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RADIOECOLOGICAL STUDIES IN THE URALS

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The principal findings of 30 years radioecological research at the Institute of Plant and Animal Ecology, Urals Scientific Center, Academy of Sciences of the USSR, are summarized. The paper emphasizes the contribution of this research to the problems of continental radioecology.

The Institute of Biology, Urals branch (now the Institute of Plant and Animal Ecology, Urals Scientific Center, Academy of Sciences of the USSR) has been the recognized center of radioecological research in our country since the '50s. Its work during this period has been conducted in the field of experimental biogeocoenology, developed by I. V. Timofeev-Resovskii, and which he later preferred to call radiation biogeocoenology. Radiactive isotopes were regarded as "labelled atoms" enabling the fate of chemical elements in biogeocoenoeses to be traced, and ionizing radiation regarded as a convenient and easily administered factor in the study of organismic activity (Timofeev-Resovskii, 1962).

The experimental foundations of this research were provided by the biophysical station Miassovo in the Lenin State National Park at Il'mensk in the Chelyabinsk region. At this station, towards the end of the '50s, the first radioecological study was carried out by G. G. Polikarpov, who subsequently founded the school of marine radioecology at the Institute of Marine Biology in Sevastopol, and by A. A. Peredel'skii who established the radioecology group at the Severtsev Institute of Evolutionary Morphology in Moscow. This was the beginning of research by the Komi branch of the Academy of Sciences, later to become a well-known center for the radioecology of biogeocoenoses, and pollution by natural radionuclides. A group of researchers headed by A. B. Getsovoi (Zoological Institure, Academy of Sciences of the USSR, Leningrad) and researchers from a number of other scientific establishments also worked at Miassovo. Thus, work begun in the '50s in the Urals, under the leadership of I. V. Timofeev-Resovskii, stimulated the emergence of radioecological centers in several other regions of the country.

The development of radioecological studies in the Urals may be divided into three main stages, largely reflecting the history of the subject.

The first stage, between 1955-1965, marked the development of experimental or radiation biogeocoenology. This decade saw the completion and publication of a mass of experimental work concerning the behavior of radionuclides and numerous chemical elements in soil-solution, soil-plant, water-subsoil, water-hydrobiont systems. Studies were carried out using simplified models in either laboratory conditions (test tubes, vessels or small aquaria) or else in small scale or specialized aquarial experiments on open ground. The results provided the first evidence on the speed and extent of radionuclide absorption in soils and groundwater, their persistence in these media and their movement into primary ecological soil-plant and water-hydrobiont links. For many freshwater flora and fauna in laboratory conditions, significant coefficients of accumulation of radionuclides were determined for nearly 20 chemical elements, showing the number of times the concentration of these nuclides in the organism exceeded their concentration in the surrounding water. This marked accumulatory ability of aquatic vegetation has led to the possibility of its use in slow-running reservoir settling tanks as a prepurifier of mildly radioactive waste water.

In addition, batteries of expeirments were performed on the relative radiosensitivities of more than 100 species and varieties of mainly cultivated plants. The majority confirmed the fact that relatively small doses of ionizing radiation have a stimulating action on plant growth and size, and provided the first theoretical interpretation of this phenomenon. In experiments using artificial associations of terrestrial plants, soil micro-organisms and freshwater periphyton, it was shown that relatively small doses of radioactivity appeared

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to have a general stimulatory effect without any noticeable restructuring, while higher doses produced profound damage to species composition and structure. The principal research findings during this period were published in a series of issues of the transactions of the Institute of Biology, Urals branch, Academy of Sciences of the USSR, and in other publications (Collected works of the Laboratory of Biophysics; I, 1957; II, 1960; III, 1960; IV, 1962; Problems of Radiation Biogeocoenology, 1965; Behavior of Radioisotopes in Model Systems of Terrestrial and Freshwater Biogeocoenoses, 1968; Timofeev-Resovskii, 1956; Preobrazhenskaya, 1971; Timofeeva-Resovskaya, 1963).

The second stage in the development of radioecological research occurred between 1965 and 1975. It was characterized by a transition to radioecology proper, involving the study of migration processes and biological activities of radionuclides not only in model systems and small-scale experiments, but in real naturally occurring ecosystems. The work during these years was mainly concerned with longlived ^{90}Sr and ^{137}Cs fragments entering the earth's surface from radioactive fallout. These radionuclides and ionizing radiation were the immediate objects of the research together with the corresponding ecosystem components.

