

CURRENT RADIOLOGICAL SITUATION AND DOSE ASSESSMENT ON THE POPULATION LIVING IN THE TECHA RIVER BASIN

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INTRODUCTION

In the beginning of the fifties, planned releases of liquid radioactive wastes were performed from the radiochemical enterprise "Mayak" to the riverbed of the Techa river flowing in the area of the Chelyabinsk region. These releases caused high contamination of the riverbed and water meadows of the Techa river especially by ⁹⁰Sr and ¹³⁷Cs. After the termination of intensive releases, a part of the population living in the riverside settlements (15 settlements with total population of 72000 persons) was resettled from 1954 - 1962. Within the Chelyabinsk region, four inhabited settlements remained on the river: Muslyumovo, Brodokalmak, Russkaya Techa and Nizhnepetropavlovskoye with a total population of 9229 persons according to the census of 1989. The second, but much less significant, source of contamination to this environment was the dispersion and transport of contaminated sediments from Lake Karachay in 1967 [Romanov et al. 1995; Kryshev et al. 1998; Kravtsova et al. 1998].

The overall purpose of this work was determination of ways and estimation of current levels of exposure to population of two settlements, Muslyumovo and Brodokalmak, which is necessary for development of measures on radiation and social protection of population.

MATERIALS AND METHODS

As input data for dose assessment, we used results from studies of the current radiation situation in the Techa river basin performed in the 1990's by a number of institutions of the Urals region (Kravtsova et.al. 1998; Report 1994). In 1998, in villages of the Techa river basin, joint field work was performed by the RTC "Protection" and the Chelyabinsk CSEN with participation from NRPA, Norway, and CEH (formerly ITE), UK. During the campaign, samples of soil, grass, vegetable and animal food products, fish from the river and lakes were taken in the Techa river basin and in Muslyumovo and Brodokalmak. Gamma spectrometric and radiochemical analysis of the samples for ⁹⁰Sr and ¹³⁷Cs content were performed and reported earlier [Shutov et. al. 2002]. Measurement data of gamma dose rate in the Techa river basin and in Muslyumovo and Brodokalmak from Report 1994 were used for calculation of external exposure of inhabitants.

The computational model for the estimation external and internal doses

The conditions of external exposure to people living within the Techa river drainage area are considerably different from those, for example, in Chernobyl contaminated areas since the main radiation source here is a small part of the river-flooded meadows. The area of the

settlements was subjected to considerably weaker radioactive contamination (mainly from Lake Karachai in 1967). In this case data of measurements of dose rate attributed to artificial contamination of the environment were used as a measure of an external gamma field. To measure the total dose rate of gamma radiation in air, we used high-sensitivity digital mobile dosimeter DRG-001 (Jacob et al. 1996). To assess the contribution to the total dose rate from gamma radiation of natural radionuclides, we used the device for measuring concentration of natural radionuclides in soil RKP-305M (Roed et al. 1996). This device is a field gamma-spectrometer with recording gamma radiation from the typical lines ^{40}K ($E = 1.46$ MeV), nuclides of the ^{238}U series ($E = 1.76$ MeV) and ^{232}Th series ($E = 2.62$ MeV). After measurement of potassium, uranium and thorium concentrations in assumption of their homogeneous distribution in soil, we calculated the dose rate attributed to gamma radiation of natural radionuclides. The dose rate in air due to gamma radiation of artificial radionuclides was determined as the difference between the measured total dose rate and the dose of gamma radiation of natural radionuclides. The gamma dose rates was measured in the floodplains, in the settlements themselves, and around the settlements outside the floodplain. Their mean values were 1520 nGy h^{-1} , 15 nGy h^{-1} , 22 nGy h^{-1} ; and 440 nGy h^{-1} , 8 nGy h^{-1} , and 14 nGy h^{-1} for Muslyumovo and Brodokalmak respectively.

