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RESEARCH ARTICLE

# Radiation and Hygiene Assessment of the Consequences of Nuclear Tests at the Semipalatinsk Test Site

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## Abstract

The analysis of the spatial and intra-profile distribution of cesium-137 (137Cs) reserves in the soils of the Altai Mountains, as well as the dynamics of the specific activity of this radionuclide in food products produced in the territory of the Republic of Altai and the Altai territory, in 1966-1985, was performed. Individual annual effective doses of internal radiation of the adult population of the Republic of Altai and the Altai territory due to the receipt of 137Cs with food were calculated and a forecast of long-term radiological consequences for the population of the Republic of Altai was made.

**Keywords**: *Radioactivity; Radio nuclides; Cesium-137; Semipalatinsk.*

## Introduction

The territories of the Semipalatinsk region, the Republic of Altai (RA) and the Altai territory (AT) were exposed to radioactive contamination due to atmospheric nuclear tests at the Semipalatinsk test site (STS) [1-10]. As a result of many years of radio ecological research in these territories data on the distribution of long lived radionuclides 137Cs in the soil were obtained.

The mosaic of the spatial distribution of 137Cs was revealed, the maximum densities of which are confined to the tops of ridges and soils bordering basins, and the minimum-in the soils of the bottoms of basins and river valleys. It is noted that 137Cs is mainly concentrated in the upper 5 cm layer of soil and much less-at a depth of more than 15-20 cm and generally does not exceed the background values [11-22].

After the completion of atmospheric nuclear tests on STS, the formation of radiation doses to the population occurred due to the ingestion of 137Cs with locally produced food, suspended dust particles contained in the inhaled air, and with the ingested soil [23-28, 21, 22, 29].

The main sources of 137Cs in the human body are animal and vegetable food (dairy and cereals). The content of radio cesium in a liter of cow's milk was 0.8-1.1% of the daily intake [30-35]. In the Semipalatinsk region, the body of residents living near the STS received 77.0 Bq/year 137Cs with milk, and 75.1 Bq/year with meat [36-42].

In this regard, it is relevant to study the possible radiation consequences for the health of the population in modern conditions in the territories that were exposed to radioactive contamination during atmospheric tests on the STS. The purpose m of the study is radiation and hygiene assessment of the consequences of atmospheric testing of nuclear devices at the STS.

## Materials and Methods

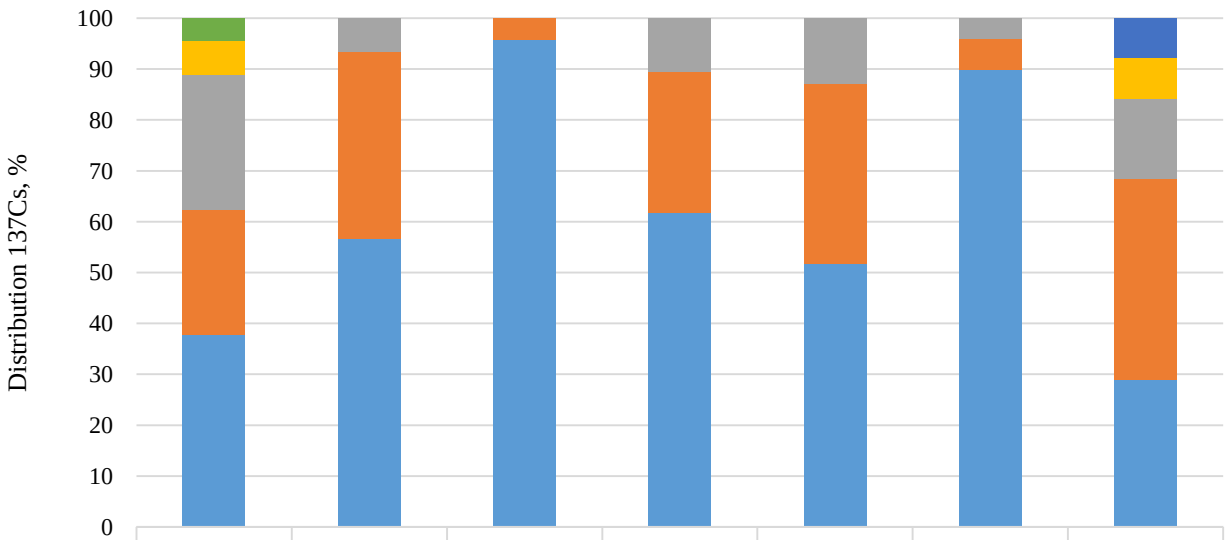
This work was done at Sechenov University with supported by the "Russian Academic Excellence Project 5-100". The object of the study is the food chain of 137Cs intake into the body of the population living in the territories that were exposed to radioactive

