Monitoring of the Uranium Mining Industry Impact on the Water Ecosystem in the Middle Part of the Svratka River Basin

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Abstract
The article presents results obtained from the monitoring of the uranium mining impact on the chemical and ecological state of water ecosystem, especially on the surface water quality, which was studied in the period 2005 – 2007 in the middle part of the Svratka River basin in detail. In the frame of the research project MZP0002071101 and the VUV T.G.M. research project No. 1323 the study of the state and load of selected streams in the area of interest in relation to radiological analysis and assessment of ecotoxicity and genotoxicity was made. Also sediment, suspended particulate matter (SPM) and biological material were tested for various selected parameters.

Key words: Surface water quality, uranium mining industry, radiological analysis, acute toxicity, genotoxicity

Introduction
The mining of the uranium in the studied area of the middle part of the Svratka River basin was started in 1958. The mining and modification of uranium ore from the 50-ies to the late 80-ies caused significant stress of the environment by accumulation of huge slag heaps, sludge settling lagoons and surface water and groundwater contamination.
Reduction of uranium industry started in the 80-ies and from the year 1990 the uranium mining has been concentrated only on the mine Rožná. It is currently the last operated mine in the middle Europe. The mine was supposed to be closed at the end of the year 2005, but the date was postponed to the end of 2008. The worldwide rise of the uranium price caused continuation of mining to the resource depletion in the future.

Methods
The research sampling sites, which were sampled between the years 2005 and 2007, were situated on the selected localities in the middle part of the Svratka River Basin as it is shown in the map of the Figure 3 (Annex 1). Photos of the most important profiles located on the Hadůvka stream, the part of the MWTP Olší - Drahonín with the discharging pipe and the Nedvědička river are showed below (Figures 1a, 1b and 2).

Figure 1a *Photos of the discharge pipe and the building of the MWTP on the Hadůvka stream*

Figure 1b *Photos of the sampling profiles 4-Hadůvka-Olší (left) and 6-Hadůvka-Skryje (right)*

Figure 2 *Photos of the sampling profiles 1-Nedvědička-Rožná (left) and 2-Nedvědička-Nedvědice (right)*

Samples of water were collected from these sites once monthly during the whole monitoring period. Samples of sediments, suspended matters (SPM) and biota were collected once a year (only in the years 2005 and 2006).

The actual values of the water flow were obtained from the nearest gauge stations (data sources: Morava River Basin Authority, CHMI Brno) or, on some of the sites, by means of the water velocity measurements and subsequent calculations.

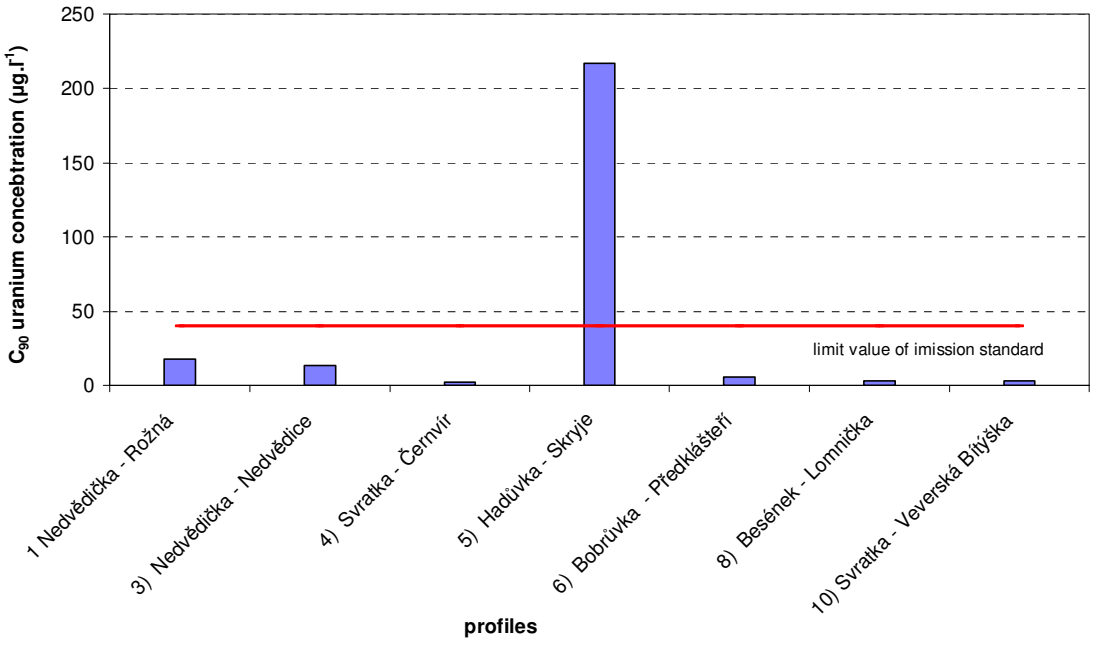
The following parameters of water quality were measured – physico-chemical parameters (water temperature, pH, conductivity, dissolved oxygen), chemical parameters (total organic carbon, sulphates, nitrates, chlorides) and radiological parameters (uranium ^{238}U and radium ^{226}Ra).

