ; 40 ; 49]. At the same time, attention is not focused on a role of ecosystem biogeochemical processes and a biogeochemical type of radioisotope behavior in the ecosystem determining the main ways of radioisotope redistribution in a water body. Meanwhile, these are very significant components participating in formation of radiation dose commitments to biota in aquatic ecosystems [4 ; 9 ; 13 ; 16 ; 17 ; 21 ; 22 ; 24 ; 46]. One of the objectives of our work is to draw attention to consideration of migration aspect in assessing ecosystem ecological state in relation to IR effect, which source is anthropogenic radioisotopes entering the ecosystem. Significant results were achieved in this sphere, and a complex approach has been proposed by us to assess ecological status of marine areas in relation to long-lived radionuclides using the example of $^{239+240}Pu$ [19 ; 20].

The complex approach is based on the premise as follows: different living organisms may experience different dose commitments being in the same aquatic environment, as it is seen from the examples above. Therefore, the complex approach combines assessment of state of aquatic environment and representatives of different groups of hydrobionts by mutual addition of biogeochemical [5 ; 16 ; 17 ; 18 ; 19 ; 20 ; 21 ; 46] and equidosimetric [13 ; 15 ; 19 ; 20 ; 40 ; 41] aspects of radioisotope presence in an aquatic ecosystem (Fig. 2). The biogeochemical approach implies taking into account real quantitative indicators of influence of characteristics and functioning processes of the ecosystem itself, its components, and physical and chemical features of the pollutant on its redistribution in the water body and, therefore, on the formation of its concentration in water.

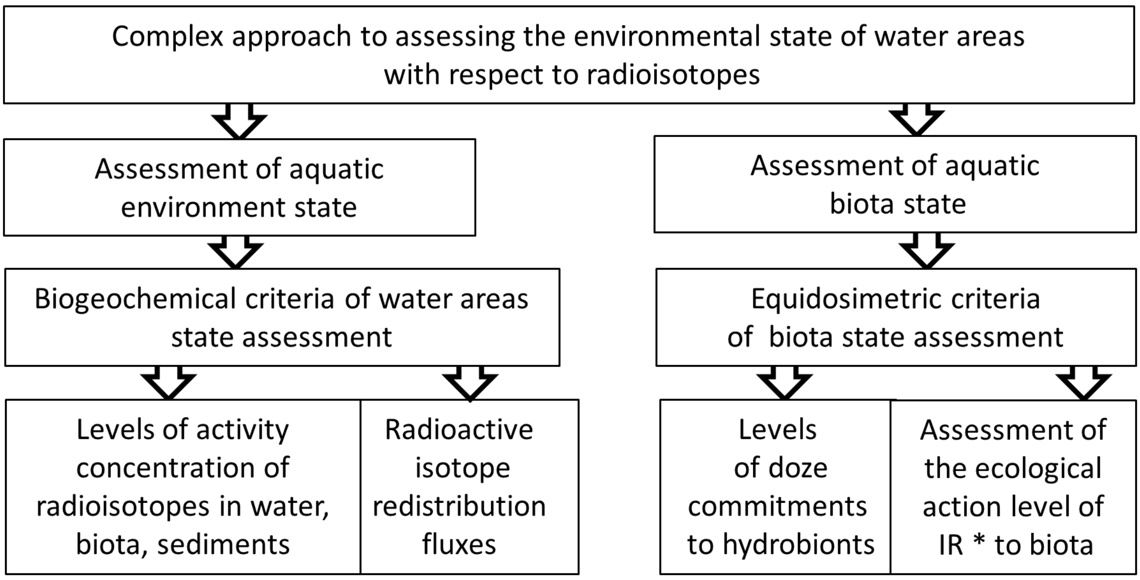

Fig. 2. Flowchart of the complex approach to assessing ecological state of water areas (IR* is ionizing radiation)

