Health risk assessment of potable water containing small amount of tritium oxide

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Abstract: The problem of groundwater pollution with tritium in a vicinity of radiation-dangerous facilities in Obninsk is considered. The information on the specific activity of tritium in Obninsk water sources is provided. The formula for the calculation of the β-radiation absorbed dose from tritium ingestion is proposed, reflecting the biological behavior of tritium in a human body. To establish the extent of tritium effects on human, the health risk is assessed. It is shown that if the specific activity of tritium in drinking water amounts to 10 Bq/l, the risk of stochastic effects of radiation will not exceed the limit of the individual lifetime risk.

1. Introduction

Obninsk is situated in the Kaluga region 100 km south-west of Moscow on the left bank of the Protva river. Several enterprises utilizing nuclear energy are operating in the town, the main of which are State Scientific Centre of the Russian Federation – the “Institute of Physics and Power Engineering” (IPPE) and the Branch of JSC «Karpov Institute of Physical Chemistry». Development of nuclear technologies, the available centers of utilization, reprocessing and disposal of radioactive materials and wastes have caused the need for studying technogenic radionuclide behavior and migration in this region. The primary effects associated with Obninsk radiation-dangerous facilities are gas and aerosol releases into the atmosphere, liquid waste discharges into the Protva river and groundwater pollution. Special emphasis should be pointed at the problem of environmental pollution with tritium [1].

The aim of this work is to provide radiological characteristics of drinking water sources of Obninsk based on the tritium content and to evaluate the impact of tritium on the Obninsk citizens, using the risk assessment methodology.

2. Characterization of groundwater in Obninsk

Groundwater sources are used for Obninsk water supply. Municipal intakes involve 34 wells arranged 15 km apart in a sequence north-south along the foot of the left slope of the Protva river valley. Northern and southern water intakes are upstream and downstream of the town, respectively. They belong to river valley intakes with mixed feeding, i.e. precipitation infiltration is responsible for a smaller part of groundwater and a greater amount is being formed by overflowing from Protva. Water reserves are maintained by the Protva river runoff, the volume of which depends on the precipitation fallen out and watershed area.

Groundwater reserves in the intakes upstream of the town are much smaller as compared to those located downstream as feeding in the latter case is maintained also by a runoff of the Luzha river, a large tributary 1000 km^2 in area.

Actual water production is distributed between municipal intakes just “on the contrary”, i.e. three fourth of water is drawn from the northern intakes and only a third from the southern one in Dobroe settlement. Such a “disrepancy” in groundwater production has caused more than 40 m lowering in a piezometric level of the industrial water bearing horizon for the very northern intake in Vashutino. Along the Obninsk intakes, a hydraulic slope is formed in an industrial water bearing horizon that is directed upstream opposite to the natural runoff of surface and groundwater. The inverse flow of river water ingressing into a groundwater bearing horizon, on the one hand, compensates the depletion of groundwater reserves in the northern intakes and, on the other hand, gives rise to the pollutant transfer from the Protva river into municipal water intakes [2].

Piezometric depression has essentially changed hydrodynamics and geochemistry of groundwater and is one of the reasons for dewatering of the upper water bearing horizons, the rocks of which turned out to be in the aeration zone. Rock oxidation in the aeration zone has stipulated the ingress of oxidation products into groundwater. Industrial and domestic wastes, the outlets for which are arranged in the south and downstream of the town, partially enter the northern intakes together with an inverse flow of river water.

The interaction of natural and anthropogenic factors led to a decline in the quality of produced water. Table 1 presents the results of laboratory testing of drinking water quality on organoleptic and chemical indicators of centralized drinking water supply systems of Obninsk, averaged for 2015 [3]. Among these indicators, only the content of ammonia nitrogen is above the established hygienic standards for drinking water (MPC), the rest are in the normal range.

Table 1. Results of laboratory analysis of drinking water in Obninsk

Sample	Indicator							
	Colour, degree	Turbidity, mg/l	Fe, mg/l	Dry residue, mg/l	General rigidity, mEq/l	Cl^-, mg/l	NH^{4+}, mg/l	Oil, mg/l
Average	5	0.5	0.21	448	5.77	2	7.25	0.009
MPC	20	1.5	0.3	1000	7	350	2	0.1

The previously described hydrodynamic and hydrochemical conditions are conducive for the radionuclides migration in Obninsk groundwater. Despite the nuclear specialization of large enterprises in Obninsk, groundwater pollution by radioisotopes is studied much worse and mainly in a course of initiative research surveys, because in frames of the Regional and National radiation monitoring networks there is no obligation to perform radiation monitoring of groundwater in monitor wells.

