ASSESSMENT OF THE RADIATION SAFETY OF THE RURAL POPULATION OF THE CENTRAL FOREST-STEPPE OF UKRAINE IN THE REMOTE PERIOD AFTER THE CHERNOBYL CATASTROPHE

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Abstract: In Ukraine, as a result of the Chernobyl disaster, 2,218 villages and cities with a population of about 2.4 million residents were in the zone of radioactive contamination. Pollution has undergone almost the entire territory of Polesia and a significant part of the Forest-Steppe. The population living in radioactively contaminated areas receives an additional more natural dose level of external and internal exposure. External irradiation is due to the high content of ^{137}Cs in soils, with the decay of which increases the power of gamma radiation on the ground. Internal exposure is caused by the ingestion of ^{137}Cs and ^{90}Sr during the consumption of food products. The rural population with the consumption of products grown in household plots, receives significantly higher doses of radiation than the city. The activity of ^{137}Cs and ^{90}Sr in milk, meat, potatoes and other vegetable products is grown on the backyards of residents of the villages Osypivka and Tarasivka of the Bila Tserkva district of the Kyiv region, who have been subjected to radioactive contamination due to the Chernobyl disaster. The research results show that milk, meat and vegetable products grown in radioactively contaminated areas of the forest-steppe zone meet the radiation safety criteria for ^{137}Cs and ^{90}Sr. The internal exposure dose of the residents of the Osypivka village with the consumption of food products is 0.065 mSv/year, and that of the Tarasivka village – 0.028 mSv/year. Consumption of milk and potatoes makes the greatest contribution to the dose of internal exposure. The external radiation dose due to pollution of the territory of the settlement of ^{137}Cs residents of the Osypivka village is 0.72 mSv/year, and that of the Tarasivka village – 0.27 mSv/year. The annual effective dose to residents of the Osypivka village – 0.78 mSv/year, and the residents of the Tarasivka village – 0.30 mSv/year, which does not exceed the dose of radiation established by current legislation at 1 mSv/year.

Keywords: Chernobyl disaster, Central Forest-Steppe of Ukraine, rural population, food products, cesium-137, strontium-90, radiation dose.

1. Introduction

The Chernobyl disaster, the largest technogenic accident in the entire history of mankind, led to pollution of more than 145 thousand km^2 of the territory of Ukraine, the Republic of Belarus and the Russian Federation, where the ^{137}Cs pollution density exceeded 37 kBq/m^2. The influence of the Chernobyl disaster was also felt by Sweden, Norway, Poland, the United Kingdom and other European countries [1].

In Ukraine, 2,218 villages and cities with a population of about 2.4 million residents were in the zone of radioactive contamination. Pollution has undergone almost the entire territory of Polesia and a significant part of the Forest-Steppe [2]. One of the main objects of the biosphere, where ^{137}Cs and ^{90}Sr radionuclides were concentrated, was the soil of agrolandscapes. Having chemical properties like potassium and calcium, ^{137}Cs and ^{90}Sr are rather intensively involved in biogenic migration accumulating in food products and subsequently entering the human body [2–4].

More than 30 years have passed since the Chernobyl disaster. As a result of the decay of ^{137}Cs and ^{90}Sr, the area of high contamination density decreased on average by 2 times, but the problem of radioactive contamination remains urgent now [2, 3]. A sufficiently large number of scientific studies on the study of ^{137}Cs and ^{90}Sr migration in objects of agricultural production and their accumulation in food products were carried out [5–10]. Mainly attention of scientists focused on the area of Polesia. In addition, in the radioactively contaminated areas of the Forest-Steppe, a significant contribution to pollution occurs in ^{90}Sr, the migration intensity of which, according to scientists, will gradually increase [4, 6]. For the rural population, food products produced in household plots are the main source of food and intake of ^{137}Cs and ^{90}Sr [7–10]. All this led to the need to study the radioecological situation in the backyards of the radioactively contaminated territories of the forest-steppe zone of the southern part of the Kyiv region in the remote period after the Chernobyl disaster.

