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REMEDIATION STRATEGY AND PRACTICE ON AGRICULTURAL LAND CONTAMINATED WITH ^{137}Cs AND ^{90}Sr IN BELARUS

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Abstract: This paper is intended to review existing data on the efficiency and acceptability of agricultural countermeasures for reducing of internal exposures introduced by consumption of foodstuff produced on land contaminated by ^{137}Cs and ^{90}Sr. Currently, there are strongly reduced state budget resources for mitigating the consequences of the Chernobyl accident. No more than 50% of the required agricultural protective measures could be financed in the last years. There is an increased need for an optimal use of available resources. New efforts are needed to identify sustainable ways to make use of the most affected areas that reflect the radiation hazard, but also revive the economic potential for the benefit of the community. In this reason the practical complex assessment and justifying of countermeasure application in the most contaminated rural districts of Belarus is the main direction of rehabilitation activity for radiation protection of people in the remote period after Chernobyl accident. Countermeasures have to lead to the profitable or self-sufficient production of extra yield with low radionuclide contamination. The complex of the effective countermeasures has been worked out and implemented mostly in public sector of agriculture. However, particular attention must be given to the production of private farms of several hundred settlements, where samples of milk still contain radionuclides of ^{137}Cs and ^{90}Sr in excess of the established limits.

1. INTRODUCTION

The Chernobyl accident has resulted in Belarus with the radioactive contamination covering about 23% of territory then populated by 2.2 million people. The land of 265,000 hectares with deposition of ^{137}Cs over 1480 kBq m^{-2}, ^{90}Sr – over 111 kBq m^{-2}, and Plutonium isotopes – over 3.7 kBq m^{-2}, have been excluded from agricultural use. Now agricultural production is conducted on 1.2 million hectares of land contaminated by ^{137}Cs with deposition 37-1480 kBq m^{-2}. Some part of this land, 0.4 million hectares, is simultaneously contaminated with ^{90}Sr as well (6 -111 kBq m^{-2}). Iodine -131 was released with very high activities and contaminated large areas were comparable to ^{137}Cs. However, because of the short half-life of 8 days, ^{131}I decayed very fast, its long-term harmful effect on humans is presently evident [1].
As active soil particles continue to decay, leaching of radionuclides out of them results, with their subsequent transformation into forms available to plants. This proves that the risk of radioactive contamination of vegetable products continues to exist, especially with ^{90}Sr. The risk is equally true in respect of edible, feeding, and herbs. Vertical migration in soil of ^{137}Cs and ^{90}Sr goes very slowly. On non-arable lands all the stock of radionuclides is concentrated practically in the top layer of humus. On arable soils, radionuclides are distributed rather uniformly along the whole depth of the tilled layer. Radionuclides in the topsoil are potentially available for uptake by plant roots for long time period.
The agricultural sector has been the area of the economy worst hit by the effects of the accident. Imposing radiological controls has reduced the markets for foodstuffs from the affected areas. This problem has been aggravated by the Chernobyl psychological stain, which has caused some urban consumers to reject products from these areas. As a result, revenues from agricultural activities have fallen and main types of production have declined. The removing of the best fertile arable land, due to radioactive fallout, as well as the outflow of young educated manpower, has affected the whole economy. However, the Government has provided significant financial support and promoted the idea of the rehabilitation of contaminated territories, lack of understanding of how to conduct an active economic farm regeneration activity has meant that much more efforts have to be done to develop an appropriate strategy and its practical implementation.

2. REMEDIATION STRATEGIES AND PRACTICE

The implementation of countermeasures is a main element of the radiation protection people on contaminated land. The main task for the agriculture on the contaminated territory is the output of products with the radionuclide content within the permissible levels. The level of contamination of agricultural products depends on several factors, including the radionuclide deposition, the soil types, texture and chemical properties, the biological characteristics of the growing plants etc. Technological cycles of the agro-industrial production allow applying countermeasures in the key chains of radionuclides transfer: soil-plant, fodder-animal, raw material-foodstuffs. The protective measures have been implemented in two stages.