The main biogeochemical indicators are radioisotope activity concentration in water and a ratio of its input and removal fluxes. This ratio forms radioisotope activity concentration in water, and it should not exceed the permissible radioisotope activity concentration in water and biota (Fig. 3). Therefore, in order to assess biota ecological state in a water body, it is necessary to know permissible activity concentration ($C_{permissible}$, see Fig. 3) in water, the exceeding of which leads to negative consequences for hydrobionts populations, and to choose a method for determining the level of IR ecological influence from this radioisotopes level in water on biota of a water body. These questions can be solved by combining biogeochemical and equidosimetric aspects of radioisotopes presence in a marine ecosystem within the framework of a complex approach to assess hydrobionts ecological state, which is closely related to migration processes and includes an assessment of the influence of different concentrations of technogenic substances on aquatic ecosystems biota.

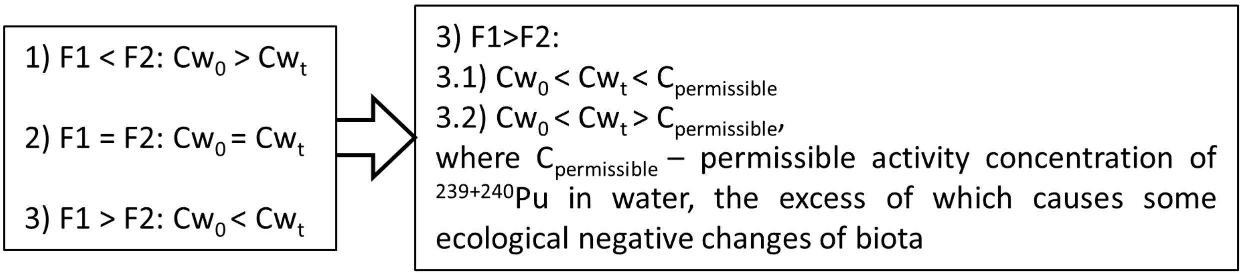

Fig. 3. Flowchart of formation of $^{239,\,240}Pu$ activity concentration levels in water at different ratios of F1 and F2;
F1 is radioisotope input flux;
F2 is radioisotope removal flux from water environment ($Bq \cdot m^{-2} \cdot year^{-1}$ or $Bq \cdot m^{-2} \cdot day^{-1}$);
Cw_0 is radioisotope activity concentration in water at the initial moment of time (background),
Cw_t – at time t ($Bq \cdot m^{-3}$)

Determination of biogeochemical indicators is based on the study of migration aspect of plutonium radioecology in the Black Sea: behavior of radioisotopes in a natural ecosystem. It includes identification of a type of biogeochemical behavior of the radionuclide, determination of its levels in ecosystem components, assessment of radioisotopes input and removal fluxes from aquatic environment, and identification of leading mechanisms of these processes [19 ; 20 ; 21]. As a result of long-term observations in the Black Sea in the post-Chernobyl period, quantitative characteristics of plutonium radioisotopes redistribution in water areas were determined [13 ; 16 ; 17 ; 18 ; 46 ; 47], which made it possible to establish the pedotropic type of plutonium behavior in the Black Sea. On the basis of these data, it was determined that plutonium sedimentation flux with suspended matter into bottom sediments serves as the main removal flux from a water column [5 ; 16 ; 19 ; 47]. The concentration factors (C_f) of $^{239,240}Pu$ by biota representatives of different taxonomic groups of hydrobionts were also determined, being necessary for calculating dose rates of chronic internal IR irradiation of biota from $^{239,240}Pu$ [13 ; 15 ; 17 ; 46]. C_f values, along with radioisotope activity concentration level in aquatic environment, type of radionuclide biogeochemical behavior in a water body, and IR quality, play an important role in formation of dose rate level of chronic exposure in hydrobionts [17 ; 18 ; 19].

