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CHANGES IN BIOCENOSES IN THE CHERNOBYL NPP ACCIDENT ZONE

Currently, 25 years after the Chernobyl NPP accident, even in areas with high levels of radionuclide contamination overt threats for the existence of plants and animals are not detected. However, the reactions that show clear and undeniable signs of radiation lesions of certain species are obvious. Genetic effects, which are the result of the genome stability violations, cause mutations, separation of populations, loss of individual species and possibly other effects are of particularly importance.

Keywords: Chernobyl NPP accident, radionuclide contamination, phytocenosis, zoocenosis.

In 25 years since the Chernobyl accident, biocenosis species composition as well as the ratio between its single components has changed significantly in certain areas near the station. However, these changes are essentially due to changes in the entity character – dramatic limitation of agricultural activity up to its termination in the exclusion zone and zone of compulsory resettlement and reduction of anthropogenic impact in many times.

However, taking into account the multifaceted human activity it is usually very difficult to distinguish the impact of a particular factor on the expression of some biological effects, including changes in biocenoses. In contrast, almost complete cessation of agricultural activity, as happened in the area of the accident, which was accompanied by evacuation of the population and a large number of domestic animals, resulted in a fairly short time to a very intense changes in nature of the vegetation not only in the former agrocenoses, but also in natural phytocenoses, zoocenoses, mikrocenoses and biocenoses in general.

Nevertheless, ionizing radiation should be considered as one of the main factors that impacted biota in the area of the accident. That is why in these conditions it is important to evaluate impact on the succession phenomena directly the radiobiological effects that could cause some changes in biocenoses that occurred during a quarter of century.

Influence of ionizing radiation on groups of organisms of different taxonomic groups, even in relatively low doses, far from the lethal level for the most radiosensitive components of biocenosis may cause significant changes in its structure. This is because even a slight inhibition of growth and development, reproductive capacity of one or two species may be accompanied by violations in coenotic relations and to provide favorable conditions for other species.

In this situation prolonged chronic exposure can be more dangerous for biocenosis than a single sharp as acting on plant or animal for many successive generations, it can lead to gradual accumulation of variations in development of any specie. While at the same time after acute exposure irregularities in biocenoses can recover during the next years.

In general the problem of natural autochthonous biota conservation on technologically disturbed areas, including contaminated, is extremely important. Therefore, investigation of situation and changes in biocenoses during present, already remote period after the Chernobyl accident should be considered extremely important in order to explore the possibility of its restoration.

Changes in phytocenosis

Undoubtedly, the main factor that causes violations in coenotic links in biocenoses, including phytocoenosis, is radiobiological reactions of the most radiosensitive species. And for all of this it is essential that under influence of irradiation the certain level of some species reproductive ability is reached. The widespread idea that in comparison with animals, and especially mammals, man, plants have extremely high radiation resistance is wrong. It is based on the first study, conducted with the seeds – during the phase, when plants are in a deep calm state and in indeed have a low sensitivity to all factors, including to ionizing radiation. At the beginning of germination of seeds and plant vegetation radiosensitivity increases tenfold. And if comparing radiosensitivity of organisms of different taxonomic groups in these periods, it is clear that among species of higher plants there are some very radiosensitive types, and some are really radioresistant (Table 1).

The level of hazardous for plant communities' doses can differ significantly from doses that cause noticeable violations of growing parts or some other reactions in some species. That's why a comparative study of phytocenotic components radiosensitivity plays a significant role in addressing the issues of radiation safety for it. It should be borne in mind that coenotic changes may occur not only at inhibitory doses of radiation, but also at stimulating which is ten times less than specified in the Table 1 halflethal ones. Increased growth and development of one species due to radiation hormesis implementation creates for them certain advantages in plant communities that can be accompanied by worsening conditions for the development of other phytocenosis components up to their complete loss.

Table 1. **Comparative radiosensitivity of higher plants and mammals (acute γ-irradiation)** [1]

Embryophytes		Mammals	
Specie	LD_{50}, Gy	Specie	LD_{50}, Gy
Trillium	0,5 - 1	Guinea-pig	1,5 - 3
Lily	1,5 - 2	Sheep	1,3 - 4
Pine tree	1 - 3	Cow	1,5 - 5,5
Fir tree	3 - 5	Goat	2 - 5,5
Birch	3 - 5	Donkey	2 - 5,5
Beans	3 - 5	Camel	2,5
Peas	7 - 9	Human	2,5 - 4
Onion	9 - 11	Monkey	2,5 - 5,5
Beans	10 - 13	Pig	2,5 - 6
Barley	13 - 17	Horse	2,5 - 6
Wheat	13 - 18	Dog	3,5 - 4
Tomato	15 - 18	Mouse	4,5 - 7
Corn	18 - 22	Cat	5 - 7
Cucumber	20 - 24	Gopher	6 - 9,5
Clover	25 - 30	Rabbit	8 - 10
Radishes	45 - 50	Mongolian gerbil	10 - 13

As phytocenosis changes are caused mainly by chronic exposure, the dose rate is more important characteristic of effects it than the total dose of radiation. Safe dose rate for biocenosis should be considered the one that at any time of irradiation will not cause its changes. There are many reasons to believe that it should not much exceed the natural background radiation.

With high levels of natural radioactivity, such as in areas of natural radionuclide anomalies in India, Brazil, Iran, where the rate of background radiation being measured by hundreds of micro-roentgen per hour, for the thousands of years by natural selection were formed phytocenoses, which are stable in conditions of existing dose rates. Moving such plant communities in terms of normal radiation background can also cause certain changes over time.