The average annual effective dose from artificial external exposure E_i to representative of the i -th population group it is possible to write the following way:

$$E_i = 8760 K_s \cdot d_i^{ext} \cdot \sum_j F_{ij} \cdot P_j^{art}, \text{ mSv} \cdot \text{year}^{-1} \quad (1)$$

where: 8760 is the number of hours per year; P_j^{art} is the absorbed dose rate at the height of 1 m above the ground attributed to artificial contamination ($\text{mGy} \cdot \text{h}^{-1}$) at location j ; K_s is the dimensionless factor characterising the average annual influence of snow cover on the gamma radiation dose rate; F_{ij} is the relative frequency of stay for members of population group i at location j (occupancy factor), and d_i^{ext} is the conversion factor from the gamma dose rate in air to effective dose ($\text{Sv} \cdot \text{Gy}^{-1}$).

Occupancy factor values for floodplains were assessed on the basis of observation data on visits of representatives of different age groups to the river floodplain within the settlements. The values of occupancy factors for other locations (inside of house, outside of house, virgin land) were assessed on the basis of similar investigations in the other regions of Russia []. We used conversion factors values of $0.7 \text{ Sv} \cdot \text{Gy}^{-1}$, $0.75 \text{ Sv} \cdot \text{Gy}^{-1}$ and $0.85 \text{ Sv} \cdot \text{Gy}^{-1}$ for adults, school children and pre-schools respectively.

Data obtained during the fieldwork expeditions on the diets of different population groups and radioactive contamination of different food items were used to estimate current radionuclide intakes and ingestion doses. The following equation was used for assessment of the annual effective dose of internal exposure E_{int} :

$$E_{int} = 365 \cdot \sum_p (d_p^{int} \cdot I_p), \text{ mSv} \cdot \text{year}^{-1} \quad (2)$$

where: d_p^{int} - is the dose factor for ingestion of p -th nuclide in the body of an adult; d_p^{int} is equal to $1.3 \cdot 10^{-5}$ and $2.8 \cdot 10^{-5} \text{ mSv} \cdot \text{Bq}^{-1}$ for ^{137}Cs and ^{90}Sr respectively [ICRP, 1993]; I_p - is the

daily intake of the p -th nuclide in the body with food, Bq/day; 365 - is the number of days in a year.

The daily intake of radionuclide in the human body is then estimated by combining the intake with different food products in the diet:

$$I_p = \sum_k (C_{pk} \cdot V_k \cdot Q_{pk}), \text{ Bq} \cdot \text{day}^{-1} \quad (3)$$

where: C_{pk} - concentration of p -th radionuclide in the k -th food product, $\text{Bq} \cdot \text{kg}^{-1}$; V_{pk} - daily consumption rate of the k -th product, $\text{kg} \cdot \text{day}^{-1}$; Q_{pk} - culinary factor accounting for the loss of p -th radionuclide during cooking of the k -th food product, rel. un.

RESULTS AND ACHIEVEMENTS

Contamination of the environment and food products

Analysis of the data about surface contamination by long-lived artificial radionuclides in soils on the territory of the village Muslyumovo gave the following results: i) the ^{137}Cs surface contamination varied from 15 to 70 $\text{kBq} \cdot \text{m}^{-2}$, which is by 6 to 27 times higher than the expected global fallout value of 2-3 $\text{kBq} \cdot \text{m}^{-2}$ (Kravtsova et al. 1998); ii) the ^{90}Sr surface contamination varied from 7 to 33 $\text{kBq} \cdot \text{m}^{-2}$, which is 4 to 18 times higher than the global value of ^{90}Sr content in soils of 1-2 $\text{kBq} \cdot \text{m}^{-2}$ (Kravtsova et al. 1998). The surface contamination of ^{137}Cs in undisturbed soils in Brodokalmak village varied within 3 $\text{kBq} \cdot \text{m}^{-2}$ to 47 $\text{kBq} \cdot \text{m}^{-2}$, with an average of 14 $\text{kBq} \cdot \text{m}^{-2}$. This value exceeds by 5 times the global fallout level of ^{137}Cs contamination. The surface contamination of ^{90}Sr in soils in the village is somewhat lower, varying from 1.5 to 35 $\text{kBq} \cdot \text{m}^{-2}$, with an average value of 7 $\text{kBq} \cdot \text{m}^{-2}$. This is 3.8 times higher than the global fallout level of ^{90}Sr . The mean surface contamination ^{137}Cs in flood-land in the vicinity of the two settlements were estimated as 2070 $\text{kBq} \cdot \text{m}^{-2}$ and 500 $\text{kBq} \cdot \text{m}^{-2}$ for Muslyumovo and Brodokalmak, respectively. These data are for contamination due to overflow of the river whilst the previous data on ^{137}Cs and ^{90}Sr contamination of soil for settlements and other territories where for atmospheric contamination from Lake Karachay in 1967.