As an equidosimetric criterion for assessing IR influence on Black Sea biota, IR equivalent dose rate was used, with subsequent determination of its ecological exposure level through comparative equidosimetric analysis of data on dose rates using the G. G. Polikarpov conceptual model [13 ; 40 ; 41]. A comparative analysis of the ecological state in Black Sea areas and in stagnant water bodies of the 30-km zone of the Chernobyl NPP in relation to radioisotopes after the Chernobyl NPP accident in terms of radiation exposure levels to biota is presented in Fig. 4. At current $^{239+240}Pu$ activity concentration levels in components of Black Sea ecosystems, the dose rates, formed from their IR, do not affect negatively Black Sea biota. According to the zonality of ionizing radiations effect, the levels of their environmental action do not exceed the influence being characteristic of the Radiation Well-being Zone. IR dose commitments from ^{239,240}Pu for molluscs and from a sum of $^{239+240}$Pu, ^{137}Cs, and ^{90}Sr for different groups of hydrobionts in the 30-km zone of the Chernobyl NPP exceeded background exposure levels. According to the G. G. Polikarpov conceptual model, these levels belong to the Physiological Masking Zone and the Ecological Masking Zone, and reach the lower boundary of the Damage to Ecosystems Zone.

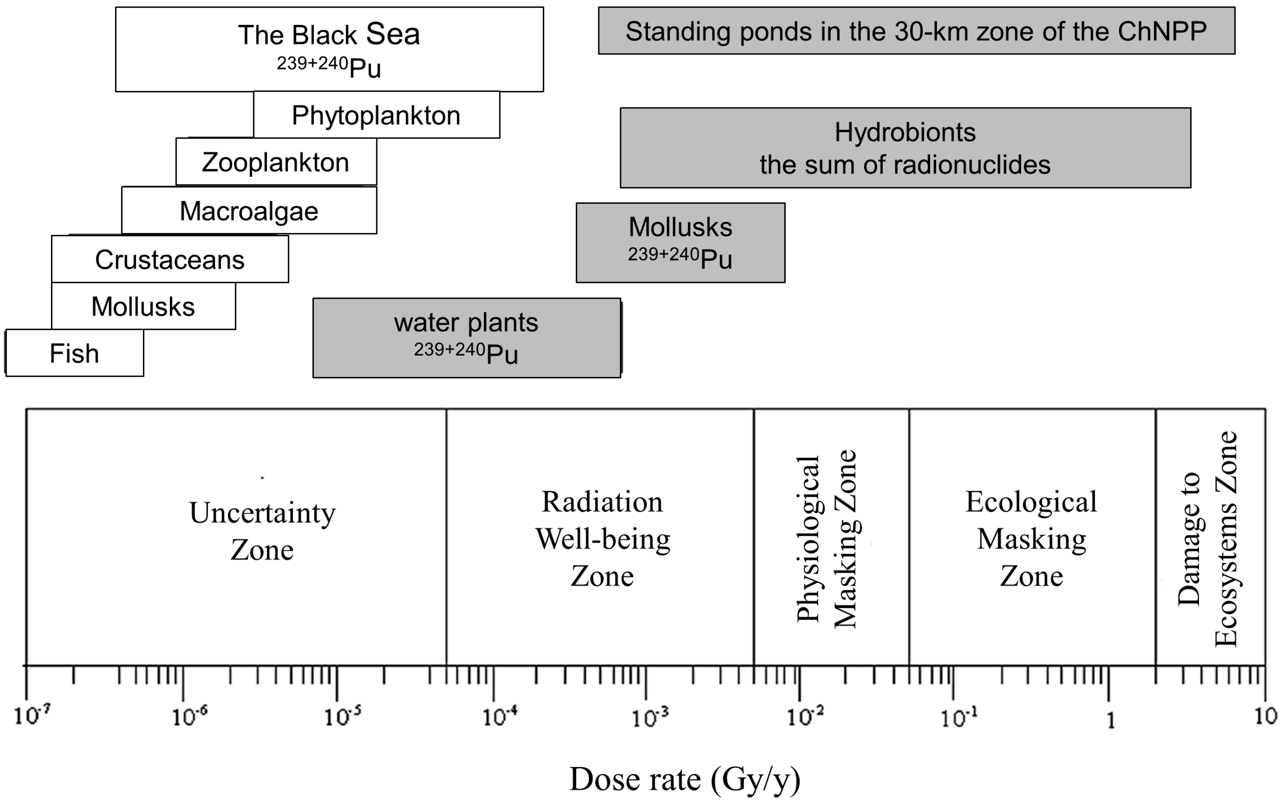

Fig. 4. Assessment of biological effect levels of ionizing radiation of plutonium radioisotopes, as well as of a sum of the main man-made dose-forming radionuclides (strontium, cesium, and plutonium) in the post-Chernobyl period

