TRANSBOUNDARY IMPACT OF THE CHERNAVODSKA NPP ON TRITIUM POLLUTION OF THE DANUBE RIVER ON THE TERRITORY OF UKRAINE

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ABSTRACT. - Transboundary impact of the Chernavodska NPP on tritium pollution of the Danube River on the territory of Ukraine. This article reviews the influence of the Chernavodska nuclear power plant on the aquatic environment of the Danube River in the transboundary context. Data of tritium discharges, dependence of volume activity of tritium in the Danube River, and its inflows from the surrounding areas to its mouth. The average annual volume activities of tritium are provided. Assessments of the impact of the Chernavodska NPP in conditions that are different from the norm have been given.

Keywords: transboundary impact, discharge, volume activity of tritium, the Danube River, nuclear power plant (NPP).

INTRODUCTION

The territory of the Danube River basin has nine NPPs operating along it which now include 21 units. In Slovakia, two WWER-440 units in Bogunitsa, and two WWER-440 units in Mokhovtsa; Czech Republic has four WWER-440 units in Dukovany; Bulgaria has two WWER-1000 units in Kozloduy; Hungary has four WWER-440 units in Paksh; Romania has two PHWR (CANDU) units in Chernavoda, in Slovenia there is one PWR-700 unit in Krshko and in Germany there are two units at the Izarsky NPP and two units at the Gindermmingenska NPP. The general rated capacity is about 15000 MW. Construction of six more units of NPPs with a general power of 3200 MW is planned.

As a result of the operation of these NPPs annually about 1085 TBq of tritium enter the atmosphere and about 700 TBq of tritium enters the rivers located in the Danube basin and consequently lead to an increase in volume activity of tritium in the Danube River. The tritium which enters into the atmosphere is shedded in the form of atmospheric precipitation and drops down onto the territory of the Danube River basin. Additionally, part of this rainfall through inflows, also

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makes its way to the Danube River.

Two PHWR (CANDU) blocks (Canadian Deuterium Uranium-Pressurized Heavy Water Reactor (the reactor on heavy water under pressure)) of the Chernavodska NPP make a significant contribution to pollution by expelling tritium into the atmospheric air (about 840 TBq/year) and the Danube River (about 250 TBq/year).

In this regard, these factors must be properly represented in order to accurately estimate the transboundary influence of the Chernavodska NPP on pollution by tritium on the Ukrainian part of the Danube River.

1. Main characteristics of the Chernavodska NPP

The Chernavodska NPP is located 2 km south-east from the border of Chernavoda city and 1,5 km north-east of the first dam of the Danube canal –From this location, the Black Sea is a short distance from the Danube River, which is on the North side of the Danube canal.

In between Selestra and Kalarasha, the Danube shares two sleeves: Dunarea Veche (eastern) and Borche (western) which unite below on a river bend from Harshovi.

The Distance from the Chernavodska NPP to the Ukrainian border along the banks of the Danube River is about 160 km.

At this industrial site is the placed the Chernavodska power plant. It was initially designed to house 5 units PHWR (CANDU) with a power output of 700 MW each. Also there are constructed some elements and services which are standard for all power units (Figure 1).

Water, necessary for cooling power units, arrives from the Dunarea Veche, through the first stage of the Danube-Black Sea canal, then via an open special canal to a reservoir for the water intake of the Chernavodska NPP. In cold seasons, for the prevention of water freezing (necessary for technological indicators observations) diluted sewage intake waters are provided which have an increased temperature (reusing partially the return water). The used water (about 90%) comes back in the Danube River through a duct branch or in the Danube –Black Sea canal which takes the remainder (about 10%) partially used return water.

Nowadays there are two PHWR (CANDU) units with a power output of 700 MW each, operating on the industrial site. The First power unit was put into operation on December 2, 1996, the second – on October 5, 2007. Operation of both of the reactors of the only NPP in the country at regular capacity provides about 20% of the Romania's electric power needs. The third and fourth units were planned to be put into operation in 2014 and in 2015 respectively. The date of their commissioning has been postponed to 2016-2017.