contamination during atmospheric nuclear tests on STS: soil-plants-bread, milk and meat products, and the long-term consequences of radiation exposure for health. The subject of the study is the specific activity of 137Cs in the soil and the main food products that make up the diet of the adult population; exposed to radioactive contamination during atmospheric nuclear tests, and the forecast of radiological consequences of radiation exposure on the population of the RA. The forecast of radiological consequences is made in accordance with Publication 103 of the International Commission on radiation protection [43-45].

To analyze the spatial and intra-profile distribution of 137Cs in the soils of the RA, we used the results of radio ecological studies performed within the framework of the Federal Target Program for providing medical and social assistance to the population and normalizing the sanitary and hygienic condition of settlements of the RA that were exposed to radiation as a result of nuclear tests at the STS [15, 23, 25]. The content of 137Cs in food products was studied according to radiation monitoring data performed by the radiological group of the Sanitary and epidemiological service of the AT. The dynamics of the specific activity of radioactive caesium in bread, milk, potatoes and meat (beef and mutton) produced and grown on the territory of the AT and the Altai Mountains in 1966-1985 was analyzed [23, 46-47].

## Results and Discussions

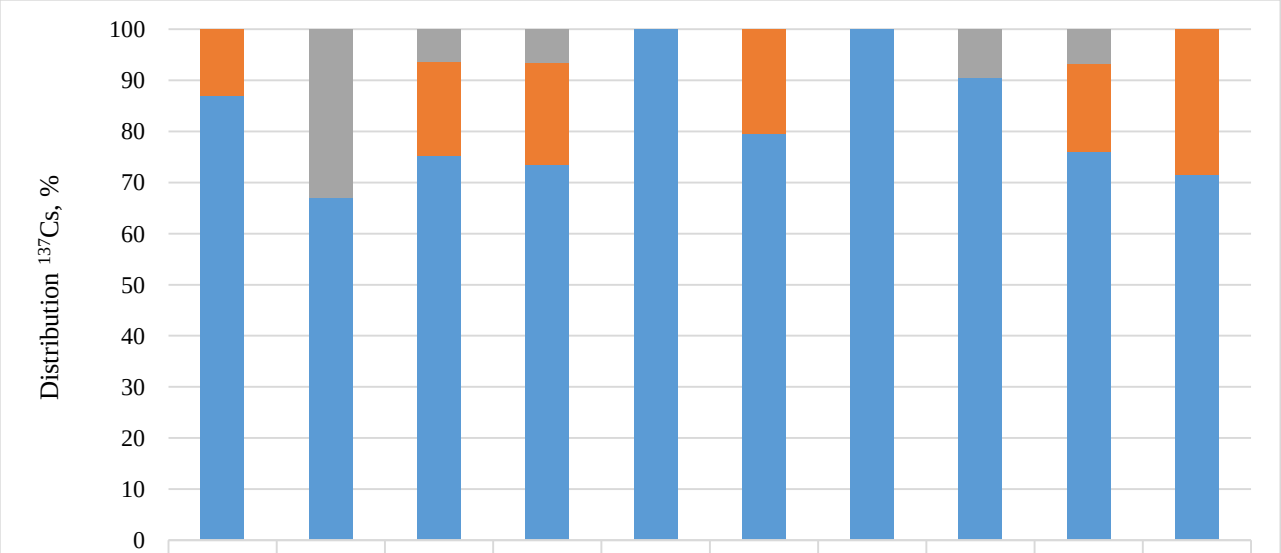
A study of the spatial and intra-profile distribution of 137Cs activity in the soils of the RA revealed uneven reserves of this radionuclide in the soil depending on its genesis (Figure 1).




