Review of the symposium "Radioecology of aquatic animals"

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1. Patterns of accumulation and exchange of radionuclides between hydrobionts and the aquatic environment

G. V. Barinov communicated that the general content of an element in an organism is not modified at an exchange of isotopes; there is only an interchange between a stable isotope and a radioactive one, or vice versa.

When studying the removal of an isotope from an organism, it is convenient to use the concept 'removal coefficient' (K), in analogy to the concept 'accumulation coefficient' (K). The latter represents the ratio of
radioisotopic concentration within the hydrobiont and in the surrounding water. The removal coefficient equals the ratio of the radioisotopic concentration which left the organism to the radioisotopic concentration in the medium where the radioisotopic accumulation took place. To determine the magnitudes $K$, $\hat{K}$, as well as the time for achieving equilibrium or, more exactly, the stationary state ($t_s$), one may utilize the computing method, in case the functions of accumulation and removal of the radioisotope are known.

In present-day thinking the kinetics of isotopic exchange in complex systems (Roginskii) are not subject to the exponential law, although it retains its validity for describing the single elementary processes of which the complex process consists. The kinetics of isotope exchange of higher complexity as a whole is determined by the functional aspect of the statistical distribution of the velocity constants of the individual elementary processes. Bearing in mind the composite, multiphase, microheterogeneous structure of organisms, the universality of statistical rules, the subjection of elementary biochemical processes to the exponential law (Bray and White; Troshin; et al.), the assumption might be made that Roginskii's theory of isotope exchange of higher complexity will be applicable to biological systems as well. Then the function of isotope exchange between organisms and the aquatic environment will be determined by the statistics of distribution of the exchange constants of the individual analogous microfunds.\footnote{At present there are few data on the nature and magnitude of the exchange constants of the microfunds.\footnote{At present there are few data on the nature and magnitude of the exchange constants of the microfunds.\footnote{At present there are few data on the nature and magnitude of the exchange constants of the microfunds.}
which constitute the general exchange fund of the element in the organism. According to S.Z. Roginskii, the uniform, the exponential, and the power distribution represent the basic functions of the statistical distribution. The corresponding isotherms for these distributions are: the logarithmic, the power, and the power-logarithmic isotherm. The aspect of isotope exchange kinetics is definitely established by experiment. The constant coefficients of the equations are calculated by processing the data by the method of least squares. The degree of concurrence between the calculated and the experimental magnitudes of $K$ and $\bar{K}$ may serve as criterion for the correctness or the chosen formula. When devising tests for studying the radioactive isotope exchange between an organism and its environment, it is necessary to take care that the general element concentration in the medium remains practically unchanged after introducing the radioactive isotope into the solution.

Research into the accumulation and the removal of $^{45}$Ca, $^{89}$Sr, $^{91}$Y, $^{137}$Cs, and $^{144}$Ce, conducted on the example of Black-Sea algae - macrophytes - has demonstrated that the statistical theory of kinetics of isotope exchange of higher complexity is applicable to a hydrobiological system, and it has also shown that it is possible to utilize the calculating method based on this theory. Thus, for instance, it was revealed that the $^{45}$Ca exchange by the green alga Ulva rigida is described by the power function, while the $^{45}$Ca exchange by the brown alga Sy-stoseira barbata is expressed by the logarithmic function.
The functional aspect of isotope exchange depends not only on the biological peculiarities of an organism but also on the position of the element in Mendeleyev's Table. Despite the great chemical likeness of calcium and strontium, their exchange might be subject to different norms. While the exchange kinetics of Ca\(^{45}\) proceeds in the \textit{Cystoseira} according to the logarithmic rule, the exchange kinetics of Sr\(^{89}\) in the very same \textit{Cystoseira} is described by the power-logarithmic isotherm, in accordance with the power distribution of the strontium microfunds in this alga. Hence, the general exchange fund of calcium, strontium, and certain other elements in marine algae is not uniform and consists of a great number of microfunds. The statistics of the distribution of the microfund exchange constants determines the functional aspect of the isotopic exchange as a whole. The calculated magnitudes obtained for κ and \(\bar{\kappa}\) were in fair agreement with the experimental ones.

Thus, the patterns found in the isotope exchange provide the possibility to predict the levels of contamination and disactivation of hydrobionts, as well as to determine the speeds of these processes, depending on the concrete radioecological and experimental conditions.

N. A. Timofeyeva investigated the accumulation of radiostrontium by various species of limnetic organisms and its release back into the water from these organisms, as well as the influence which stable strontium, calcium, magnesium, and radiostrontium contained in the water have on the uptake
of strontium-90 by living organisms.

At microconcentrations, stable strontium content in the water did not have a noticeable effect on the uptake of radiostrontium by the organisms: the accumulation coefficients of radiostrontium remained constant; their appreciable decline was observed only at the application of macroconcentrations (\(>10^4\, M\)).

As microconcentrations in the water increased, concentrations in the organisms increased correspondingly and, consequently, the coefficients of radiostrontium accumulations remained constant.

When macroconcentrations of calcium and magnesium were increased in the water, the coefficients of radiostrontium accumulation of the hydrobionts decreased. The correlation of radiostrontium and calcium changed when absorbed by organisms. And the magnitude of the discrimination coefficient varied from species to species and did not depend on wide fluctuations of the calcium content in the water. For example, the mean discrimination coefficient for the cladophora (\textit{Cladophora}) and the foxtail (\textit{Myriophyllum}) was around 0.6, while it was 0.3 for three species of molluscs (\textit{Lymnea stagnalis}, \textit{Physa fontinalis}, \textit{Galba palustris}), and about 1 for \textit{Elodea}.