The results demonstrated that whereas the coefficients of accumulation of ^{90}Sr in aquatic vegetation in the laboratory were similar to those found in natural water reservoirs, in the case of ^{137}Cs, accumulation coefficients in the laboratory were significantly lower than those found in natural conditions. This may be explained as a consequence of the shortterm nature of laboratory experiments and the impossibility of reproducing the conditions occurring in natural water reservoirs (Kulikov et al., 1968).

From studies of the seasonal dynamics of nuclide dispersal in minor reservoirs, it was established that as water freezes in winter, the content of some macroelements and radionuclides in thick ice falls by a factor of 10, while in the underlying water and sediments they increase (Bochenin et al., 1980). This natural mechanism has found application in special settling ponds and tanks for the purification of radioactive contaminated water and the desalination of highly mineralized coal water.

A major series of experiments was carried out to determine the ^{90}Sr and ^{137}Cs content in freshwater fish. The accumulation of radionuclides in these organisms was found to depend on the trophic status of the reservoir, the species of fish, their age and sex, and the season of the year. A quantitative evaluation was made of radionuclide migration from fish to their offspring via the eggs during spawning. In experimental conditions, the accumulation of artificial radionuclides was studied in fish eggs and larvae in relation to water temperature, the degree of radioactive pollution and the corresponding radiation burden exerting a damaging influence on fish embryogenesis (Action of Ionizing Radiation on Hydrobionts and Terrestrial vegetation, 1970; Kulikov et al., 1972; Kulikov and Kulikova, 1977). The content of radionuclides in ground sediments and subsoils was determined, as was the declining role of aquatic vegetation in the radionuclide accumulation. The behavior of numerous natural radioactive elements was also studied in water-freshwater plant systems and water-subsoil systems (Iskra et al., 1970; Lyubimova, 1971; Problems in the Radioecology of Aquatic Organisms, 1971).

Migration and dispersal of ^{90}Sr and ^{137}Cs was studied in organic topsoil in tundra regions to the Northern Urals and in mountainous, forested landscape to the Southern Urals. Experiments were carried out on the role of water-soluble plant litter products and wet soil regimes in the migration of radionuclides in soil-solution and soil-vegetation systems. A cycle of experiments were completed comparing the behavior in these systems of artificial radionuclides such as ^{59}Fe, ^{60}Co, ^{90}Y, and ^{144}Ce (Molchanova and Kulikov, 1972; Molchanova et al., 1971; Karavaeva and Molchanova, 1976; Karavaeva, 1973; Chebotina, 1967; Chebotina and Molchanova, 1975; Chebotina and Kulikov, 1973; Radioecological Studies of Soil and Plants, 1975; Radioactive Isotopes in Organic Topsoil, 1979).

During this period research began into the comparative radiosensitivity of the principal forest-forming species in the Urals, during early developmental stages. It was shown that relatively small radiation doses (within a dose range stimulating plant growth and development by irradiating seeds prior to sowing) produced defensive reactions (Action on Ionizing Radiation on Hydrobionts and Terrestrial Plants, 1970; Kulikov et al., 1971; Al'shits and Pozolotin, 1974). This was the first formulation of the concept of continental radioecology as the radioecology of terrestrial and aquatic biogeocoenoses (Kulikov and Molchanova, 1975).

Finally, the third phase in the development of radioecology begun around 1975 and extending to the present day, concerns the elaboration of the problems connected with the development of atomic energy (Problems of Radioecology in Cooling Ponds of Atomic Energy Sta-

tions, 1978; Radioactive Isotopes in Soil and Freshwater Systems, 1981; Behavior of Radioisotopes in Water Reservoirs and Soils, 1983).

Data from the preceding studies was instrumental in formulating a very important empirical generalization which states that the natural environment must not be thought of as a passive diluter of radionuclides impinging upon it. By virtue of their structural-functional peculiarities and physico-chemical properties, natural ecosystems are able to draw in radioactive substances through biogeochemical migration cycles. As a result, concentrations of radionuclides and the corresponding radiation burden may, in certain ecological nodal points, reach very high levels, It follows that these features must be taken into account when attempting to predict radionuclide contents in different ecosystems (Kulikov, 1978).

Radioecological research was conducted during this period on the experimental base provided by the Biophysical Station of the Institute of Plant and Animal Ecology, Urals Scientific Center, Academy of Sciences of the USSR near the I. V. Kurchatov Nuclear Power Station (AES) at Beloyarsk. Since 1980, a systematic radioecological research programme has been in process here involving terrestrial, aquatic, and wetland ecosystems.