It is clear that any changes in the phytocenosis structure do have consequences for biocenosis as a whole, affecting the microbial and zoological components, various regulatory relationships between them. This, in turn, can lead to changes in the region and even biocenosis ecosystems.

Intensive economic activities lead to the replacement of natural biocenoses by agrobiocenoses and phytobiocenoses – by agrophytocenoses or agrocenoses. If the phytocenosis consists of complex vegetation with a huge quantity of families being formed for a quite long period of time, in a man-created agrocenoses it can be represented by one species, even one sort of a plant that is cultivated. Does this mean that in this case radiosensitivity of this phytocenosis it will be determined only by radiosensitivity of this species or sort? The answer will be "significantly, but not completely". In addition in agrocenoses along with cultivated plants can grow related wild plants – weeds, which tend to have higher radioresistance, as crops have been selected on any ground, but not for radioresistance. The least inhibition of growth and development of plant cultures, barely noticeable only in experimental conditions may lead to increased development of weeds and increase their oppression. At the same time stimulating the growth of culture may lead to substantial reduction of weeds. Therefore, it gives an opportunity to suggest that even a slight increase in radiation background the behavior of cultivated plants in agrocenoses and its efficiency can vary markedly over time. In particular, this leads to the formation of entirely different point of view on the effects of small doses of irradiation.

Based on many years of observations, not only in the area of radiation impact of the Chernobyl accident, but also in areas of the East-Ural radioactive trace, Semipalatinsk nuclear test site V. A. Shevchenko et al. [2] consider genetic effects, caused by radioactive fallout ionizing radiation to be critical changes for biocenoses. On their opinion genetic effects are the main cause of changes in both groups of plants and animals. Below there are data representing changes in different dose rates for chronic irradiation of biocenoses, which may differ up to six-nine orders of magnitude (Table 2).

Table 2. **Radiobiological effects in radiosensitive species and biocenosis in general for different capacities doses**

Level	Radiobiological effect	Dose rate, Gy/h
1	Biochemical changes	$\leq 10^{-6}$
2	Chromosome aberrations	10^{-6} - 10^{-5}
3	Visible mutations	10^{-3} - 10^{-5}
4	Changes in population structure	10^{-2} - 10^{-3}
5	Deletion of certain species	10^{-2}
6	Biocenosis Depletion	$>10^{-2}$
7	Biocenosis degradation	$> 10^{-1}$

With increasing such changes in coenoses will take place: biochemical changes, chromosome aberrations, visible mutations, changes in genetic structure of populations, loss of radiosensitive species, depletion of certain groups and, ultimately, as the strongest effect – cenoses degradation. Authors outlined power range of doses for which obvious genetic effects begin to appear – only 10^{-6} - 10^{-4} Gy/day. For example for dose $2 \cdot 10^{-5}$ Gy/day genetic effects are consistently recorded in conifers. If the dose extends 0, 1 Gy/day almost all kinds of genetic effects in most species of plants and animals can be noticed. Removal of radiosensitive species of plants and animals starts from 10^{-2} Gy/day. The dose dependence curves which was built while calculating genetic effects, had a classic linear or convex type and had no threshold, which shows once again loyalty to the nonthreshold concept and shows a high susceptibility of biocenoses by ionizing radiation.

The advantages of this approach to assess changes in biocenoses are clear and justified – the registration of genetic changes in the groups that are irradiated chronically, allows operating with tests that are much more sensitive versus criteria for somatic effects. In accordance with his idea, radiobiological effects of phytocenotic level starting from the dose, which causes lesions of the most radiosensitive species such as pine.

In one of the works authors shows the results of long-term radiation-genetic monitoring of pine (*Pinus sylvestris* L.) [3] in the area of radiation impact of the Chernobyl accident. In the first mitosis of root meristem of seeds, collected at 1986 and 1987 in areas with radionuclide contamination that creates the plants absorbed dose from 0,1 to 20 Gy, the number of cells with chromosome aberration was 1,5 - 7 times higher than control. In 1993, in areas with a noticeable (0,1 - 1 Gy) and low (1 - 5 Gy) degree of trees lesion the cytogenetic effect was close to control level, but in areas with moderate damage (6 - 10 Gy) remained at 1986 - 1987 years levels. In 1997 - 1998 reducing the number of cells with aberrations was observed. The frequency of 20 enzyme loci mutation changes in all irradiated populations, was in 4 - 17 times higher than control. In general use of genetic criteria of radiosensitive plant, which is pine in the monitoring facility, allowed to evaluate the effects of exposure in the area of the accident by 1 - 2 orders of magnitude below those measured using traditional criteria radiobiological somatic type.

Thus, genetic damage of phytocoenoses and biocenoses in general can lead to irreversible changes in distant generations until the twentieth [4]. Continuing research started in 1986 by V. A. Shevchenko and L. I. Grynikch [5 - 7] according to quantitative assessment of cells with chromosome aberration in meristem and frequency of detection of embryonic lethal mutations the course of the mutation process in populations of some herbaceous, shrub and tree species was studied. Results obtained by authors clearly show that with increasing the density of radionuclide contamination the genetic load increased during the first 2 - 3 years. Later, in subsequent generations the frequency of mutations decreased, but the speed of genetic effects expression in offspring reduced and continued lagging in comparison with the rate of radiation dose reduction, which fell by three orders of magnitude during 10 years.