| | Mountain-forest-blackearth-like | Mountain-meadow loam | Mountain tundra | Mountain-forest-blackearth-like | Blackearth-like | Mountain-meadow-steppe | Turf peat humus |
|---|---|---|---|---|---|---|---|
| 25-30 cm | 4.4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20-25 cm | 0 | 0 | 0 | 0 | 0 | 0 | 7.9 |
| 15-20 cm | 6.7 | 0 | 0 | 0 | 0 | 0 | 7.9 |
| 10-15 cm | 26.7 | 6.7 | 0 | 10.5 | 12.9 | 4.1 | 15.8 |
| 5-10 cm | 24.4 | 36.7 | 4.2 | 27.6 | 35.5 | 6.1 | 39.5 |
| 0-5 cm | 37.8 | 56.7 | 95.8 | 61.8 | 51.6 | 89.8 | 28.9 |

**Figure 1: Intra-profile distribution of 137Cs in the soils of the RA of different genesis**

As can be seen in figure 1, the main reserves of 137Cs are concentrated in the upper (0-5 and 5-10 cm) layers of the humus horizon and differ in size depending on the type of soil: in the 1st place, mountain-tundra soil, in the 2nd and 3rd places-mountain-meadow steppe and mountain-forest-black earth-like. Regions of the RA differ significantly in soil types and, accordingly, in the reserves of 137Cs and its distribution in soil profiles. The vertical distribution of 137Cs in the soils of the regions of the RA is shown in Figure 2.




| | Kosh-Agachsky | Ulagansky | Ust-Koksinsky | Ust-Kansky | Onguday | Shebalinsky | Chemalsky | Maiminsky | Choysky | Turochaksky |
|---|---|---|---|---|---|---|---|---|---|---|
| 20-40 cm | 0 | 32.9 | 6.4 | 6.5 | 0 | 0 | 0 | 9.5 | 6.7 | 0 |
| 10-20 cm | 13.1 | 0 | 18.3 | 20.1 | 0 | 20.5 | 0 | 0 | 17.3 | 28.4 |
| 0-10 cm | 86.9 | 67.1 | 75.3 | 73.4 | 100 | 79.5 | 100 | 90.5 | 76 | 71.6 |

**Figure 2: Intra-profile distribution of 137Cs in the soils of the regions of the RA**

Figure 2 shows that 100% of the radionuclide reserves are concentrated in the 0-10 cm soil layer in the Ongudai and Chemal districts and maimin and Kosh-Agach districts are located in the 2nd and 3rd places according to this indicator. On average, the Republic has 82.0 (73.7-90.4) % of 137Cs reserves in the 0-10 cm layer, and in the 10-20 cm and 20-40 cm layers, respectively 19.6 (14.3 – 24.9) % and 12.4 (1.9-26.7) %.The content of 137Cs in soil layers of 0-10 cm and 10-20 cm in the regions of the RA is shown in Figures 3 and 4.