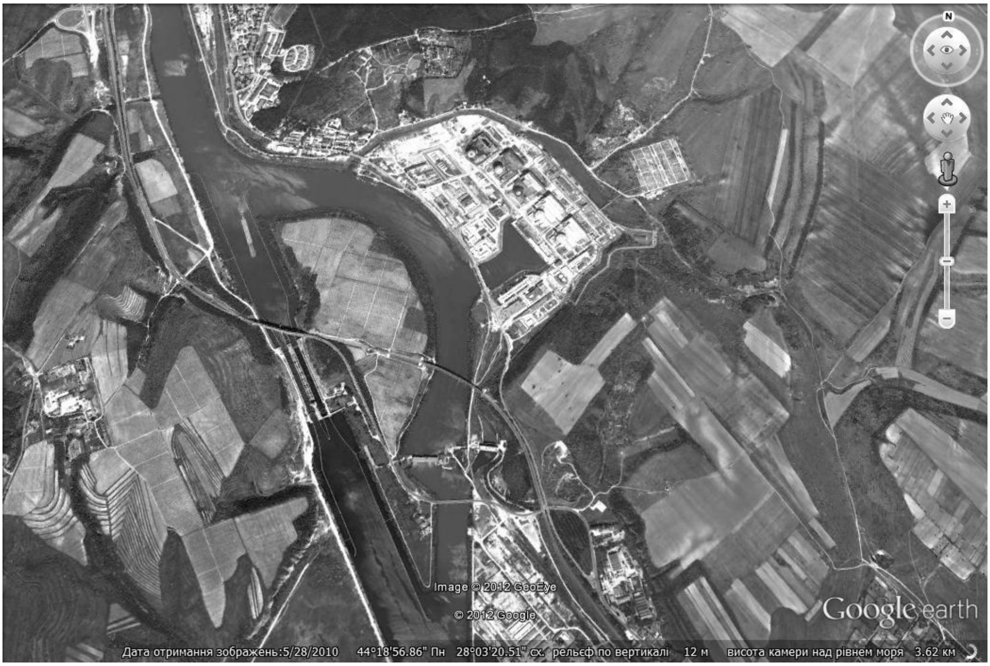


Figure 1. Location of PHWR (CANDU) units at the Chernavodska industrial site

Among the important unpleasant feature of the PHWR (CANDU) is the positive steam effect of reactivity (growth of reactivity at loss of heavy water in canals) which is difficult to eliminate, especially in reactors with natural fuel, which consequently results in the need for the creation of a second system, for the fast emergency clearing of the reactor. The shortcomings of this reactor in comparison with WWER reactors, used in Ukraine, makes it necessary to shed significantly bigger emissions of tritium into surrounding environments by unit of rated capacity. Tritium enters into the hydrosphere from the PHWR (CANDU) reactors at almost six times the rate of the WWER reactors. The Ingression of tritium into the atmospheric air from PHWR (CANDU) occurs at almost thirty times the rate, in comparison to that of the WWER [1] reactors.

On average, for one PHWR (CANDU) unit are necessary 54 m^3/s water for cooling the condensers and other auxiliary services of the reactor. The Danube's flow rate at this junction averages 2370 m^3/s.

The average annual dumping of tritium from one unit into the Danube River and canal is given in the tab. 1 [2].

Table 1. Tritium discharge into the Danube River (D) and canal (C), kBq/year.

Nuclide		Year					
		1999	**2000**	**2001**	**2002**	**2003**	**2004**
H-3	D	1,40E+10	4,13E+10	5,21E+10	7,05E+10	1,02E+11	1,71E+11
	C	5,29E+09	2,15E+09		1,42E+10	1,23E+10	2,41E+10

Romania ranks sixth in the world for emissions of tritium into the surrounding environment. The average annual value of the general dumping of tritium from the Chernavodska NPP into water objects is 1082 TBq. The minimum size of the average annual dumping is about 35 TBq, and maximum – 3424 TBq [3].