In the first short period after the accident on the Chernobyl NPP the specialists developed recommendations on farm activity on contaminated land. The priority in countermeasure strategy has been addressed at the changing the crops and at the chemical amendments, trying to improve the soil fertility and reduce the level of radionuclides in soil solution by applying adsorbents and increasing the concentration in soil solution of competitive ions, as K, Ca, and Mg. In the following years those recommendations were several times revised and updated. In the first stage (1987-1991) severely contaminated land was taken out of use. Crops, such as lupine, peas, buckwheat and clover, which accumulate high levels of radionuclides, were completely or partly excluded from the crop sequence. The acid soil was chalked, increased amounts of phosphorus and potassium fertilizers were introduced, and some marshy plots were drained, deep ploughed, improved and used as grassland. Feeding animals with clean fodder at the final stage before slaughter has proven to be very efficient. Overall, the countermeasures implemented mostly in public agriculture sector, had been effective. The ^{137}Cs transfer into agricultural products decreased than by a factor of 3.5. [3]

The second stage of detailed countermeasures has been under way since 1992, taking into account the characteristics of every individual field or cattle farm. Methods are being developed to reduce vegetable product contamination by means of controlled mineral nutrition, by using traditional and new types of fertilizers. In animal farming, such approaches as selection of fodder depending on its contamination level, nutritional value and additives were suggested. At last period the countermeasure priority has been directed on meadows improvement for the cows of personal farms where the milk contaminated above permissible level (100 Bq l^{-1}) was produced. It was suggested to improve of 1 hectare of pasture and meadow per cow, as well as 0.5 kg of combined fodder with caesium-binding additives per cow and per day has been prescribed [4]. Programs have been developed for the cooperative and personal farms of the 11 most contaminated districts. The countermeasures applied allowed producing the main foodstuffs with ^{137}Cs and ^{90}Sr levels below "Republican permissible levels" (RPL-99). These activities significantly contribute to reducing individual doses and maintaining the confidence of urban residents in the safety of food products in the shops and markets. Nowadays the radiation situation is comparatively favorable in the public sector. The protective measures carried out so far, in combination with natural sorption and fixation of ^{137}Cs in soils, enabled a 10-12 times reduction in the inflow of Cs-137 to agricultural products. In the last 5 years production of milk with excess content of Cs-137 in the public sector fell 5.5 times. Due to a system of yearlong monitoring of Cs-137 content in the animals, the return ratio of cattle did not exceed 0.1% of the overall amount of cattle entering processing for meat production.

The ^{90}Sr content in agricultural products is monitored selectively; its concentration in food products has decreased by approximately 2-3 times since 1987. However the concentrations of ^{90}Sr above permissible levels are still found in samples of cereal grain and leguminous crops, as well as in samples of whole milk produced in several districts of Gomel region [2].

In spite of the considerable progress already made, more work is needed to reduce the excessive contamination of some foodstuff produced on small personal plots and farms. The main problem today relates to internal irradiation resulting from the consumption of contaminated foodstuffs, especially milk, meat and forest products. During the 1997-2001, the number of settlements where production of milk with Cs-137 content in excess of 100 Bq per liter was recorded dropped by 1.8 times [2], (Table 1).

Table 1. The number of settlements in contaminated area of Belarus where the milk produced at personal farms exceeded the permissible level of ^{137}Cs activity (> 100 Bq l^{-1}).

Region	1997	1998	1999	2000	2001
Brest	97	90	73	54	49
Gomel	380	351	143	225	225
Grodno	7	2	4	4	1
Minsk	7	7	3	1	1
Mogilev	89	66	56	43	50
Belarus	580	516	379	327	326

The low pace of this number's decline is of special concern. Overall, up to 10% of milk produced in private households still contains radionuclides in excess of the established limits. Private households use milk mainly for personal consumption, putting people's health at risk, especially that of children.