Monitoring of groundwater pollution on the IPPE industrial site is carried out by the external dosimetry service of the IPPE. In 2015, it was revealed that total β-activity in water of monitor wells in the sanitary-protective zone varied from 0.15 to 1.7 Bq/l, in the observation zone (5-km zone around IPPE) – from 0.15 to 14.4 Bq/l. Total α- and β-activity in water of Protva river was 0.1 and 0.15 Bq/l and did not exceed the reference levels for drinking water (0.2 Bq/l (Σα) and 1.0 Bq/l (Σβ)), according the RSS-99/2009 [4].

3. Contamination of Obninsk groundwater with tritium

Contamination of groundwater with tritium was first revealed in the sanitary-protective zone of IPPE by employees of Roshydromet performing the "Radiological monitoring program for territory of a nuclear energy and industry enterprise" [5].

A comprehensive survey of the IPPE's industrial site and adjacent territories has revealed that research nuclear reactors and accelerators where tritium targets are applied as well as radioactive waste storages are considered to be the sources of technogenic tritium. All the above sources are located within the sanitary controlled area of intakes. The expected release of tritium into the environment by this enterprise ranges from $2.5 \cdot 10^2$ to $2.5 \cdot 10^3$ Ci/year [6].

Table 2 presents data on tritium activity measurements in water of monitor wells located on-site of the solid radioactive waste (SRW) storage facility of IPPE and in water of the oxbow located in the observation zone of IPPE [7].

Table 2. Specific activity of tritium in monitoring points in 2010

Date of sampling	Specific activity of tritium in monitoring points, Bq/l			
	Well N-1	Well N-2	Well P-5	Oxbow
15.03	–	163	–	–
26.04	–	–	2472	–
17.05	–	–	14990	730
15.06	–	120	–	–
22.07	380	380	3020	1870
20.10	764	164	2436	1145
intervention level	7600	7600	7600	7600

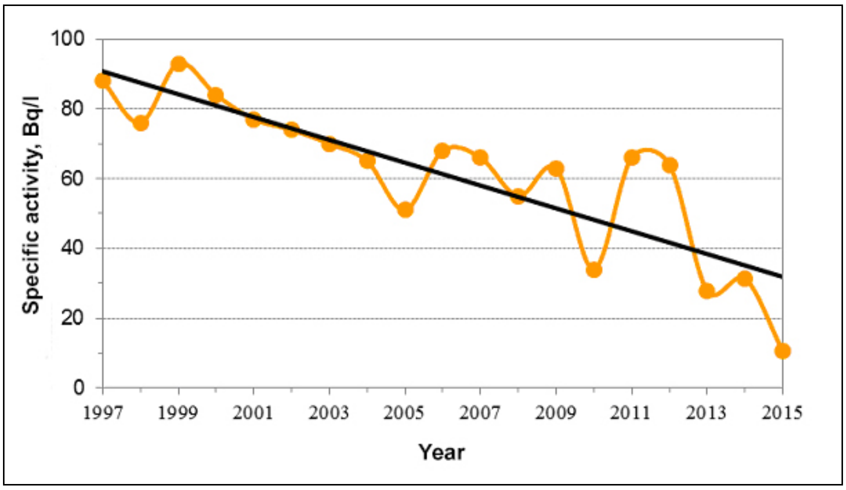
As can be seen from table 2, in the monitoring wells of IPPE the increased levels of tritium are observed compared to background level (1.9 Bq/l), and even two-fold excess of the intervention level (IL=7600 Bq/l) is detected. The flow of tritium in groundwater have resulted from a leakage of the SRW storage at IPPE [6]. In this regard, SPA "Typhoon" of Roshydromet carries out periodic sampling of water from the intakes and drinking water communications in different sites of Obninsk and other nearby settlements (in Maloyaroslavets, Belousovo, Balabanovo, Mishkovo) to measure and control tritium levels.

A survey of drinking water in the city of Obninsk within the territory of SPA "Typhoon" in 2015 (table 3) showed that the content of tritium in drinking water from March to November ranged from 5.7 to 16.1 Bq/l with an average value of 10.6 Bq/l, which was about two orders of magnitude below the IL [3] and 5.6 times higher than the average content of tritium in fresh water rivers of the European part of Russia (1.9 Bq/l) [8]. In 2015, a decrease of the tritium concentration in drinking water was observed compared to 2014; this was due to the large amount of atmospheric precipitation in the study area. In 2014, precipitation was 288 mm less than in 2015 [9], which significantly affected the quality of groundwater. As a result, in 2015 the underground water was more watered, their dilution occurred, which resulted in a decrease in the tritium level.

