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Comparative Efficiency of Countermeasures in Agriculture at the Radionuclide-Contaminated Territories

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The efficiency of various countermeasures (radioprotective measures) in agricultural production at the radionuclide-contaminated territories after the radiation accidents in the South Ural, at the Chernobyl NPP and NPP Fukushima I are compared. The influence of these accidents on the decreasing of radionuclides uptake and accumulation in plant-breading and animal-breeding products, and consequently, on internal radiation dose for the human being due to foodstuffs varies in different conditions and mainly depends on radionuclide composition of contamination, soil type and manufacturing profile of production.

Key words: radiation accidents, Chernobyl NPP, NPP Fukushima I, agricultural production, radionuclides, radioactive contamination, countermeasures.

One among the most severe environmental implications of the radiation incidents (nuclear weapon explosions, emergencies in the nuclear power plants) is the radioactive contamination of agricultural land and natural ecosystems, i.e. meadows, pastures, forests, since soil is not only the first and basic link, whereto radionuclides fall from the atmosphere, but also their storage battery and depositor. The radionuclides begin their way to the human body and form the internal radiation dose just from it by means of plant growing and animal breeding products via trophic chains. In the population inhabiting within the radionuclide-contaminated territories the part of internal radiation dose obtained with food products can be up to 70-90 per cent of total radiation dose [1]. That is why, development and implementation of special radioprotective steps (or, countermeasures) decreasing the transition of radionuclides into plant growing and animal breeding products is the basic way of radiation dose reduction for the agrarian manufacturing.

The emergencies in the South Ural, at the Chernobyl NPP, NPP Fukushima I (Fukushima Daiichi) have in common not only their immensity, as these are the greatest radiation emergencies during the entire nuclear power history [2, 3], but also their agricultural effect, even more, forest agricultural, while all three occurred in the agrarian-developed zones significantly covered with forests (Table 1). Thus, the population of the radionuclide-contaminated territories is mainly the rural inhabitants often obtaining many times as large internal radiation dose, than the city dwellers, as a result of the local agrarian products and also natural forest food consumption. So, the radiation dose obtained not only by the inhabitants of rural localities, but also the city population also consuming these products depends on the implementation of the countermeasures in the agrarian production directed toward the decrease of radionuclides entering and accumulation in plant growing and animal breeding products. Consequently, the agriculture manufacturers bear responsibility for radiation safety of the state population.

Even during the so-called Kyshtym emergency mitigation in the South Ural, at the Mayak Enterprise in the Chelyabinsk Region, that occurred in 1957, the basic managerial and agrarian-technological principles of agricultural production within the radionuclide-contaminated territories have been developed. The so-called countermeasures, or radioprotective methods contributed to the decrease of the radionuclides accumulation in food products were approved for plant growing and animal breeding [4]. They successfully passed tests under the conditions of after-emergency period in the contaminated zone of the Chernobyl NPP, were improved and augmented [5–7]. In the Polissia zone, on the radionuclide-contaminated sod-podzol soils of the various degree of podzolization, and also acid peat-bog soils, poor practically in all nutrients, such methods as liming, introduction of the increased standards of phosphoric and potassium fertilizers, organic fertilizers, used both separately, and in various combinations, allow decreasing the entering of ^{137}Cs into the plants in 2.5–4 times, while ^{90}Sr – in 1.5–2.5 times, and consequently, decreasing the internal radiation dose of the human-being in 1.5–3 times [5–8].

But these measures proved to be inefficient under conditions of the radionuclide contamination of agricultural land as a result of the NPP Fukushima I emergency, where the loamy and clay red soil of heavy texture with the powerful humus horizon predominate. First, these soils are slightly acid, close to neutral pH, that is why, liming insignificantly influences on the radionuclides mobility. Secondly, under conditions of the land contamination as a result of the Chernobyl NPP emergency the lime, as the source of calcium, acts as ^{90}Sr radiation blocker. But this very radionuclide is practically absent in the emergency ejections at the NPP Fukushima I. For the same reason, there is no need for the introduction of the increased standards of the phosphoric fertilizers, as their effect is connected to the formation of the weakly-dissoluble secondary and tertiary phosphates of ^{90}Sr. Thirdly, these soils are considerably greater provided with the nourishing elements, including potassium, so the introduction of both the potassium and organic fertilizers insufficiently influences on entering of ^{137}Cs into plants [9]. And, fourthly, due to high content of the humus (up to 6 per cent), macro- and micro-elements, powerful soil absorbing complex, these soils are capable of this radionuclide's fixation and its acceleration of its so-called "aging" – transition into the state almost inaccessible for the plants. The latter, surely, should be carried to the positive qualities of these soils, since it gives evidences on their high auto-rehabilitative potential.

All mentioned above suggests that if only the radiation accident in the territory of Ukraine occurred not in the Polissia zone, *i. e*. in the forest zone, but in the steppe, where powerful chernozem soils predominate, its consequences would be considerably less not only in the agriculture, but also in total. This is another evidence of the very unsuccessful selection of place for building of the Chernobyl NPP and necessity for thorough comprehensive approach for similar issues.