Most extensive was the database for the content of ^{137}Cs and ^{90}Sr in milk (1185 and 1061 values, respectively). This database included the data of measurements since 1992 up to 1998. All milk samples were divided in two groups. The first one – milk produced by cows grazing inside, another one - outside of the floodplain. The mean content of ^{137}Cs and ^{90}Sr in these two sample groups differed approximately by 10 times. The content of ^{137}Cs in milk was approximately by 4 times higher than content of ^{90}Sr .

Most extensive was database for the content of ^{137}Cs and ^{90}Sr in milk (1190 and 1061 values respectively). This database included data of measurements obtained earlier (since 1992 up to 1996) by the Chelyabinsk Regional Centre for State Sanitary and Epidemiological Inspection (Kravtsova et.al 1998). The average activity concentrations of ^{137}Cs and ^{90}Sr in milk (range) are 5.9 $\text{Bq} \cdot \text{kg}^{-1}$ (0.1-200) and 2.2 $\text{Bq} \cdot \text{kg}^{-1}$ (0.1-66) and 1.8 $\text{Bq} \cdot \text{kg}^{-1}$ (0.1-34) and 1.2 $\text{Bq} \cdot \text{kg}^{-1}$ (0.1-6) in Muslyumovo and Brodokalmak, respectively. After that all milk samples were divided in two groups. The first one – milk produced by cows grazing inside, another one -

outside of the floodplain. The mean content of ^{137}Cs and ^{90}Sr in these two sample groups differed approximately by 10 times.

The average activity concentrations in fish muscle from the river (samples of mixed species) was higher than any other measured local biota, 79 and 9 $\text{Bq}\cdot\text{kg}^{-1}$ for ^{90}Sr and 218 and 69 $\text{Bq}\cdot\text{kg}^{-1}$ of ^{137}Cs near Muslyumovo and Brodokalmak, respectively. The activity concentrations of ^{90}Sr in fish bones are considerably higher with mean values of 6180 and 140 $\text{Bq}\cdot\text{kg}^{-1}$ near Muslyumovo and Brodokalmak, respectively.

For the majority of vegetables, root crops and garden berries grown both in Muslyumovo and Brodokalmak, the activity concentration of both ^{90}Sr and ^{137}Cs are about 1 to 2 $\text{Bq}\cdot\text{kg}^{-1}$.

In 1998, a survey of the dietary habits of the population in Muslyumovo and Brodokalmak was carried out. In all, 112 persons of both sexes were polled in Muslyumovo, and 20 persons in Brodokalmak. The current values of dietary intake for a range of food products was as follows ($\text{kg}\cdot\text{day}^{-1}$): milk, 0.7 (0-3.5); meat, 0.15 (0-0.48); potatoes, 0.4 (0.07-1.0); vegetables, 0.15 (0-0.3); fish, 0.1 (0-0.5).

The level of exposure of inhabitants

Using equations (1, 2 and 3) in the two considered settlements were calculated the values of the average annual effective doses of external, internal and total exposure for different population groups (deterministic estimations). Then using distributions of main parameters of the both models the dose distributions (the arithmetical and geometrical means and the 5th and 95th percentiles) attributed to artificial contamination of the environment were calculated.