Serious concerns primarily relate to the so-called "highly contaminated territories" where ^{137}Cs deposition is above 555 kBqm^{-2}. Presently more than 150 thousand people permanently reside in these areas. The areas with contamination level between 185 and 555 kBqm^{-2} on poor sandy and peat soils or marshy and low-production pastures are also problematic for production of the required quality foodstuff. The overall level of contamination is falling gradually as a result of natural radioactive decay. The high-risk groups, however, face stable or sometimes even increased exposure as a result of the decline in the use of protective soil treatments. A psychological barrier has radically reduced the export of agricultural produce, particularly from the contaminated areas of Belarus to other countries of the CIS. This factor, combined with others, has led to an essential decline in the total agricultural production. Highly contaminated districts of Belarus are characterized by poor demographic structure. Totally more than 135 thousand people were relocated and about 200 thousand people became forced migrants who left the contaminated regions unorganized. As a result, the majority of young, well-educated and skilled specialists leaved the contaminated area. [2]. Poverty forces many people to eat contaminated mushrooms, berries and game, to feed contaminated hay to their cattle and eat contaminated milk and meat.

Currently, there are strongly reduced state budget resources for mitigating the consequences of the Chernobyl accident. No more than 50% of the required agricultural protective measures could be financed in the last years. It is evident that resources should be concentrated on the most contaminated areas with poor or vulnerable soils where country people grow and consume their own food – and on efforts to revive the economies of the affected areas in ways, which are compatible with the continuing radiation hazard.

Remediation strategies are defined here as combination of different countermeasures that may be applied in rural settlements in the long term after Chernobyl accident with the aim to reduce annual doses below 1mSv and to produce final agricultural product with radionuclide ^{137}Cs and ^{90}Sr concentration below the national permissible levels. Therefore, the choice of the economically sound countermeasures for application in the specific local conditions is the task of first priority. Innovative ways need to be developed to increase the knowledge and ability about how to live safely in environments affected by radioactive contamination.

Several approachas to reduce population exposures and improve the competitiveness of agriculture, economic and technical aspects are being studied. These include: 1) using the contaminated land for growing industrial crops, such as rape, sunflower and sugar beet, or high proritable potato and 2) modernizing and upgrading the present facilities for processing of wegetable oil, and also potato and grain processing into starch and alcohol . The solution to these problems requires international cooperation and large scale investment. Therefore the lessons of the pilot projects carried out with international assistance have to thoroughly considered [5,6,7,8,9].

Presently neither rapid self-recovery of the affected territories or direct restorations of the objects of the national economy are possible. But we may accelerate the long-term process of rehabilitation with profitable or self-sufficient activities that are possible on radioactive contaminated areas to improve the conditions for living and economic development. The complex estimation and assessment of efficiency of the countermeasures are the first initial step of above-mentioned development.

3. COUNTERMEASURE EFFICIENCY

The justification of the countermeasure application includes analysis of radiological situation and assessment of efficiency of different countermeasures. The efficiency of the countermeasures is based on limitation of radionuclide transfer to final products and is defined by range of the specific factors. Traditionally, the main criterion for comparable evaluation of countermeasure efficiency is a reduction factor (RF) of radionuclide content in final product. Unfortunately, many countermeasures require large subsidies or the self-cost of final produce is too expensive to sell. When selecting an appropriate countermeasure for a contaminated area the optimal solution to a given problem will consider radiological criteria as well as economic and social factors [10].

From the point of view of protecting critical groups, only a narrow range of countermeasures (such as improving private pastures, distributing fodder with caesium binders and restriction for consumption of contaminated forest products) are effective. But from the point of view of overcoming environmental constraints to economic development, only those countermeasures, which allow production at competitive or

self-sufficient costs, can be considered as effective. The efficiency may be evaluated by economical parameters, averted dose and cost-benefit analysis of averted dose per man-Sv [11].
Many studies have been targeting possible agricultural countermeasures, in response to high concentration levels in food and agricultural crops. The evaluation of countermeasure efficiency carried out on natural and agricultural ecosystems radioactive contaminated by the Chernobyl accident had been done recently in the framework of the Project "Radioecology" of the French-German Initiative for Chernobyl. The database "Countermeasures" which include the results of 5261 experiments carried out during 1987-1999 on land affected by the Chernobyl accident was compiled by experts from Belarus, Russia and Ukraine in cooperation with scientists from France (IRSN) and Germany (GRS) [12, 13].

