# Reduction in annual intake of $^{137}$Cs by the population after countermeasures application on leached and podzolized chernozems

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The influence of various countermeasures on the annual intake of $^{137}$Cs by the local population was investigated in experiments on fields in the Tula region contaminated after the accident on ChNPP. The effectiveness was evaluated by the reduction factor of the radionuclide accumulation in crop products. The most effective countermeasures in the region of leached and podzolized chernozems (black earth soil with whitish coating of depleted nutrients) are: liming, application of mineral fertilisers at increased rates of phosphorus and potassium, selection of species and varieties. After complex application of countermeasures on chernozems intake of $^{137}$Cs by local population due to the consumption of staples was reduced by up to 2 times.

The accident at the Chernobyl nuclear power plant has resulted in the contamination of large areas by the long-lived radiologically significant radionuclide $^{137}$Cs. Internal exposure from the consumption of contaminated farm products becomes one of the major sources of extra irradiation of the population over a long period of time. In this context, a topical problem is to reduce dose burdens to the population by means of decreasing radionuclide accumulation in the human diet as a result of the application of special effective countermeasures in plant growing. The implementation of countermeasures based on traditional agricultural practice is an economically more realistic task than costly decontamination of large areas [3, 4].

Justification of a system of countermeasures should take into account special features of $^{137}$Cs behaviour in soil, the influence of different factors on the biological mobility of the radionuclide, as well as natural-climatic conditions and regional distinctions of farming. Following the Chernobyl accident, in the regions dominated by chernozemic soils practically no studies into the effectiveness of countermeasures for reducing $^{137}$Cs accumulation in farm products have bee carried out, since the contamination levels of these areas were not high and farm products contamination did not exceed the DILs. Considerable study has been given to the regions with high levels of agricultural land contamination, where soils of light mechanical composition prevailed. Meanwhile, the need for countermeasures is primarily based on the use of the ALARA (As Low As Reasonably Achievable) principle: irradiation doses must be maintained "at as low levels as reasonably achievable". Therefore, to substantiate the need for countermeasures in the contaminated areas where soils are mainly leached and podzolic chernozems showing relatively high radionuclide mobility is a real practical task.

The studies were conducted in the Plavsky district of the Tula region on the fields of collective-farms. The soils of the experimental plots are typical for this area deeply leached and podzolic (depleted of nutrients) chernozems (black earth soils) and dark grey forest soil. The agrochemical characteristics of the control variants are given in Table 1. Seven field experiments were made to evaluate the effect on $^{137}$Cs transfer to plant products of the following elements of the cultivation technology for different crops: the application of mineral fertilisers and meliorants at various rates and combinations, the application of pesticides, different types of ploughing, selection of species and varieties with minimum radionuclide accumulation.

The following criteria were employed to assess the effectiveness of countermeasures:

- reduction factors of $^{137}$Cs accumulation in farm crops;
- changes in the yield of $^{137}$Cs in the above ground mass of plant per unit area;
- decrease in the annual intake of $^{137}$Cs by the local population from the main food products (bread, milk, meat, potatoes).

The studies of the effects of agrochemical and agrotechnical countermeasures on $^{137}$Cs transfer to crops have revealed three most effective ways for reducing the contamination of farm crops (Table 2). In the given area these include: soil liming, application of increased rates of $P_2O_5$ and $K_2O$ fertilisers, selection of crop species and varieties.

The prime objective of the implementation of countermeasures is to reduce the intake of radionuclides in the human diet. To evaluate the countermeasure effectiveness from this point of view, we have calculated the value of $^{137}$Cs intake with the major foodstuffs (potatoes, bread, meat, milk) for two variants: with and without the application of countermeasures. The intake of $^{137}$Cs for one type of produce was calculated as follows [1, 2]:

- <u>for cereals and potatoes</u>:

$$C = AC \times A_n \times k_1 \times m_1,$$

- <u>for annual grasses</u> with estimating further migration in the trophic chain to milk and meat:

$$C = AC \times A_n \times k \times m \times k_1 \times m_1,$$

where ***C*** is $^{137}$Cs intake by man with products, Bq/year; ***AC*** is the coefficient of the $^{137}$Cs accumulation in the crop yield; $A_n$ is the radionuclide content in soil, Bq/kg; ***m*** is the fodder mass consumed by animals (dry weight), kg/day; ***k*** is the transfer factor from cattle diet to milk (meat); $\boldsymbol{m_1}$ is the product consumption by man, kg/year; $\boldsymbol{k_1}$ is the coefficient of cooking decrease in $^{137}$Cs content during processing.