O. D. Kolomiets [7] for 15 generations, since 1986, investigated the kinetics of the mutational variability of the four genotypes of winter wheat subjected to irradiation in the 10-kilometer zone NPP during April - August 1986 (in August of that year, the level of soil contamination in areas of research by $^{134+137}$Cs was $n \cdot 10^{6}$ Bq/kg and for plants – 1 - $2 \cdot 10^{5}$Bq/kg, while at the same time the fraction of exposure due to radioactive cesium was not more than 10 % of the total dose).

During the first vegetation the amount of plants with morphological abnormalities was 60 - 80 %, during the second, also in exclusion zone in self-seeding conditions it reached 60 %. Herewith clearly distinguished families of sharp deviations from the initial signs of form, the main cause which was the ear sterility. In plants, the third vegetation of which took place also in the exclusion zone partial and complete sterility is also dominated, grain missing, shortened ear and others. In plants of this generation grown on the relatively clean soil outside the zone, sterility developed in 2 - 3 times less, but the formation of morphological abnormalities continued to occur with high frequency. Observed changes in linear dimensions and shape of individual organs, the number of organs, coloring, tilling degree, the appearance of wax bloom on leaves and others.

Very important was the establishment of the tendency to preserve the level of mutagenesis induced by a stay of two generations of plants in conditions of chronic exposure in the coming years both in terms of the exclusion zone and outside it in relatively pure selection-research fields. The intensity of it wawely changed over time, but during the last 15 years a significant decline in this process was not observed. In 1999 1345 mutant lines of wheat was selected, which were characterized by different levels of stability for the splitting intensity in future generations.

Thus, the mutagenic effects on plants of radionuclide contaminated environment, as well as the effects of acute and chronic exposure to ionizing radiation over many years could be realized in many subsequent generations. Perhaps the increase in genetic load in agrocenoses should not cause special concern, since the system of periodical update of seeds practically eliminates the spread of mutation in cultural species. However, we cannot exclude that genetic effects can lead to some shifts in the structure of natural plant communities, which in turn may indirectly affect and agrocenoses.

Some plant species, including families legumes, cereals, cabbage, Rosaceae, Ranunculaceae, having high ability to accumulate ^{90}Sr and (or) ^{137}Cs, which is caused by their, respectively, high consumption of calcium and (or) potassium in the metabolism, in same area with the similar degree of contamination on account of internal irradiation can receive significantly higher dose than other types, including those with higher radiosensitivity. Thus, there are some works of Ukrainian and Russian researchers on the loss or weakening in phytocoenosis some plant species. And it is not always representatives of the most radiosensitive families.

While watching for five years after the accident after orchard grass (*Dactylis glomerata* L.) – plant from relatively radioresistant cereal family in the 30-kilometer zone around the NPP V. I. Shershunova in V. G. Zaynullin found that in areas with high density of radionuclide contamination its amount in phytocenosis decreases until complete loss [9]. In similar conditions P. G. Sidorenko et al. [10] noted an increase to 30 % of non-viable pollen of white clover (*Trifolium repens* L.), willow-herb (*Chamaenerium angustifolium* L.) and white campion (*Melandrium album* L.). Also, other species that gradually reduce their reproductive function had been identified.

The study of annual plants seeds quality that grows for several generations in the contaminated areas are evidence mainly of the production process stability. Thus, O. M. Popova et al. in a series of works [11 - 14] provides data on the study of seed progeny of more than 20 species of embryophytes with several cenopopulations that were subjected to irradiation of the at dose rates from 0, 1 to 800 mR/hr (gamma background in August, 1986). It turned out that by both the weight of 1000 seeds and germination most species did not differ from conventional control, which grew at the lowest levels of exposure. However, in some species, including narrowleaf plantain (*Plantago lanceolata* L.), seed productivity decreased markedly.

Significant decline of seed viability of cancerwort (*Taraxacum officinale* L.) was revealed by V. M. Pozolotina [15].

Suppression of morning violet (*Viola matutina* Klok.) [16], winter vetch (*Vicia villosa* L.) and cow vetch (*V. cracca* L.) [17] and some other species were also described.

Most of these species also belongs to the radiosensitive families. However, our data shows some of them need increased amount calcium and potassium in their metabolism, so they can accumulate in the tissues increased the quantity of their chemical analogues - isotopes, including radioactive, of strontium and cesium respectively (Table 3).

Exactly due to this plants being under the same radionuclide contamination may form a high dose of internal radiation, much higher than in other more radiosensitive species. Moreover, the absorbed radiation dose for various types even in the same ecosystem, in the same conditions of contamination depends on several other factors including the type of radionuclide contamination, other than mentioned biological characteristics of plants. For example cesium, including radioactive, which is uniformly distributed in the body of vertebrates, in plants concentrates mainly in cells that divide, creating sometimes very high doses of local irradiation of critical tissues of higher plants – meristem. Strontium, which in vertebrates mainly accumulates in the skeleton, in plants is more or less evenly distributed along it, forming the main component of cell membranes [18]. Therefore, doses of plants that grow in similar conditions can differ in dozens of times. And that explains the inconsistency degree of radiobiological effects manifestation of under relatively low doses of radiation, which is often observed in the contaminated territories.