3.1. Radical improvement of meadows

Radical improvement is the most efficient practical countermeasure on meadow ecosystem contaminated after Chernobyl fallout. Radical improvement of meadows is applying for creation of new sod by destroying the old root mat, soil cultivation, fertilization, liming and sowing of mixture of valuable legume and cereal grasses. The nature of action and efficiency of countermeasures applied at radical improvement of hay-land and pastures strongly depend on types of meadow and soil properties. The improvements of water regime by drainage on over moisten peat and mineral soils are extremely expensive nowadays, about 3000-4000 Euro per hectare. During last decade in Belarus radical improvement of meadows was conducted mainly on soils with satisfactory water regime.
The traditional surface improvement is less effective; it includes fertilization, surface liming and soil cultivation without destruction of sod. Generalization of collected experimental data shoved that radical improvement of meadow with liming, application of high rates of P-K fertilizers, sowing of grass mixtures allows to reduce ^{137}Cs transfer from soil to hay by 1.3-4.4 times [13]. Surface improvement of meadows with liming, fertilization and under sowing of grasses by special seed-drill may be also very effective (Table 2).

Table 2. Influence of fertilizers on productivity of natural and improved meadow and ^{137}Cs transfer from alluvial soil to hay of perennial grass (^{137}Cs deposition 1110 kBq.m^{-2}, average for 5 years, 1994-1999)

Treatments	Yield of dry mass		Net profit € ha^{-1}	Profitability, %	Hay activity ^{137}Cs Bq kg^{-1}	Reduction factor
	t ha^{-1}	Increase factor				
Natural meadow						
Control	2.3	1.0	-	-	1764	1.0
$N_{120}P_{60}K_{120}$	7.7	3.3	66	72	798	2.2
N_{120} $P_{60}K_{180}$	8.0	3.5	65	64	411	4.3
Improved (undersowing) meadow						
Control	2.6	1.0	-	-	1455	
$N_{120}P_{60}K_{120}$	8.6	3.3	80	83	432	3.4
N_{120} $P_{60}K_{180}$	8.7	3.3	74	70	354	4.1

The radical improvement of meadows and pastures for private cows of rural inhabitants is the countermeasure of high priority nowadays. It has been supported and financed by Chernobyl Committee of Belarus on area 7700 ha in 2002. The radiological effectiveness of radical improvement of meadows in practice may be evaluated by factor 2-3. The total cost of radical meadow improvement is calculated as 604 Euro on 4 years of using meadow. Annual gain from milk yield response to meadow improvement can be calculated as 200 € per cow, and net profit as 49 €. Thus we have the economically effective countermeasure with adverted dose of internal irradiation up to 0.5 mSv-man at initial ^{137}Cs activity of milk 220 Bq l^{-1}and reduction factor 3.

3.2. Prussian blue for cows

Caesium - selective sorbents are most distributed and known, concerning to group of salts of trivalent iron of ferrocyanide acids: Prussian Blue (ferrocyn), Giza salt, Nigrovitch salt from which higher selectivity and capacity of absorption possess Prussian Blue [14]. The studies in territory of the CIS' countries have shown that caesium binders reduce the ^{137}Cs transfer from fodder to the animal products milk and meat by factor 1.5-6.0 [13,14,15]. The easiest and cheapest method of feeding is by direct incorporation of PB into concentrate during manufacturing. In this way, it is not necessary to give any special instruction to the farmer on how to use the PB. This procedure is currently in use in Belarus, where a special concentrate with PB is produced and distributed in rate of 0.5 kg of concentrate per cow daily. For the conditions of the actual agricultural practice, the average value for reduction factor 3 for milk is assumed. The Prussian blue application is especially effective at settlements where lack of meadows suitable to improvement is observed. Annual cost per cow (28 Euro) and cost of adverted dose (4850 Euro per man-Sv) are acceptable for decision-makers.