**Table 1**
**Soil agrochemical characteristics**

| Soil | pHKcl | Hg | Ña$^{2+}$ | Ìg$^{2+}$ | S | Humus, % | $N_{hyd}$ | $P_2O_5$ | $K_2O$ |
|---|---|---|---|---|---|---|---|---|---|
| | | mg·eq/100 g soil | | | | | mg/100 g soil | | |
| 1 | 4.8-5.7 | 6.5-8.5 | 17-20 | 2-5 | 29-32 | 6-8 | 4-5 | 7.5-9.5 | 18-19 |
| 2 | 5.1 | 4.5 | – | – | 32 | 7 | – | 13 | 18 |
| 3 | 5.3–6.2 | 3.5–5.8 | – | – | 27–30 | 6–7 | – | 5–17 | 20–22 |

1 – leached medium loam chernozem;
2 – podzolic heavy loam chernozem;
3 – dark grey forest heavy loam soil.

**pHKCl** is acidity of a salt extract which defines soil exchange acidity. Exchange acidity is determined by the number of titrated H+ and Al3+ ions in the extract prepared with 1 n KCl.

**Hg** is hydrolytic acidity determined by the acid titration in the extract prepared using sodium acetate.

**S** is the sum of exchangeable bases, i.e., the total content of all exchangeable cations, except for H+ and Al3+.

**Nhyd** is hydrolyzable nitrogen. Nitrogen of readily hydrolyzable compounds is solubilized by soil interacting with 0.5 n H2SO4 solution in the ratio of 1:5. Amides and amino acids incorporated into humus, as well as N mineral compounds pass into hydrolysate.

**"-"** signify that these values have not been determined.

**Chernozym** (FAO/UNESCO classification) is a black earth soil.

**Table 2**

**Countermeasure effectiveness**

| Countermeasure | Crop | ***AC*** $^{137}$Cs | | $^{137}$Cs yield | |
|---|---|---|---|---|---|
| | | Effect | Reduction factor | Effect | Reduction factor |
| *Application of meliorants* | | | | | |
| **Lime** | annual grasses | No | - | increases | 2.4 |
| | winter wheat | Reduces | 1.3 | reduces | 1.4 |
| | spring cereals | Reduces | 1.3–1.6 | reduces | 1.4 |
| | oats | Reduces | 1.4–1.5 | reduces | 1.6 |
| **Bentonite** | oats | Reduces | 1.2 | reduces | 1.2 |
| | lucerne | Increases | 1.2–1.3 | increases | 1.5 |
| *Application of higher rates of mineral fertilisers* | | | | | |
| $\mathbf{N_{150}}P_{60}K_{60}$ | annual grasses | Increases | 1.2–1.3 | increases | 1.4 |
| | winter wheat | Increases | 1.4–1.5 | increases | 1.9 |
| | spring cereals | Increases | 1.3–1.6 | increases | 1.7 |
| | oats | Increases | 1.5–1.7 | increases | 1.6 |
| $N_{90}\mathbf{P_{120}}K_{60}$ | annual grasses | Reduces | 1.3 | no | – |
| | winter wheat | Reduces | 1.2–1.3 | no | – |
| | spring cereals | Reduces | 1.4–1.5 | reduces | 1.8 |
| | oats | Reduces | 1.3 | reduces | 1.2 |
| $N_{90}P_{60}\mathbf{K_{150}}$ | annual grasses | Reduces | 1.7–1.8 | reduces | 1.5 |
| | winter wheat | Reduces | 1.8 | reduces | 1.7 |
| | spring cereals | Reduces | 2.0–2.3 | reduces | 2.5 |
| | oats | Reduces | 2.1–2.6 | reduces | 2.3 |
| **Pesticides** | winter wheat | No | – | no | – |
| | barley | No | – | no | – |
| | spring cereals | No | – | no | – |
| | potatoes | No | – | no | – |
| **Species selection** | grain, grainlegume, cereals, fodder, potatoes | Reduces | 37 | reduces | 8 |
| **Variety selection** | potatoes | Reduces | 2.9 | reduces | 1.7 |