Table 3. **Radiosensitivity, calcium and potassium content and, accordingly, ^{90}Sr and ^{137}Cs in some plant species, which have been under radioactive fallout after the Chernobyl**

Species	LD_{50}, Gy*	LD_{100}, Gy *	Ca, mg/100 g	K, mg/100 g	^{90}Sr, Bq/kg	^{137}Cs, Bq/kg
Orchard grass (*Dactylis glomerata* L.)	–	25	85 ± 26	146 ± 38	67 ± 7	102 ± 23
White clover (*Trifolium repens* L.)	125	–	96 ± 18	160 ± 23	78 ± 7	89 ± 10
Willow-herb (*Chamaenerion angustifolium* L.)	–	–	69 ± 17	236 ± 40	56 ± 8	139 ± 14
White campion [*Melandrium album* (Mill.)]	≥50	≥100	74 ± 31	143 ± 30	60 ± 12	98 ± 12
Greater plantain (*Plantago major* L.)	10	–	78 ± 22	151 ± 24	68 ± 11	96 ± 21
Narrowleaf plantain (*P. lanceolata* L.)	–	–	82 ± 34	124 ± 22	56 ± 16	87 ± 9

Continuation of the Table 3

Species	LD_{50}, Gy*	LD_{100}, Gy *	Ca, mg/100 g	K, mg/100 g	^{90}Sr, Bq/kg	^{137}Cs, Bq/kg
Morning violet (*Viola matutina* Klok.)	-	-	119 ± 34	170 ± 28	99 ± 22	124 ± 18
Winter vetch (*Vicia villosa* L.)	≥18	≥37	105 ± 42	163 ± 18	96 ± 12	109 ± 12
Cow vetch (*V. cracca* L.)	17	37	112 ± 25	156 ± 15	89 ± 9	115 ± 18
Cancerwort (*Taraxacum oficinalis* L.)	≈25	≈50	67 ± 38	151 ± 17	39 ± 7	107 ± 22
Horse sorrel (*Rumex confertus* Willd.)	≈100	–	64 ± 12	33 ± 12	40 ± 10	24 ± 4
Tall oat-grass (*Arrhenatherus* elatius M.K.)	≈25	≈50	42 ± 23	45 ± 16	34 ± 7	56 ± 8
Coltsfoot (*Asarum europaeum* L.)	–	–	79 ± 16	21 ± 19	71 ± 15	20 ± 6

*According to O. I. Preobrazjens'ka for seeds [19].

In conditions of prolonged exposure of biocenosis by ionizing radiation there is a problem of joint action of radiation and non-radiation nature factors becoming more important. No need to emphasize the importance of the ability to assess the possible synergistic interaction between chronic exposure to low doses of ionizing radiation and environmental pollutants of chemical nature. One cannot exclude a possibility that this to some extent determines the abnormally large impact of small doses. The exact definition of synergism ratios and the other requires a new approach to rationing doses per person. Unfortunately, such data are very poor not only for the conditions prevailing in the area of radiation impact of the Chernobyl accident, but in general, for plants, animals and humans.

V. I. Kryukov et al. [20] taking into account the notorious experience of fighting the fourth reactor block and the subsequent contamination of large agricultural areas by lead, examined the impact of adding lead nitrate in the black soil, contaminated by Chernobyl-origin radiocaesium to mouse-ear cress [*Arabidopsis thaliana* (L.) Heynh] mutagenesis. It was shown that the addition of salt in an amount 16 - 32 mg of metal per kilogram of soil against the backdrop of its natural content of about 20 mg led to a decrease in the number of embryonic lethal mutations, which increased many times in a pure radionuclide contamination of soil. But increasing to 64 mg/kg and above resulted progressive increasing of their frequency. The authors do not aggravate the note on synergistic effects of ionizing radiation and lead, but analysis of a large filed of the primary material indicates that some combinations of dose and concentration effects of these agents significantly greater than additive one. In addition, quite an interesting effect is described in this work. If being analyzed apart, the effects of radiation and lead in fenospektrah of plants mutations chlorophyll mutations almost was not observed. But in case of their joint action, which is adding of lead to the contaminated soil, they had been noticed.

After the insertion salts of zinc, iron and cobalt in quantities of kilograms per hectare, calculated on the metal, in sod-podzolic soils in the 10-kilometer zone around the Chernobyl NPP, a significant weakening of the radiation factor for plants was observed. Also reducing of the degree of manifestation of some morphological violations of horse beans (*Vicia faba* L.) – classical radiobiological test system of one of the most radiosensitive annual species of cultivated plants was registered and reducing the number of cells with chromosome aberration in root meristem of seedlings from seeds of these plants [21].

It is well known that Polesie refers to those biogeochemical provinces in soils and plants of which there is a traditional lack of many trace elements. And in these poor on all vital elements conditions, on a background of soil radionuclide contamination may appear a variety of interactions, including antagonistic, between ionizing radiation and radionuclides on the one hand, and heavy metals, which in small concentrations may act as a necessary micronutrient for plants, on the other hand, what, finally, can lead to radioprotective effects.

In experiments with the same radiosensitive horse beans we were able to register the increase in the number of cells with chromosome aberration in root meristem of germinating seeds, derived from plants that were formed in the zone of the accident at dose rates of 10^{-3} - 10^{-2} Gy/day [22]. It is worth noting, that under these exposure levels the acceleration of plant growth, i.e. radiation stimulation was observed in the parent plants, and in the meristem of seedlings against increasing the number of cells with aberration increase in mitotic cells, which may also indicate stimulating processes was marked.

In general, when considering the effects of ionizing radiation on phytocenosis and biocenoses in general, one may not ignore the possible manifestation of stimulation effect. Even in autumn 1986 in some countries of central Europe recorded some significant harvest growth of many agricultural plant species. In some northern regions of Ukraine harvests of grain and leguminous crops by 10 - 30 % higher than average for the previous and next 20 - 24 years.

It was in 1986, Ukraine had harvested a record for all its history harvest of grain – 51 million tons.