In recent years, the most interesting radionuclides, from the point of view of ecological and hygenic consequences of radionuclides impinging on the external environment around Beloyarsk AES, have been ^{60}Co, ^{90}Sr, and ^{137}Cs. These radionuclides are predominantly found in weakly radioactive water discarded into the Ol'khovskii marsh-river ecosystem up to 5 km from the AES and frequently occur in the cooling ponds where surplus heat is lost from the AES as hot water (Beskrestnov et al., 1978; Molchanova et al., 1982; Chebotina et al., 1984).

At the higher temperature zones where the heated water is discarded, there is an increase in accumulation of certain radionuclides by aquatic vegetation, sediments, and subsoils (normally in that order of importance). In fish the accumulation is 2-3 times greater compared with other areas. In addition, it has been shown that ^{137}Cs content in the farmed fish living in heated wastewater ponds is several times smaller than that found in free-living fish. This may be explained as a result of the fact that farmed fish are artificially fed on "radioactively clean" meal and live in the ponds for only a year, whereas free-living fish feed continuously on radionuclide-enriched natural foods and live in the reservoir for several years from birth until capture.

The results of this research stimulated the foundation of the Beloyarsk reservoir fish farm for the raising of fish in heated water. Between 1983-1985 more than 100 tons of live fish per year were raised for sale and within the next few years productivity is planned to reach 300 tons per year. It should be noted that in 20 years of exploiting the AES, permissible levels of radionuclides have not been exceeded in Beloyarsk reservoir (Trapeznikov et al., 1983; Kulikov et al., 1984; Trapeznikova et al., 1984).

Research has also shown that wastewater from the AES emptied into the Ol'khovskii marsh-river system has virtually had no impact on ^{90}Sr levels. The concentrations of radionuclides in ecosystem components have only slightly exceeded background levels caused by global atmospheric fallout. Together with this has been noted a rather high concentration of ^{137}Cs exceeding controlled areas by a factor of 10 in water and by two orders of magnitude in sediments. Increases in tritium concentration were also noted in the aqueous phase but they did not exceed the levels permitted by NRB-76 (Molchanova et al., 1982).

Riverside marshes serve as a distinctive natural screen for the migratory path of radionuclides to the banks and surrounding areas of the Ol'khovskii marsh organic toposil. At distances greater than 300-500 m from the bank, ^{137}Cs contents in vegetation and soil do not exceed background levels. This confirms other work on ^{90}Sr and ^{137}Cs in perennial grasses, edible fungi, mosses, and lichens in the neighborhood of the Beloyarsk AES (Infontova and Kulikov, 1981, 1984), Consequently, at the present time, the hygenic buffer zone around the Belyarsk AES may be utilized for normal farming without danger to health. This is also borne out by estimates of the yearly radiation dose impinging upon the neighborhood of the Belyarsk AES using thermoluminescent disometry (Gotlib et al., 1982).

In the course of the last ten years a cycle of experiments has been conducted on the comparative radiosensitivities of forest forming species in the Urals. Attention has mainly centered on the modifying effect on seed radiosensitivity of environmental factors such as humidity, length of storage, temperature, germination conditions, prior exposure to ionizing radiation (Tarchevskaya, 1975; Pozolotina, 1980; Radiostability of Seeds and Its Variability, 1980; Modification of Growth in Radiation-Damaged Seeds, 1983). It has been established that

defensive reactions, to relatively low levels of gamma radiation, and consequently to sublethal radiation effects, are connected with an intensification (stimulation) of the cell repair system, which normally arises spontaneously to restore cytogenetic damage (Al'shits et al., 1981).

In 1985, the I. V. Kurchatov AES at Beloyarsk and the Institute of Plant and Animal Ecology, Urals Scientific Center, Academy of Sciences of the USSR mounted an All-Russian Conference on Radioecological Research in the Vicinity of Nuclear Power Stations at which was raised the perspectives of radioecological research at sites allocated for nuclear fuel enterprises. In particular, the conference approved of the experiments and principle findings of the ecological research conducted in connection with the Beloyarsk AES, regarding them as a positive example of the complex study of the effects of nucelare power stations and similar establishment on the ecosystem.

The foregoing evidence demonstrates that radioecological research is able to both deepen the understanding of the structural-functional organization of ecological systems, and to help solve important practical problems of interrelations between nuclear fuel enterprises and the natural environment.

LITERATURE CITED

Al'shits, L. K., and Pozolotin, A. A., "The influence of prior gamma-ray irradiation on subsequent radiosensitivity in pea seeds," Radiobiologiya, 14, No. 1, 154-157 (1974).