2. The content of tritium in the Danube River

In August – September, 2007 an international expedition on monitoring the quality of water of the Danube River was carried out [4]. During this expedition, measurements of the content of tritium in the Danube River and its inflows were also taken. Results of the measurements are given in pic. 2. Unfortunately, during the expedition, the site of the Danube River around the arrangement of the Chernavodska NPP wasn't investigated.

The increase in volume activity of tritium in inflows (Morava and Vag), and also in the area of the left (West) coast of the Danube River is caused by the influence of the NPP of the Czech Republic (Dukovana NPP) and Slovakia (Mokhovtsa and Bogunitsa NPP) which are located on the basins of these rivers. Through nearly 600 km, the volume activities of tritium in the area of the left and right coast were leveled and approximately equal to 15 T.U. (1.9 Bq/l).

Average annual concentrations of tritium in the Danube River in 2011 and 2012 for various sites are given on figure 3 [5, 6]. The average annual volume of

tritium activity in the Danube inflows (Syret and Rod) for 2011 is equal to 2,5 Bq/l and 3,5 Bq/l for 2012 [5, 6].

The comparison of these results indicates that during 2012 the volume activity of tritium in the Danube River in comparison with 2011 grew almost two fold, and in comparison with 2007 – grew almost three fold [4].

Average activities of tritium in the water of the branch duct according to pilot studies in 2004 made 65,8 ± 3,5 Bq/l (9,3 ± 1,5 Bq/l – 297,4 ± 9,0 Bq/l), and in the Danube River water, further downstream from the Chernavodska NPP (distance from the mouth of the river of 296 km), activity of tritium made it from 7,2 ± 1,2 Bq/l to 19,0 ± 2,1 Bq/l [2].