Calculation of dose commitments for Black Sea hydrobionts in a wide range of possible levels of ^{239,240}Pu activity concentration in water was performed according to known approaches [13 ; 15 ; 28], taking into account $W_R = 20$ for ^{239,240}Pu alpha-particles. The results of equivalent dose rate calculation are presented in Table 2. They reflect a relationship between the activity concentration of ^{239,240}Pu in water and the dose rate, and, therefore, the level of IR biological exposure to representatives of different groups of hydrobionts.

These data also illustrate relationship between biogeochemical and equidosimetric indicators for assessing aquatic environment and hydrobionts state. As it is evident from Table 2, at the same aquatic environment state with respect to ^{239,240}Pu levels, the level of these radioisotopes IR effect to different groups of hydrobionts is different, which is largely determined by accumulation capacity of hydrobionts in relation to plutonium. There is no doubt, that ontogenetic and radiobiological states of organisms can modify the lower boundary of the Damage to Ecosystems Zone; it will be refined as knowledge in this sphere accumulates.

Table 2. Dose commitments (HR is equivalent dose rate) at different levels of $^{239,240}Pu$ activity concentration in seawater (C_W Pu) and concentration factor in regard to $^{239,240}Pu$ (C_f Pu); 4 Gy·year^{-1} (IAEA and ICRP recommended dose rate limit, exceeding of which leads to negative changes in biota populations) is the boundary of Ecological Masking Zone and Damage to Ecosystems Zone (underlined in the Table) [32 ; 34 ; 42 ; 49]

Groups of hydrobionts	HR in hydrobionts at different C_W and C_f $^{239+240}Pu$, Gr·year^{-1}						
	C_W Pu, Bq·kg^{-1} / C_f Pu	0.000001	0.08	0.8	8	16	80
Phytoplankton	$1 \cdot 10^5$	$1 \cdot 10^{-4}$	$\underline{4 \cdot 10^0}$	$4 \cdot 10^1$	$4 \cdot 10^2$	$8 \cdot 10^2$	$16 \cdot 10^3$
Macroalgae	$5 \cdot 10^4$	$1 \cdot 10^{-5}$	$4 \cdot 10^{-1}$	$\underline{4 \cdot 10^0}$	$4 \cdot 10^1$	$8 \cdot 10^1$	$16 \cdot 10^2$
Zooplankton	$1 \cdot 10^3$	$1 \cdot 10^{-6}$	$4 \cdot 10^{-2}$	$4 \cdot 10^{-1}$	$\underline{4 \cdot 10^0}$	$8 \cdot 10^0$	$16 \cdot 10^1$
Molluscs	$5 \cdot 10^2$	$5 \cdot 10^{-7}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-1}$	$2 \cdot 10^0$	$\underline{4 \cdot 10^0}$	$8 \cdot 10^1$
Fish	$1 \cdot 10^2$	$3 \cdot 10^{-8}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-2}$	$1 \cdot 10^{-1}$	$2 \cdot 10^{-1}$	$\underline{4 \cdot 10^0}$

Summarizing the researches made, we have drawn up (Fig. 5) a general scheme of a complex approach to assessing water areas ecological state in relation to IR from long-lived radioisotopes [18 ; 19]. This approach takes into account specific biogeochemical characteristics of the ecosystem under study. First of all, these are biogeochemical sedimentation fluxes, accumulation capacity of ecosystem components, and hydrological regime of a water area. The features of the pollutant studied (type of radionuclide biogeochemical behavior and its physical-chemical and radiological characteristics) also play an important role. Taking these indicators into account makes it possible to more accurately assess self-purification capacity of photic layer surface waters (precisely in this particular ecosystem with respect to the pollutant under consideration). Applying the complex approach allows performing express assessments of current or expected level of pollutant environmental influence, as well as calculating fluxes of radioisotopes, at which they are formed, and time to reach control concentrations. Within the framework of the complex approach, it is recommended to use for the regulation a flux of radionuclides into the water area, avoiding contamination critical levels and preventing negative effect on biota.