Al'shits, L. K., Kulikov, I. V., Shevchenko, V. A., and Yushkov, P. I., "Changes in pea seed radiosensitivity in response to low radiation doses," Radiobiologiya, 21, No. 3, 459-461 (1981).

Beskrestnov, I. V., Fat'kin, A. G., and Koltik, I. I., "Dosimetric controls in cooling ponds at the Beolyarsk AES," in: Problems of Radioecology in Atomic Electric Power-Stations [in Russian], Sverdlovsk (1978), pp. 61-64.

Bochenin, V. F., Chebotina, M. Ya., and Kulikov, I. V., "Seasonal distribution of ^{90}Sr and Ca in reservoir water and sediments," Ékologiya, No. 5, 96-98 (1980).

Chebotina, M. Ya., "Influence of aqueous plant extracts on radioisotope movements through the soil," Doctoral Dissertation, Inst. Plant and Animal Ecol., UFAN SSSR, Sverdlovsk (1967).

Chebotina, M. Ya., and Kulikov, I. V., "Influence of water-soluble breakdown products of grasses on the absorption of radioisotopes in the soil," Ékologiya, No. 1, 102-103 (1973).

Chebotina, M. Ya., and Molchanova, I. V., "Role of tree litter on the vertical migration of strontium-90 in the soil," Ékologiya, No. 2, 78-80 (1975).

Chebotina, M. Ya., Rech, T. A., and Kulikov, I. V., "Tritium in water and snow in the region of the Beloyarsk Nuclear Power Station," Ékologiya, No. 3, 74-76 (1984).

Gotlib, V. I., Zyryanov, A. P., Koltik, I. I., and Fat'kin, A. G., "Radiation conditions in the neighborhoor of the I. V. Kurchatov AES at Beloyarsk," in: Radiation Protection and Security at AESs [in Russian], No. 7, Énergoizdat, Moscow (1982), pp. 182-185.

Iskra, A. A., Kulikov, I. V., and Bakhurov, V. G., "Role of freshwater vegetation in the migration and dispersal of natural radioactive elements in reservoirs," Ékologiya, No. 2, 83-89 (1970).

Karavaeva, E. N., "Influence of soil moisture on the behavior of strontium, caesium, and cerium radioisotopes in models of soil-solution and soil-plant systems," Doctoral Dissertation, Inst. Plant Anim. Ecol., UNTs AN SSSR (1973).

Karavaeva, E. N., and Molchanova, I. V., "Dependence of vertical migration of strontium-90 in soils on the soil moisture regime," Ékologiya, No. 3, 105-107 (1976).

Kulikov, I. V., "Bioindicators of radioactive pollution in reservoirs," in: Biological Methods in the Evaluation of Natural Systems [in Russian], Nauka, Moscow (1978), pp. 152-158.

Kulikov, I. V., Al'shits, L. K., Pozolotin, A. A., and Tarchevskaya, S. V., "Changes in plant radiosensitivity as a result of previous radioactive influence," Radiobiologiya, 11, No. 4, 630-632 (1971).

Kulikov, I. V., and Kulikova, V. G., "Accumulation of ^{90}Sr and ^{137}Cs by several species of freashwater fish in natural conditions," Ékologiya, No. 5, 45-50 (1977).

Kulikov, I. V., Kulikova, V. G., and Beregovaya, E. I., "Transmission of strontium-90 from fish to their offspring," Ekologiya, No. 4, 48-52 (1972).

Kulikov, I. V., Lyubimova, S. A., and Fleishman, D. G., "Accumulation of cesium 137 by freshwater plants in experimental conditions and natural reservoirs," Dokl. Akad. Nauk SSSR, 178, No. 6, 1407-1409 (1968).

Kulikov, I. V., and Molchanova, I. V., Continental Radioecology (Soil and Freshwater Ecosystems), Nauk, Moscow (1975).

Kulikov, I. V., Rech, T. A., and Chebotina, M. Ya., "Tritium in water of marsh-river ecosystems," Ékologiya, No. 4, 85-87 (1984).

