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ASSESSMENT OF CARCINOGENIC HEALTH RISK CAUSED BY DRINKING WATER INTAKE FOR POPULATION IN KHAKASS REPUBLIC

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63.2% of drinking water samples taken over 2011-2015 in Khakass Republic were characterized with dangerously high A_a levels; it was caused by natural ^{234}U, ^{238}U radionuclides. Such carcinogenic dangerous substances as cadmium, lead, arsenic, beryllium, and chromium, were also found in the samples, though their concentration did not exceed maximum permissible one. Individual risks of such stochastic effects as malignant neoplasms caused by natural radionuclides contained in drinking water vary in different administrative districts in the republic. The range is from 3,14x10^{-6} to 7,81x10^{-6} cases per year; collective risks are 0,013-0,288 cases per year for corresponding population size. Individual carcinogenic risks caused by content of carcinogenic chemical substances in drinking water vary in different administrative districts in the republic within the range from 5,29 x10^{-5} to 1,04x10^{-4} cases per year; collective risks are 0,88-2,704 cases per year for corresponding population size.

Total population carcinogenic risks caused by content of carcinogenic chemical substances and natural radionuclides in drinking water over the observations period amounted to the following values: Altaiskiy district (2,903 per 26000 people), Beyskiy district (1,123 per 18500 people), Bogradskiy district (0,98 per 15000 population), Shirinskiy district (2,63 per 27100 people), Ordzhonikidzevskiy district (1,178 per 11900 population), Ust-Abakanskiy district (2,79 per 41100 population).

Drinking water contribution into primary oncologic morbidity of population amounted to 0.5-1% in administrative districts of the republic. And today, in relation to that, implementation of any measures aimed at lowering carcinogenic risks caused by drinking water is not obligatory. But still, as seismic activity in the republic has been considered rather high over the last 5 years, laboratory monitoring of household water supply as per radiation safety and carcinogenic risks assessment are carried out as planned.

***Key words:** drinking water, specific total alpha-activity, chemical substances, health risk.*

Introduction. The issue of qualitative drinking water supply to population becomes more vital every year due to depletion of fresh water resources, considerable anthropogenic load on surface water ponds and underground water-bearing horizons, water contamination with chemicals including carcinogenic ones [2–4,7,9,16,17]. Drinking water quality and safety exert significant influence on population health. And in relation to that an existing assessment system based on the principle of water "conformity / inconformity" to hygienic standards cannot be considered efficient. And a new integral system assessing qualitative and quantitative characteristics of harmful influence on population health and based on risk assessment methodology is becoming more widely used [1,8,10–12,14,15].

Research devoted to risks of carcinogenic and non-carcinogenic effects caused by drinking water containing chemical pollutants was accomplished in a number of Russian regions. It determined unacceptable risk levels exceeding maximum permissible population health risk [2,3,4,9,16].

Vasilevskiy et al (2015) examined drinking water in Krasnoyarsk region and assessed carcinogenic risks caused by drinking water containing carcinogenic chemicals (arsenic, lead, cadmium, chromium, beryllium, chlorine-organic compounds and others); they stated that total carcinogenic individual risks varied in settlements of different types. Thus, they amounted to 25,47x10^{-5} in big cities; to 46,18x10^{-5} in average-size towns, to 48,42x10^{-5} – 59,88x10^{-5} in countryside settlements. Arsenic, chromium, aldrin, atrasin, heptachlorine and brominedichlorinemethane make the greatest

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contribution into total carcinogenic individual risks [4].

Zavodova (2014) determined such carcinogenic substances as lead, cadmium, and chromium, in drinking water in Saransk in her work. As per her calculation results, individual risk varied within $1x10^{-5}$–$1x10^{-7}$ range. Average total carcinogenic risks in Saransk amounted to $5,7x10^{-5}$. Population carcinogenic risks (PCR) amounted to 17 cases (total city population is 297.9 thousand people) [6].

Total individual carcinogenic risk for population health caused by chemical contamination of drinking water was $8,5x10^{-5}$ in Omsk region. Arsenic accounted for 80.5% of this carcinogenic risk value [16].