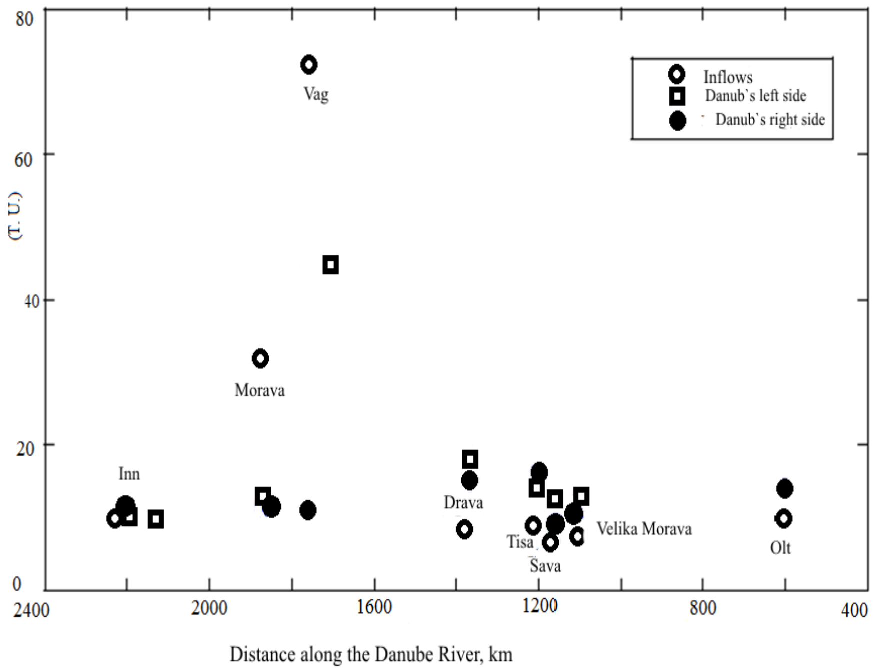
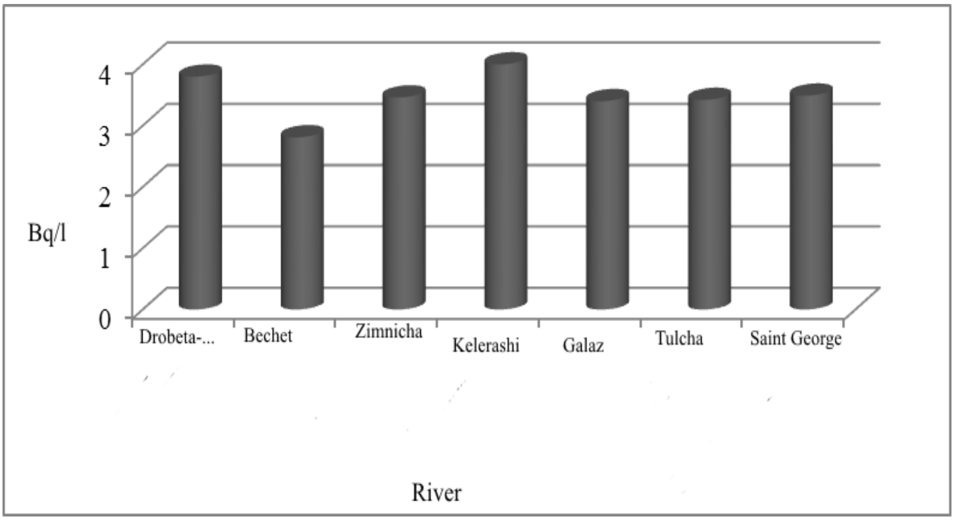
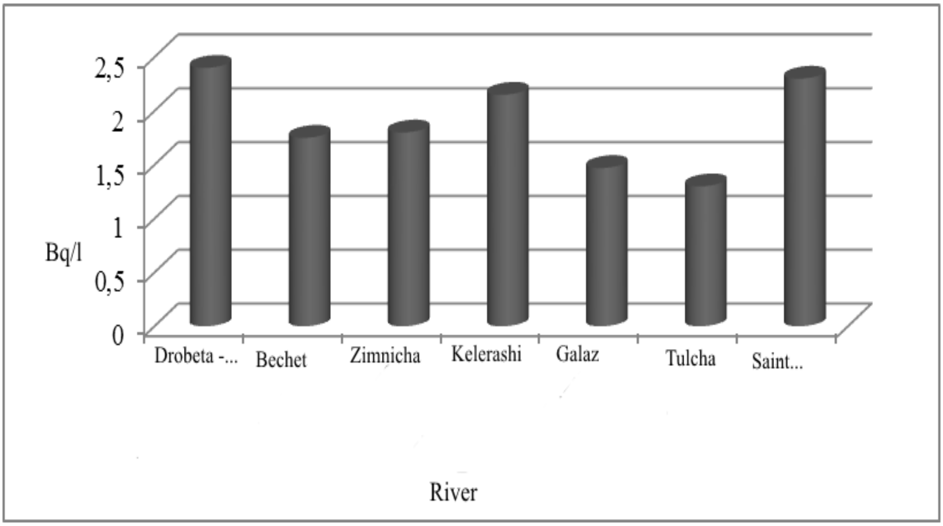


Figure 2. Dependence of volume activity of tritium into the Danube River (area on the left and right coast) and its inflows by distance.



a) 2011 year

Figure 3. Average annual volume activities of tritium in the Danube River.



b) 2012 year

Figure 3. Average annual volume activities of tritium in the Danube River.