Stimulating effects for wild herbaceous plant species were marked in Belarus [23]. During the vegetative season in 1986 as a 30-kilometer zone and outside it a very strong stimulation of growth of some tree species annual shoots was noticed [3].

Hungarian researcher A. Sabo calculated the total dose of external radiation, which could be got by the plants in some regions in Hungary during the vegetative season 1986, and showed that many species are close to the stimulating doses. That's how he explains fast growth and development of plants and their biomass accumulation which many researchers noticed in that dramatic year [24].

Increasing similarities and vigor of seeds, power and speed of plant growth, increasing of some physiological and biochemical processes, accelerating of cell division in the meristem and, ultimately, productivity was noted by many authors when growing plants in experimental plots in the area of radiation impact of the accident in later years.

Certainly, these phenomena, which can be interpreted as a manifestation of radiation hormesis could not be regarded as a positive – they are one of the manifestations of somatic effects of ionizing radiation on plants, specific reaction, consequences of which is difficult to predict for systemic manifestations in terms of plant communities.

And the work of Moldovan researchers which was reported during the All-USSR Conference on Applied Radiobiology in Kishinev in 1970 should also be mentioned [25]; it was discussed quite vividly, but was not published in professional journals. Authors proved the existence of two ranges of gamma radiation doses, under influence of which effect of radiation stimulation appears. The first one – in the usual dose levels and the second – smaller in order of magnitude. Experiments were held in conditions of a single acute irradiation of seeds. However, these doses, taking into account certain dependence, can be transformed for the conditions of chronic exposure of vegetating plants. And it appears that obtained as a result, maybe controversial, data about the level of stimulating doses are very close to those in which in the conditions of chronic exposure stimulating processes in pine plants were observed on gamma-field by A. Sparrow, and later on the first in the Soviet Union gamma-field near Moscow, were described by V. M. Zezyulinskyy and T. M. Hrechanovska [26] on some crops. In these cases it is about a dose rate that only an order of magnitude higher than background, which means that during a vegetative season it creates an external radiation dose of about 0,5 R.

All these data clearly show that the succession process can be caused just by the weakening of the species as a result of ionizing radiation.

Changes in zoocenosis

For correct understanding of the consequences of the Chernobyl NPP accident for faunal complexes in the contaminated territories, including the exclusion zone, in the first postaccident years direct and indirect impact of radioactive contamination on them should be distinguished. As the direct influence of irradiation, radiobiological effects arising in organs and systems of organs in wild animals' organism should be understood. As the indirect ones – the changes occurring in faunistic components of radiation coenoses. The direct effects were observed only during the 1986 - 1987 biennium, while the indirect ones are observed till now.

It should be noted that there is a few information about the death of animals due to exposure in natural coenoses. In September, 1986 decrease in the number of murine rodents in about 3 - 5 times was observed [27] for the estimated absorbed dose of 22 Gy for γ- and 860 Gy for β-radiation. Also should be mentioned that in the near zone significant differences in the number of murine averages agrocenosis of Ukrainian Polesssye was not found. Average rates are up to 30 - 40 individuals per hectare [28]. At the same time the composition of invertebrate faunistic complexes - people litter and lichens population changed significantly. There were representatives of mesofauna in the territories, where absorbed dose reached 30 Gy – 3 km south of the emergency unit – were not found at all [29]. Due to the decline of soil invertebrates' amount – 3 orders of magnitude, their age structure significantly changed, so now mature animals are dominating.

Outside the exclusion zone on the poultry farm for wild waterfowl breeding (left bank of Kiev water storage basin) in 1986 experienced a 100 % destruction of mallard embryos and substantial reduction in reproduction of other species with a gradual restoration of breeding success in 1992 [30].

Starting from 1987 to 1993 the question of direct effects of ionizing radiation on organs and organ systems of exclusion zone wildlife animals were studied in detail by mentioned above group of researchers the Institute of Biology of Komi Scientific Centre of Ural Department of Russian Academy of Sciences. At that time a comprehensive study of systems of cellular regulation in the tissues was conducted, as well as the relationships between indicators of different parts of regulatory systems of lipid peroxidation (LPO) and energy providing tissues of rodents from natural populations [31]. Based on a big amount of research data a hypothesis about the formation of new subpopulations of murine rodents due to the transition of cellular regulation systems to a new level of functioning during the first period after the accident was expressed [32]. Also some quite interesting hypotheses about chronic low-dose irradiation as a factor of selection according to changes in the genetic structure of populations have been formulated in the study of ecological and genetic characteristics of murine populations [33], as well as hypothesis about the mechanisms of information breaches emergence in the body of exposed animal, leading to massive ATP hydrolysis and heat shock. The assumption about the possibility of physiological adaptation of animals to conditions of existence in radiation coenoses were also proposed [34]. The instability of the murine rodents' genome is evidenced by the fact that high frequency of chromosomal aberrations such as translocations and large number of associations telomeric sites of somatic chromosomes was detected in domestic mice genome [35].

Morphogenetic analysis of the Anopheles larvae, yellow dragonfly, and some rodents also showed the impact of radioactive pollution, which results increasing of the phenotypic diversity, which is accompanied by destabilization of previously stable and integrated genetic and morphogenetic systems of these animals [36].