Chemical analyses were provided by the following methods: analyses of uranium by extraction spectrofotometric method (ČSN 75 7614); analyses of radium by precipitation method in the years 2005 – 2006 and by the method which consists in the determination of the radium as equivalent ^{222}Rn after radioactive balance by LSC method in the year 2007.

Separation of the medium into the liquid samples was provided for ^{238}U and ^{226}Ra measurement in sediment, SPM and biota, which were consequently analysed.
Determination of the acute toxicity in water samples and sediments was provided by accredited methods ČSN EN ISO 6341, TNV 75 7754 a TNV 75 7741 in the year 2006.
For genotoxicity determinations made in the years 2006 and 2007 two variants of the Ames fluctuated test (with and without S9 liver fraction) (Kajtová, Soldán, 2001) were used.

Results and Discussion
The obtained results show that the highest values of uranium and other components are in the surface water in the Hadůvka stream, which is the very small stream situated under the former uranium mine Olší and the mine water treatment plant. Concentration of uranium in water calculated as the 90-percentile value (C_{90}) is 217 $\mu g.l^{-1}$ ^{238}U, which belongs to 5th class of the water quality - the worst degree of water quality according to the standards of the Czech Republic (ČSN 75 7221) and exceeds the limit of immission standard given by the Gov. Decree No. 61/2003 Coll. (C_{90} = 40 $\mu g.l^{-1}$ ^{238}U), as amended by the Decree No. 229/2007 Coll. (see Figure 4).

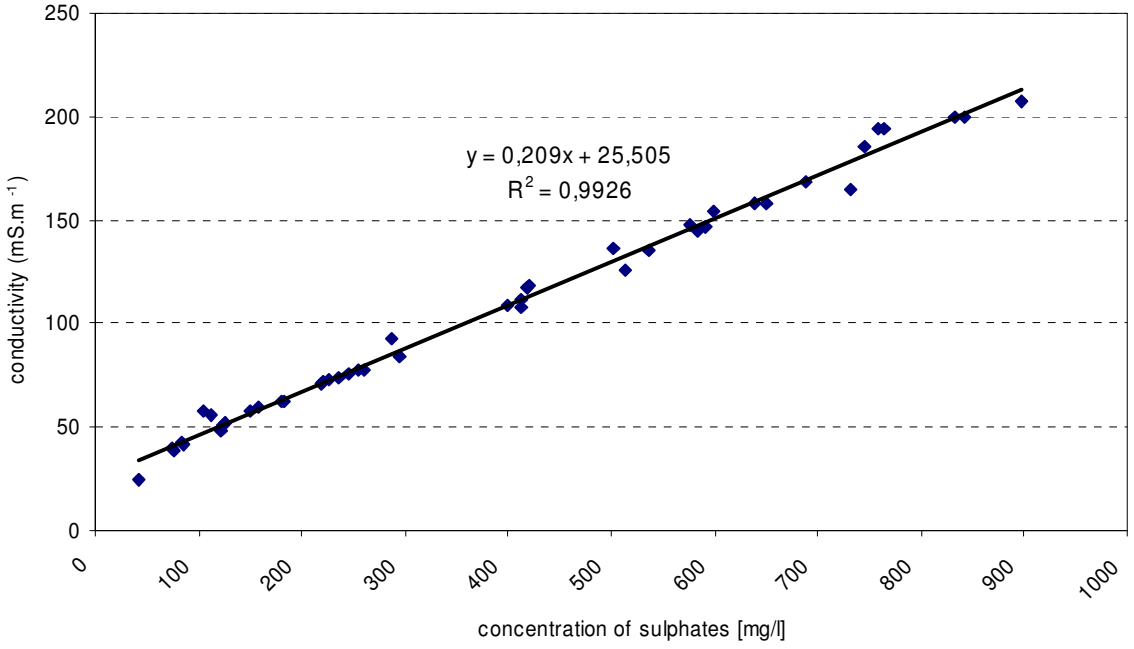
Figure 4 *Concentrations of uranium in water samples from the studied localities*