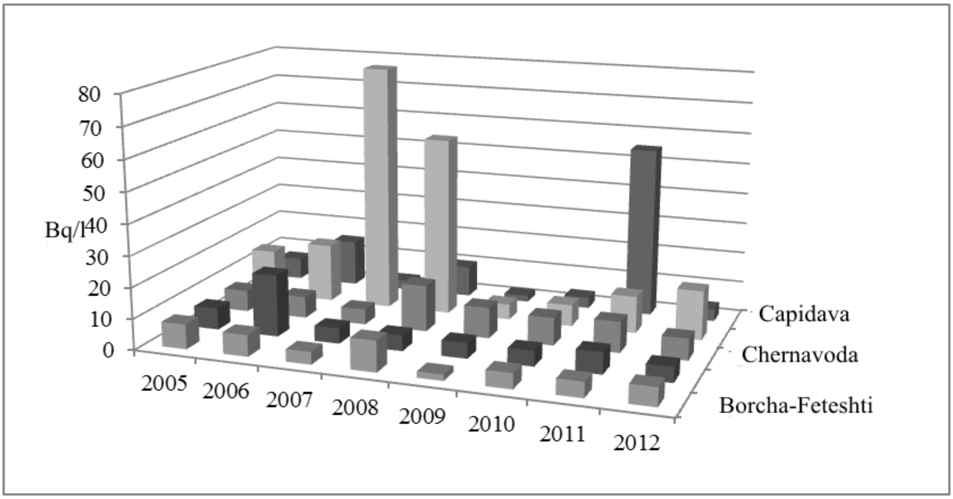


Figure 4. Average annual activity of tritium in the Danube River around the arrangement of the Chernavodska NPP.

On fig. 4, the results of the average annual concentration of tritium are given in the Danube River around an arrangement of the Chernavodska NPP from 2005 till 2012 [6].

The distance from the Chernavodska NPP to Seymen is 7 km, to Kapidava – 20 km, to Kokirlen – 7 km, to Borcha-Feteshti – 20 km. The location of water discharge after cooling the reactors is at the right river bank four kilometers down from Chernavoda city and three kilometers up river from Seimen. The point of sampling from Cochirleni is before the dumping point of the sewage, and Borcha-Feteshti's point is located on other bank of the Danube River, opposite the Chernavodska NPP.

The maximum average annual volume activities of tritium around Seimen were observed in 2007 to be about 80 Bq/l and in 2008 about 55 Bq/l. In 2011 and 2012, average annual volume activities didn't exceed 15 Bq/l. On fig. 5 the distribution of volume activity of tritium around the arrangement of the Chernavodska NPP for the months of 2007 is shown [7].

From the graph, it is clear that from June till October, the volume activity of tritium around Seimen increased from 8 to almost 2000 Bq/l. As a result of averaging, in a year, about 80 Bq/l accumulated.

For the assessment of the transboundary impact of the Chernavodska NPP on the content of tritium in the Danube River on the territory of Ukraine there were selected tests of water in the surrounding areas of the following cities: Renie, Izmail and Vilkovo.