Carcinogenic risks for population health in rural districts of Irkutsk region caused by chemical contamination of underground sources water amounted to $1,56x10^{-5}$-$2,1x10^{-5}$ for 22,2 thousand rural inhabitants. The main carcinogenic substances were arsenic (56.3-100% contribution), hexavalent chromium (29.9-35.8% contribution) [2].

Drinking water was assessed in Tuymazinskiy district settlements in Bashkortostan. Total individual carcinogenic risks for population health caused by chemical substances in drinking water (chromium, cadmium, DDT, 2.4 dimethylpentane, lindane) varied within $3.5x10^{-5}$ – $1.6x10^{-4}$ range. Carcinogenic risk was caused by lindane exposure (CR was $3.4x10^{-5}$–$1.2x10^{-4}$) and chromium exposure (CR equal to $1.5x10^{-5}$ – $2.9x10^{-5}$) [3].

Research accomplished in Novosibirsk showed that drinking water quality lowered after purification at pump and filter stations as carcinogenic risk grew; it was due to chlorine-organic substances content. Still, carcinogenic effects risks did not exceed acceptable levels (0.00001). We should note that non-carcinogenic effects risks decrease after water treatment [17].

Research goal. Our goal was to assess carcinogenic risks for the population of Khakass Republic caused by drinking water intake, and to determine if any measures aimed at risk reduction were necessary.

Research tasks. Our tasks were to accomplish hygienic assessment of drinking water in Khakass Republic as per radiological parameters and carcinogenic chemicals content. We also had to calculate annual effective dozes of internal irradiation caused by natural radionuclides contained in drinking water. Other tasks were to assess carcinogenic risks for population health caused by drinking water intake and to determine necessity of health risk management and implementation of measures aimed at risk reduction.

Data and methods. Household water supply to population of Khakass Republic was our research object. We accomplished hygienic assessment of drinking water as per radiation safety and carcinogenic chemicals content basing on the results of laboratory research carried out by FBHO "Hygiene and Epidemiology Center in Khakass Republic" test laboratory center (accreditation certificate ГСЭН.RU.ЦОА.085). To accomplish research we used the following techniques: alpha-beta radiometric technique with radiochemical preparation of countable samples; gamma-spectrometry; alpha-spectrometry with radiochemical preparation and spontaneous electrochemical deposition; chromatography; atomic absorption; and others.

Over 2011-2015 observation period 2,624 drinking water samples and water from water supply sources were examined as per radiological parameters and carcinogenic chemicals content. Total research number amounted to approximately 12,775; research took place in all administrative districts of the republic; cities: Abakan, Sayanogorsk, Chernogorsk (Prigorsk urban settlement), Abiza, Sorsk; districts: Altayskiy, Askizskiy, Beyskiy, Bogradskiy, Ordzhonikidzevskiy, Tashtyipskiy, Ust-Abakanskiy, and Shirinskiy. The assessment objects were household water supply sources; they included 97.5% of drinking water supply in the republic providing water for about 97% of all the republic population.

Assessment of carcinogenic risk for population health caused by chemicals polluting drinking water was accomplished according to P 2.1.10.1920-04 "Guidelines on assessment of population health risk under exposure to chemicals which pollute environment" [15]. In order to assess carcinogenic effects risks we calculated individual carcinogenic risks for each carcinogenic substance (CR) in drinking water; individual carcinogenic risks for substances mixture in drinking water; and population carcinogenic risks (PCR).

Individual carcinogenic risks (CR) for each "carcinogenic" substance in drinking water were determined as per average "carcinogenic" substances concentrations in drinking water (LADC) taking unitary risk values (risk per 1 mgr/l) (UR) into account. Unitary risk values (UR) were calculated with the use of SF values, standard human body weight (70 kg) and daily drinking water intake (2 liters per day). Unitary risk values were: 0.0108 mgr/l for cadmium; 0.0013 mgr/l for lead; 0.0428 mgr/l for arsenic; 0.1228 mgr/l for beryllium; 0.012 mgr/l for chromium.