E. A. Gileva investigated the influence of a concentration of sulphur, cobalt, strontium, yttrium, caesium, and mercury in solution on the accumulation of the corresponding radionuclides by Cladophora.
Within ranges of microconcentrations \((10^{-12}-10^{-6} \, M)\) the coefficients of accumulation of radionuclides (the ratio of concentration of the element in the solution to the one in the water) were constant and did not depend on the content of the element in the environment.

In tests with differing pH's it was revealed that yttrium in colloidal form was by two to three times less accessible to the Cladophora cells by comparison with the ionic form of this element.

T. V. Zharova demonstrated that for filamentous bacteria of the Sphaerotilus type the coefficients of accumulation of strontium-89, calcium-45, ruthenium-106, caesium-137, and cerium-144 reached several thousand units (on dry weight). Owing to their ability to accumulate many kinds of radionuclides, and considering their remarkable biomass (up to several tons per 1 km\(^2\)) in polluted river sections, the filamentous bacteria may cause a hazard of radionuclide concentrations both in zones of microepibioses and in zones of pure water into which masses of radioactive bacteria might be carried.

G. D. Lebedeva adduced data about the effect of stable potassium and sodium on the intensity of accumulation and removal of caesium-137 in carps.

It was found that the time for maximum accumulations of caesium-137 was one to two months for the muscle tissues of the fish, while it was two-and-a-half to three months for bone tissue.
When stable potassium was introduced into the solution of radioactive caesium at concentrations of 10 and of 40 mg/l, which represent concentrations by 10 and 40 times in excess of their concentration in Moscow tap water, the content of caesium-137 in the muscle tissue of the fish dropped by 1.5 and 3 times respectively, while, at a 40-mg/l addition of potassium, the radionuclide content in bone tissue decreased only by 1.5 times. When still greater quantities of stable potassium (100 and 400 mg/l) were added, the content in radioactive caesium in muscle tissue fell by 4 and 7 times respectively, in bone tissue by 3 and 6 times. Stable sodium, added to the solution of radioactive caesium at a quantity of 100 mg/l, which means a tenfold excess of its content by comparison with the Moscow water supply, diminished the caesium-137 concentration in the muscles of fish by two times, while its accumulation in the bone tissue remained virtually unchanged. At the simultaneous introduction of the two stable elements (potassium and sodium) into the solution of radioactive caesium in a proportion which is normal for natural conditions \( \frac{K}{Na} = \frac{1}{9} \), but in quantities exceeding the content of these elements in tap water (40 mg/l sodium) by forty times, the caesium-137 accumulation decreased by 5 times in muscle tissue and by 4 times in bone tissue, during the four-month test period.

As the maximum accumulation of radiocaesium in the tissues of the fish was reached, a certain number of them was transferred into pure water, another number into water with a
yet higher content of potassium (10 and 40 mg/l). The biological period of half-removal of caesium-137 for yearling carps was six times 24 hours for muscle tissue, and 15 times 24 hours for bone tissue. The effective period for both kinds of tissue remained unchanged. The fish placed in water with an increased dose of potassium did not reveal any changes in the speed of radiocaesium removal.

While keeping the fish four months in solutions with heightened contents of potassium and sodium, no visible modifications were observed in the behaviour and the growth of the experimental fish by comparison with the control.

II. The content and distribution of radionuclides and their carriers in organisms and communities of hydrobionts

V. P. Nesterov and I. A. Skul'skii presented a report on the content of lithium, sodium, potassium, rubidium, and caesium in muscles of organisms inhabiting the Barents and the Black Seas, whereas V. G. Leontyev and I. A. Skul'skii contributed a paper about the interconnection between the mineral and the lipide compositions in marine-organism tissues. Both reports provided data of utmost importance concerning concentrations and norms in the biochemical distribution of chemical elements belonging to group I of the Periodic System, and these data were obtained by utilizing the latest precision methods of investigation. These materials are of the highest interest for marine radioecology.
A. I. Sherstnev and O. P. Vasilyev communicated some results of studies into the composition and the level of radioactivity in plankton of the discontinuity layer in the equatorial waters of the Atlantic as well as on the shelf of the northwestern African shore. Sample collections were conducted in the central part of the Gulf of Guinea and along the coast of Northwest Africa. Radioactivity was measured on the UMF-1500 apparatus. Strontium-90 was determined by radio-chemical methods, the gamma-spectrum study was done on a 100-channel analyser.

The quantity of crustacea (Copepoda and Euphausiacea) in the plankton biomass averaged around 80%. The remaining part of the biomass consisted of Chaetognatha, Hydrozoa, Gastropoda, Polychaeta, and others. The ichyoplankton (among them larvae of Sardinella, Pleuronectes, Cynoglossus, Leptocephalus) amounted on an average to 3% of the general biomass. Quantities of a considerable percentage in the single hauls consisted of Ctenophora, larvae of Amphiioxus lanceolatus, and detritus.

The beta-activity of the investigated samples from the central part of the Gulf of Guinea equaled \(1.33 - 8.37 \times 10^{-8}\) curie/kg. The beta-activity in samples taken along the coast of North-West Africa from Conakry to Tangier ranged within the limits of \(1.26 - 8.62 \times 10^{-8}\) curie/kg. The radioactivity of the investigated samples was found to average one order higher by comparison with the activity in samples taken in the north-western part of the Atlantic. Content in Strontium-90 in the hauls of the investigated
regions fluctuated between $1.63-3.23 \times 10^{-10}$ curie/kg on wet weight. The gamma-spectrum of the samples was exclusively characterized by a peak height of potassium-40 with an energy of 1.46 MeV.