Mediate effects of wild animals living in conditions of continuous irradiation with a mixture of radionuclides of Chernobyl origin were observed immediately after the accident. Thus, in the first three years after the death of pine trees the whole system of trophic relations of pine forest ecosystems was almost completely destroyed, which, talking about insects, in particular, led to a decrease of quantity and species composition larvae of Diprionidae and butterflies, Adelges tardus, aphids and ants that feed upon the secretions of aphids. First of all it concerned the animal inhabitants of soil and aboveground stage in which there were significant violations of group structures, as well as birds that nested in hollows. The replacement of dominant groups arise in a structure of the complex soil insects – ground beetles was almost replaced by carrions. Thus, in the Red Forest territory the amount of insects in soil was minimal. In general, only in five years after the accident the structure of entomologycal complexes was dominated by ground beetles and phytophagous, especially weevils, which due to the loss of the main fodder tree – pine-tree – were accumulated on the soil surface [37].

In the other forest biocenoses the total number of soil insects also significantly decreased, the number of species and trophic groups of this animals reduced, in particular the amount of rove beetles. General structure of soil invertebrates, was dominated by coprophagous, especially in areas with high initial levels of contamination [38]. Only six years after the accident in almost all types of biocenoses a gradual normalization of the structure and stabilization of species composition of soil entomocomplexes started. This enabled us to talk about beginning the process of biocenosis stabilization. In fallows, which formed on the spot of former farmlands, favorable conditions for development of polyphagous ground beetles emerged.

During this period similar changes were recorded also in the composition and structure of bird complexes. During the six post-accidental years was recorded a gradual decrease of artificial nests places colonization of on different sections of forest ecosystems, by great tits, and an increasing of the nesting there motley flycatchers. One reasons for the reduction of big tits quantity – the type which is not only multiplies in radiation coenoses, but also winters there – may be caused by effects of irradiation. Pied flycatcher (migratory species) takes free environmental niche, where it finds favorable conditions for living. Interestingly, that the pert of other birds at different sites in different years are more or less constant and amounted to about 7 - 10 % [39].

The pollution of areas by radioactive emissions reflected in mammals, both small and large to a much lesser extent. It should be noted that favorable environmental conditions prevailing in the exclusion zone, has smoothed the negative effect of ionizing radiation on the animals and led to the described by G. G. Polikarpov phenomenon of "ecological masking," despite the fact that the contamination of ecosystems, including their faunal components was significant [40].

The trend of the number increase of the main types of games was noted in 1987 - 1992. The peak of number, associated with the fodder capacity of territory, has not been achieved. In comparison to the pre-accident levels the growth of elk and deer populations assessed as moderate, and the quantity of such polycarpous species as the wild boar it was estimated to be significant, in 8 - 10 times [41]. Since 1993 and until now the number of major groups of hunting animals in the exclusion zone decreases due to various reasons, including poaching. However, now the exclusion zone has become a kind of reserve, which appeared such rare animals as bison, otter, lynx, swallowtail, and others.

The study of the general state of faunal complexes of the exclusion zone allows estimating the consequential changes in the structure and quantity of terraneous animals for post accidental years and conventionally distinguish three periods of the impact of the consequences of accident [42]. The first period – approximately the first 60 - 80 days after the explosion of the reactor – are characterized by an acute (or subacute) influence of ionizing radiation on living organisms. As a result of the death of 600 ha of pine forests around Chernobyl trophic links in biogeocenosis were affected, which led to significant changes in faunal complexes. In particular this applies to invertebrates – inhabitants of litter and insectivorous birds of the forest complex. Species diversity during that time was minimal.

The second period – the period of total suppression of some biogeocenosis – was stretched till the end of 1991. This time was marked [43] by a general depression of faunal complexes, related in their vital functions with the contaminated soil. It was expressed in a steady decrease in species diversity of almost all groups of soil insects, during this period ground beetles was almost replaced by carrions.

The third period (from 1992 to 2000) was characterized by gradual recovery in quantity and population structure of entomological and ornithological complexes and some decrease in the number of mammals. Currently, the structure of terrestrial fauna complexes almost returned to the characteristic of pre-accident period, and species diversity recovered almost to the initial status [44].

It is known that the part of animals in transport of radionuclides through biological chains and in their redistributing in components biogeocenosis quite substantial [45]. Significant impact on the degree of redistribution caused by wild animals also has inter- species relationships in the ecosystem. The results of the study, in particular, of ^{137}Cs behavior in its elevation through the trophic chain indicate the processes of its intensive accumulation on the path from soil to animal-saprophages. It was noted that transfer and accumulation factors are increasing more than twofold in pre-absorption part (phytophagous → nekrophagous) of trophic chain and almost fivefold - in the link “excrement → koprophagous”, ie in their own saprobity part of the chain. This allows to make sure that the accumulation factor increases not only when moving ^{137}Cs through parts “vegetation → phytophagous → predators” with a maximum concentration of the isotope in the soft tissues of mammals, as it was defined previously [46], but also in parts “soil → plants →phytophagous → saprophagous” with maximum concentration in insects [47].

A specific issue of clarifying the living conditions of terrestrial animals in the Chernobyl exclusion zone is the flow and accumulation of cesium and strontium radionuclides and the effect of the absorbed dose to the basic ecological characteristics of populations of these animals. In conditions of chronic exposure, non-equable in time and in the distribution of radionuclides in organs and tissues of animals, exactly this type of irradiation is specific to biological objects, which were exposed to contamination of Chernobyl origin, till this time there is no single value that adequately reflects the arising biological effects. Study of the principles of absorbed dose formation in wild animals allowed to distinguish the most significant ways of exposure impact on the organism as a whole and take into account that the magnitude of doses, both for external and internal exposure, in addition to characteristics of the sources, significantly affect the biological characteristics of the animal, its body structure, lifestyle and behavior in natural conditions [42]. Consider the example of East-European vole (Microtus epiroticus), who lives in open biocenoses of Chernobyl exclusion zone, it was shown that decisive in the formation of absorbed doses was external γ-and β-irradiation, and the contribution of internal β-radiation is negligible. At the same absorbed dose of external β-irradiation was more than an order of magnitude higher than the external γ-irradiation and almost four orders of magnitude higher than the internal β, γ-irradiation. Similar study on forest species – East-European vole [48] also showed that a general pattern of formation of absorbed doses in murine rodents.