**Table 3**
**$^{137}$Cs intake by the local population from contaminated agricultural lands without countermeasures and after their application**

| Crop, product | Countermeasure | *AC*, n·$10^{-2}$ | $^{137}$Cs content in soil, Bq/kg | Daily consumption of dry fodder by cattle, kg/day | $^{137}$Cs transfer to milk and meat, % | Cooking reduction factor | Product consumption by man, kg/year | $^{137}$Cs annual intake in human diet, Bq/year | RF for $^{137}$Cs after countermeasures, times |
|---|---|---|---|---|---|---|---|---|---|
| Winter wheat | Control * | 0.52 | 880 | – | – | 0.3 | 130 | 178 | |
| | $N_{90}P_{60}K_{150}$ | 0.30 | 850 | – | – | 0.3 | 130 | 99 | 1.8 |
| Spring wheat | Control * | 0.46 | 810 | – | – | 0.3 | 130 | 145 | |
| | $N_{90}P_{60}K_{150}$ | | | | | 0.3 | 130 | 78 | 1.9 |
| Potatoes | varieties: | | | | | | | | |
| | "Bronnitsky " | 0.44 | 860 | – | – | 0.8 | 140 | 421 | |
| | "Nevsky " | 0.15 | 860 | – | – | 0.8 | 140 | 144 | 2.9 |
| Annual grasses | Control * | 2.97 | 880 | 10 | 1 | 1 | 340 | 886 | |
| (milk) | $N_{90}P_{60}K_{150}$ | 1.55 | 850 | 10 | 1 | 1 | 340 | 448 | 2.0 |
| (meat) | Control * | 2.97 | 880 | 8 | 4 | 0.9 | 70 | 584 | |
| | $N_{90}P_{60}K_{150}$ | 1.55 | 850 | 8 | 4 | 0.9 | 70 | 295 | 2.0 |
| Ration (total) | Control * | | | | | | | 2121 | |
| | $N_{90}P_{60}K_{150}$ | | | | | | | 1021 | 2.0 |
| Annual intake of $^{137}$Cs according to standard 76/87 | | | | | | | | 444000 | |

* Control - crop cultivation without countermeasures.

The values for $^{137}Cs$ annual intake derived for one product were summed over all products and compared with the annual limit of the radionuclide consumption adopted for the local population in the Standard 76/87.

The annual $^{137}Cs$ intake was calculated for those countermeasure variants which showed the maximum effectiveness for a given crop:

- application of complete mineral fertiliser with higher rates of potassium (for cereal crops and annual grasses);
- selection of crop varieties with minimum accumulation of radionuclides (for potatoes).

The results are presented in Table 3. The intake of radionuclides with the diet studied amounted to 1.7% of the adopted annual intake value (without countermeasures) and 0.8% (with countermeasures).

The analysis of the data derived allows a conclusion to be drawn that the application of countermeasures to reduce $^{137}Cs$ accumulation in plant products on chernozemic soils is an effective and radiologically justified step. A combined application of countermeasures results in the up to 2-fold decrease in $^{137}Cs$ intake with food-stuffs. Of paramount importance is the radionuclide decrease in the vegetative mass of grasses used for animal feeding and production of milk and meat, since $^{137}Cs$ intake with these products is the most important pathway of radionuclide transfer to the human diet.

### References

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