In order to ascertain whether the general radioactive contamination of the aquatic equatorium could be ascribed to the continental drainage in the explored zone of the Atlantic, a radiological survey of the western coast of Africa was carried out.

A certain quota of radioactivity in specific representatives of the zooplankton might be caused by the additional source of radioactive pollution of the hydrosphere - the discharges from the continent.

V. P. Parchevskii presented data of research into the content of fission products in certain hydrobionts of the Black Sea and the Gulf of Guinea in 1961 - 1964. The strontium-90 content was determined by extracting yttrium-90 with tributyl phosphate from carbonates of alkaline earth elements which had been isolated beforehand. Yttrium-90 was counted on a counter with a fluid scintillator and on the low-background apparatus UMF-1500. The content of gamma-emitters was analysed with the aid of multi-channel pulse-height analysers. Crystals of sodium iodide, size 70x70 mm, served as detecting element. The resolution of the gamma-spectrometer for caesium-137 (661 keV) was 14%. Calcium was determined in the ash of plants and animals by the chemical method, and potassium - with the aid of the flame photometer. The highest content
of radionuclides in Black-Sea plants was observed by the end of 1961, the beginning of 1962, when their artificial radioactivity exceeded 20 r C/g on wet weight. In the brown alga Padina pavonia the increase of artificial radioactivity above the natural one was more than 50 times.

The highest amount of radiostrontium was found in the tests of grass crabs and the shells of mysids. For Cystoseira and the shells of Mytilidae, which were most circumstantially analysed, it was established that concentrations of strontium-90 grew with time.

Research results of L. G. Chernaya showed that during the period of her observations (May - September, 1964), the content of strontium-90 grew in the brown Cystoseira alga. The increase of strontium-90 in Cystoseira for the time interval in question might be described by the formula

$$C_t = C_1 t^n,$$

where $C_t$ - is the concentration of strontium-90 at the time moment $t$, $t$ - the time in days, $C_1$ - the initial activity at the moment when measuring began, $n$ - a constant magnitude characterizing the speed of the process (or the angle tangent of the curve inclination).

The author analysed data on materials obtained by Japanese investigators with regard to strontium-90 content in marine hydrobionts of the Japanese Sea during 1954 - 1961, and ascertained that the concentration of said radionuclide in animals and plants was also increasing according to the power dependency.
The gamma-spectral analysis of Black-Sea hydrobionts collected in 1959 - 1963 resulted in establishing that their isotopic components were basically determined by the same radionuclide group: cerium-141+144, ruthenium-103+106, zirconium-95, niobium-95. A comparison of the spectrogram of atmospheric fallout with those of algae showed that in both cases the radionuclide series was identical. The highest counts of cerium-141+144 (3.04 r C/g on wet weight) and zirconium-95 along with niobium-95 (5.94 r C/g on wet weight) were found in Cystoseira collected in the fall of 1962. From July, 1962, through February, 1963, the radioactivity levels of the plants remained approximately unchanged. In 1962, all of the Cystoseira, the overall quantity of which represents 0.5 million tons in the Black Sea, contained cerium-141+144, ruthenium-103+106, zirconium-90 and niobium-90 in a total amount of 2.6 curie.

The artificial radioactivity of the skipjacks Trachurus (gills and skin with scales), caught in the Gulf of Guinea in the fall of 1961, was caused by cerium-144 and consisted of 0.012 (gills) and 1.47 rC/g (skin with scales) on wet weight. At the beginning of 1963, cerium-144 and caesium-137 content in the Black-Sea Trachurus and in Atlantic fish (Trachurus crucians, Scomber) from the Gulf of Guinea ranged from a few units to tens of r C/kg on wet weight. The highest amount of caesium-137, ascertained in the muscles, the inner organs and the skin of the Atlantic Trachurus was respectively 33,37 and 29 r C/kg on wet weight at the beginning of 1963. It should be
noted that the radioactivity of the analysed fish caused by caesium-137 fluctuated widely - from trace amounts to certain maximum quantities. In 1964, the presence of caesium-137 was ascertained in the muscle tissues of dolphins.

During 1963-1964, the content of ruthenium-103, zirconium-95, and niobium-95 decreased considerably in Black Sea plants. At the present time, fragmentary radioactivity in marine plants is brought about essentially by cerium-144.

According to research results of V.P. Shvedov and co-workers, the strontium-90 concentration in Black Sea water ranged from 0.2 to 0.3 r C/l in 1961. Proceeding from the strontium-90 content in Cystoseira in that year, which was 8 r C/kg on wet weight, and its accumulation coefficient, which equaled 42, the concentration of this radionuclide in the water was calculated and it turned out to be in good agreement with the concentrations obtained by V.P. Shvedov and co-workers, namely 0.2 r C/l.

The following plants and animals might be recommended as bioindicators for fission products: for strontium-90 - Cystoseira, Padina, the shells of mysids, tests of grass crabs; for caesium-137 - Trachurus; for cerium-141+144, ruthenium-103+106, zirconium-95, and niobium-95 - Cystoseira, Padina, Ulva, Enteromorpha, Zostera, and soft tissues of mysids.

E. I. Popova gave an account of investigations into radium accumulation by certain aquatic plants, growing in and at water bodies with a naturally high radium content. This research was conducted on a brook flowing from underneath a ground section
of maximum uranium concentration and of radium in its solid phase as well as in parts of the river influenced by the brook. During the study of these distinctive naturally radiological microbiocoenoses, the radium distribution was ascertained in the water, the ground, the hydrobionts and aquatic plants on the banks which are typical for this kind of water bodies: the water moss *Fontinalis antipyretica* L., the burreed *Sparganium simplex* L., the heterophyllous pondweed *Potamogeton heterophyllus* Schreb, the pectinate pondweed *P. pectinatus* L., the sedge *Carex sp.*, the nardosmium *N. laevigata* Rchb., the arrow grass *Triglochin palustris* L. River sections characterized by a background content of radium both in the water and in the ground (situated 15 km upstream) served as controls. Over 260 plant specimens, 320 water and soil samples were analysed for radium content. The radiochemists V.Y.Ovchenkov and A.N.Basyrova determined the radium content in the plant specimens by the emanation method.