Evaluation of same positions absorbed doses for ash birds showed that, unlike small mammals, the greatest dose load for birds that live in the hollows creates an external γ-irradiation, due to a longer term of stay in crown of trees than in the nest and on soil surface. In this case β-component is not so big – because of the high mobility of animals and short period of stay in crown of the trees it can be neglected.

A bit different picture is observed in large mammals. There is a definite relationship between trophic level of animals, their daily activity, mobility, size of rear areas in conditions of high spot of contamination and internal radiation doses [49]. Thus, the maximum dose of internal radiation is typical [50] for the European roe deer, which fed in the vegetative season mainly by grassy vegetation and in winter by leaf litter and trees branch bark. The formation of wild boars absorbed dose is strongly affected by their lifestyle and particularities of nutrition, including seasonal variability of specific activity of organs and tissues [51, 52].

Reproductive features of such an important group of terrestrial animals like birds, and actually the presence of calcium in the egg shell, led to the study of peculiarities of the equivalent dose formation of embryo, which in fact is inside of a source of ionizing radiation. Radiometric and radiochemical studies of specific activity of birds eggs shell on different ecological levels showed very high concentration of ^{90}Sr, comparable with the activity of radioactive waste (about 104 Bq/kg). A [53] model of an equivalent dose of bird embryos at early stages of embryogenesis (stage drive) formation under continuous irradiation by ^{90}Sr proved the possibility to calculate the equivalent dose to the embryo of the shell remnants, i.e. without removing eggs from nests, and also showed that the dose formation (from $8 \cdot 10^{-3}$ to $396 \cdot 10^{-3}$ sSv during the first 7 days of incubation) occurs only because eggs shell in the immediate proximity of the embryo, taking into account the absorption of electrons by the egg white and yolk. Naturally, with the growth of the embryo and the occupation by it the total volume of eggs, the exposure situation changes significantly. At the same time, exposure by itself on the early stages of embryogenesis leads to embryogenesis inhibition and, consequently, to emergence of a significant number of non vital eggs what was mentioned by many authors [49].

A considerable amount of works is devoted to studying of peculiarities of major long-lived artificial radionuclides flow and accumulation in animals. Almost all scholars were interested in questions about what are the paths of radionuclides coming, the way they are distributed in organs and tissues and quantity and paths of extirpation. Only two sections of the international conference "Biological and Radiological Aspects of the Chernobyl nuclear power plant" (1990) contained 27 scientific papers on the subject. Such increased interest to it was caused by the fact that that is one of the main problems of radiobiology and radioecology without answers on which even the simplest conclusions about biological and ecological consequences of accident for zoocenosis cannot be done. Note that Ukrainian researchers from the Institute for Nuclear Research of National Academy of Sciences of Ukraine research group, Chernobyl Center for International Studies, Schmalhausen Institute of Zoology of National Academy of Sciences of Ukraine, Institute of Hydrobiology of National Academy of Sciences of Ukraine, Ukrainian Institute of Agricultural Radiology, Polessky branch of URIFFM and many others worked and still work in this area with a great success. Research results generally confirming the known patterns, but and some interesting features of this process were figured out.

Thus, the study of ^{137}Cs i ^{90}Sr accumulation, which was carried out within the framework of international projects ESR5 and ESR9 revealed features of seasonal accumulation of radionuclides in wild boars and European roe deer [54]. In particular two features have been found. The first one is dependence between the values of ^{137}Cs concentrations in muscle and levels of soil contamination. The second is the seasonal variability of this index. It is noteworthy that for wild boar and European roebuck, they have different character [55]. In winter adult boars differs significantly higher values of ^{137}Cs accumulation. From winter to August inclusive a tenfold decrease of specific activity of muscles takes in absolute values of activity, and in autumn it reaches its minimum.

As in wild boar, but less intensely and in the opposite direction changes the nature of the radionuclides accumulation and specific activity of European roebuck deer muscles during the year. Winter season is marked by a minimum value, thus a significant effect of snow cover was found, which leads to increased accumulation of radionuclide. In late summer and fall roebuck have maximum values of ^{137}Cs specific activity in muscles. Overall, intake of radioactive isotopes of cesium and strontium to wild boars and roebuck is a complex picture, depending on the physiological status of animals, seasonal changes in forage, fodder behavioral characteristics of different age and sex groups, radiological and soil characteristics of forage plots.

Similar studies conducted by German [56] and local researchers in the Ukrainian Polessye territory [57] also showed seasonal changes in accumulation of ^{137}Cs by European roebuck with a maximum in autumn and minimum in spring.

In contrast to the accumulation of ^{137}Cs in muscle, accumulation of ^{90}Sr in the skeleton of animals has a clear seasonal variability, which is associated with a long period of his effective half-time extraction. However, due to the seasonal variability of food of these animals similar patterns should be expected for this radionuclide. On the possibility of such a phenomenon reflects the seasonal variability of ^{90}Sr specific activity in the murine rodents' skull bones with an increase from spring to fall [58].

