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N.V. Timofeev-Resovsky's Ideas in Present Studies of Radioactive Contamination Zones of the Urals

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INTRODUCTION

The theory of living substance and the Earth biosphere by the brilliant Russian scientist V.I. Vernadsky has produced a great worldview effect. Basing on this theory another prominent Russian researcher N.V. Timofeev-Resovsky came up to formation of a new scientific discipline – radioecology. He identified two basic areas of research in radioecology (radiation biocenology): 1) studies of the radionuclide fate in natural ecosystems and 2) assessment of biological effects of ionizing radiation on living organisms, population, ecosystems. In our research activities conducted in the East Uralian Radioactive Trail (EURT) zone resulted from an accident at the Mayak concern in 1957, we attempted to advance some ideas of Timofeev-Resovsky (1957). The objectives of research were1) to assess recent levels and distribution of radionuclides between ecosystem components along the contamination gradient and 2) to study effects of low levels of chronic radiation exposure on populations of herbaceous plants.

MATERIALS AND METHODS

During a Kyshtym accident about 74 PBq of radioactive substances (^{90}Sr was the main contaminant) were released into the atmosphere, resulting in contamination of a vast area (Nikipelov, 1989). The samples of soils within EURT were taken layer-by-layer at a maximum depth of 50 cm in different ecosystems. Some plant species were sampled in the immediate vicinity of the soil cuts. Concentrations of ^{90}Sr and isotopes of Pu in all samples were radiochemically determined and ^{137}Cs was determined using a Canberra multichannel gamma-analyser. The statistical error of measurements did not exceed 15%, and the radionuclide detection limit was 1 Bq/kg. Biological effects were evaluated based on viability, mutability and radioresistance of plant seed progenies that were formed in the contamination gradient. For this purpose the seeds were couched in filter paper rolls during one month and their germination levels, survival rates, growth characteristics and anomalies frequencies were recorded. Analysis of allozymes revealed certain features of the ecological and genetic structure of cenopopulations in the contamination gradient.

RESULTS AND CONCLUSIONS

The following idea by Timofeev-Resovsky is fundamental to radioecology: "The fate of radionuclides in ecosystems depends on the ways and speed of their migration from the centers of pollution, and also on their distribution patterns in various components of biological systems". In accordance with tasks of our work we nominally divided the whole Eastern Ural Radioactive Trace (EURT) area into impact, buffer, and background zones. Impact zone comprises an area that adjoins the EURT epicentre (6-30 km from the accident epicentre). The buffer zone comprises the area that stretches along the EURT central line at a distance of 30-100 km. The background site was located beyond the contaminated area. As the distance from the contamination source increases, ^{90}Sr soil contamination declines from 25000 kBq/m^2 to 4000 kBq/m^2 within the central transect of the impact zone (A), and from 3000 to 70 kBq/m^2 in the buffer zone (Fig. 1). This decline follows the exponential law and can be described by the equation: $y=13687e^{-0.0605x}$. It should be noted that even at a distance of 100 km from the contamination source the ^{90}Sr concentrations are 20 times grater than the background level normally ranging within 1.5–1.8 kBq/m^2.

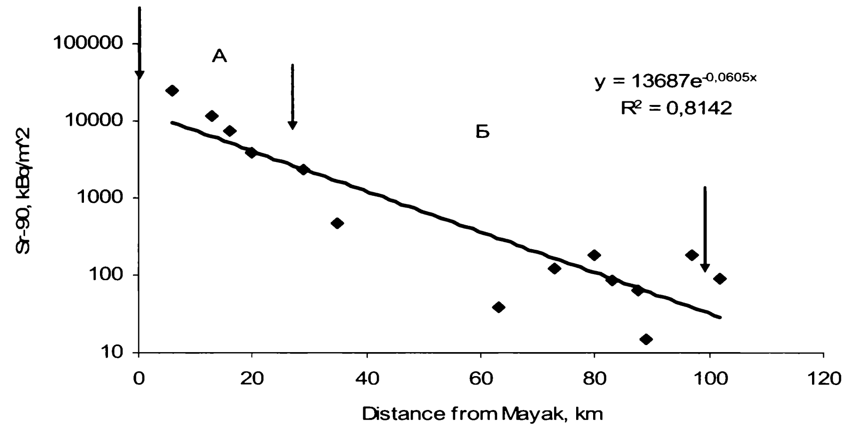

Figure 1. ^{90}Sr concentrations in soils along the EURT central axis, depending on the distance from the accident location.