3.3. Agrochemical countermeasures

Raising and maintaining the level of soil fertility is of primary importance. This is mainly because of nature of soil-forming processes, which have led to the development of predominantly low-yield Sod-podzolic (Podzoluvisol) and swampy soils. Balanced rates of fertilizers on the background of acid soil liming and manure application are the most widespread, applicable and effective countermeasures to restrict of soil-to-plant radionuclide transfer and provide the profitable increase of crop yields.
It was found that liming changed the reaction of Podzoluvisol soils from pH (KCl) 5.0 to pH 6.5-7.0, and reduced the ^{137}Cs accumulation in perennial grass up to 2 times. But pH values for maximum yield of growing plants on Sod-podzolic loamy sand soil were different: 6.7 for barley, 5.9 for potatoes and 4.9 for lupine. The priority criterion for the choice of the countermeasure treatments has to take into consideration the value of extra yield obtained. An example of combined radiological and economical justification the optimal liming treatment for potato plants is presented in Table 3.

Table 3. Influence of fertilizers and liming on potato yield and radionuclide accumulation on Podzoluvisol loamy sand soil (Deposition of ^{137}Cs – 370 and ^{90}Sr - 37 kBqm^{-2}, ^{137}Cs activity of potato tubers on Control treatment - 10.2 Bq kg^{-1}, ^{90}Sr activity of tubers - 11 Bq kg^{-1}).

Treatments	Yield of potato t/ha	Net return € ha^{-1}	^{137}Cs activity RF	^{90}Sr activity RF
Control (pH 4.9)	16.2	-	1.0	1.0
Dolomite 6 t (pH 5.9)	17.6	67	1.6	-
Dolomite 18 t (pH 6.7)	15.4	-95	1.7	-
N70P60K160 (pH 4.9)	24.3	403	1.8	1.2
N70P60K160 (pH 5.9)	26.4	509	2.1	1.5
N70P60K160 (pH 6.7)	23.1	298	2.3	1.7
LSD_{05}	1.4			

It can be seen that the highest yield of potato in experiment, 26.4 tons per ha and ^{137}Cs accumulation reduction by factor 2.1, has been achieved on 6 tons dolomite + N70P60K160 (pH 5.9) treatment. This treatment resulted in net profit 509 € per hectare. The liming with higher rate of dolomite (18 t.ha^{-1}) provided the neutral soil reaction (pH 6.7), but resulted also in sufficient decrease of yield and net profit. However, production of potato on fertilized background remained profitable (298 € ha^{-1}), application of 18 tons of dolomite per hectare on unfertilized background was evidently excessive, as provided the net economic loss 95 € ha^{-1}. Application of dolomite 18 t ha^{-1} on fertilized background was profitable and it reduced activity of tubers by factor 2.3 for ^{137}Cs and by factor 1.7 for ^{90}Sr in comparison with control treatment.
It is well known that potassium, as a chemical analogue of caesium, could effectively inhibit the transfer of radiocaesium from soil to plants. However, the inhibitory effect is strongly dependent of K status of soil, which will determine the effect of K fertilization as countermeasure to reduce the Cs concentration in crop production. The genotypic differences in ^{137}Cs uptake between the various crops are very important, however these also depend on exchangeable potassium content in soil [16]. The experiments in Belarus were carried out on soils characterized by different levels of K supply. Increasing doses of potassium, balanced with NP fertilizers were applied on each level of K supply. The example of experiment with spring wheat is shown in Table 4. It was found that improvement of K supply level of Podzoluvisol loamy sand soil from exchangeable K_2O 150 to 250 mg kg^{-1} allowed to increase significantly crop yields and to

reduce of radionuclide ^{137}Cs transfer from soil to potato tubers and wheat grain by factor 1.8-2.0. High K-fertilizer rates up to 160 - 240 kg K_2O per hectare are effective for crop cultivation on loamy sand soils with low potassium content. Only moderate potash fertilizer rates are needed for rich K-supplied soils (K_2O 250-mg kg^{-1} and more) to replace of the crop K-removal

Table 4. Yield and ^{137}Cs activity of wheat grain depending of fertilizer rates and K-status of Podzoluvisol loamy sand soil related to ^{137}Cs deposition 370 kBq m^{-2}.