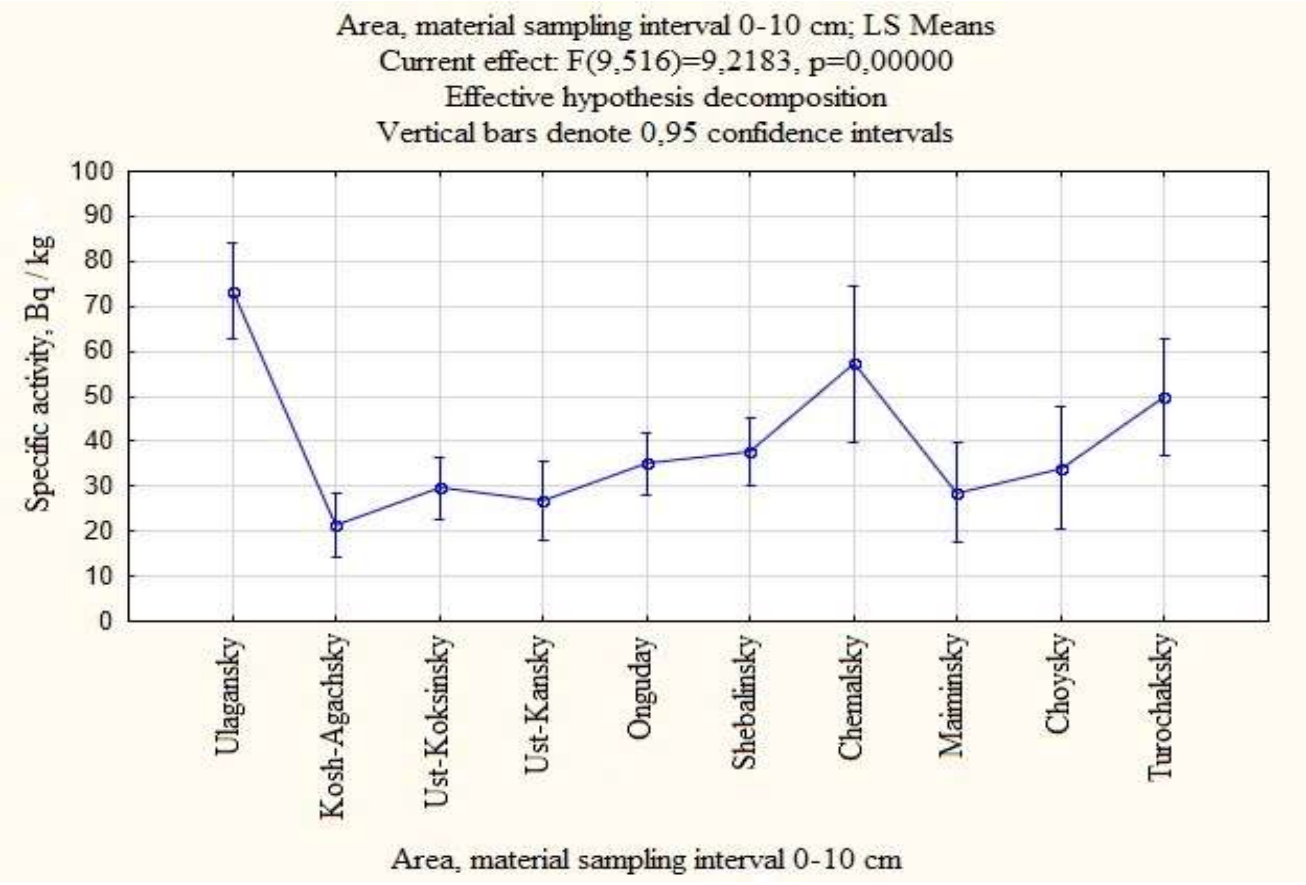



**Figure 3: Specific activity of 137Cs in the range 0-10 cm**

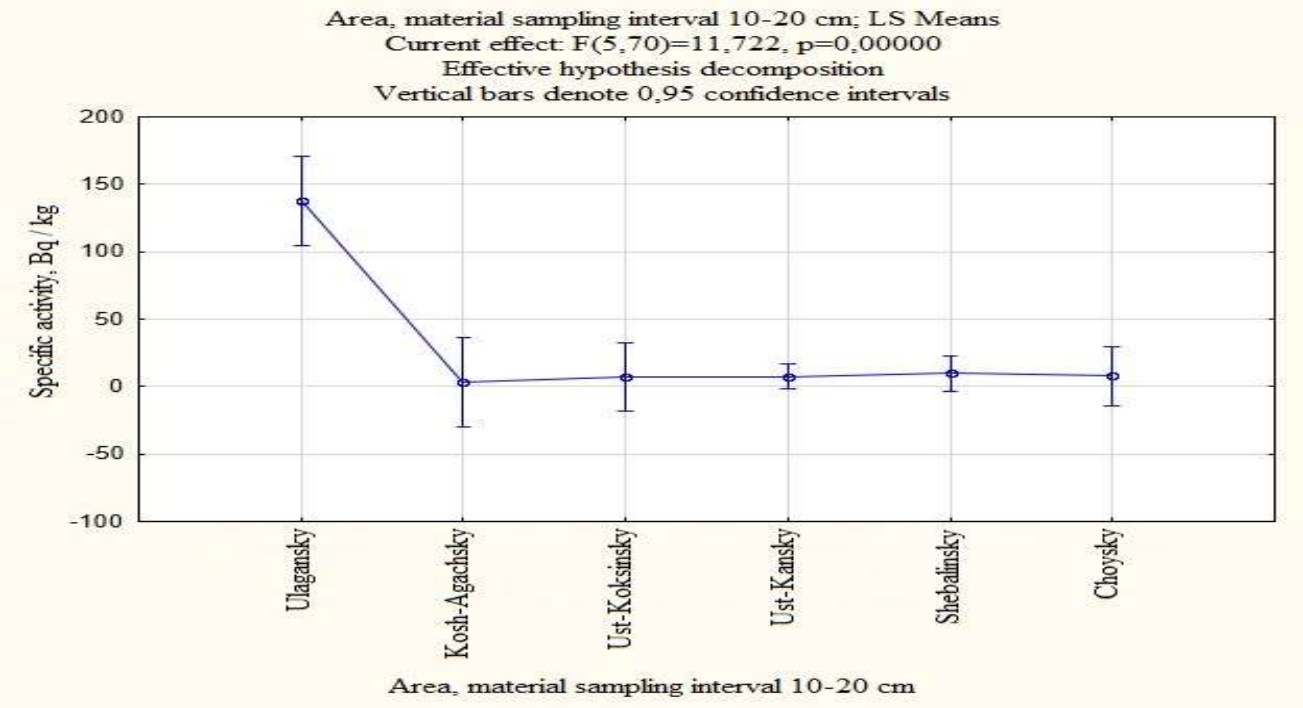



**Figure 4: Specific activity of 137Cs in the range of 10-20 cm**

As can be seen in figures 3 and 4, the highest activity of 137Cs in layers 0-10 cm and 10-20 cm is accumulated in the soil of the Ulagan district-73.4 (50.9-96.0) and 36.0 (-26.3-98.3) Bq/kg, respectively. On the 2nd place in terms of reserves of 137Cs in the soil layer of 0-10 cm is Chemalsky district 57.2 (43.8-70.7) Bq/kg, on the 3rd-Turochaksky 49.9 (35.9-63.8) Bq/kg. In the soil layer of 10-20 cm, the 2nd and 3rd places in terms of reserves of 137Cs are occupied by Shebali 9.7 (6.6-12.8) Bq/kg and Choi districts 7.7 (3.3-12.1) Bq/kg, respectively.