The ^{137}Cs density of contamination in close proximity to the accident epicentre (6 km) totals 670 kBq/m^2. Then, it gradually decreases and at a distance of more than 30 km from the Mayak concern remains within 5-10 kBq/m^2. Density of contamination of ^{137}Cs in the central transect also follows the exponential function. In the impact zone, Pu isotopes content changes from 100 to 20 kBq/m^2, depending on the distance from the accident location and ecosystem type. These values are over 300-100 times the background level being characteristic for the middle latitudes.

Timofeev-Resovsky paid special attention to study of the role of living organisms in radionuclide accumulation. For quantitative assessment he used an accumulation coefficient that is a concentration ratio of a radionuclide in the organism and environment under equilibrium conditions. Using this criterion we compared accumulation capability of a wide range of grass and trees species from the contaminated area (Pozolotina, *et al.,* 2005). In all investigated species from the impact zone the radionuclide concentrations in plants were higher and accumulation coefficients were definitely lower than in the buffer and the background areas. These differences were especially prominent for ^{90}Sr. One of the reasons for this phenomenon may be physical-chemical conditions of ^{90}Sr in soil, because the content of ^{90}Sr mobile forms in soils of the impact area is lower. The other reason may be in biological characteristics of plants that have undergone process of long adaptation. As an example, the data for two species indicate that the radionuclide concentrations in the aboveground phytomass and plant seeds from the impact zone exceed 3-4 times background level (Table 1). $^{90}Sr/^{137}Cs$ ratios decrease in the seeds and aboveground mass during the transition from the background to impact zone.

Table 1. Radionuclide concentrations and accumulation coefficients (AC) in the air-dry phytomass of some plant species and their seeds

Plot	Species	Above-ground phytomass				Seeds	
		^{90}Sr		^{137}Cs		^{90}Sr	^{137}Cs
		Bq/kg	AC	Bq/kg	AC	Bq/kg	Bq/kg
Impact	*Urtica dioica* L.	134150	1.5	960	0.4	28406	267
	Plantago major L	71600	0.8	149	0.06	3536	40
Buffer	*Urtica dioica* L.	150	8.8	5	0.1	135	-
	Plantago major L	400	13.2	8	0.3	197	61
Background	*Urtica dioica* L.	57	5.7	1	0.1	25	1
	Plantago major L	13	1.6	2	0.1	10	1

The data on ^{90}Sr and ^{137}Cs contents in seeds were used for calculations of incorporated radionuclide dozes per germ by including them into a simple model: $M=q_1L_{(Sr+Y)}+q_2L_{(Cs)}$, where q_1 and q_2 – measured concentrations of each radionuclide in the seeds, L – absorbed dose rate, cGy/s, which is created by these radionuclides inside of uniformly contaminated volume under $q_0 = 3.7\times10^4$ Bq/g (Gorshkov, 1967). Radiation load on the seed germs of the impact zone varied from 1.6 to 70mGy per month, in the buffer zone from 0.17 to 0.21 mGy; in the background areas it totals 0.001-0.007 mGy per month. These loads do not consider the natural radiation background and are associated with the area of small dozes for plant objects. The next idea stated by N. Timofeev-Resovsky is as follows: "Biological effects of ionizing radiation are evident from their impacts on the growth, development, fertility and mortality rates of organisms. Low-level irradiation, in particular permanent internal exposure may be also biologically effective". No reduction in flora diversity was found within EURT over the past years (Lagunov, Smagin, 2007). The survey of ten plant species (*Rumex confertus* Willd., *Melandryum album* Mill., *Stellaria graminea* L., *Bromopsis inermis* Leyss. Holub, *Linaria vulgaris* Mill., *Plantago media* L., *Geum aleppicum* Jacq., *Centaurea scabiosa* L., *Berteroa incana* L., *Urtica dioica* L.) from the contamination gradient found no any significant relation between the viability of seed progeny and soil contamination levels. An overall regularity is the increase in mutability (anomalies frequency) in the seed progeny samples of all species from the EURT zone and high level of variability of all viability indicators. Assessment of the adaptation potential of plant species from all populations using provocative radiation method showed the ambiguity of response. Radioadaptation effects were not found.