The highest influence on the Svratka River, measured by the mass load calculation, is caused by the Nedvědička River, where the uranium concentration in water is not as high as in the Hadůvka stream – see Figure 4. In the sampling site Nedvědička – Rožná the value of C_{90} 17.9 $\mu g.l^{-1}$ ^{238}U and the maximum value = 28 $\mu g.l^{-1}$ ^{238}U were calculated. In the sampling site Nedvědička – Nedvědice there were calculated these values 13.3 $\mu g.l^{-1}$ ^{238}U (C_{90}) and 19.7 $\mu g.l^{-1}$ ^{238}U (max.). The contamination comes from the Rožná mining area.
In the sampling sites located on the Hadůvka stream and the Nedvědička River, there were measured high - alarming concentrations of sulphates. Concentration of sulphates in water calculated as the 90-percentile value (C_{90}) of the data set was 753 $mg.l^{-1}$ in the Hadůvka stream. This value corresponds to the 5th class of the water quality - the worst degree of water quality according to the standards of the Czech Republic (ČSN 75 7221). Such high values are most likely connected with the mine water outflow from the mine water treatment plant Olší – Drahonín, which is situated on a bank of the Hadůvka stream near the village Drahonín. Concentration of sulphates in water

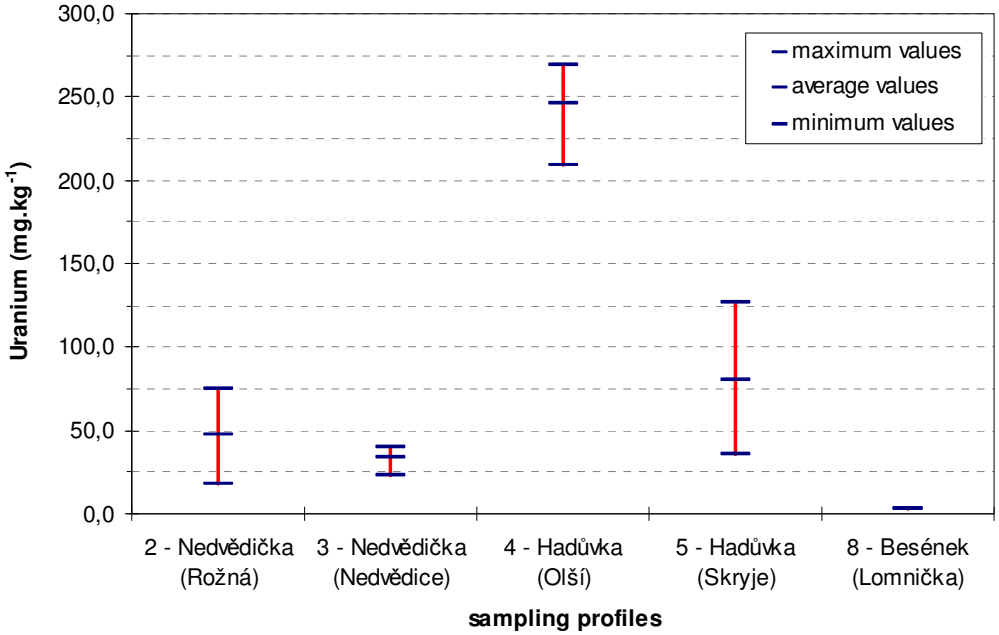
of the Nedvědička River in both monitored sites belongs to the 4th class of the water quality according to the standards of the Czech Republic (ČSN 75 7221). The values of sulphates concentration in the Hadůvka and Nedvědička exceed the limit of immission standard given by Gov. Decree No. 61/2003 Coll., as amended by the Decree No. 229/2007 Coll.
Measured concentrations of sulphates in water of the Hadůvka and Nedvědička streams correlate well with the values of water conductivity (Fig. 5), which corresponds with the 5th class of the water quality in the Hadůvka stream and 4th class of the water quality in the Nedvědička River. On the other sites of the monitored streams, which are not affected by the uranium mining, lower values of the conductivity were measured, which correlate more with the concentrations of the other ions - with nitrates and chlorides (the Besének stream).