Soil test level K_2O mg kg^{-1}	Treatment	Yield of grain t ha^{-1}	Net return € ha^{-1}	^{137}Cs activity of grain Bq kg^{-1}	Reduction factor
150	Control	3.24		10.2	1.0
	N70P60	4.06	25	8.9	1.1
	N70P60K80	4.58	54	8.9	1.1
	N70P60K160	4.79	61	6.4	1.6
	N70P60K240	4.90	60	5.1	2.0
250	N70P60K80	4.90	77	5.1	2.0
	N70P60K160	4.90	69	3.8	2.7
	N70P60K240	5.00	67	3.6	2.8
350	N70P60K80	5.00	85	3.8	2.7
	N70P60K160	51.3	86	3.6	2.8
	N70P60K240	52.1	81	3.5	2.9

The introduction of leguminous plants to crop sequence is very important for the increase of protein yield and for the soil fertility improvement. It is especially valuable on contaminated land, where after Chernobyl accident leguminous crops were excluded due to high concentration of radionuclides in plants. The research work has been done to determine parameters of radionuclide transfer to leguminous plants depending on soil fertility status and potassium fertilizer rates. The field experiments with pea and clover were conducted on Podzoluvisol loamy sand soil at experimental farm "Strelichevo" in Gomel region. Treatments include different levels of soil acidity and the increasing K-fertilizer rates 60, 120, 180 kg ha^{-1}. Radionuclide deposition of ^{137}Cs - 407-503 kBq m^{-2}, ^{90}Sr - 41- 44 kBq m^{-2}. Application of optimal K-fertilizer rates ($P_{60}K_{120}$ for peas and $P_{60}K_{180}$ for clover) promoted sufficient yield increase of peas (on 30%) and clover (on78%) with reduction of radionuclide concentration in crops by factor 1.8-2.2. Balanced plant nutrition resulted both in the essential net return (30-50 € ha^{-1}) and the possibility of expanding area of legumes cultivation on the soils contaminated by radionuclides.

3.4. Growing potatoes on personal fields

Potatoes and milk are the basis food products of man diet, especially in country area. Recent research has shown that ^{137}Cs content in potato tubers does not exceed the permissible level at the potato growing on radioactive contaminated land in Belarus. However up to 240-300 kg of potatoes is consumed per man during year and potato yield determines significant share of the outcome of families. Therefore the reducing of ^{137}Cs content in potatoes and increasing of potato yield could be allowed to improve of quality life of rural inhabitants on contaminated areas. The application of protection measures on private plots are restricted by lack of the knowledge and financial deficit. The involvement of rural inhabitants in processes of self-rehabilitation and self-development could be a way to improve the quality life on radioactive contaminated territory [6,7,9].

Within the ETHOS approach the project "Potatoes" was carried out in four villages of Stolin district of Brest region of Belarus during 2000-2002 [9]. In 2003 the project has been expanded on Slavgorod district of Mogilev region. The inhabitants of six villages were participants of teams involved to reduce of radionuclide content in potatoes and to increase the potato yield. The ^{137}Cs content in potato tubers varied from 10 to 69 Bq.kg^{-1}. The potato was grown on the background of manure 40-80 t.ha^{-1}. The yields of potatoes on private plots were low and made of 15-20 t.ha^{-1}. The participants tested on their plots the experimental technology of potato cultivation developed by BRISSA on the background of traditional technology that farmers used before the experiment. The experimental technology included the selections the seeds of new potato varieties, application of fertilizers and plant protection means. The developed technology of potato cultivation has allowed increasing a yield of potato tubers in 1,6 times and reduce the radionuclide concentration on 20-30% in comparison with control plots. The 1€ invested to the potato experiment provided 1.5-2.0 € of net return. Therefore the management of yield and radiological quality of potatoes cultivated on private contaminated plots allowed to reduce of irradiation dose on rural inhabitants and increase the outcome of their family.

