SCIENTIFIC ARTICLES

Agricultural Radioecology: Results, currently central tasks and prospects (results of the 10 year investigations in the area of the Chernobyl nuclear power plant accident in 1986)

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Results are presented of investigations of radionuclide migration in agricultural chains in the system soil-plant-animal-food products on the territory affected by the Chernobyl nuclear power plant accident in 1986. The principal countermeasures in the agroindustrial complex that decreased of radionuclide content in agricultural produce and reduction in the internal dose of irradiation are described. The impact of this accident on agriculture is considered.

The liquidation of the consequences of the radiation accident in the South Urals in the autumn of 1957 responsible for the formation of the East Urals radioactive trace has clearly demonstrated that solving of the problem of agricultural production on contaminated areas is one of the central tasks in the rehabilitation of the affected territories. The basic argument in support of this statement is the fact that internal irradiation of the population, i.e. exposure from the consumption of farm products containing radionuclides, is one of the key (and in some cases dominant) sources of extra irradiation. For different periods of radioactive contamination (this causes changes in the radionuclide composition), the contribution of internal irradiation to the overall dose burden may amount to between 20 and 100% depending on different environmental conditions (soil type, etc.), types of human economic activity and a number of other factors (including social). In most cases it varies between 30 and 70%. Not the least of the factors indicating the importance of mitigating the consequences of radioactive contamination of agricultural lands and obtaining of safe products are the high potentialities of agricultural production to regulate radionuclide fluxes in food chains (i.e. to reduce doses of internal irradiation) in comparison with the complex decrease in the external exposure dose involving considerable expense. And, finally, it is of fundamental importance to exclude the production of foodstuffs with radionuclide content above the Derived Intervention Levels (DILs) for stabilizing the rural infrastructure and agricultural economy sector, as well as for overcoming the phenomena such as radiophobia in the population [1].

So, by the time of the Chernobyl NPP accident in 1986, agricultural science and practice had conceptual schemes for liquidating the consequences of this accident in the agroindustrial complex (AIC), even though a successful realisation of these schemes was inhibited by a number of factors.

Firstly, the Chernobyl accident covered a very large territory. The area where ^{137}Cs contamination density was above 1 Ci/km^2 (37 kBq/m^2) amounted to 240 km^2. For instance, at these contamination levels in unfavorable situations, the abundance of low-fertile sandy podzolic and peaty soils in the contaminated area, it was necessary that a system of countermeasures were introduced in agricultural production).

Secondly, the accident occurred at the time which was most unfavorable for agriculture, when sowing and planting of crops had been already completed. What is more important from a radiological point of view, the husbandry had been changed from feeding indoors to grazing on open pasture (the supplies of "clean" feeds were actually unavailable).

Thirdly, the main dose in the affected area was from the radionuclide ^{137}Cs (along with ^{134}Cs at early times). Although the biogeochemistry and the behavior in food chains and metabolism in the body of animals of this radionuclide have been rather adequately studied, it is ^{90}Sr that can be considered the best understood radionuclide in the former USSR. It was ^{90}Sr which defined the radiological character of the accident in the South Urals in 1957 and its behaviour in the environment was thoroughly investigated. In comparison, migration of ^{137}Cs in the natural environment was less well known.

Fourthly, and finally, in the former USSR studies of radiation accidents in general and agricultural radioecology in particular were classified. Therefore, information about the behavior of radionuclides in the environment and radiological aspects of accidents with the release of radionuclides was only available to a limited circle of specialists. Nevertheless, immediately after the Chernobyl NPP accident, the experience gained after the South Urals accident played an extremely important role. One cannot, therefore, overestimate the participation of specialists who had this experience.