The aim of the research is estimation of the annual effective dose of radiation to the rural population living in the radioactively polluted territories of the forest-steppe zone of the southern part of the Kyiv region. The objective of this research is investigation of the activity of ^{137}Cs and ^{90}Sr radionuclides in the soils of household plots, potatoes and other vegetable products, milk, meat and to calculate the doses of external and internal exposure of the population.

2. Methods

Studies were conducted on the backyards of Osypivka and Tarasivka villages of the Bila Tserkva district of the Kyiv region. Osypivka village is assigned to the zone of voluntary guaranteed resettlement, and Tarasivka – to the zone of enhanced radiological control.

Research methods: gamma-spectrometry using the Progress 2000 software for determining ^{137}Cs activity; radiochemical and beta spectrometry using Progress 2000 software to isolate and determine the ^{90}Sr activity.

Medium samples of soil, potatoes and other vegetable products, milk of cows, and meat were selected for carrying out studies on personal plots. The activity of ^{137}Cs and ^{90}Sr was determined at the USK "Gamma Plus U" with the software "Progress 2000" in the laboratory of the Department of Life Safety at Bila Tserkva NAU. ^{137}Cs activity was determined on a scintillation gamma-spectrometric tract in a Marinelli-type vessel with a volume of 1 l in native samples or after their physical concentration, and ^{90}Sr – after radiochemical extraction on a scintillation beta-spectrometric tract according to the measurement procedures [11, 12].

The calculation of the annual effective dose of internal exposure was carried out in accordance with the method [13] according to the formula (1):

$$D_{int} = k_d \, {}^{137}Cs \cdot \sum_{i=1}^{N} m_i \cdot A_{{}^{137}Cs} + k_d \, {}^{90}Sr \cdot \sum_{i=1}^{N} m_i \cdot A_{{}^{90}Sr}, \qquad (1)$$

where k_d ^{137}Cs and k_d ^{90}Sr – dose-rate of ^{137}Cs and ^{90}Sr (k_d ^{137}Cs – 1,3E-08 Sv/Bq; k_d ^{90}Sr – 2,8E-08 Sv/Bq); m_i – the annual consumption of the i-th food product (kg); $A_{^{137}Cs}$ and $A_{^{90}Sr}$ – the specific activity of ^{137}Cs and ^{90}Sr in the product (Bq/kg).

The calculation of the annual effective dose of external exposure was carried out according to the formula (2):

$$D_{ext} = 0.0026 \cdot P, \quad (2)$$

where 0.0026 – conversion factor (mSv/year/kBq/m^2); P – the pollution density of the territory settlement by ^{137}Cs (kBq/m^2).

3. Results

Investigation of ^{137}Cs and ^{90}Sr activity in personal plots soils of Osypivka village showed that the density of ^{137}Cs contamination is 206.4–380.7 kBq/m^2 and ^{90}Sr – 24.2-38.2 kBq/m^2. On average, the level of ^{137}Cs contamination is 277.7 kBq/m^2, and ^{90}Sr – 31.8 kBq/m^2. The level of soil contamination in personal plots soils of Tarasivka village by ^{137}Cs is 57.5-136.5 kBq/m^2, and ^{90}Sr – 10.5–19.7 kBq/m^2. On average, the ^{137}Cs contamination density is 104.0±23.7 kBq/m^2, and ^{90}Sr – 16.0±3.4 kBq/m^2.

Research results of the specific activity of ^{137}Cs and ^{90}Sr in vegetable crops grown in the household plots of Osypivka and Tarasivka villages showed that the lowest activity of ^{137}Cs compared to other vegetables was in potatoes, onions and cucumbers, in squash and sweet peppers it was twice as high, carrots and tomatoes almost 4 times, beets – almost 8, and beans – 10 times (**Table 1**). Onion had the lowest activity of ^{90}Sr, twice as high in tomatoes and cucumbers, four times higher in sweet pepper, almost 10 times in potatoes and cabbage, in the twenties zucchini and 30 times higher in table beets, carrots and beans.