Lyubimova, S. A., "Migration of strontium-90 and caesium-137 in freshwater lakes," Doctoral Dissertation, Inst. Plant Anim. Ecol., UNTs AN USSR, Sverdlovsk (1971).
Molchanova, I. V., Karavaeva, E. N., Chebotina, M. Ya., and Kulikov, I. V., "Dispersal of ^{90}Sr and ^{137}Cs in march-river ecosystems," Ékologiya, No. 2, 45-49 (1982).
Molchanova, I. V., and Kulikov, I. V., Radioactive Isotopes in Soil-Plant Systems [in Russian], Atomizdat, Moscow (1972).
Molchanova, I. V., Mironov, B. A., and Kulikov, I. V., "Dispersal of Strontium-90 in soil geochemistry of Northern and Southern Urals landscapes," Radiphiol., Info. Bull., No. 13, 26-30 (1971).
Nifontova, M. G. and Kulikov, I. V., "Accumulation of ^{90}Sr and ^{137}Cs by lower plant-life in the neighborhood of the Beloyarsk AES," Ékologiya, No. 6, 94-96 (1981).
Nifontova, M. G., and Kulikov, I. V., "^{137}Cs in plants in the neighborhood of the I. V. Kurchatov Nuclear Power Station at Beloyarsk," Ékologiya, No. 5, 81-83 (1984).
Pozolotina, V. N., "Ecological aspects of radiosensitivity in the common birch and white birch during early growth phases," Doctoral Dissertation, Inst. Plant Anim. Ecol., UNTs AN USSR, Sverdlovsk (1980).
Preobrazhenskaya, E. I., Radiosensitivity of Plant Seeds [in Russian], Atomizdat, Moscow (1971).
Tarchevskaya, S. V., "Radiosensitivity of pines during early growth phases," Doctoral Dissertation, Inst. Plant Anom. Ecol., UNTs AN USSR, Sverdlovsk (1975).
Timofeev-Resovskii, I. V., "A biophysical interpretation of plant radiostimulation," Biophysika, 1, 616-620 (1956).
Timofeev-Resovskii, I. V., Some Problems of Radiation Biogeocoenology [in Russian], Sverdlovsk (1962).
Timofeeva-Resovskaya, E. A., "Dispersal of radioisotopes in the principal components of freshwater reservoirs," Trans. Inst. Biol., UFAN USSR, No. 30, Sverdlovsk (1963).
Trapeznikov, A. V., Chebotina, M. Ya., Trapeznikova, V. N., and Kulikov, I. V., "Influence of heated water on the accumulation of ^{60}Co, ^{90}Sr, ^{137}Cs, Ca, and K by freshwater plants," Ékologiya, No. 4, 68-70 (1983).
Trapeznikova, V. N., Trapeznikov, A. V., and Kulikov, I. V., "Accumulation of ^{137}Cs by fish farmed in cooling ponds of the Beloyarsk AES," Ékologiya, No. 6, 36-40 (1984).

Transactions and Reports Cited

Action of Ionizing Radiation on Hydrobionts and Terrestrial Plants, Trans. Inst. Plant Anim. Ecol., UNTs AN SSSR, No. 74, Sverdlovsk (1970).
Behavior of Radioisotopes in Models of Terrestrial and Freshwater Bioceonoses, Trans. Inst. Plant Anim. Ecol., UFAN SSSR, No. 61, Sverdlovsk (1968).
Behavior of Radioisotopes in Reservoirs and Soils, Sci, Rep. Inst. Plant Anim. Ecol., UNTs AN SSSR, Sverdlovsk (1983).
Collected Works of the Biophysical Laboratory, Sverdlovsk (1980).
Modification of Growth in Radiation-Damaged Seeds, Sci. Rep. Inst. Plant Anim. Ecol., UNTs AN SSSR, Sverdlovsk (1983), p. 62.
Problems of Radiation Biogeocoenology, Trans. Inst. Biol., UFAN USSR, No. 45, Sverdlovsk (1965).
Problems of Radioecology in Aquatic Organisms, Trans. Inst. Plant Anim. Ecol., UNTs AN USSR, No. 78, Sverdlovsk (1971).
Problems of Radioecology in AES Cooling Ponds, Trans. Inst. Plant Anim. Ecol., UNTs AN SSSR, No. 110, Sverdlovsk (1978).
Radioactive Isotopes in Organic Topsoil. Sci. Rep. Inst. Plant Anim. Ecol., UNTs AN USSR, Sverdlovsk.
Radioactive Isotopes in Soil and Freshwater, Sci. Rep. Inst. Plant Anim. Ecol., UNTs AN SSSR, Sverdlovsk (1981).
Radiostability of Seeds and Its Variability, Sci. Rep. Inst. Plant Anim. Ecol., UNTs AN SSSR, Sverdlovsk (1980).
Radioecological Studies of Soil and Plants, Trans. Inst. Biol., UFAN SSSR, Sverdlovsk, No. 9, p. 202 (1957); No. 12, p. 28 (1960); No. 13, pp. 5-48 (1960); No. 22, pp. 7-67 (1962).