Figure 5 *Correlation between concentration of sulphates and conductivity in the Hadůvka and Nedvědička streams*



Results of the amount of uranium in the sediments showed that the data obtained in the years 2005 – 2006 are heterogeneous. Due to this information, the samples of sediment taken in the year 2007 were sieved on 63 μm size fraction before all analysis.
The highest amount of uranium in sediment during the year 2006 was occurred in the Hadůvka stream upstream and downstream the mine water treatment plant Olší- Drahonín (see Figure 6). The plant location is marked in the map of the Figure 3. In the graph there are also showed the results of uranium content analysis from the sediment taken at the comparative profile located on the Besének stream. The amount of uranium found in the sediment samples from that profile was almost 80times lower than in the sediment samples from the profile Hadůvka - Olší in average and 25times lower than in the samples from the profile Hadůvka - Skryje (the stream mouth).
The content of uranium in the sieved samples of sediment, which were taken in July 2007, reached the next values: Nedvědička - Rožná – 42.9 $mg.kg^{-1}$; Nedvědička - Nedvědice – 64.6 $mg.kg^{-1}$; Hadůvka - Olší – 395.0 $mg.kg^{-1}$; Hadůvka - Skryje - 221,0 $mg.kg^{-1}$ and Besének - Lomnička – 15.2 $mg.kg^{-1}$. The comparison of the results shows that the next research of the uranium content in sediment and the link to the grain composition of sediment is necessary.

Figure 6 *Uranium content in the sediment samples taken during the year 2006*



The study of accumulation uranium and radium in the selected species of macrophyta (filamentous algae and mosses) was provided in the year 2006. As it was found out for the samples of sediment, there were also obtained very heterogeneous results of the content of uranium in the biomass. The reasons seem to be quite high species.

In the same year, there were determined the acute toxicity in the water samples and the samples of sediments on selected, important sampling sites. Acute toxicity is evaluated by two parameters: toxicity unit (TU) and percent of inhibition (% of dead organism). Toxic effect by toxicity unit evaluation was not able determined and was evaluated only by % inhibition. The samples are considered as toxic, if inhibition reaches more then 10% for invertebrates and more than 30% for algae.

The toxic effect was not proved in the water samples on tested micro-organisms *Daphnia magna* and *Thamnocephalus platyurus* (decomposers - invertebrate) (Table 1).

Table 1 *Results of acute toxicity determination on decomposers in surface water*

Name of sample (stream – sampling site)	Decomposers			
	Daphnia magna		*Thamnocephalus platyurus*	
	% inhibition	**evaluation**	**% inhibition**	**evaluation**
Nedvědička - Rožná	0	negative	0	negative
Nedvědička - Nedvědice	5	negative	0	negative
Hadůvka - Olší	5	negative	0	negative
Hadůvka - Skryje	5	negative	0	negative
Besének - Lomnička	5	negative	0	negative

However inhibition effect on the producer – green algae *Desmodesmus communis* - was found for both matrices on the site Nedvědička – Rožná (Table 2).

Table 2 *Results of acute toxicity determination on a producer in surface water¨*

Name of sample (stream – sampling site)	Producer	
	Desmodesmus communis	
	% inhibition	**evaluation**
Nedvědička - Rožná	53,8	**positive**
Nedvědička - Nedvědice	14,7	negative
Hadůvka - Olší	20,2	negative
Hadůvka - Skryje	5,8	negative
Besének - Lomnička	-2,2	negative - stimulate

In the samples of sediment there was not the toxic effect showed for the tested micro-organisms *Daphnia magna* and *Thamnocephalus platyurus* (Table 3). Toxic effect by toxicity unit evaluation was not able determined and was evaluated only by % inhibition.