Table 1
^{137}Cs and ^{90}Sr accumulation by vegetable crops

Crop	Activity, Bq/kg, M±m, n = 12			
	Osypivka		Tarasivka	
	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr
Potatoes	2,78±0,56 2,06–3,81	2,40±0,49 1,73–3,35	1,04±0,23 0,58–1,37	1,51±0,24 0,95–1,94
Cabbage	5,55±1,1 4,13–7,61	2,42±0,48 1,72–3,36	2,10±0,18 1,15–2,73	1,52±0,23 0,96–1,97
Beetroot	13,89±2,82 10,32–19,04	8,00±1,75 5,76–11,53	5,22±1,17 2,88–6,84	5,05±0,98 3,17–6,46
Carrot	8,33±1,69 6,19–11,42	7,53±1,51 5,57–10,79	3,12±0,69 1,73–4,12	4,71±0,92 2,96–6,03
Onion	2,82±0,56 2,07–3,82	0,27±0,05 0,19–0,37	1,06±0,22 0,62–1,41	0,17±0,03 0,11–0,22
Tomatoes	8,22±1,68 6,22–11,38	0,54±0,11 0,37–0,75	3,12±0,68 1,73–4,10	0,35±0,06 0,22–0,44
Cucumbers	2,8±0,56 2,08–3,78	0,54±0,10 0,38–0,74	1,02±0,21 0,60–1,36	0,34±0,07 0,21–0,43
Zucchini	5,62±1,11 4,18–7,64	4,56±0,86 3,26–6,16	2,08±0,47 1,15–2,73	2,86±0,55 1,80–3,66
Sweet pepper	5,64±1,12 4,22–7,82	1,07±0,22 0,77–1,49	2,02±0,42 1,22–2,72	0,67±0,13 0,42–0,86
Beans	25,2±5,08 18,58–34,26	7,95±1,65 5,57–11,16	9,38±2,11 5,18–12,26	5,04±0,98 3,17–6,46

A study of ^{137}Cs and ^{90}Sr activity in milk and meat obtained in the subsidiary farms of residents of Osypivka and Tarasivka villages showed that in both settlements, the highest activity of ^{137}Cs and ^{90}Sr was in pork meat and milk of cows (**Table 2**).

Table 2
Specific activity of ^{137}Cs and ^{90}Sr in milk and meat, Bq/kg, n=5

Product	Osypivka		Tarasivka	
	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr
milk	6,28±1,86 3,5–9,31	2,12±0,6 1,16–2,82	2,21±0,67 1,12–3,34	0,69±0,10 0,35–1,12
pork meat	9,5±2,4 7,45–12,9	<0,50	3,93±1,18 2,14–5,37	<0,50
chicken meat	1,2±0,17 0,67–1,8	–	0,25±0,09 0,12–0,32	–
goose meat	1,8±0,27 0,82–2,6	–	0,46±0,11 0,21–0,81	–
eggs	0,41	–	0,11	–

At the same time, the activity of ^{137}Cs and ^{90}Sr in milk was two to three times higher in the spring-summer period than in the autumn-winter period, due to the grazing of cows on natural pastures, where the level of soil pollution is much higher than on arable land. The low activity of ^{137}Cs and ^{90}Sr was in poultry meat, which mainly consumes up to 120 grams of concentrated feed or grain, and the volumes of accumulation of radionuclides are low.

4. Discussion

The soils on the household plots of Osypivka and Tarasivka villages are typical light and medium loamy chernozem with an average humus content (3.2–3.6 %), neutral reaction of the aqueous extract (6.80–7.72), soil density 1.18–1.25 g/cm^3, with an average content of exchangeable potassium (82–120 mg/kg) and calcium (15–20 mg-eq/100 g).