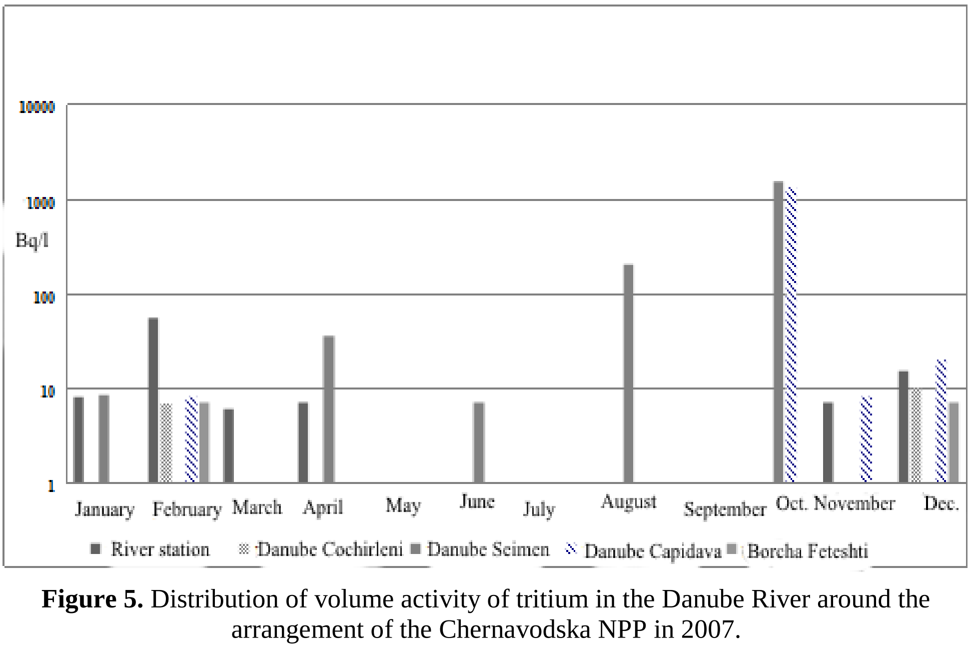


Figure 5. Distribution of volume activity of tritium in the Danube River around the arrangement of the Chernavodska NPP in 2007.

Sampling and preparation for the samples of water for the measurements of tritium was carried out according to DSTU ISO 9698-2001. The summary relative error taking into account preparation of samples is ± 20%

The results of the measurements of volume activity of tritium in the Danube River for this period are given on fig. 6 [8,9]. Continuous curves in the graph show the linear approximations of the results of the measurements. The dotted line depicts the average value of the volume activity of tritium during the study period.

From the results of the measurements, it is possible to draw a conclusion that from 1993 till 2004 the size of the volume activity of tritium in the Danube River within the errors of measurements didn't change. From 2004 to 2014 there was an increase in the volume activity of tritium under the linear law of 2,5 to 15 Bq/l.

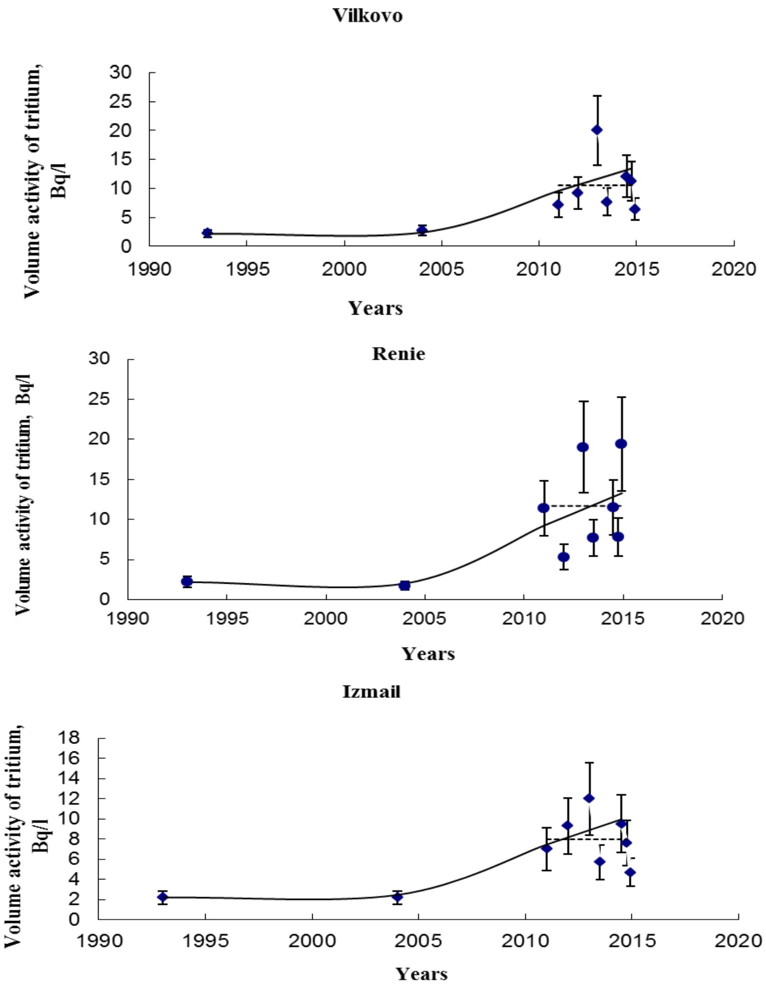


Figure 6. Results of the measurements of volume activity of tritium in the Danube River. (Ukrainian part).