Absorptions of radium by aquatic plants were revealed in amounts which exceeded the control specimens by hundreds and thousands of times. The range of radium content per 1 g plant material of various species and from various localities was wide: 0.2·10^{-12} - 1.0·10^{-8} g/g on dry weight.

As for the brook which is flowing out of the zone with the maximum radium concentration in its solid phase - it yielded the highest magnitudes of radium content, both in the water and in the rusty bottom, a characteristic feature of this brook. The maximum radium concentration in the bog-plant arrow grass which
is typical for this brook was near the utmost permissible for
the plant: up to $2.8 \times 10^{-9}$ g/g, at accumulation coefficients
up to 30 to 40 on dry weight and 3 - 5 on wet weight.

The radium content in the water of sections near the
river banks in zones influenced by the radioactive brook was
mostly expressed in a background concentration and reached
values of $10^{-10}$ g/l only rarely. In river sections disposed
downstream of the brook discharge, high levels of radium accu-
mulation in certain parts of the bottom and particularly, in some
plants testified to the constant and, in places, considerable
radium content. Plants which grew in such river sections con-
tained hundreds and thousands of times more radium per unit
weight than the same plants in the control section. It is par-
ticularly worthy of mentioning that under these conditions
quite a few plants revealed a radium concentration which ex-
cceeded the one of the river bottom by many times.

It was perfectly natural that the radium concentration
decreased with an increasing distance from the source of con-
tamination.

Utmost radium concentrations were found in water moss
(up to $1.3 \times 10^{-9}$ g/g). Water moss growing in less 'active' con-
ditions (the river and the mouth of the brook) accumulated ra-
dium far more intensively than the arrow grass in conditions
of the radioactive brook. The high absorbing capacity of water-
moss was confirmed by tests where the moss was transplanted
from 'clean' into 'polluted' sections of the river: as fast as
within 24 hours the radium concentration in the water moss grew by three to four orders. Consequently, one can view the water moss as being one of the best radium accumulators among the investigated plants. A particularly high amount of radium was found in 'rusty' samples of the water moss - up to $8.8 \times 10^{-9}$ g/g. Apparently, the presence of iron in plants (and in the ground) heightens their absorbing properties with regard to radium. However, the part of water moss was not considerable in the investigated biocoenose which was composed of macrophyte thickets in the shallow sections near the banks. For this reason, the radium content in the profusely growing forms of flora along the banks were of special interest, namely: the burreed and the pondweed, the density of which reached several hundred specimens per 1 m², their biomass 3 to 6 kg/m².

The level of radium concentration in the investigated plants from highest to lowest was approximately as follows: water moss - burreed - arrow grass - pondweed - sedge - nardosmia - algae.

The radium absorbed by the above plants was distributed thus in parts above the roots: in arrow grass radium concentration was usually by three to six times higher in the immersed sections of leaves and stalks by comparison with the ones above water. Nardosmia showed a decrease in radium content per 1 kg of its weight in the following order: rhizome, submerged parts of the pedicels, above-water parts of the pedicels, leaves.

In all of the studied plants an increase in radium content
per unit weight was taking place in the course of growth. Thus, a sample of fully grown arrow grass in the water body, at 20 m from the place where they had been detached (by the end of July), contained 20 times more radium than was found in the bulbs (beginning of June).

The availability of chemical elements in the biosphere is not only circumscribed by their accumulation and exchange patterns within the hydrobionts but also by the reaction of these elements upon the death of the organisms. It seems that the further fate of radium accumulated by aquatic and riverside plants depends on the intensity degree at which the dead plants will decompose.

It cannot be doubted that with the dying-off of the soft aquatic vegetation (pondweed, burreed) the radium will pass on faster into the organic matter of the bottom deposits and into the water. However, in dead leaves of the burreed which did not yet sink to the bottom radium content was usually higher than in the living leaves on the same plant specimen. It is possible that the adsorbing capacity of the soft aquatic vegetation is, for a certain time, higher in dead tissues than in live ones.

Exclusively through radium accumulation by the flora, radium content in the general plant biomass, which represented 1 to 3,6 kg per 1 m² of the bottom surface, reached 2.2·10⁻⁸ to 3.8·10⁻⁷ g/m² for a section near the brook discharge, and for a section at a distance of 30 m from the mouth of the brook it was 1.0·10⁻⁸ g/m².
With the dying-off of the vegetation the radium passes into the ooze deposits, and from there it is either resorbed by the solid phase of the earth or is leached out again into the water and migrates with the current.

In a report of I.P.Lubyanov information was ad-duced about the sum-total of beta-radioactivity of the water, the bottom deposits, the vegetation and various fish species in reservoirs of the southern Ukraine.

A. Y. Zesenko studied the distribution of ruthenium-106, zirconium-95, niobium-95, cerium-144, and silver-110 in mass species of Black-Sea arthropods (mysids and crabs), as well as the ruthenium-106 and zirconium-95 distribution in two species of marine fish.

It was established that ruthenium-106, cerium-144, zirconium-95, and niobium-95, which are present in sea water both in particulate and in colloidal form, are accumulated above all on the biological surfaces of animals which are in direct contact with the aquatic environment of the organisms. Silver, present in sea water in ion form, was accumulated both by the internal organs of crabs and on the surfaces washed by sea water.