Detailed ecologo-genetic studies of several model plant species were done. For the dandelion (*Taraxacum officinale* s.l.), it was shown that the least indices of viability were recorded in the impact sample. In this cenopopulation seed progeny showed high levels of mutability. This confirms the conclusion made for another species. The studies of 8 enzyme systems showed, that the number of phenes common for the three cenopopulations totals 42. In the buffer cenopopulation the number of unique phenes (occurred only in this sample) was 8 of 32, and in the impact one - 8 of 34. In the background sample with 20 morphs not unique phenes were revealed. It was found that the dandelion had a directed frequency shift of morphs in the majority of ferment systems with great increase of rear morphs share.

Research of the clonal structure of dandelion cenopopulation found that all surveyed locations included 21 clones i.e. groups of plants having identical multilocus phenotype of six ferment systems (Fig. 2). Background cenopopulation incorporated 10 clones, including 78% of the investigated plants. In the buffer samples 7 clones were identified that made 87% of the total number of plants. In the impact samples 6 clones were identified, and 42% of plants were associated with them. The buffer and the impact cenopopulations had only one similar allozymatic phenotype (No 2) which dominated in both samples (53.7 and 27.8% respectively). Thus, phenogenetic variety of dandelion cenopopulations from the EURT area is wider, compared with the background sample and the portion of rare morphs in these samples were significantly higher.

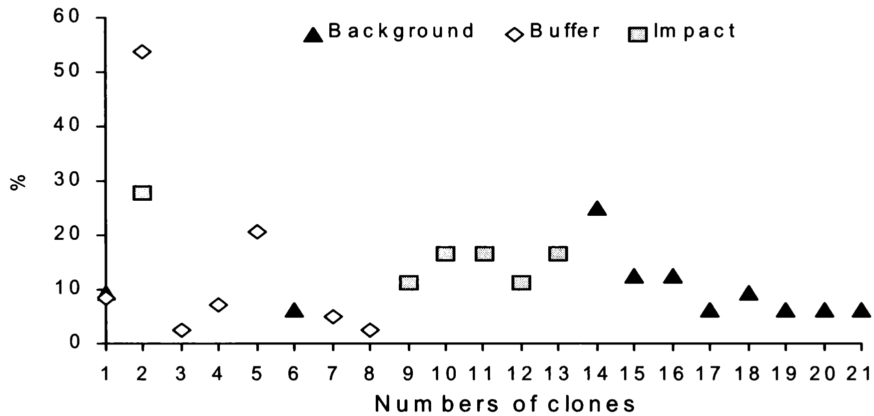

Figure 2. Clonical structure of dandelion coenopopulations from the EURT zone.

The seed progeny of plantain (*Plantago major* L.) from radiated cenopopulations was characterized by a wider variability in morpho-phisiological factors, high mutability and abnormal reaction to provocative radiation. The analysis of allozyme structure showed that rare alleles were occurred more frequently and genotype variability became lower as the dose loads in the population increased (Pozolotina *et al.*, 2005). The results indicate high genome instability of plants and intensive process of mutations in populations under conditions of chronic radiation.

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