As the practical experience of the first years stated, in Japan such methods, as the deep-plowing with a trench plow or specially designed so-called soil horizons mixer proved to be effective (Fig. 1). This mounted equipment allows removing the upper contaminated layer at thickness up to 20–25 cm and moving it at depth of 0.5–0.7 m by the trench plow and 0.8–1 m by the soil horizons mixer [10].

Among efficient steps are: the upper contaminated ground layer removal in thickness up to 3–5 cm (Fig. 2) [11], covering the surface with sorbent materials followed with their collection and removal [12], water turbidity in the rice paddyfields with its subsequent selection and cleaning from radionuclides [13], as well. These measures allow cleaning soil radionuclides, decreasing their transition into the plants ten times or even more, and consequently, lessen the internal radiation dose of the human-being for 3–5 times.

Such well-known and even described in the textbooks methods, except for the last one, were tested and applied at the radionuclide-contaminated agricultural land after emergencies in the South Ural and at the Chernobyl NPP. Concerning the deep-plowing method

Table 1. Common and Distinctive Characteristics of Three Greatest Radiation Accidents

Characteristic	Mayak Enterprise	Chernobyl NPP	NPP Fukushima I
Emergency Location	ex-USSR, Chelyabinsk Region	ex-USSR, Kyiv Region	Japan, Fukishima Prefecture
Year	1957	1986	2011
Date	September, 29	April, 26	March, 11
Region	Asia	Europe	Asia
Geographic zone	Forest	Forest	Forest
Regional economic profile	Crop farming, forestry	Crop farming, forestry	Crop farming, forestry
Emergency facility	Radioactive waste storage	NPP	NPP
Radioactive emission cumulative volume, Bq	$7.4 \cdot 10^{16}$	$5.3 \cdot 10^{18}$	$1.4 \cdot 10^{18}$
INIS emergency coefficient	6	7	7
Long-lived radionuclides	^{90}Sr	^{137}Cs, ^{90}Sr, ^{239}Pu	^{137}Cs
Radionuclides' physical-chemical state	Aerosol, hydrosol	Aerosol	Aerosol
Contaminated territory square, thousand km^2	23	195	55
Wind direction in the moment of the emergency	NE	NW	NW
Prevailed soils	Grey forest, leached chernozem	Sod-podzol, peat-bog	Red soil, forest

Fig. 1. Deep-plowing method with soil horizons mixing (Japan)

Fig. 2. Upper contaminated ground layer removal (Japan)

with soil horizons mixing, it is suitable for the fertile soils with powerful humus layer typical for the Fukushima Prefecture [14]. Though, as the Chernobyl experience proved, this technique was not suitable for the light texture sandy and sandy loam soils in the Polissia. Its drawback under these conditions is the actual liquidation of the fertile horizon and the large power requirement of the technology that needs the use of heavy muling vehicles.

The rest of the measures causes huge amount of radioactive wastes requiring utilization or burial. The removal of only 3–5 cm of soil layer within 1 hectare of agriculture land results in 300-500 m^3 of radionuclide-contaminated soil, about 500−700 tons of total weight.

As may well be imagined, what will happen to a field of sod-podzol sandy soil in the Polissia zone, where the fertile layer is measured by the depth of the arable horizon, after the application of the soil horizons mixer. Or, just picture the piles of radioactive soil after the upper 5-cm layer removal.

Both the research works and rehabilitative measures implemented in Japan are caused by struggle for each are (100 m^2) of agricultural land (in Japan there are 4 ares of arable land per capita, while in Ukraine – almost 70 ares per capita). Relatively small amounts of contaminated soil are stored in the large plastic bags and temporarily placed within the concrete constructions limiting it as the source of external radiation in Japan. There are attempts to decrease the amount of such wastes due to the burning-out of radioactive cesium from the soil by heating in special furnaces at temperature 1300 °C with their subsequent catching with filters, concentrating and burial. It is believed that the mineral product appearing after soil burning-out can be used both as a construction material and also for road furnishing. However, the usefulness of this technology is negligible thus far [15] and, of course, it is also very energy-consuming.

Both under conditions of emergencies at the Mayak Enterprise, or Chernobyl NPP and at NPP Fukushima I the soil phyto-decontamination techniques has demonstrated its low effectiveness. It means cleaning from radionuclides by means of those plants cultivation, which have the high ability to accumulate radionuclides while forming large biomass (sunflower, amaranth, lupine and others) [16, 17]. Moreover, its application is also accompanied with the formation of radioactive wastes in immense amount. Furthermore, in whole it is acknowledged inadvisable to use the plants – radionuclides accumulators for soil cleaning [18].

In the animal production forage improvement is highly effective for the limitation of the radioactive cesium accumulation in milk and meat due to the meadows and pastures management, especially radical one, also addition of enterosorbent, in particular hexacyanoferrate (Prussian blue) to the nutrient budget of animals, first of all the cattle. As the experience of the Russian [19], Belorussian [20] and Ukrainian [1] scientists, also confirmed by the Japanese researchers [21–23] proves, these methods allow to reduce the rate of ^{137}Cs in production of animal breeding for 3–6 times and so, decrease the radiation dose of the human-being correspondingly.