Muscle tissues of molluscs and crabs absorbed ruthenium-106 and zirconium-95 approximately in like quantities: their accumulation coefficients (the ratio of isotope concentration in the organism or its part and in the water) were of the same order of magnitudes - single units. Muscle tissues of fish
accumulated ruthenium-106 and zirconium-95 to a considerably lesser degree; their accumulation coefficients were expressed by hundredth parts of a single unit.

Internal organs of fish accumulated zirconium-95 and ruthenium-106 with accumulation coefficients below a single unit. The skin (with the scales), the stomach and the gills of fish concentrated zirconium and ruthenium with accumulation coefficients of 5 to 10 units. The accumulation coefficient for the entire body of a fish for absorbing these nuclides was 1.5 units. The accumulation of the radionuclides cerium, ruthenium, zirconium, niobium by internal organs of crabs were expressed by the same order of magnitudes of accumulation coefficients - by single units; however, the chitin cover and the gills of crabs concentrated the enumerated radionuclides to a considerably higher degree, and the magnitudes of accumulation coefficients for these organs were expressed in tens and hundreds of units.

The heart, the gonads and the muscles of crabs accumulated silver with accumulation coefficients of 10 to 20 units, the accumulation coefficient for liver and gills was 60, for tests - 150 units. The gills of mysids which serve as filters accumulated the enumerated radionuclides to the same degree, the accumulation coefficient equaled 20 units. As is known, mysids are able to catch bacteria not smaller than 1 - 2 mk. Japanese investigators have demonstrated that the size of cerium particles in sea water does not exceed 600 mk. One may
assume, then, that the greatest part of cerium particles escapes through the gill filter and that the cerium accumulation in the gills of Mytilus is due to adsorption and not to filter retention on the gills. Some authors have ascertained that there is no discrimination for mysids in swallowing either nutrient or non-nutrient particles and, therefore, the cerium accumulation in their visceral mass might be explained by their swallowing mucus of the gills contaminated with minute particles. Cerium, zirconium, ruthenium and niobium in the muscles, the mantle and the foot were absorbed with accumulation coefficients of about one unit, and in the shell of 50 - 60 units. The identical degree of accumulation of the enumerated isotopes can be explained by their identical physical condition in sea water.

G. V. Feodorova studied the transfer of radio-carbon from the environment into developing eggs and larvae of fish spawning in spring (crucians, roaches, bleaks, alburnus, and ruffs), and those spawning in autumn (pelleus and bull-throats). Experiments were also conducted on adult fish - carps and crucians.

The eggs and larvae were placed into an active solution and after fixed intervals of time, they were washed in pure water, dried on filter paper and thereafter spread on little dishes of polyethylene film, the weight of which was determined beforehand. Thereupon, the eggs and larvae were crushed, weighed, and dried. One sample consisted of 5 - 8 eggs and of 3 - 5 larvae.

The fish were kept in 30-liter aquariums, in water of
a 2·10⁻⁵-curie/l radioactivity. C¹⁴ was used in the form of sodium acetate. To prepare radiometric samples, the following organs and tissues of fish were taken: scales, fins, skin, gills, head, brain, digestive tract, eyes, liver, blood, muscles, and bones (spinal column). The enumerated organs and tissues were weighed, dried to a constant weight, and then prepared as thinly laminated samples (10 mg) on little aluminum dishes.

All the prepared samples were counted on a B-2 apparatus with an end-window counter. The mica-window was 1,7 mg/cm² thick. The count was effected with an accuracy up to 5%. Simultaneously with the samples the thinly laminated radioactive standard of C¹⁴ was counted. The radioactivity of eggs, larvae, organs and tissues of the fish were expressed in microcurie per 1 kg on wet weight.

To study the absorption of C¹⁴ by internal organs and tissues of larvae, the histoautoradiographic technique was employed.

The eggs of crucians, roaches, ruffs, and Alburnus had been kept in various concentrations of sodium acetate, (2·10⁻⁵-2·10⁻⁴ curie/l), from the start of the cell-division stage (4–8 blastomeres). The embryonic development of roaches, alburnus, and ruffs lasted 4 to 6 times 24 hours, that of crucians 7 to 9 times 24 hours. The first day, the development proceeded very energetically and the radioactivity of roach eggs reached almost the activity of the water by the end of the first 24 hours. Thereafter the rate of absorption slowed
down. By the end of four times 24 hours, the radioactivity of the eggs of roaches, ruffs and *Alburnus* was twice as high or up to 3.12 times higher than that of the water.

Prior to hatching, on the seventh day of development, the radiocarbon contamination was lower in the eggs of crucians than in the eggs of the other fish on the fourth day of development.

Larvae hatched in contaminated water turned out to be less radioactive than the eggs themselves. Larvae hatched from radioactive eggs and developing in water of like activity, continued to absorb $^{14}$C. From the moment when the larvae had but a small yolk sac, they were given additional food in the form of *Chlorella* and *Scenedesmus* introduced directly into the radioactive water. The unicellular algae, having become radioactive, were consumed by the larvae.

The eggs of *Coregonus pelea* and *Salvelinus lepechini*, representatives of fish spawning in the autumn, need over three months for their development. Experiments with *Coregonus pelea* eggs were made with sodium acetate and sodium carbonate.