The global background precipitation level [12] exceeded 1.6 times ($p = 0.05$) only in the Ulagan region. It should be noted that local areas that exceed the global background are usually confined to mountain peaks. In general, the reserves of 137Cs in the territory of the RA are at the level of global precipitation and below. A comparison of the activity of 137Cs in the soil of the RA 30 and 40 years after atmospheric tests (AT) and 30 years later in the Semipalatinsk region (SR) is shown in Figure 5.

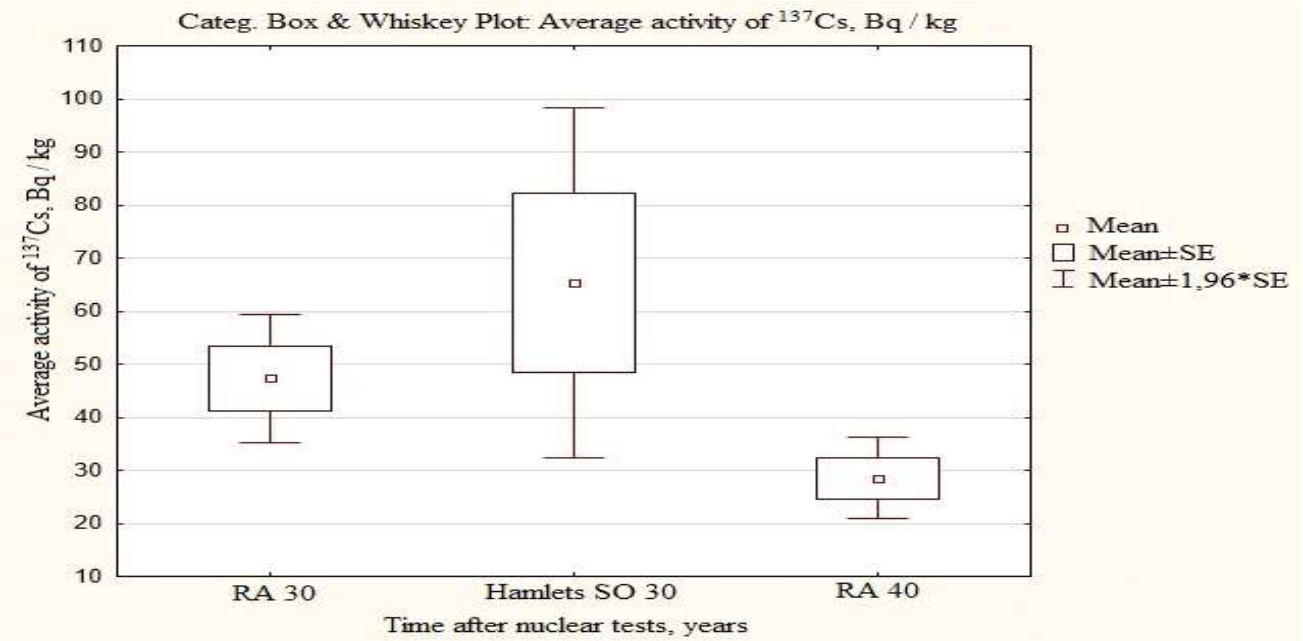
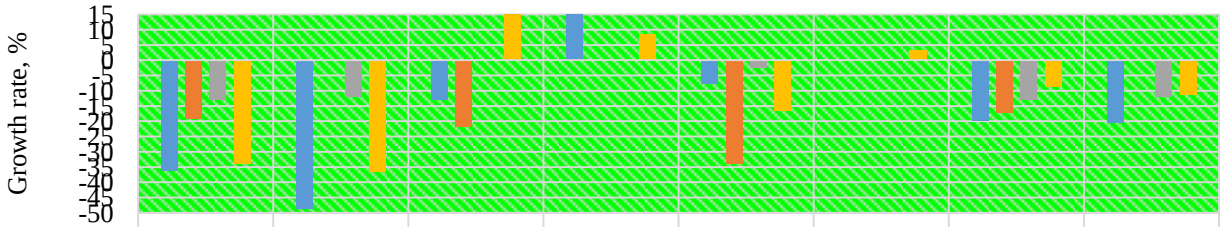