Assessment of carcinogenic health risk for population caused by drinking water intake in case of its inconformity to requirements set for radiological parameters was accomplished in accordance with 2.6.1.2523-09 Sanitary and Epidemiologic Requirements [7]. We used principles of linear non-threshold theory explaining dependence of stochastic effects risk on radiation doze as grounds for risks calculation. According to this theory risk value is proportional to radiation doze and correlates with this doze through linear coefficients of radiation risk [8]. We calculated annual effective doze of internal irradiation caused by natural radionuclides contained in drinking water in accordance with 2.6.1.2523-09 Sanitary and Epidemiologic Requirements [7] and 2.6.1.2397-08 Methodical Guidelines [13]. To process all the obtained data statistically, we used Microsoft Office Excel application.

Results and discussion. We determined that over 2011-2015 observation period 63.2% of examined drinking water samples exceeded control level as per specific total alpha-activity (A_a). We detected no control level excess in case of specific total beta-activity.

A_a values in examined samples varied within 0.03-4.9 Bq/kg range (control level is 0.2 Bq/kg). Water samples with A_a values exceeding control level were detected in Sorsk, Shirinskiy, Ordzhonikidzevskiy, Bogradskiy, Ust-Abakanskiy, Altayskiy, Beyskiy, and Tashtyipskiy districts, Prigorsk urban settlement. We carried out radionuclide water composition in those areas in order to determine specific activities of uranium-238 (^{238}U), uranium-234 (^{234}U), polonium-210 (^{210}Po), lead-210 (^{210}Pb), radium-228 (^{228}Ra), radium-226 (^{226}Ra) (table 1).

We defined that A_a high levels were caused by ^{238}U, ^{234}U natural radionuclides. Maximum specific activities of ^{234}U were detected in Novotroitskoye village of Beyskiy district (3.46±0.32 Bq/kg) and in Novorossiyskoye village of Altaiskiy district (2.18±0.27 Bq/kg).

Natural radionuclides in drinking water found in the republic cause increased annual individual effective dozes of internal irradiation (0.065 mSv/year), which are two times higher than average level in Russia (0.035 mSv/year) [5]. Average individual annual effective dozes of internal irradiation in Khakass Republic caused by radionuclides in drinking water vary within 0.01 – 0.11 mSv/year (table 2).

Table 1

Natural radionuclides' specific activities (average values over 2011-2015), Bq/kg

Areas	^{238}U	^{234}U	^{210}Pb	^{210}Po	^{222}Rn	^{228}Ra	^{226}Ra
Altayskiy district	0,27	0,74	0,05	0,02	13	0,05	0,03
Beyskiy district	0,28	0,76	0,05	0,02	13	0,05	0,03
Bogradskiy district	0,13	0,34	0,05	0,02	17	0,05	0,03
Ordzhonikidzevskiy district	0,07	0,18	0,05	0,02	18	0,05	0,03
Prigorsk urban settlement	0,12	0,2	0,05	0,02	14	0,05	0,03
Sorsk	0,13	0,34	0,05	0,02	19	0,05	0,03
Tashtyipskiy district	0,1	0,21	0,05	0,02	13	0,05	0,03
Ust-Abakanskiy distrcit	0,16	0,44	0,05	0,02	14	0,05	0,03
Shirinskiy district	0,1	0,28	0,05	0,02	16	0,05	0,03
Interference levels	3,0	2,8	0,2	0,11	60	0,2	0,49

Table 2

Assessment of average annual collective and individual effective dozes of internal irradiation caused by natural radionuclides in drinking water (average values for 2011-2015)

Administrative territories	Individual dozes, mSv/year	Population people	Collective dozes, people-mSv/year
Altayskiy district	0,107 ± 0,0037	26000	2,79 ± 0,097
Beyskiy district	0,106 ± 0,005	18500	1,96 ± 0,101
Bogradskiy district	0,091 ± 0,0013	15000	1,37 ± 0,02
Ordzhonikidzevskiy district	0,083 ± 0,0018	11900	0,98 ± 0,02
Prigorsk urban settlement	0,078 ± 0,0007	2434	0,189 ± 0,001
Sorsk	0,09 ± 0,001	11500	1,04 ± 0,021
Tashtyipskiy district	0,043 ± 0,006	15700	0,66 ± 0,13
Ust-Abakanskiy district	0,096 ± 0,0034	41100	3,94 ± 0,154
Shirinskiy district	0,087 ± 0,002	27100	2,36 ± 0,06

The values were less than 0.1 mSv/year in Ordzhonikidzevskiy district, Bogradskiy district, Ust-Abakanskiy district, Shirinskiy district, Tashtyipskiy district, Askizskiy district, Sorsk, Prigorsk urban settlement. And they were within 0.1-0.11 mSv/year exceeding 0.1 mSv/year [7,13].