Table 2. Multiplicity of Radionuclides Rate Decrease in the Agricultural Products, and so – the Radiation Dose For the Human-Being, Applying the Countermeasures

Countermeasures	Multiplicity of Rate Decrease in Agricultural Products		Approximate Multiplicity of Radiation Dose Decrease
	^{137}Cs	^{90}Sr	
Deep-plowing method with soil horizons mixing	6–10	3–7	3–5
Upper contaminated ground layer removal	4–8	3–6	2–5
Acid soils liming	1.5–4	1.5–2.5	2–3
Introduction of the increased standards of potassium fertilizers	2–4	0–1.5	1.5–2.5
Introduction of the increased standards of phosphoric fertilizers	0–1.5	1.5–2.5	1.5–2
Introduction of organic fertilizers	2–3	1.5–2	1.5–2
Meadows and pastures radical management	2.5–10	2–6	2–5
Addition of hexacyanoferrate to the nutrient budget of animals	2–8	–	1.5–4
Milk dehydration	10–30	5–10	3–5
Meat, vegetables, mushrooms, etc boiling-out	1.5–3	1.5–3	up to 1.5
Clean nutrient budget of animals for one month before butchering	2	0–1.5	up to 1.5

Table 2 gives the averaged data on the influence of separate basic countermeasures on the radionuclides accumulation decrease in plant growing and animal breeding products taken in whole and based on the experience of the Ukrainian, Russian, Belorussian and Japanese scientists. While taking into account the average rate of various agricultural products in the diet of an ordinary person (no doubt, the diets in the Fukushima Prefecture and Ukrainian or Belorussian Polissia is difficult to be compared), it was tried to estimate approximately the multiplicity of the radiation dose decrease due to one or another countermeasure applying the standard methods of estimation and calculation of internal radiation dose for the human-being [8]. The results give evidences on the great potential of the efficiency of the latter.

It should also be mentioned that the combinations of separate countermeasures, for example, liming and simultaneous introduction of potassium, phosphoric and organic fertilizers or, forage improvement together with hexacyanoferrate addition to the animals diet, and so on, have not been researched yet. Indisputably, the strengthening effect will be observed in that case, since the decreasing mechanisms of the radionuclides transition into products are various, although it is not worth expecting their additivity, as simple summation. However, some combinations allow to hope for the probability of the internal radiation dose reduction for the human-being by an order less.

Clean nutrient budget of cattle for one month before butchering allows to decrease the ^{137}Cs content in meat twice, and the same for two months – for four times.

The particular role in cleaning of agrarian products can belong to the primary cooking and processing concerning some kinds of plant growing and stock breeding products: in particular, to the meat, vegetables, mushrooms boiling-out during 10–30 min, the milk dehydration, as it is the basic supplier of radionuclides, due to the serum and skim milk separation. That allows to delete up to 90 per cent of radionuclides.

Conclusions. 28-year experience of the Chernobyl NPP emergency consequences minimization in the agrarian sphere together with three-year experience of Japan (the latter is not so small – judging from the large amount of the executed works) give clear evidences on the necessity of the differentiated approach to the application of the peculiar countermeasures in the case of the agricultural land radioactive contamination in the result of the radiation incidents. This approach can be determined by many factors, but first of all – the radionuclide composition of contamination, the physical-chemical state of radionuclides, soil type and regional economic profile.

Порівняльна ефективність контрзаходів в аграрному виробництві на забруднених радіонуклідами територіях

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Порівнюється ефективність різних контрзаходів (радіозахисних дій) при веденні сільськогосподарського виробництва на забруднених радіонуклідами територіях у зонах радіаційних аварій на Південному Уралі, Чор-

нобильській АЕС і АЕС «Фукусіма-1». Показано, що їхній вплив на зниження надходження і накопичення радіонуклідів у продукції рослинництва і тваринництва та, відповідно, на формування дози внутрішнього опромінення людини за різних умов не є однаковим і залежить, головним чином, від радіонуклідного складу забруднення, типу ґрунтів та профільної спрямованості і спеціалізації виробництв.

Ключові слова: радіаційні аварії, Чорнобильська АЕС, АЕС «Фукусіма-1», аграрне виробництво, радіонукліди, радіоактивне забруднення, контрзаходи.

Сравнительная эффективность контрприемов в аграрном производстве на загрязненных радионуклидами территориях

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Сравнивается эффективность различных контрприемов (радиозащитных действий) при ведении сельскохозяйственного производства на загрязненных радионуклидами территориях в зонах радиационных аварий на Южном Урале, Чернобыльской АЭС и АЭС «Фукусима-1». Показано, что их влияние на снижение поступления и накопления радионуклидов в продукции растениеводства и животноводства и, следовательно, формирование дозы внутреннего облучения человека за счет продуктов питания, в различных условиях неодинаково и зависит, главным образом, от радионуклидного состава загрязнения, типа почвы и профильной направленности и специализации производства.

Ключевые слова: радиационные аварии, Чернобыльская АЭС, АЭС «Фукусима-1», аграрное производство, радионуклиды, радиоактивное загрязнение, контрприемы.

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