*Coregonus pelea* eggs placed into the radioactive solution at the cell-division stage (4 to 8 blastomeres), became radioactive from the first minutes of their being in the solution, just as the eggs of spring-spawning fish; however, the speed of radioactive penetration was much lower in the eggs of fall-spawning fish. Thus, in the experiments with sodium acetate, the radioactivity of the eggs reached the one of the water only by the 20th to 30th day of the test, and in experiments with
soda - towards the 30th to 40th day. While the radioactivity of eggs of spring-spawning fish exceeded the activity of the water where they developed by two to three times towards the completion of embryonic growth, the radioactivity of Coregonus-pellea eggs was ten to twenty times higher. The rate and quantity of $^{14}C$ pervading the eggs depended on the stage at which they were placed into the solution. Eggs introduced into the radioactive medium at the cell-division stage absorbed $^{14}C$ with less intensity than when placed there at later stages of embryonic development, namely at the start of embryo formation and when the embryo had been formed. As the embryos continued their development, these differences became less marked.

A. Y. Zesenko and G. G. Polikarpov presented a report on the quantitative correlations in marine radioecology based on coefficients of accumulation, and they adduced formulae for the calculation of the following accumulation coefficients: a) of chemical elements (radionuclides) in hydrobionts; b) of chemical elements (radionuclides) in organs and tissues of hydrobionts; c) of chemical elements (radionuclides) in populations and biocoenoses. Possessing accumulation coefficients of the diverse chemical elements (radionuclides) and in some cases coefficients of discrimination as well, and executing measurements for only one of the parameters, one can calculate the concentration and the content of the element (the radionuclide) in all of the organism and its parts, and also in biocoenoses and populations, according to the correlations
contained in the report.

With the aid of the accumulation coefficients it becomes possible to calculate: a) the quota of the chemical element (the radionuclide) in an organ (tissue) from the general radionuclide quantity in all of the organism; b) the quota of the mixture of chemical elements (radionuclides) in an organ (the tissue) from the general quantity of the chemical-element (radionuclide) mixture in the entire organism; c) the quota of the chemical element (radionuclide) in the general mixture of chemical elements (radionuclides) of the organism; d) the quota of the chemical element (the radionuclide) of an individual organ in the general mixture of chemical elements (radionuclides) of the entire organism. And analogous parameters for biocoenoses and their component parts can be computed.

It ought to be emphasized that this parameter, namely the coefficient of accumulation of the chemical-element (radionuclide) mixture, always has a real and clearly determined physical meaning for stable elements. As a matter of fact, it can be expressed as the ratio of ash-residue concentration of the organism to the salt concentration in the water. For radionuclides the accumulation coefficient of their mixture will depend on the constituent parts of that mixture; if, however, the composition (qualitative as well as quantitative) of the radioactive pollution of the aquatory is undetermined, the accumulation coefficient of the summated nuclides gives very scant information, which is difficult to interpret. Disposing of the magnitudes of the
radionuclide accumulation coefficients, it is possible to undertake the minutest amounts of measurements on the radioactivity in hydrobionts and can restrict such measurements to the indicator organs. Moreover, the application of the proposed formulae will allow to interpret with greater precision quite a number of questions relating to species, age, and seasonal differences in these accumulation coefficients of chemical elements (radioisotopes) between entire hydrobionts or their communities. The practical and theoretical importance to carry out radioecological analyses of the radioactive contamination of water bodies demands an intensive effort in determining the magnitudes of (chemical-element) radionuclide accumulation coefficients both for economically valuable and other numerically prominent hydrobionts.

In connection with the second category of reports, over forty questions were asked and answers given. More than ten participants of the symposium took part in the discussions.

III. Biological effects of radioactive substances

O. P. Vasilyev and A. I. Sherstnev communicated results of their research into the effect of strontium-90 on the morphological blood elements of fish. The tests were conducted on three groups of two-year-old scaly and mirror carps: group 0 - non-contaminated fish; group I - fish kept under a regime of accumulation, that is, in water with dissolved strontium-90, solution concentration $3.7 \times 10^{-7}$ curie/l; group II - fish under a regime of removal, i.e., placed into pure water after an exposition to the contaminated medium of 25 days.
Living conditions for the fish were identical for all three groups and in all aquariums throughout the period of the experiment.

At fixed time intervals, the morphological blood composition of the fish was determined. The blood was taken from the tail artery. The quantities of hemoglobin, erythrocytes, and leukocytes were counted; also, the leukocyte formula was checked. Hemoglobin was determined by the method of Sahli in gram-per cent. The Goryayev chamber was used for counting the erythrocytes and leukocytes per 1 mm$^3$ of blood and the techniques of G.G. Golodets, P.A. Korzhuyev, and N.V. Puchkov were applied. The fixed smears were tinted with the Romanovski-Gimsa color.

The inhaled and oral uptake of strontium-90 from its solution of $10^{-7}$ curie/l radioactivity by the carp organism caused both quantitative and qualitative modifications in the red blood as well as in the serum. These changes may be characterized as the initial phases of disturbances in the hemopoiesis.

It was characteristic for the effect of strontium-90 on the fish organism during the period of accumulation that the number of erythrocytes decreased markedly by comparison with the average level of erythrocyte numbers in the control fish. Thus, after an interval of 25 times 24 hours, the number of erythrocytes decreased by 26% in the fish of group I. This drop in the numbers of erythrocytes continued during the first ten days of the recovery period, whereupon the erythrocytes in fish of group II began to increase gradually until, on the 25th day
of the removal period it reached the initial level. Under identical conditions of existence (temperature, food, oxygen content of the water, etc.), the number of erythrocytes did not change in the blood of the control fish. The described modifications may be caused by the effect of strontium-90 on the erythropoiesis during the first half of the accumulation period. The slow increase in the erythrocyte numbers during the second half of the removal period might be explained as the gradual restoration of the process of erythropoiesis.