3.5. Alternative land uses

The utilization of contaminated land aimed at cultivation some industrial crops are of significant scientific and practical interest. For last decade in Belarus within the framework the international projects the attempts were undertaking to realize ideas of processing of rapeseed into biodiesel and biolubricants. Despite of high safety for an environment, these products do not maintain a price competition to products made from mineral oil. Presently the edible oils are competitive on Belorussian market and processing of rapeseed for edible oil have long-term outlook for rural economics. The studies and manufacturing application were carried out in 1995-2201 within the framework of IAEA TC Project BYE 5/004. In a unit area the straw and pod's part of rapeseed plants accumulates 70.2% of ^{137}Cs and 88.3% of ^{90}Sr, the roots 26.5 and 5.9% respectively of the total absorbed radionuclides in biomass. Only 3.2% of ^{137}Cs and 5.8% of ^{90}Sr contained in rapeseed from this overall uptake are potentially involved in the food chain "soil-plant/forage-animal-man [8]. There was an opportunity to compare of the efficiency of different countermeasures applied for growing and processing rapeseed (Table 5.)

Table 5. Efficiency of countermeasures on rapeseed production

Countermeasures	Activity reduction of rapeseed products	
	^{137}Cs	^{90}Sr
Liming	14%	42%
Fertilization $N_{90}P_{90}K_{180}$	42%	27%
Liming 6 t/ha and fertilization $N_{90}P_{90}K_{180}$	45%	59%
Variety selection	2,5 times	3,0 times
Rape oil processing (crude oil)	250 times	600 times

The developed agrochemical measures allow reducing the radionuclide concentration in rapeseeds on 45-59%. The introducing of rapeseed varieties with minimum sizes of radionuclide accumulation allows to reduce radionuclides uptake by rapeseed in 2,5-3,0 times and technological measures in oil product in 250-600 times. Determination of ^{137}Cs and ^{90}Sr in refined oil samples have shown that both radionuclides concentrations were below the limit of detection, in spite of the rapeseed grown on loamy sand soil with high deposition level up to 555 and 55 kBq m^{-2} respectively. Usually the additive of rapeseed cake in concentrated forages to average 10%, so that ^{137}Cs and ^{90}Sr concentration in cake were in permissible limits and it allowed feed a cake to all kinds of animals without restrictions. The rapeseed production and processing are profitable technologies, both for the farmers and for the processing industry. Farmers can receive net return up to 30 € per 1 t of rapeseed, and processing enterprises up to 103 € from sale of 1 t of edible rapeseed oil. During the implementation of the project, the production area of rapeseed on contaminated land has increased 4 times.

4. CONCLUSIONS

The priority in countermeasure application should be directed on personal fields and farms to remedial actions that provide the profitable agricultural production as well as provide the dose reduction. The radical and surface improvement of meadows is the most effective countermeasures in husbandry. They provide RF of ^{137}Cs grass activity about 3 times in average. These countermeasures are profitable. ^{137}Cs binders (Prussian blue) are also effective with RF 3 and with reasonable requirement for investment.

Soil fertility improvement through liming, manure and NPK application is the basic remediation measure in the long-term period after Chernobyl accident. Balanced fertilizers with K-fertilizer rates up to 160 -

240 kg K_2O per hectare are profitable for crop cultivation on soils with low potassium content. Improvement of K supply level of Podzoluvisol loamy sand soil from exchangeable K_2O 150 to 250 mg kg^{-1} allowed to increase crop yields and to reduce of radionuclide ^{137}Cs transfer from soil to crops factor1.8-2 Only moderate potash fertilizer rates are needed for rich K-supplied soils (K_2O 250-mg kg^{-1} and more) to replace of the crop K-removal. The implementation of project of modern technology of potato growing on personal plots (ETHOS approach) has a high social significance. The involvement of rural inhabitants in processes of self-rehabilitation and self-development could be a way to improve the quality people life on radioactive contaminated territory as a common heritage.

Growing and processing rapeseed allow gains from contaminated territories Food-grade oil practically free from radionuclides. The IAEA TC project BYE/5004 is successful combination of scientific development, technical decisions, maximal use of local resources and productive cooperation Belarus with the international organizations.