**Figure 5: Average activity of 137Cs in the soils of the RA and SO 30 and 40 years after nuclear tests in the atmosphere, Bq / kg**

Figure 5 shows that the average activity of 137Cs in the soil of the RA 30 years after the completion of atmospheric tests of nuclear devices is 1.4 times lower than in the SR ($p > 0.05$). After 40 years, the average activity of 137Cs in the soil of the RA decreased by 1.7 times (Mann-Whitney U Test-$p < 0.004$; Kolmogorov-Smirnov Test-$p < 0.025$).

The analysis of the dynamics of the average specific activity of 137Cs in bread, meat (beef and lamb), milk and potatoes in RA and AR was carried out in the period from 1966, 3 years after the cessation of nuclear tests in the atmosphere, to 1985. (1 year before the Chernobyl accident). To analyze the dynamics in this time series, 3 periods were identified: 1966-1975, 1976-1980, and 1981-1985. In the RA in the 2nd period there were no data on the content of 137Cs in potatoes, and in the AR data on the content of this radionuclide in milk for 1966-1985 and in potatoes-in the period from 1976 to 1985. The results of time series analysis of the average specific activity of 137Cs in these foods are shown in Figure 6.




| | RA 1966-75 years | AR 1966-75 years | RA 1976-80 years | AR 1976-80 years | RA 1981-85 years | AR 1981-85 years | RA 1966-85 years | AR 1966-85 years |
|---|---|---|---|---|---|---|---|---|
| Bread | -36.3 | -48.7 | -12.9 | 14.9 | -7.8 | -0.3 | -19.9 | -20.6 |
| Milk | -19.3 | 0 | -21.7 | 0 | -34 | 0 | -17.1 | 0 |
| Potatoes | -12.9 | -12 | 0 | 0 | -2.3 | 0 | -12.9 | -12 |
| Meat | -34 | -36.5 | 14.9 | 8.4 | -16.7 | 3.1 | -8.8 | -11.3 |

**Figure 6: Growth rates of specific activity of 137Cs in food products in the RA and in the AR in 1966-1985, %**

Figure 6 shows that the content of 137Cs in food products in 1966-1985 steadily decreased in both RA and AR. However, this dynamics differed significantly for individual products. Thus, in 1976-1980 in RA and AR there was a positive growth rate of specific activity of 137Cs in meat-14.9 and 8.4%, respectively, and in AR also in bread -14.9%. In AR, a weakly expressed rate of increase in the specific activity of 137Cs in meat was observed in 1981-1985-3.1%. The content of 137Cs in milk, meat and potatoes in the RA in 1981-85 is comparable to the data of S. N. Lukashenko on the STS [17].