According to conventional linear non-threshold theory of stochastic effects risks dependence on radiation doze, risk value is proportional to radiation doze and correlates with it through linear coefficients of radiation risk (coefficient risk for malignant neoplasms is equal to $5.5x10^{-2}$ $Зв^{-1}$) [7].

As per results of our calculations individual risks of stochastic effects evolvement (here we mean malignant neoplasms) varied within $3.14x10^{-6}$-$7.81x10^{-6}$ cases per year in different administrative districts of the republic (table 3).

The obtained calculations results exceeded the level of negligible small risk equal to $1*10^{-6}$ and fixed by 2.6.1.2523-09 Sanitary and Epidemiologic Requirements [7].

Table 3

Assessment of collective and individual risks of stochastic effects evolvement (in the form of malignant neoplasms), cases per year

Administrative districts	Individual risks	Population, people	Collective risks
Altayskiy district	$7{,}81\cdot10^{-6} \pm 2{,}7\cdot10^{-7}$	26000	0,203 ± 0,007
Beyskiy district	$7{,}74\cdot10^{-6} \pm 3{,}65\cdot10^{-7}$	18500	0,143 ± 0,006
Bogradskiy district	$6{,}64\cdot10^{-6} \pm 9{,}49\cdot10^{-8}$	15000	0,099 ± 0,001
Ordzhonikidzevskiy district	$6{,}06\cdot10^{-6} \pm 1{,}31\cdot10^{-7}$	11900	0,072 ± 0,001
Prigorsk urban settlement	$5{,}69\cdot10^{-6} \pm 5{,}11\cdot10^{-8}$	2434	0,013 ± 0,0001
Sorsk	$6{,}57\cdot10^{-6} \pm 8{,}76\cdot10^{-7}$	11500	0,075 ± 0,01
Tashtyipskiy district	$3{,}14\cdot10^{-6} \pm 4{,}38\cdot10^{-7}$	15700	0,049 ± 0,006
Ust-Abakanskiy district	$7{,}01\cdot10^{-6} \pm 2{,}78\cdot10^{-7}$	41100	0,288 ± 0,011
Shirinskiy district	$6{,}35\cdot10^{-6} \pm 1{,}46\cdot10^{-7}$	27100	0,172 ± 0,003

Assessment of carcinogenic health risk caused by drinking water intake for population of Khakass Republic.

Over 2011-2015 observation period accomplished laboratory research showed that carcinogenic chemicals content in drinking water and in household water supply sources did not exceed hygienic standards. We could not detect DDT, hexachloran, 2.4 dimethylpentane acid, benzene, chlorine benzene, ethylbenzene, styrene, xylene, toluene, benzpyrene, 1.2 dichloroethane, carbon tetrachloride, chloroform, aluminium, and manganese, in drinking water in all administrative districts even at the lower level of devices' (methods) receptiveness.

But still, such dangerous carcinogenic substances as cadmium, lead, arsenic, beryllium, and chromium, were detected within maximum permissible concentrations in household water in Ordzhonikidzevskiy district, Shirinskiy district, Ust-Abakanskiy district, and Bogradskiy district. Chromium, lead, beryllium, and arsenic were detected within maximum permissible concentrations in Beyskiy district and Altayskiy district (table 4).

Table 4

Average carcinogenic substances concentrations (average values over 2011-2015), mgr/l

Administrative districts	Beryllium	Cadmium	Arsenic	Lead	Chromium
Altayskiy district	0,000064	–	0,0015	0,0009	0,003
Beyskiy district	0,000056	–	0,001	0,00015	0,001
Bogradskiy district	0,000066	0,0002	0,001	0,00009	0,0015
Ordzhonikidzevskiy district	0,000042	0,00013	0,002	0,00024	0,001
Ust-Abakanskiy district	0,000058	0,0002	0,0007	0,0009	0,0025
Shirinskiy district	0,000034	0,0003	0,0015	0,0027	0,0025
Maximum permissible concentration	0,0002	0,001	0,05	0,03	0,05

According to calculation results individual carcinogenic risks (CR) for each "carcinogenic" substance were contained in drinking water in concentrations which didn't exceed upper limit of acceptable risk $1x10^{-4}$ (less than 0.0001). But still, individual carcinogenic risks caused by arsenic content in drinking water were equal to upper level of acceptable risk ($0,6x10^{-4}$ – $0,8x10^{-4}$) in Altayskiy district. Shirinskiy district, and Ordzhonikidzevskiy district (table 5).