Sizes of the measured volume activities of tritium in the Danube River on the territory of Ukraine exceed background activity by 3 to 5 times (~ 4 Bq/l).

The Chernavodska NPP located in Romania, 160 km from the border with Ukraine can be one of the possible sources, leading to the changes of the volume activity of tritium.

According to NRBU-97, volume activity of tritium in drinking water shouldn't exceed the amount of $3 \cdot 10^4$ Bq/l [10], in Russia – 7700, in the USA – 740 Bq/l, and in EU countries – 100 Bq/l. The established standard in Ukraine exceeds the standard of 7610 Bq/l by four times, which is recommended by the WHO and EURATOM [3].

3. Transboundary influences of the Chernavodska NPP on the content of tritium in the Danube River flowing across the territory of Ukraine, under normal operational conditions

The program complex PC CREAM [11] was used for modeling the distribution of tritium from the Chernavodska NPP to the territory of Ukraine. The program system is intended for calculating radiative effects of long (not emergency) outliers into the atmosphere, and discharges into the surrounding rivers and seas by radioactive materials. The effective doses (determined by the Publication MKRZ No. 60 [12]) are calculated using this methodology [13].

For the use of the calculations, it was assumed that the two units of the NPP evenly discharge tritium into the river at a total annual discharge equal to $1{,}08 \cdot 10^{15}$ Bq [3].

The "dynamic model" that allows for the consideration of some hydrological parameters of the river was used during modeling. All of the site modeling from the Chernavodska NPP to the territory of Ukraine was divided into four sites (cameras). At the 1st sample site, 48 km away, distribution of tritium was modeled from the discharge canal of the NPP on the right sleeve of the Danube River before it merged to the left sleeve. The average speed of the flow for all of the sites was accepted to be roughly 1,66 m/s. The outflow of water in the discharge channel was 108 m^3/s. Water consumption in the course was 2300 m^3/s. At the 2nd sample site, 93 km away, the distribution of tritium into the river was considered at the confluence with a big inflow – the Siret River. Water consumption on this site was 4600 m^3/s. The 3rd sample site, 23 km away, was on the Danube River between two inflows: the Siret and Rod Rivers. Here water consumption was 4795 m^3/s (water flow from the Siret River with an expense of 195 m^3/s was added). The 4th sample site, 40 km away, shows movement of tritium across the Ukrainian territory after the confluence of the Rod River. Water consumption here was 4900 m^3/s [14].

The speed for the washout of the top layer of ground deposits on all sites is equal to 5·10-5 m/s - that is the characteristic for the big European rivers. The quantity of suspensions in the water we sampled equaled 2·10-4 t/m^3 [13].

The results of the calculations of volume activity during the normal operation of the Chernavodska NPP are given on pic. 7 (a curve 1).

The calculations show, that the volume activity on the right sleeve of the Danube River after the discharge from the NPP, equaled about 15 Bq/l after dilution, and the interaction with impurities of the Ukrainian territory decreased to 7 Bq/l. This data doesn't consider the background volume activity of tritium in the Danube River.

In consideration of the background activity of tritium in the Danube River equal to 4 Bq/l, by the carried-out calculation - discharges of tritium from one unit of the Chernavodska NPP during normal conditions, increases the general volume activity of tritium in the Ukrainian territory by 4 to 11 Bq/l which was coordinated with the results of the measurements from the period of 2011 - 2014.

Thus, due to the operation of the two units of the Chernavodska NPP, volume activity of tritium in the Ukrainian waters of the Danube River increased by 7 Bq/l.

4. Assessment of the transboundary impact of the Chernavodska NPP in conditions other than normal

On fig. 5, data on the measured specific activity of tritium are given at a distance of 2,5 km below the release of the discharge channel. In October, abnormally high volume activities of tritium, approximately equal 2000 Bq/l were observed.

According to the approach of the IAEA [15], when modeling distribution of radionuclides in the rivers, there are three distinct phases.