In general, the study of the activity of ^{137}Cs and ^{90}Sr in the soils showed that the contamination of the household plots of Osypivka and Tarasivka villages is uneven, patchy both in terms of the level of contamination and radionuclide composition. The main contribution to pollution of land (about 90 %) is ^{137}C. Compared to the 1991 data, soil contamination levels have halved.

Studies have shown that the activity of ^{137}Cs and ^{90}Sr in vegetable products, milk and meat of personal subsidiary farms of the Central Forest-Steppe does not exceed acceptable levels. According to state hygienic standards [14], the activity of ^{137}Cs in potatoes should not exceed 60 Bq/kg, in fresh vegetable and leguminous crops – 20 Bq/kg; and ^{90}Sr – 40 Bq/kg in potatoes and fresh vegetables and legumes – 20 Bq/kg. In milk, the specific activity of ^{137}Cs should not exceed 100 and ^{90}Sr – 20 Bq/kg, and in meat the activity of ^{137}Cs should not exceed 200 and ^{90}Sr – 20 Bq/kg.

The data (**Tables 1, 2**) show that the activity of ^{137}Cs in milk, meat, potatoes and other vegetable products obtained at home gardens by residents of villages of the Central Forest-Steppe of Ukraine is on average 10-20 times lower than in Polesia [8–10, 15].

The amounts of ^{137}Cs and ^{90}Sr entering the body of the residents of Osypivka and Tarasivka villages (**Table 3**) do not exceed the permissible level of radionuclide intake through the digestive organs for the population established by the radiation safety standards [16] (^{137}Cs – 50000 Bq/year and ^{90}Sr – 4000 Bq/year) . Calculations show that with the consumption of food products grown in the subsidiary farm, the annual effective dose of internal exposure of Osypivka residents is 0.065 mSv, and Tarasivka – 0.028 mSv (**Table 3**). The dose of internal exposure of residents of Tarasivka is 2.3 times lower than in Osypivka, since the average density of pollution in the territory of this settlement ^{137}Cs is 2.7, and ^{90}Sr is 2 times lower.

From the data in **Table 3**, it can be seen that the consumption of milk and potatoes makes the largest contribution to the dose of internal exposure. So residents of Osypivka with milk receive 33.2 %, potatoes – 23.5 %, and residents of Tarasivka with milk receive 21.2 %, potatoes – 29.3 % of the total dose of internal irradiation. Calculation of the external dose shows that residents of Osypivka due to pollution of the territory of the settlement of ^{137}Cs receive a radiation dose of 0.72 mSv/year, and residents of Tarasivka – 0.27 mSv/year. This shows that, mainly for residents of these villages, the dose of irradiation is formed precisely due to external irradiation.

In general, due to external and internal exposure, residents of the Osypivka village receive an effective dose of 0.78 mSv/year, and residents of the Tarasivka village receive 0.30 mSv/year, which does not exceed the statutory effective equivalent radiation dose of 1 mSv/year.

Table 3

Effective internal dose, mSv/year

Products	Osypivka		Tarasivka	
	Consumption for 1 year, kg	Radiation dose, mSv/year	Consumption for 1 year, kg	Radiation dose, mSv/year
potatoes	132	0,0154	125	0,0083
cabbage	32	0,0046	30	0,0023
beetroot	9	0,0039	8	0,0019
carrot	12	0,0043	14	0,0029
onion	12,5	0,0005	14	0,0002
tomatoes	22	0,0022	24	0,0011
cucumbers	22	0,0011	20	0,0005
zucchini	6	0,0013	5	0,0006
sweet pepper	8	0,0008	7	0,0003
white radish	4	0,0017	4,5	0,0010
beans	6,5	0,0035	5	0,0014
milk	154	0,0218	132	0,0060
pork	32,8	0,0037	29,2	0,0017
chicken meat	25,5	0,0005	21,9	0,0001
eggs, kg/pc	21,3/320	0,0001	18,7/280	0,00001
Total in year	499,9	0,0655	458,3	0,0283

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