Radiologically, any radiation accident connected with the environmental contamination is the most hazardous in the early period marked by the highest exposure doses and maximum radionuclide concentrations in the environment. In this respect agricultural production is no exception. There was no experience of farming in the situations with the release into agrosphere of a large amount of short- and medium-lived radionuclides. In the South Urals accident in 1957, ^{90}Sr and relatively long-lived radionuclides - ^{144}Ce, ^{95}Zr and ^{106}Ru were released into the environment. Comparatively little information had been accumulated on ^{131}I migration in food chains, as well as on the combined action of the released radionuclides and external irradiation (even though semi-field experiments on these problems had been conducted at the pilot station of the Industrial Association "Mayak" and at the Russian Institute of Agricultural Radiology and Agroecology) [2].

During the mitigation of the consequences of the Chernobyl accident in AIC, unique data were accumulated on the effects of radiation from ^{131}I on farm animals (damage to the thyroid). It was possible to avoid cattle losses as a result of radiation injury because of properly applied countermeasures in animal production.

At the early phase of the liquidation of the consequences of the accident the major countermeasures in agricultural are restrictive (or in a special emergency prohibitory) ones in respect of the use of farm products, on the one hand, and agricultural management (e.g. a discontinuance of animal grazing), on the other hand. A radiation monitoring of agricultural lands is considered an obligatory step in a complex of these countermeasures. In this regard the experience of liquidating the consequences of the Chernobyl accident has yielded very important results. Radiation monitoring principles were worked out for both large territories using aerial and other monitoring and large volumes of feeds and farm products (including private farms where such a monitoring has many specific features). Considerable progress was achieved in the development of relevant radiometric and dosimetric equipment.

The presence in the Chernobyl fallout of long-lived radionuclides (mainly ^{137}Cs, and to a lesser extent ^{90}Sr and ^{239}Pu) has provided conditions for prolonged dangerous accumulation in farm products. It is therefore necessary that a long-term program of countermeasures be realized in AIC. While in the early phase after the Chernobyl accident restrictive (prohibitory) measures were prevalent in agricultural production, the later phase was dominant by long-term countermeasures aimed at persistent decrease in radionuclide content in foodstuffs. A top priority task of these countermeasures is to exclude the production of foodstuffs that do not comply with the radiological standards, i.e. foodstuffs in which content of radiologically significant nuclides is above DILs.

To realize this long-term strategy for regularly decreasing the radionuclide content in agricultural products in the Chernobyl affected region, a comprehensive research program in the field of agricultural radioecology has been implemented over 10 years. This provided scientific support for the practical introduction of recommendations on agricultural production in areas subjected to radioactive contamination.

In general terms, the results of research on agricultural radioecology in the Chernobyl affected zone can be defined as follows. Low fertile soils: soddy-podzolic of light mechanical composition (sandy and sandy loam), as well as hydromorphous peaty soils are common in this region. These soils, show maximum ^{137}Cs soil to plant transfer factors. For these transfer parameters for this radionuclide within the soil-plant system were estimated. The dynamics of changes in ^{137}Cs biological availability in soils was carefully tracked and ^{137}Cs "ageing" rates in soils were determined. These included enhancement of fixation due to crystallochemical reactions with some soil minerals, such as klinoptilolite and other biogeochemical processes. Ecological half-life periods were calculated for a decrease in ^{137}Cs concentration in major agricultural products (milk, meat, plant products), i.e. time needed for ^{137}Cs concentration to be cut in half. Two post accidental periods were identified which differ significantly in the pace of decrease in ^{137}Cs migration rate in the soil-plant system (within the first period, 2-5 years after the accident, the rate of decrease in ^{137}Cs transfer from soil to plants and further to animal products is by a factor of 3-5 higher than that within the second period).

The radioecology of the Chernobyl accident is primarily the radioecology of ^{137}Cs. In the field of agrochemistry, the role of antagonistic relations in root assimilation of ^{137}Cs and its chemical analoque and non-isotopic carrier alkaline macroelement - potassium - was assessed. These studies provided the scientific justification for applying higher rates of potassium fertilisers (2-3 times higher than conventional rates) to suppress ^{137}Cs transfer from soil to plants. A positive role of phosphorus fertilisers in decreasing ^{137}Cs plant uptake was identified and the proposition that higher rates of nitrogen fertilisers enhance ^{137}Cs accumulation by plants was confirmed. New data were obtained on ^{137}Cs soil chemistry in peaty soils. Special schemes were developed for applying fertilisers on these soils. For contaminated lands a problem of the application of peat and organic fertilisers with increased radionuclide content was solved.