The first phase – the area of initial dilution and hashing on the course depth, extends by a distance of about one hundred times more than the depth of the river. It is a phase of initial hashing. In relation to the Danube River around the discharge of activity from the Chernavodska NPP this distance is about 500 m.

The second phase – a phase of full hashing in which there is a hashing practically encompassing the width of the river or, on all cross sections of the rivers surrounding course. This process can happen at distances of approximately several to tens of kilometers. [13,15].

The third phase begins after the termination of the second phase and is characterized by dispersion at long distances and the interaction of radionuclides with substance weight - creating bottom deposits.

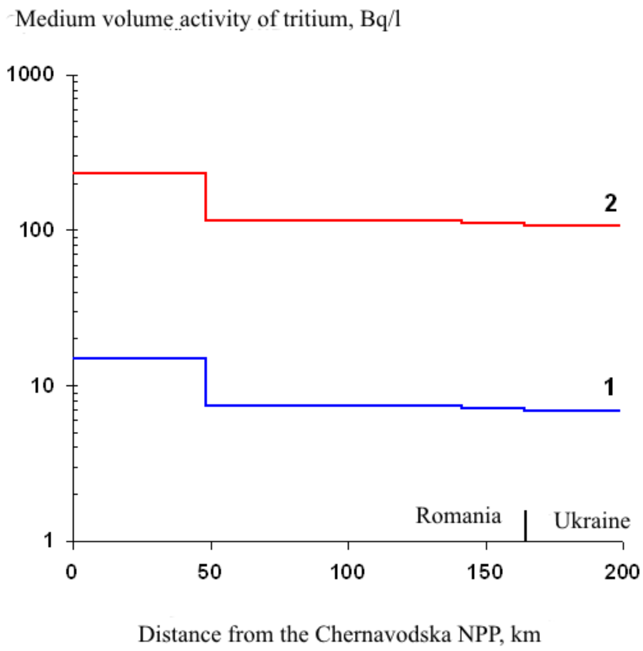


Figure 7. Calculation of volume activity of tritium in the Danube River from the Chernavodska NPP to the territory of Ukraine for two variants of discharge.

Using the solution of the two-dimensional diffusive equation for phase 2 [16], we calculated that after hashing at a distance of 2,5 km (distance from the dumping point to a point of measurement), volume activity in the discharge canal exceeds volume activity at the coast, at a discharge of 2,46 times. I.e. The described volume activity in the discharge canal had higher hashing conditions on the 1st site of 4920 Bq/l. at an annual discharge of $1{,}08 \cdot 10^{15}$ Bq and the consumption of water in the waste channel – 108 m^3/s, - the volume activity in it was 317 Bq/l.

Under conditions of abnormal discharge in October, 2007 volume activity in the discharge canal grew in comparison with normal conditions by 15,5 times. At this time, volume activities of tritium from the sample sites surrounding the Chernavodska NPP on the territory of Ukraine are illustrated by a broken curve - 2 on pic. 7. The average volume activity of tritium was equal in the Ukrainian waters of the Danube River to 108 Bq/l.

Thus, based on the data given on fig. 4 and the obtained calculations, it is possible to assume that due to the discharge of tritium by the Chernavodska NPP in the Ukrainian waters of the Danube River, the volume activity of tritium can range from 7 to 108 Bq/l. For obtaining the general volume activity it is necessary to add the background value equal to 4 Bq/l to the figures given above.

5. Summary

From the data results regarding the research of the volume activity of tritium, it is possible to draw a conclusion that the operation of the Chernavodska NPP led to an increase in volume activity of tritium in the Danube River in the territory of Ukraine by 3 – 5 times in comparison with the background value. In certain cases volume activity of tritium could increase to 108 Bq/l. The additional commissioning of two more units will lead to increases in volume activity of tritium in the Danube River by 15 – 20 Bq/l, and in certain cases volume activity of tritium may exceed 100 Bq/l.

Consequently, it is necessary to resume regular controls of the volume activity of tritium in the Danube River, in alignment with the cities of Rennie, Izmail and Vilkovo.

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