To assess the radiation impact on residents of territories that were exposed to radioactive contamination during the passage of clouds of nuclear explosions, we studied the intake of 137Cs with basic food products and the total intake with the diet of the adult population of RA and AR. Due to the lack of data on the content of 137Cs in milk for AR, the content of this radionuclide in milk in RA was compared with data for the Russian Soviet Federative Socialist Republic (RSFSR) for zone 1 and zone 2. The comparison results are shown in Figure 7.

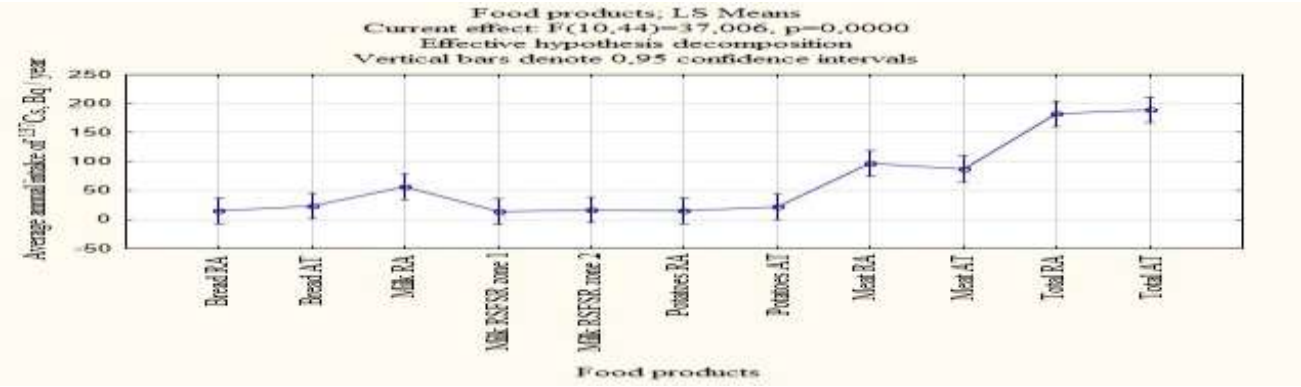



**Figure 7: Average annual intake of 137Cs in the adult population of the RA and the AT with basic food products, Bq / year**

Figure 7 shows that in both RA and AT, the largest amount of 137Cs enters the body of the adult population with meat. In RA, the average annual intake of 137Cs with meat is higher than with bread (Mann-Whitney U Test – $p < 0.04$) and potatoes (Mann-Whitney U Test – $p < 0.05$), the difference with milk does not reach statistical significance ($p < 0.12$). A similar situation occurs in AT-$p < 0.01$ (Mann-Whitney U Test) and $p < 0.01$ (Mann-Whitney U Test), respectively. The content of 137Cs in RA milk is significantly higher than in zones 1 and 2 of the RSFSR - $p < 0.01$ (Mann-Whitney U Test) and $p < 0.01$ (Mann-Whitney U Test), respectively.

Comparison of annual income levels of 137Cs with a basic food with a limit of annual income (LAI) for critical groups of population in 80-ies of the Radiation Safety Standards (RSS) -76/87 [43] showed that realized annual intake of the adult population of the RA and the AT is for 137Cs, respectively, of 0.04% and 0.03% of the LAI, while the LAI in comparison with the RSS-99/2009 [16], respectively 0.24% and 0.25% of LAI, that is far less the permissible level. The average individual annual effective radiation doses of the adult population of the AT due to locally produced products (bread, dairy products, potatoes and meat) are presented in Table 1.

**Table 1: Individual annual effective radiation doses of the adult population of the RA due to the intake of 137Cs in the body with basic food products (bread, milk, meat, potatoes), mSv / year**

| Territories | Dose, mSv / year in the period (95%CI) | |
|---|---|---|
| | 1981-1985 years | 2010 r. [20] |
| Republic of Altai | 0,124 (0,079-0,272) | 0,017 (0,011-0,037) |
| Altai Territory | 0,115 (0,074-0,254) | 0,027 (0,017-0,059) |
| Russian Federation | 0,141 (0,09-0,31) | 0,029 (0,019-0,064) |

As can be seen from table 1, individual annual effective doses of the adult population of the RA, AT and Russian Federation in 2010 much less than in 1981-1985 years

When predicting long-term consequences, it was assumed that the total risk from fatal cancer, inherited effects and non-fatal cancer for one person at a dose of 1 Sv is assumed to be 0.057 [18]. The risk was estimated by the product of the individual risk and the collective dose calculated for the population [25] exposed to radiation during atmospheric nuclear tests, by internal radiation doses due to the intake of 137Cs into the body of the adult population with basic foodstuffs in 1981-1985 (I-st period) and in 2010 (II-nd period). The forecast of long-term consequences of internal radiation exposure of the adult population of the RA when receiving 137Cs with basic food products is presented in Table 2.