When comparing the undulatory oscillation in the number of erythrocytes with the fact of a stable level of hemoglobin content throughout the period of the experiment, one may assume that the erythrocytes develop an increase in hemoglobin concentration or that the minutest fragments of erythrocytes which, most likely, develop as a consequence of the inhibitor activity of the lysis of erythrocytes, do not lose hemoglobin while being in the vascular system.

As was demonstrated by analyses of the leukocyte formula, the noticeable neutrophil leukopenia observed at the beginning of the accumulation period was replaced on the 20th day by a growing neutrophil leukocytosis on the background of a certain lymphopenia still noticeable in the fish at the period of recovery. The described dynamics of modifications in the serum white blood composition may be explained by the destructive disturbance both of the mature lymphocytes and the elements of lymphopoiesis, as well as by the activation of the granulopoiesis.
(after its short-term suppression); and it may also be a consequence of the defensive reaction of the organism. This concerns the activation of the granulopoiesis and the appearance of considerable numbers of neutrophil leukocytes which, apparently, fulfill a phagocytic function in relation to the injured morphological elements of the blood. One can view this disturbance of the equilibrium as a pathological phenomenon arising as a result of the effect of ionizing radiation. No noticeable changes were observed in the number of monocytes of all three fish groups.

V. N. Ivanov explored the susceptibility to radium of developing eggs of certain Black-Sea fish. Experiments were conducted on the roe of: anchovy - Engraulis eucrasicholus ponticus, skipjack - Trachurus medirreaneous ponticus, haddock - Odontogadus merlangus euxinus, flounder brills - Rhombus maeoticus, gobies - Trachinus draco, mullets - Mullus barbatus ponticus, and others.

The number of embryos, both of the experimental specimens and the controls, which perished in various stages of their development could be reliably distinguished from the moment when the strontium-90 - yttrium-90 concentration equaled \(10^{-9}-10^{-10}\) curie/l and higher; the numbers of pre-larval embryos which showed various morphological deformities could be reliably distinguished at concentrations of the order of \(10^{-10}\) curie/l and higher. Deformities in hatched pre-larvae were of a great variety, most frequently they showed crooked spinal columns. Abnormal pre-larvae were usually shorter than the controls.
and they were less mobile.

Y. P. Zaitsev and G. G. Polikarpov gave a description of the hyponeiston, defined its relationships with the atmosphere, the thickness of the water mass, the benthos, and the continent. The authors indicated the peculiarities of interaction between the hyponeiston and the radioactive environment.

IV. Problems of radioecology of aquatic organisms

A substantial part of two reports was devoted to the above topic, namely: I. P. Lubyanov "Radioactivity of hydrobionts in the steppe zone and problems of limnetic radioecology" and A. L. Arge, M. M. Telitchenko "Tasks, methods and development trends in limnetic radioecology." Discussions among the participants of the symposium as well as the concluding report of G. G. Polikarpov "Radioactivity of the hydrosphere and problems of radioecology of aquatic organisms" centered also on this timely subject. The last-named report demonstrated that the attempt to calculate the general quantity of naturally radioactive substances in the hydrosphere is restrained by the fact that their content in limnetic pieces of water has not been studied thoroughly enough. At the moment, a realistic solution of this problem is possible only for the following nuclides: $^{40}K$, $^{87}Rb$, $^{14}C$, and $^3H$. In the first place, the concentrations of $^{40}K$ and $^{87}Rb$ are related to salinity which is much higher in seas and oceans than the mean salinity of
freshwater. Secondly, owing to the stratospheric origin of $^{14}O$ and $H_3$, more or less similar concentrations ought to develop in different water bodies. Thirdly, only about 5% of the total volume of the hydrosphere is represented by rivers, lakes, and bogs. Based on these considerations, the general radioactivity of the above-enumerated nuclides in the hydrosphere might be estimated as being 500 milliards curie.

At the present time, a general theoretical radioecology is still inexistent, namely a branch of knowledge which would concern itself with the discovery of radioecological norms of the most general validity for various environments, and which could equip science with guiding principles, that is to say, with a generalized radioecological theory. This is a task of the immediate future. In our country the theoretical level of studies into radioecology (the search for norms and patterns in the domain of radioecology of aquatic organisms) is superior to the one abroad. It is necessary to fight for a continued accelerated progress in this branch of science, and the basis for such a progress is to ensure material means for the existing and for new radioecological institutions.

Which are, at the moment, the essential areas of research and the problems of contemporary radioecology of aquatic organisms?

The kinetic, the physico-chemical, and the molecular foundations of radioecology. The significance of this side of our science is obvious, but it is only recently that its development began (The Biological Institute of Southern Seas, The
Ural Branch of the Academy of Sciences of the USSR, The Institute of Evolutionary Physiology and Biochemistry). Experimental investigations and a theoretical analysis of kinetic processes in radioisotopic exchange within hydrobiological systems were initially devised and are being successfully developed by G.V. Barin (Sevastopol). Work on physico-chemical aspects is conducted with fine results by N.A. Timofeyeva and E.A. Gileva (Sverdlovsk). Problems of molecular radioecology are being solved with the aid of newest techniques by I.A. Skul'skii, V.P. Nesterov, V.G. Leontyev (Leningrad). It would be desirable to accelerate the pace of research in this most important branch of radioecology.