It is also important, in our opinion, that the scheme-algorithm proposed focuses monitoring or expert studies not only on contamination levels in aquatic ecosystem components, but also on identifying basic patterns of radionuclide behavior in it. Of key importance are determination of a type of radionuclide biogeochemical behavior and studying of quantitative characteristics of biogeochemical processes in an ecosystem using radionuclides not only as a subject, but also as a method of research, *i. e.* as radioactive tracers. Such a scheme-algorithm can help in making decisions on the implementation of countermeasures necessary for the water area under study in case of radiation accidents and incidents and in predicting changes in biota ecological state.

Thus, based on the results of the study of leading processes determining redistribution of technogenic $^{239,240}Pu$ radioisotopes in the Black Sea, as well as taking into account their quantitative characteristics, identified main biogeochemical features of $^{239+240}Pu$ behavior in the sea, levels of hydrobionts accumulation capacity, and received dose commitments to hydrobionts, applicability of the G. G. Polikarpov conceptual model was shown as the final link of a scheme-algorithm of current and predicted estimates of biota ecological state in relation to long-lived radionuclides for a wide range

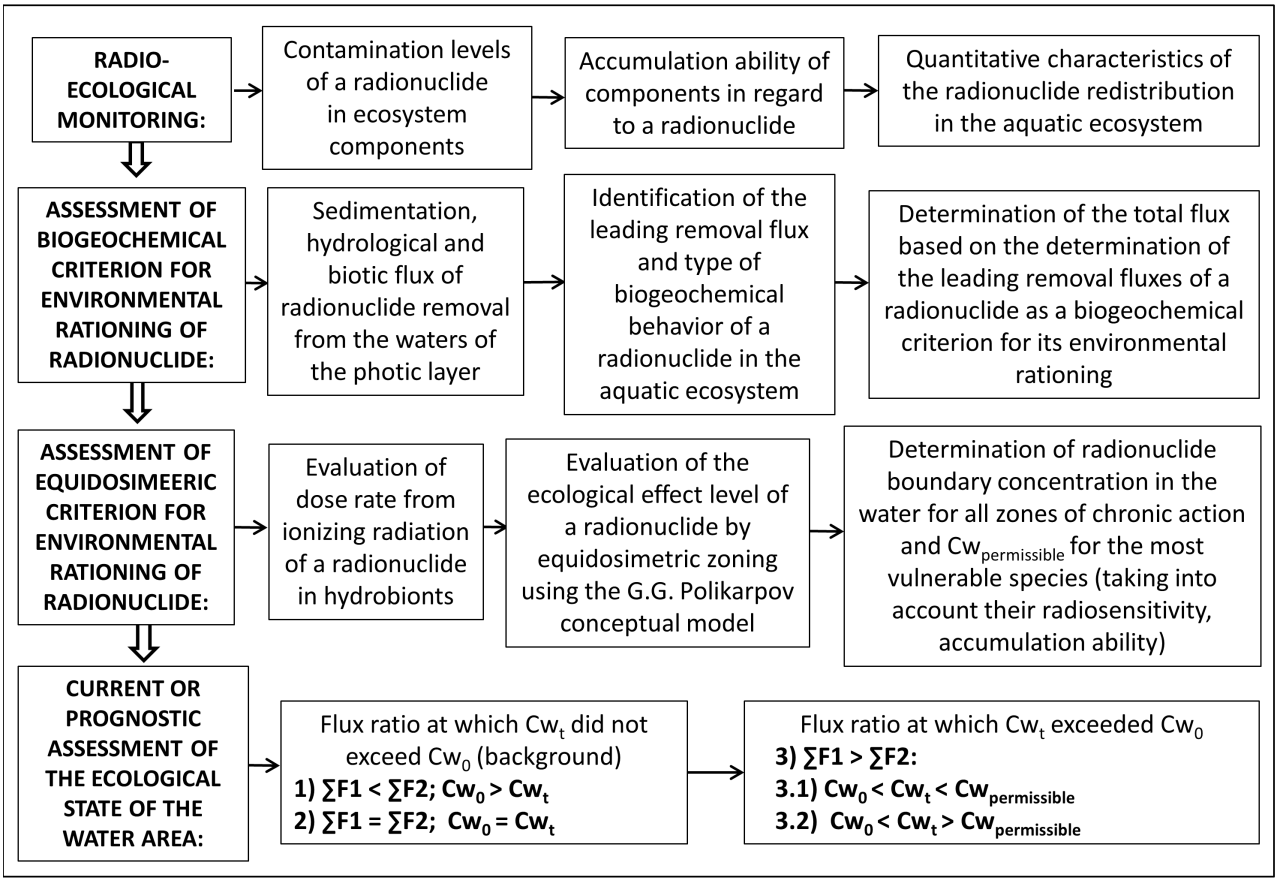

Fig. 5. Scheme for assessing biota ecological state (levels of expected ecological effect) in Black Sea water areas according to biogeochemical and equidosimetric criteria for a wide range of ^{239,240}Pu activity concentration in water;
F1 – ^{239,240}Pu input flux;
F2 – ^{239,240}Pu removal flux;
C_W – ^{239,240}Pu activity concentration in water;
Cw_0 – background level of C_W in water;
$C_{permissible}$ – ^{239,240}Pu activity concentration level in water, exceeding of which causes negative changes in hydrobionts populations