Individual carcinogenic risks (CR) caused by beryllium, cadmium, and leas contents in drinking water, were authentically lower than the negligible risks level ($1,0x10^{-6}$) in all administrative districts of the republic. Therefore, we can consider carcinogenic risks for population caused by such substances' content in drinking water to be negligible.

Individual carcinogenic risks for substances' mixture (CR_T) in drinking water were defined by summation of individual carcinogenic risks (CR) for each separate "carcinogenic" substance.

Table 5

Individual carcinogenic risks (CR), caused by "carcinogenic" substances in drinking water (per each substance) and total risks (CR_T)*

Administrative district	Beryllium	Cadmium	Arsenic	Lead	Chromium	CR_T
Altayskiy district	$0{,}78\cdot10^{-6}$	–	$0{,}6\cdot10^{-4}$	$0{,}1\cdot10^{-6}$	$3{,}6\cdot10^{-5}$	1,04 E-04
Beyskiy district	$0{,}68\cdot10^{-6}$	–	$0{,}4\cdot10^{-4}$	$0{,}2\cdot10^{-6}$	$1{,}2\cdot10^{-5}$	5,29 E-05
Bogradskiy district	$0{,}8\cdot10^{-6}$	$0{,}21\cdot10^{-6}$	$0{,}4\cdot10^{-4}$	$0{,}1\cdot10^{-6}$	$1{,}8\cdot10^{-5}$	5,91 E-05
Shirinskiy district	$0{,}4\cdot10^{-6}$	$0{,}32\cdot10^{-6}$	$0{,}6\cdot10^{-4}$	$0{,}3\cdot10^{-6}$	$3{,}0\cdot10^{-5}$	9,10 E-05
Ordzhonikidzevskiy district	$0{,}5\cdot10^{-6}$	$0{,}14\cdot10^{-6}$	$0{,}8\cdot10^{-4}$	$0{,}3\cdot10^{-6}$	$1{,}2\cdot10^{-5}$	9,29 E-05
Ust-Abakanskiy district	$0{,}7\cdot10^{-6}$	$0{,}21\cdot10^{-6}$	$0{,}3\cdot10^{-4}$	$0{,}1\cdot10^{-6}$	$3{,}0\cdot10^{-5}$	6,10 E-05

*calculated for 95%-percentile level of impurity content in drinking water.

According to calculation results, individual carcinogenic risks for substances' mixture (beryllium, cadmium, arsenic, lead, and chromium) in drinking water were detected within acceptable risk level $1\text{x}10^{-4}$ (less than 0.0001) in Beyskiy district, Bogradskiy district, and Ust-Abakanskiy district. Individual carcinogenic risks for substances' mixture (beryllium, cadmium, arsenic, lead, and chromium) in drinking water were just at the acceptable risk level $1\text{x}10^{-4}$ in Altayskiy district, Shirinskiy district, and Ordzhonikidzevskiy district.

Table 6

Individual carcinogenic risks for substances mixture (CR_T) and population carcinogenic risks (PCR)*

Administrative district	*CR_T*	Population, people	*PCR*
Altayskiy district	$1{,}04\cdot10^{-4}$	26000	2,704
Beyskiy district	$5{,}29\cdot10^{-5}$	18500	0,9787
Bogradskiy district	$5{,}91\cdot10^{-5}$	15000	0,8865
Shirinskiy district	$9{,}10\cdot10^{-5}$	27100	2,4661
Ordzhonikidzevskiy district	$9{,}29\cdot10^{-5}$	11900	1,1055
Ust-Abakanskiy district	$6{,}10\cdot10^{-5}$	41100	2,5071

*calculated for 95%-percentile level of impurity content in drinking water.