The dose values were assessed for three hypothetical groups of adult population:

- Group 1, people who do not visit the river floodplain, do not consume milk from cows pastured on the floodplain or fish from the river Techa. In other words, this is the population whose exposure doses are actually not connected with contamination of the floodplain.
- Group 2, people who visit the river floodplain in accordance with the average values of the occupancy factors for population (0.03), consume milk from cows pastured on the floodplain in the quantity of 10% of their average annual milk consumption, and fish from the river Techa in the quantity of 10% of their average annual consumption of fish. This is the population whose exposure doses mostly correspond to the average weighted dose in the settlement.
- Group 3, people who visit the river floodplain in accordance with the maximum values of the occupancy factors (0.10), consume milk from cows pastured on the river floodplain in the quantity of 100% and fish from the river Techa in the quantity of 30% of their average annual consumption of fish. This can be defined as the critical population group.

The values of the main parameters of the dose distributions for this assessment are presented in Table 1. The contribution of external exposure to a total dose of the population varies from 40 % up to 80 % depending on the group of the population. The contribution that ^{90}Sr and ^{137}Cs make to the dose from internal exposure is similar. The main products determining the internal dose are fish (29-61%) and milk (11-63%). The results of this initial dose assessment suggest that the established dose limit for population of 1 mSv per year will probably be exceeded only for the critical group in Muslyumovo.

Table 1. Distribution of current annual dose received by the different population groups in Muslyumovo and Brodokalmak in 1998.

Village	Annual effective dose, mSv											
	External				Internal				Total			
	Mean	Geom. mean	5%	95%	Mean	Geom. mean	5%	95%	Mean	Geom. mean	5%	95%
Muslyumovo												
Group1	0.05	0.04	0.03	0.07	0.07	0.06	0.02	0.16	0.12	0.11	0.05	0.21
Group2	0.28	0.23	0.08	0.70	0.09	0.07	0.03	0.19	0.39	0.34	0.15	0.78
Group3	0.89	0.67	0.19	2.34	0.25	0.20	0.06	0.62	1.13	0.93	0.34	2.57
Brodokalmak												
Group1	0.03	0.03	0.02	0.04	0.05	0.04	0.01	0.12	0.08	0.07	0.03	0.15
Group2	0.09	0.08	0.03	0.21	0.05	0.04	0.02	0.12	0.15	0.13	0.06	0.29
Group3	0.27	0.21	0.06	0.67	0.10	0.08	0.03	0.20	0.37	0.31	0.12	0.81

CONCLUSION

- The main source of external and internal artificial exposure to population of the investigated region is radioactive contamination of the flood-lands of the Techa river with ^{137}Cs radionuclide. For separate population groups (Group3), the contribution of this source in the average annual effective dose from artificial exposure is 80 to 95 %.
- Average levels of soil radioactive contamination with ^{137}Cs in the flood-lands of the river within the two considered settlements decrease with the increase of the distance from the place of the radioactive wastes release, and make $2070 \text{ kBq}\cdot\text{m}^{-2}$ and $500 \text{ kBq}\cdot\text{m}^{-2}$ for Muslyumovo and Brodokalmak, respectively.
- Radioactive contamination with ^{137}Cs of the areas of these settlements proper (outside flood-lands) is sufficiently uniform and is presumably attributed to atmospheric transfer of ^{137}Cs from the banks of Lake Karachai during the dust storm in 1967. The average level of this contamination is considerably lower than the contamination of the flood-lands and varies in these settlements from 15 to $40 \text{ kBq}\cdot\text{m}^{-2}$.
- Strong gradient of radioactive contamination of the population habitat can cause 10-fold ratio in the relation of the doses from technogenic external exposure in different population groups. Evidently, the critical parameters in the model for external dose assessment in population is duration and place of staying of representatives of different population groups in the flood-lands, because the radioactive contamination of the flood-lands proper is also non-uniform. The critical parameter in the model for internal dose assessment in population is rate of consumption of freshwater fish and milk.
- The contribution of external exposure to a total dose of the population varies from 40 % up to 80 % depending on the group of the population. The contribution that ^{90}Sr and ^{137}Cs make to the dose from internal exposure is similar. The main products determining the internal dose are fish (29-61%) and milk (11-63%).

- The results of this initial dose assessment suggest that the established dose limit for population of 1 mSv per year will probably be exceeded only for the critical group in Muslyumovo.

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