Dynamics of an average annual content of tritium in drinking water in the territory of SPA "Typhoon" since 1997 [1] shows (figure 1) that the tritium content in water is gradually decreasing. During this period, it has reduced about 8 times. The maximum measured tritium concentration was recorded in 1999 and amounted to 150 Bq/l, minimum (4 Bq/l) – in 2005.

Table 3. Specific activity of tritium in Obninsk's municipal drinking water within the territory of SPA "Typhoon" [1]

2015		2014	
Date of sampling	Specific activity of tritium, Bq/l	Date of sampling	Specific activity of tritium, Bq/l
18.03	6.9	14.01	45.1
15.06	10.4	14.02	50.6
24.07	16.1	14.03	36.4
12.08	14.6	09.04	22.3
21.09	7.4	30.05	18.2
21.10	12.9	18.06	28.8
22.11	5.7	14.07	18.5
Average	10.6	Average	31.4



Fugure 1. Dynamics of tritium concentration in drinking water within the territory of SPA "Typhoon"

However, it should be noted that the intervention level for tritium in drinking water according to the recommendations of the US Environmental Protection Agency (US EPA) is 740 Bq/l, which is lower than the value of the same guidance level in Russia, and in the directives of the European Union it is only 100 Bq/l. This demonstrates a lack of attention to the tritium problem in our country, and perhaps requires a revision of the established standards for tritium. One of the criteria of hazard from a radionuclide such as tritium is a health risk assessment of its intake by a human body.

To assess human exposure from the above-mentioned concentrations of tritium, a corresponding risk assessment was carried out.

4. Radiological risk assessment at drinking water consumption

For the most complete assessment of harm that may be caused to health from tritium irradiation at low doses, damage (risk) is calculated. In accordance with the generally accepted linear no-threshold concept, the risk (r_i) is proportional to the effective dose of radiation (E, Sv) and is related to the dose in terms of linear coefficients of radiation risk (r_E, Sv^{-1}) [4]:

$$r_i = E \cdot r_E \,. \qquad (1)$$

At the risk assessment, the average tritium specific activity in municipal drinking water for 2015 was used which amounted to 10.6 Bq/L.

For the calculation of the absorbed dose of β-radiation D_β from tritium (rad) a formula has been proposed that reflects the biological behavior of tritium in a human body:

$$D_\beta(t) = 2{,}0 \cdot 10^{-3} \cdot \frac{\overline{E}_\beta \cdot A_v \cdot V \cdot f \cdot T_{eff}}{m} \cdot \left(t + \frac{T_{eff}}{0{,}693} \cdot e^{\frac{-0{,}693 \cdot t}{T_{eff}}} - \frac{T_{eff}}{0{,}693} \right) \quad (2)$$

where t – exposure time, day;
$\overline{E}_\beta$ – average energy of β-radiation decay, MeV;
Av – specific activity of tritium in drinking water, Bq/l;
V – intake rate of drinking water, l/day;
f – transfer coefficient in the critical organ (1);
$Teff$ – the effective half-life, s;
m – body weight, g.

Doses are calculated for a reference man weighing 70 kg and consuming 2 L of water per day. With daily use of water throughout the year, an Obninsk citizen receive an average absorbed dose of $1{,}2 \cdot 10^{-7}$ Gy, which is significantly below the annual radiation exposure limit.

In studies of biological effects of tritium, the relative biological effectiveness (RBE) was experimentally evaluated [10-12]. For carcinogenic potential, the RBE value for tritium β-radiation was set equal to 2.5. Based on these data the effective dose is calculated as $E = 3 \cdot 10^{-7}$ Sv.

Using the above approach, the risk of malignant tumors at consumption of drinking water with low tritium specific activity is calculated and it is equal to $1.6 \cdot 10^{-8}$. This level of risk assessed is 3000 times lower than an individual lifetime risk for the population.

5. Conclusion

During the study implementation, a holistic picture of natural water pollution with tritium in Obninsk was obtained. The data of the specific activities of tritium in tap water suggests that the intensity of inflow of tritium into groundwater from the industrial site of IPPE for the last years has decreased 8 times. Specific activities of tritium in water from monitor wells at the IPPE site in a vicinity of the RW repository are two times higher than the intervention level. Groundwater is essentially diluted along its transit to water intakes. The tritium content in drinking water supplied to local population is 10.6 Bq/l, which is 700 times lower than the intervention level. The radiological risk assessment at consumption of tritiated water did not reveal any excess of additional cases of radiation stochastic effects.

Acknowledgements

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