Study of the impact of man-made radionuclides pollution often focuses on selection of species-indicators or species groups that respond most adequately to such pollution, and studying the characteristics of their vital functions in contaminated ecosystems. This approach is based on an analysis of separate populations of animals or of a sample of individuals making up the population and allows to determine a number of changes caused by the influence of ionizing radiation at different levels of the organization – from the organism to the population. Studies of V. E. Sokolov, D. A. Kryvolutsky, A. D. Pokarzhevsky, A. I. Ilienko and other researchers who considered to be classics are widely known and devoted to the study of wild animals as part of overall environmental monitoring [59]. In particular, based on the study of soil animals, primarily earthworms [60], the differences in biomass and abundance of these animals in conditions of ionizing radiation, changes in their immune status had been shown, defined the basic role of these animals in the environmental biological indication.

Study of indicator species population characteristics within ten years after the accident allowed verifying with high reliability a significant effect in the main population characteristics of animals, caused by permanent living in conditions of radioactive pollution. In particular, along with the fact that the number of murine rodents even in the exclusion zone is relatively stable, there are processes in their populations that indicate a substantial reorganization of their structure. Among others, the inverse dependence of murine rodent density concerning soil contamination density was proven. During the year, age structure of populations significantly changes: the fall (before winter) is dominated by arrived animals, indicating an increased mortality of animals in older age groups during the summer-early autumn period. There is also a decrease of animals' fertility to 4,5 embryos per female. Thus, young animals are being involved in the process of reproduction, and through a relatively stable number of populations being achieved [61]. This phenomenon is typical for greate tit, when on the most contaminated areas about 100 % of females participates in the second egg laying [39].

The research is devoted to studying the functioning of some faunal complexes in radiation biogeocenosis allowed to formulate the concept of environmental radioresistance of wild animals in conditions of chronic exposure, which is a measure of population response to chronic exposure under natural conditions. It depends very little on the individual radioresistance of a species, but primarily determined by ecological characteristics of a specific species of animal. The negative impact of chronic exposure primarily affects the populations of the species which are characterized by a long period of growth (soil insects), and to a lesser extent – the populations of animals with short life cycle (murine rodents). Fluctuations in the number of animals that most of their development cycle is in a larvae stage which occurs in a contaminated soil will be more significant than in number of animals with short development cycle. So the features of K-and r-strategy of survival clearly manifested in the indicator species populations [61].

Conclusion

Currently, in 25 years after the Chernobyl accident, even in areas with high levels of radionuclide contamination, except for some areas of the Exclusion Zone, including the territory under the former "red" forest and some other much smaller areas, obvious threat to the existence of flora and fauna was not revealed. However, the obvious manifestations of reactions that shows clear and undeniable signs of radiation lesions of certain species of plants and animals. Genetic effects, which are the result of genome stability violations and cause mutations, population stratification, reduced reproductive capacity, loss of individual species and, possibly, other effects.

There are no contradictions, because cumulative radiobiological processes are continuing for many generations, what allows suggesting the possibility of incomplete implementation of the remote effects of irradiation at present. In addition, powerful system of recovery processes, system reliability, resists the negative impacts of radiation, which aims to ensure the stability of the indigenous biocenosis. And as evidenced by some of the data, this system is shown at different levels of organization.

In particular radionuclide contamination of ecosystems has led to intensification of microevolutional processes in populations of some species, perhaps by changing the norm of reaction to environmental conditions. In this regard, two directions of this process are coming to the fore – adapting to new conditions and stabilizing selection. The first trend – is the increase of epigenetic (and, consequently, - genetic) variation, which manifests itself in enhancing the ability to adapt to unfavorable living conditions, followed by normal reaction displacement to these conditions – is an indication of selection of the individuals, who fitted to the press radiation in the best way, and, ultimately, populations (i.e., radiation adaptation). Evidence of the second direction is the reaction of micromammals' populations, which is reflected in relatively low variability with the stable population preservation, which allows the population to keep its own peculiarities.

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ЗМІНИ В БІОЦЕНОЗІ В ЗОНІ АВАРІЇ НА ЧОРНОБИЛЬСЬКІЙ АЕС

Нині, через 25 років після аварії на Чорнобильській АЕС навіть на територіях з високими рівнями радіонуклідного забруднення не виявлено явних загроз існуванню рослин і тварин. Проте очевидні прояви реакцій, що свідчать про явні та беззаперечні ознаки радіаційних уражень окремих видів і комплексів видів. Особливого значення набувають генетичні ефекти, які є наслідком порушень стабільності геному і є причиною виникнення мутацій, розшарування популяцій, випадіння окремих видів та, можливо, інших ефектів.

Ключові слова: аварія на Чорнобильській АЕС, радіонуклідне забруднення, фітоценози, зооценози.

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ИЗМЕНЕНИЯ В БИОЦЕНОЗЕ В ЗОНЕ АВАРИИ НА ЧЕРНОБЫЛЬСКОЙ АЭС

В настоящее время через 25 лет после аварии на Чернобыльской АЭС даже на территориях с высокими уровнями радионуклидного загрязнения не выявлены явные угрозы существованию растений и животных. Тем не менее очевидны проявления реакций, свидетельствующих о явных и несомненных радиационных поражениях отдельных видов и комплексов видов. Особое значение приобретают генетические эффекты, являющиеся последствием нарушений генома и причиной возникновения мутация, расслоения популяций, выпадения отдельных видов и, возможно, других эффектов.

Ключевые слова: авария на Чернобыльской АЭС, радионуклидное загрязнение, фитоценозы, зооценозы.

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