The concentrating ability of hydrobionts. To estimate the part of hydrobionts in the migration of radionuclides and to calculate the absorbed doses from incorporated emitters, it is indispensable to express the accumulation coefficients calculated on wet (live) weight. At the symposium, a full agreement was reached among the radioecologists that the uniform method of expressing the accumulation coefficients is on wet (live) weight. And only in certain instances, for example, when utilizing bioconcentrators for the passage of radionuclide concentrations in the organisms to their concentration in the water, it would be most expedient to use accumulation coefficients calculated on ash. Then, the accumulation coefficient, say, of 1000 units on wet weight is converted into 100 000 units on ash; consequently, for determining a radionuclide, one hundred
thousand times less ash is required than water. This simplifies the cumbersome analyses of great quantities of water (especially sea water) in the highest degree.

Unique in this context is the artificial problem of the so-called "inverse dependency of the coefficient of accumulation of a radionuclide on its radioactivity" which, unfortunately, has been advanced by certain national radiation hygienists. To demonstrate the incorrectness of this 'deduction', and even to devise special tests in order to elucidate the methodical carelessness of these authors of the "inverse dependency", a great number of publications has been written by personalities of academic institutions. In this manner, whole scientific teams have been forced to waste their time in order to experimentally prove an obvious truth which is easy to comprehend for a specialist of sufficient theoretical preparation and by means of a sufficiently accurate technique.

Progress in radiochemistry and radioecology allows the scientifically founded conclusion that in the domain of microconcentrations the coefficients of accumulation of a chemical element (a radionuclide) in hydrobionts do not depend on its concentration (other conditions being equal). In the opposite case, it would be necessary to ascribe different chemical properties to the isotopes of one and the same chemical element and thereby 'in passing' to subvert the method of radioactive tracers.

The coefficient of accumulation represents the central
concept and the quantitative base in the radioecology of aquatic organisms. Disposing of tested magnitudes denoting coefficients of accumulation of radionuclides (elements), one is enabled to pass from their concentration in hydrobionts (particularly in bioconcentrators or bioindicators) to their concentration in the water, to estimate the part of hydrobionts in the extraction of radioactive substances from the environment and, with the aid of available mathematical correlations (A.Y.Zesenko and G.G.Polikarpov), to calculate the magnitudes of many parameters. Therefore, the necessity arises to still further intensify the work on determining the accumulation coefficients for the most important radionuclides and their carriers among the numerically predominant and economically valuable hydrobionts. The time is ripe for the compilation of tables and manuals listing coefficients of accumulation. And in such manuals, an important part must be reserved for the bioconcentrators (the outstanding bioaccumulators) of the one or the other radionuclide. Bioconcentrators might be found among organs (tissues), species, populations, and even biocoenoses. These radioecological indicators are a particular kind of compass in the search for naturally radioactive waters, for ore deposits, and for radioactive pollution. On the other hand, a significant thought expressed by I.P.Lubyanov should be emphasized, namely the need for discovering hydrobionts with a feebly developed ability to accumulate radionuclides. This side, too, has a direct bearing on practical considerations.
The role of hydrobionts in the migration and distribution of natural and artificial radionuclides. In contrast to organisms inhabiting the earth, the hydrobionts of all trophic levels accumulate greater quantities of radionuclides by taking them up directly from the water than in the process of feeding. In other words, one can, apparently, disregard the part of food chains in the migration of radionuclides in a radioactive aquatic environment. In this respect, trophic relations acquire significance only in 'pure' water.

Radioecologists are confronted with a task of great magnitude - namely, to study the parts of the hyponeiston, the plankton, the nekton, and the benthos in the migration and distribution of radioactive substances in pelagic and limnetic water bodies. It is of great importance to trace the essential routes of biocirculation and to determine the most significant storage points for the various groups of radionuclides. Based on this information, it will be possible to construct prognoses about the trends and the intensity of processes in the deactivation of contaminated aquatoria, or to advance hypotheses about deposit formations of naturally radioactive elements of biogenic origin.

The radioactivity of hydrobionts in natural conditions. The work accomplished in this direction is quite insufficient. For instance, in the literature of our country there are but two publications concerning strontium-90 content in hydrobionts (V.P. Porohevs'kii). And of great importance are the investigations
E.I. Popova) about the radioecology of naturally radioactive elements in natural conditions. The latest techniques of nuclear spectrometry and radiochemistry have not yet found a wide distribution in laboratories of the radioecological type. The defining of radionuclides and their carriers in hydrobionts and the environment, with due regard to a number of variable factors in natural circumstances, is an important research object of the future. Radioecology is in great need of simultaneous determinations of accumulation coefficients for both the radioactive and the stable isotopes of the diverse chemical elements. This would make it possible to discover the volume of exchange funds for everyone of the radionuclides.

The radiosusceptibility of hydrobionts. This is the youngest branch, although, by its significance, it ought to have come of age and to represent one of the most thoroughly investigated sides of aquatic radioecology.

At the symposium, explorations of this orientation were devoted to the effect of radionuclides on the blood of fish (Sherstnev, Vasilyev) and on the development of fish eggs (Ivanov).

Among the most important problems in this area of radioecology are the following: trying to find the vulnerable links in the biological structure of the hydrosphere along with the most susceptible species (their development stages) and biocoenoses of aquatic organisms; eliciting the significance of natural radioactivity (particularly in radioactive zones) in
the life of hydrobionts and their biocoenoses; studying the stimulating and the harmful effects of small doses of ionizing radiation, the norms of irradiation injury to hydrobionts (genetic and somatic consequences).

The effect of radionuclides on populations and biocoenoses. This is perhaps the most complex, the most responsible and, at the same time, that side of radioecology on which the least research effort has been expended (see, for instance, the works of E.A. Timofeyeva-Resovskaya). A problem of great magnitude and intricacy arises with the necessity to comprehend and clarify the norms and patterns in the structural modifications of biocoenoses of aquatic organisms due to the radioecological factor. And this problem is closely linked with the duty to protect nature and its resources.