**Table 2: Forecast of long-term consequences of radiation exposure of the population of the RA as a result of nuclear tests at the STS due to the intake of 137Cs into the adult population with basic food products**

| Territories | Long-term consequences | | | | | |
|---|---|---|---|---|---|---|
| | Fatal cancers | | Hereditary pathology | | Total | |
| | Periods | | | | | |
| | I | II | I | II | I | II |
| Gorno-Altaysk | 23 | 3 | 0,6 | 0,8 | 24 | 3 |
| Maimin | 9 | 1 | 0,2 | 0,3 | 9 | 1 |
| Shebalinsky | 5 | 1 | 0,1 | 0,2 | 5 | 1 |
| Onguday | 4 | 1 | 0,1 | 0,1 | 5 | 1 |
| Ust-Kansky | 6 | 1 | 0,2 | 0,2 | 7 | 1 |
| Ust-Koksinsky | 4 | 1 | 0,1 | 0,1 | 4 | 1 |
| Ulagansky | 4 | 0,5 | 0,1 | 0,1 | 4 | 1 |
| Kosh-Agachsky | 3 | 0,4 | 0,1 | 0,1 | 3 | 0,4 |
| Turochaksky | 3 | 0,4 | 0,1 | 0,1 | 3 | 0,4 |
| Choisky | 1 | 0,1 | 0,03 | 0,04 | 1 | 0,2 |
| Total in RA | 63 | 9 | 1,5 | 2 | 64 | 9 |

Table 2 shows that by 2010, the projected long-term effects of internal radiation due to the intake of 137Cs, contained in basic food products, into the body of the adult population of the RA, decreased by 7 times

The contribution of internal radiation to the formation of long-term consequences in the Altai Republic due to the intake of 137Cs with basic food products in 1981-1985 was 6.1%, in 2010-0.9%.

## Conclusions

- Spatial and intra-profile distribution of 137Cs reserves in the soil is characterized by mosaic and unevenness depending on its genesis. Local areas that exceed the global background are associated with mountain peaks. The maximum specific activity of 137Cs is typical for mountain tundra soils of the Altai Mountains and is concentrated mainly in the surface (0-10 cm) soil horizons; its share in this soil profile on average in the RA is 82.0%, in layers of 10-20 cm and 20-40 cm-19.6% and 12.4%, respectively.

- A marked decrease in the specific activity of 137Cs in food in the RA and in the AT was observed in 1966-1975 - in bread -36.2% and -48.7%, respectively, in meat -34.0% and -36.5%. In 1976-1980, a positive rate of increase in the specific activity of 137Cs was observed in meat (14.9 and 8.4%) and in bread in the AT (14.9%). A slight increase in the specific activity of 137Cs in meat (3.1%) in the AT continued in 1981-1985.

- In the RA and in the AT, the largest amount of 137Cs enters the body of the adult population with meat ($p < 0.04$ and $p < 0.01$). The content of 137Cs in RA milk is higher than in zones 1 and 2 of the RSFSR by 4.3 and 3.5 times, respectively ($p < 0.01$). The realized annual intake of 137Cs with food into the body of the adult population of the RA and the AT in 1981-1985 was 0.04% of LAI, respectively, and in 2010-0.24% and 0.25% of LAI.

- Individual annual effective doses of internal radiation of the adult population of the RA and the AT due to the receipt of 137Cs with food in 1981-1985 (0.124 and 0.115 mSv / year) were by an order of magnitude higher than the doses in 2010 (0.017 and 0.027 mSv/year).

- The probability of long-term consequences of internal radiation due to the intake of 137Cs into the body of the adult population of the RA in 1981-1985 was 7 times higher than the similar forecast values in 2010. The contribution of internal radiation to the formation of long-term consequences in 1981-1985 and in 2010 was 6.1% and 0.9%, respectively.

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