of $^{239+240}$Pu activity concentration in seawater. Attention was focused on the importance of taking into account biogeochemical indicators for predictive dosimetric assessments, in particular C_f, quantitatively characterizing accumulation capacity of Black Sea hydrobionts and type of radioisotopes biogeochemical behavior in a water area, as well as reflecting features of plutonium biogeochemical migration of it.

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ПРИМЕНЕНИЕ КОНЦЕПТУАЛЬНОЙ МОДЕЛИ ЗОНАЛЬНОСТИ ХРОНИЧЕСКОГО ДЕЙСТВИЯ МОЩНОСТЕЙ ДОЗ ИОНИЗИРУЮЩИХ ИЗЛУЧЕНИЙ НА ОБЪЕКТЫ БИОСФЕРЫ Г. Г. ПОЛИКАРПОВА В ПРИКЛАДНОЙ ГИДРОБИОЛОГИИ*

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В работе кратко рассмотрена эволюция подхода к оценке воздействия ионизирующей радиации на живые организмы. На примере черноморских гидробионтов показана возможность применения концептуальной радиохемоэкологической модели зональности действия хронического облучения ионизирующих излучений в природе Г. Г. Поликарпова для оценки уровня экологического воздействия ионизирующего излучения от техногенных радиоизотопов на водную биоту. Эта модель может служить в прикладной гидробиологии основой комплексного подхода в оценке экологического состояния водной биоты и его прогноза для широкого диапазона концентраций активности $^{239,240}Pu$ в морской воде. Подчёркивается необходимость совместного применения биогеохимического и эквидозиметрического показателей поведения радиоизотопов в водоёме. В частности, для прогнозных дозиметрических оценок важно учитывать количественные характеристики концентрирующей способности черноморских гидробионтов и тип биогеохимического поведения радиоэлемента, отражающие особенности биогеохимической миграции плутония в морской экосистеме.

Ключевые слова: оценка экологического состояния водной биоты, Чёрное море, биогеохимическая миграция, перераспределение радиоизотопов $^{239,240}Pu$, дозовые нагрузки, гидробионты, концептуальная модель Г. Г. Поликарпова

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