References:

1. 15 Years After Chernobyl Catastrophe: Consequences in the Republic of Belarus and Their Overcoming. National Report // Edited by V.E. Shevchouk, V.L. Gourachevskiy – Minsk: Committee on the Problems of the Consequences of the Accident at the Chernobyl NPP, 2001. – 118 p.
2. Consequences of Chernobyl in Belarus. National Report // Edited by V.E. Shevchouk, V.L. Gourachevskiy – Minsk: Propilei, 2003. –54 p.
3. Present and future environmental impact of the Chernobyl accident. IAEA-TECDOC-1240. International Atomic Energy Agency, August 2001, 128 p.
4. Guide for agricultural practice on lands contaminated by radionuclides in the republic of Belarus For 2002-2005 / Ed. by Bogdevitch I.M. 74 p. Minsk, 2002 (Rus.).
5. Jacob P., Fesenko, S.. Firsakova, S.K., Likhtarev, I.A., Schotola, C., Alexakhin, R.M., Zhuchenko, Y.M., Kovgan, L., Sanzharova, N.I., Ageyets V. (2001): Remediation strategies for rural territories contminated by the Chernobyl accident. J. Environ. Radioact. 56, 51-76.
6. Dubreuil, G.H., Lochard, J., Girard, P., Guyonnet, J.F, Le Cardinal, G., Lepicard, S., Livolsi, P., Monroy, M., Ollagnon, H., Pen Vega, A., Pupin, V., Rogby, J., Rolevitch, I., Shneider, T. (1999): Chernobyl post-accident management: The ETHOS project. Health Phys. 77, 361-372.
7. Lepicard, S., Heriard Dubreuil, G. H. (2001): Journal of Environmental Radioactivity, 56, 241-253.
8. Bogdevitch, I., Putyatin, Yu., Rigney, C., Chupov A.(2002): Edible oil production from rapeseed grown on contaminated lands. Innovationsforum westschopfugsketten in der naturstoffverarbeitung. 10und 11dezember 2001 gardelegen, 148-156.
9. Tarasiuk, S., Bogdevitch, I., Heriard-Dubreuil, G., Ollagnon, H.(2002): Management of the yield and radiological quality of potatoes cultivated by population in radioactive contaminated land of Belarus. Proceedings of EUROSAFE. Seminar 4 "Environment and radiation protection", 4-5 November, Berlin 2002. Berlin, 38-42.
10. Kelly, G.N.(2001):Post accident management. Radioactive pollutants. Impact on the environment.Ed. by Brechignac, F. and Howard, B.J. IPSN. EDP Sciences, 75-96.
11. Fesenko, S. V. Sanzharova, N.I., Wilkins, B.T., Nisbet, A.F. (1996) FORCON: Local Decision Support System for the Provision of Advises in Agriculture - Methodology and Experience of Practical Implementation, *Rad. Prot. Dosim*. 64. P. 157-164.
12. G. Deville-Cavelin, R.M. Alexakhin, I.M. Bogdevitch, B.S. Prister, H. Biesold, L.V. Perepelyatnikova, N.I. Sanzharova, S.V. Tarasiuk. Countermeasures in Agriculture: assessment of efficiency. Proceeding of the International Conference “Fifteen Years after the Chernobyl Accident. Lessons Learned”, Kiev, Ukraine, April 18-20, 2001. Kiev, 2001, p. 118-128.
13. Bogdevitch, I., Sanzharova, N., Prister, B., Tarasiuk (2002): Countermeasures on natural and agricultural areas after Chernobyl accident. Kolejka J.(ed.), Role of GIS in Lifting Cloud of Chernobyl, Kluwer Academic Publishers,147-158.
14. The use of Prussian Blue to reduce radiocaesium contamination of milk and meat produced on territories affected by Chernobyl accident. Report of United Nations Project E 11, IAEA-TECDOC-926, ISSN 1011-4289, IAEA,VIENNA, 1997, 80 p.
15. Radioecological aspects of husbandry (1996) Ilyazov, R. G., Alexakhin, R. M., Korneev, N. A., Sirotkin, A. N. Et al. Homel, “ Polespechat“ –179 p.
16. Bogdevitch, I.(1999): Soil conditions of Belarus and efficiency of potassium fertilizers. Proceedings of Workshop organized by International Potash Institute at the 16 World Congress of Soil Science, Montpellier, France, 20-26 August 1998. IPI, Basel, Switzerland,21-26.