Population carcinogenic risks (PCR) were determined on the ground of individual carcinogenic risks taking population number who drank the examined water into account. According to calculation results number of neoplasms cases caused by effect of above-stated "carcinogenic" substances' content in drinking water, varied within 0.88-0.97 range in Beyskiy and Bogradskiy districts, within 2.4-2.7 in Altayskiy district, Shirinskiy district, and Ust-Abakanskiy district (table 6).

Total population carcinogenic risks caused by carcinogenic substances and natural radionuclides' content in drinking water over the observation period amounted to 2.903 per 26,000 people in Altayskiy district, 1.123 per 18,500 people in Beyskiy district, 0.98 per 15,000 people in Bogradskiy district, 2.63 per 27,100 people in Shirinskiy district, 1.178 per 11,900 people in Ordzhonikidzevskiy district, 2.79 per 41,100 people in Ust-Abakanskiy district.

We used the obtained values of population carcinogenic risks to calculate relative indexes per 100,000 people in each administrative district. The greatest indexes values were detected in Altayskiy district ($11.2^0/_{000}$), Ordzhonikidzevskiy district ($9.89^0/_{000}$), and Shirinskiy district ($9.7^0/_{000}$). The indexes amounted to $6.53^0/_{000}$; $6.07^0/_{000}$; $6.78^0/_{000}$ correspondingly in Bogradskiy district, Beyskiy district, and Ust-Abakanskiy district.

Over 2011-2015 observation period primary morbidity level for neoplasms amounted to $1103.46\pm123.5^0/_{000}$ in the republic. The highest levels were detected in Altayskiy district ($1469.5\pm366.9^0/_{000}$), Shirinskiy district ($1636.56\pm847.9^0/_{000}$), Ordzhonikidzevskiy district ($1340.16\pm548.3^0/_{000}$), Sorsk ($1513.2\pm350.9^0/_{000}$), and Chernogorsk ($1479.56\pm346.14^0/_{000}$).

Drinking water contribution into primary oncological morbidity amounted to 0.5-1% in all administrative districts of the republic. Therefore, any activities aimed at lowering carcinogenic risks associated with drinking water are not obligatory for now. But still, as seismic activity in the republic has been high over the last 5 years, laboratory monitoring of household water supply as per radiation safety and carcinogenic risks assessment are to be accomplished in fixed scope.

Conclusions. Over the observation period 63.2% of drinking water samples taken in the Khakass Republic were characterized with increased A_a control levels caused by ^{234}U and ^{238}U natural radionuclides. Such dangerous carcinogenic substances as cadmium, lead, arsenic, beryllium, and chromium, were also detected, though in quantities lower than maximum permissible concentration.

Individual risks of stochastic effects evolvement (in the form of malignant neoplasms) caused by natural radionuclides' content in drinking water varied within $3.14x10^{-6}$-$7.81x10^{-6}$cases per year in different administrative districts of the republic. Collective risks were 0.013 – 0.288 cases per year per corresponding population number. Individual carcinogenic risks caused by carcinogenic substances' content in drinking water varied within 5.29 $x10^{-5}$- 1. $04x10^{-4}$ cases per year in different administrative districts of the republic. Collective risks 0.88 – 2.704 were cases per year per corresponding population number.

Total population carcinogenic risks caused by carcinogenic substances' and natural radionuclides' content in drinking water over the observation period amounted to 3 cases per 26,000 people in Altayskiy district, 1 case per 18,500 people in Beyskiy district, 1 case per 15,000 people in Bogradskiy district, 3 cases per 27,100 people in Shirinskiy district, 1 case per 11,900 people in Ordzhonikidzevskiy district, and 3 cases per 41,100 people in Ust-Abakanskiy district. Calculated contribution of drinking water into primary oncologic morbidity was probably equal to 0.5-1% in the administrative districts of the republic. The data prove that any activities aimed at lowering carcinogenic risks associated with drinking water quality are not obligatory. Still, we advise to continue laboratory monitoring of household water supply as per radiation safety and carcinogenic risks assessment in full conformity with all programs approved by Rospotrebnadzor (Federal Service for Surveillance over Consumer Rights Protection and Human Well-being).

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