Table 3 *Results of acute toxicity determination on decomposers in sediments*

Name of sample (stream – sampling site)	Decomposers			
	Daphnia magna		*Thamnocephalus platyurus*	
	% inhibition	**evaluation**	**% inhibition**	**evaluation**
Nedvědička - Rožná	5	negative	0	negative
Nedvědička - Nedvědice	5	negative	0	negative
Hadůvka - Olší	5	negative	0	negative
Hadůvka - Skryje	0	negative	0	negative
Besének - Lomnička	0	negative	0	negative

Tests on alga *Desmodesmus communis* showed positive results of toxic effect for all selected profiles (see Table 4). Toxic effect by toxicity unit evaluation was determined for two profiles (Hadůvka – Olší and Besének – Lomnička). The highest 82% inhibition was determined on profile Hadůvka – Olší. The toxic effect can by caused not only by the uranium mining industry, but also by subsoil in the monitored area or others sources of surface water contamination. Sampling profile Besének – Lomnička is not affected by uranium mining industry.

Table 4 *Results of acute toxicity determination on a producer in sediments*

Name of sample (stream – sampling site)	Producer			
	Desmodesmus communis			
	TU	**evaluation**	**% inhibition**	**evaluation**
Nedvědička - Rožná	could not be determined	negative	40,9	**positive**
Nedvědička - Nedvědice	could not be determined	negative	72,4	**positive**
Hadůvka - Olší	4,9	negative	82,0	**positive**
Hadůvka - Skryje	could not be determined	negative	68,0	**positive**
Besének - Lomnička	1,4	negative	42,0	**positive**

Genotoxicity of water and sediment was determined also only on the important sampling sites located on the streams Hadůvka, Nedvědička and Besének, which is the comparative locality. First, in year 2006, there the occurrence of genotoxicity compounds in the surface water was found using Ames fluctuated test. The positive genotoxicity effect in the sample of surface water from Hadůvka stream was found for both variants of Ames fluctuated test (without and with S9 liver fraction). There were detected the compounds which caused transition and transversion in the test without S9 fraction by strain *Salmonella typhimurium* TA 100. In the test with S9 fraction, which is used for higher

capture of promutagens, there were measured positive results in the case of both used detection strains *S. typhimurium* TA98 and *S. typhymurium* TA 100 (see the Table 5).

Table5 *Results of genotoxicity determination in surface water*

Name of sample (stream – sampling site)	Strain *Salmonella typhimurium*				
	The variation without S9			The variation with S9	
	TA97	**TA98**	**TA100**	**TA98**	**TA100**
Nedvědička - Rožná	negative	negative	negative	**positive**	negative
Nedvědička - Nedvědice	negative	negative	negative	negative	negative
Hadůvka - Olší	negative	negative	negative	**positive**	**positive**
Hadůvka - Skryje	negative	negative	**positive**	**positive**	**positive**
Besének - Lomnička	negative	**positive**	negative	negative	negative

Based on the results from genotoxicity determination in the surface water we can state that there are two sampling sites with the highest supposed contamination by the studied radionuclides. These two sites are below the mine water treatment plant Olší - Drahonín and in them the sediment and SPM samples were analyzed by test without S9 liver fraction subsequently in year 2007.
The occurrence of genotoxic compounds was detected by the test. The only one sediment that did not show positive effect was below the mine water treatment plant (See results in Table 6)

Table 6 *Results of genotoxicity determination in sediment*

Name of sample (stream – sampling site – matrix)	Strain *Salmonella typhimurium*		
	The variation with S9		
	TA 97	**TA 98**	**TA 100**
Hadůvka ČDV - sediment	negative	negative	negative
Hadůvka Skryje - sediment	negative	negative	**positive**
Hadůvka ČDV - SPM	negative	negative	**positive**
Hadůvka Skryje - SPM	negative	**positive**	**positive**

Conclusions
The water quality research in the middle part of the Svratka River basin and performed in the years 2005-2007 proved that the impact of former and ongoing mining of the uranium ore on the chemical state of water is highest and significant in the cases of the Hadůvka stream and the Nedvědička River.
Although the values of the contamination by uranium in the present time on most of the studied localities have not reached the level given by the immission standard, it is important to emphasize – with regard to the changes of uranium prices and possibility of extension in mining – the strong need of permanent monitoring provided by the state sector. It is also necessary to ensure additional special monitoring of the toxicity of water and sediment in the mentioned streams.

Acknowledgements
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Annex 1

Figure 3 *Map of the area of interest with the marking of the studied water bodies and sampling sites*