In the field of ^{137}Cs soil chemistry, the accumulation of large amount of factual evidence made it possible to devise a model for vertical transport of this radionuclide along the profile of different types of soil, as well as to find correlations between contents of different ^{137}Cs forms and their availability for root uptake. A separate chapter of ^{137}Cs soil chemistry dealt with ^{137}Cs behaviour in the soil-plant system for situations when the radionuclide was taken in the soil-plant cover not in a relatively soluble form but in the form of hard particles (remains fuel of elements of the destroyed reactor).

A large body of information was acquired about ^{137}Cs accumulation in a wide range of farm crops which provided a basis for selecting crop species and varieties showing minimum ^{137}Cs concentrations.

Our knowledge of ^{137}Cs migration in meadow-pasture ecosystems was considerably expanded. These attracted particular interest because milk (partially meat) was the main dose-forming foodstuff. The presence of meadow root mat as the most important component of meadow biogeocenosis predetermines the long-term existence of a deposit of radionuclides with their increased availability for plant uptake (because of small amounts in the mat of mineral fraction responsible for fixation, radionuclides remain in it for a long time). The ecological half-lives for decrease of ^{137}Cs decrease in meadow-pasture vegetation are significantly longer than on arable soils. A detailed study of ^{137}Cs migration on meadows allowed the development of effective countermeasures for reducing ^{137}Cs uptake by plants and, consequently, for transfer to animal products.

In animal production, based on the analysis of ^{137}Cs metabolism in farm animals, a system for rational feeding of animals was developed. Animals were fed "clean" feed before slaughter, thus making it possible to produce meat with ^{137}Cs content below DILs. A great contribution to the production of safe meat was made by Cs-binders (compounds with ferrocyanide). In the processing industry (particularly processing for animal products), major technological schemes were analyzed which took into account changes in ^{137}Cs concentration during processing (from raw to final products). As a result rational schemes were selected that provided a minimum ^{137}Cs content in foodstuffs. In the field of agricultural mechanical engineering, special equipment and machinery were designed to be used on contaminated territories. The long-term comprehensive investigations in the field of agricultural radiology have resulted in the development of a system of countermeasures in agricultural production the introduction of which in the Chernobyl affected area significantly reduced exposure doses to the population and promoted the recovery of the environment [3].

Among the major countermeasures are:

- in plant growing - rational soil treatment with maximum deepening of radionuclides, a special system of fertilising (higher rates of phosphorus and especially potassium fertilisers, close control over the application of nitrogenous fertilisers), liming, selection of crop species and varieties with minimum radionuclide accumulation;
- in meadow culture - conversion of low-productivity natural pastures to artificial (sown grasses) pastures with the application of lime and fertilisers;
- in animal production - providing animals with feeds which ensure that animal products meet radiological standards (e.g. pre-slaughter feeding with "clean" feed, administration to animals of Cs-binders to reduce ^{137}Cs in milk and meat);
- in veterinary medicine - preventing of radiation pathology in farm animals (reduction in radionuclide uptake by animals and dose of external irradiation);
- in plant protection - optimum application of chemicals resulting in minimum contents of toxics in food products (radionuclides and nonradiation substances);
- in the processing industry - using of technologies that lower radionuclide concentrations in final (food) products in comparison with raw products (in particular processing of milk to butter).

During the 10 years that elapsed since the Chernobyl accident in 1986, a large amount of information has been gathered on the behavior of radioecologically significant radionuclides, their accumulation in farm products and ionising radiation effects on objects of agricultural production. Based on this scientific information different countermeasures have been developed and introduced into practice on the large territories with the aim of reducing the content of radionuclides in food products. The accumulated research data and the experience of mitigating the consequences of the Chernobyl accident make a great contribution to the solution of the problem of environmental protection against radioactive contamination.

References

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