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THE MONITORING OF A FORMER CONTAMINATION CAUSED BY URANIUM MINING IN LICOMĚŘICE (THE CZECH REPUBLIC)

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The paper has been focused on the development of the former uranium mining site located in Licoměřice. The orthogonal time-of-flight inductively coupled plasma mass spectrometry was the method of the choice for the uranium determination in water samples. The analytical procedure for the determination of uranium in water using the oTOF-ICP-MS method was processed. The limit of detection for uranium was 0.009 μg l^{-1}. Sixty seven samples taken from former mining sites and also from non-mining sites were analysed.

Emission limits for uranium were specified in the resolution of the State office for nuclear safety, Prague No. 9156/4.3/00 agreed on 17th July 2000. The recording level of uranium emission limits was exceeded in the case of ten water samples, the controlling level of emission limits for five water samples, and the emergency lever of emission limits for four water samples. The highest

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concentration of uranium has been found in the samples taken in the mining water treatment area in Licoměřice. According to the Government resolution No. 23/2011, Appendix 3 (the indicators and values of permissible pollution of surface water and wastewater, requisites of permit to discharge wastewater into surface water and sewerage systems and about sensitive areas) the imission limit allowed for the contamination with uranium in surface water is 40 μg l^{-1}. This value has been exceeded in four samples.

As the uranium concentration in the downstream flow has been found under the imission limit and shown the lowering tendency during the mining water treatment process, the recultivation and remedial measures taken by the state owned company DIAMO in former mining site Licoměřice can be considered as efficient.

Introduction

Uranium is a radioactive element with carcinogenic, mutagenic and teratogenic effects [1]. Its content in the environment is regularly monitored and eliminated. Uranium mining is one of the major industries, which affect significantly the landscape, with a negative impact on humans and the environment. The main problem of uranium mining is a hardly removable environmental stress resulting both from the uranium exploration industry and from mining activities. Over 3000 places with former contamination from this industry are currently registered in the Czech Republic. The biggest problems of remediation work are connected with recultivation and cleaning of contaminated mine water. Due to the government program of the Czech Republic, there is a decline in the uranium industry since 1989. Remediation and monitoring works have been realized since 1989 by the state enterprise DIAMO. It is estimated, that the remediation works will last at least until 2030 and will cost more than 2.5 MLD Euro [2].

The village Licoměřice is a part of the micro region Železné hory. The deposit is located in low to medium grade metamorphic rocks of upper Proterozoic of Železné hory and was found by radiometric survey in 1961. Due to stocks of uranium, this deposit was classified as a small deposit of uranium ore, easily mineable. The ore field is a rectangle of dimensions 1200 × 200 m. The uranium deposit in Licoměřice has specific ore and specific composition of mine water. Active mining of uranium ore was conducted there from 1968 to 1982. The total amount of extracted uranium ore was 480 tons. The uranium ore mining was finished in 1982. The place of extraction has been undermined yet. One of extraction shafts, which are more than 200 m deep, is fixed by stone. A new mine water purifier was built next to the village in the 1990s [2].

Uranium typically occurs in ultra-trace concentrations in the waters [1,3]. Several sets of determination of uranium in water have been described in

literature. In a survey conducted in 1990-1995 in Ontario, uranium concentrations in the range of 0.05-4.21 μg l^{-1} were found. The uranium level in New York in 1986 was in the range of 0.03-0.08 μg l^{-1} [1,3]. A range of < 0.0005 to 16.0 μg l^{-1} uranium (median 0.17 μg l^{-1}) was obtained in 908 bottled water samples, 0.00115 to 9.0 μg l^{-1} (median 0.073 μg l^{-1}) was obtained for tap water from 163 municipal tap water systems in Germany [4]. In 2004, a study was focused on the content of uranium in drinking water in the Olomouc Region: 175 samples of drinking water were taken within six months. Uranium concentrations below the detection limit were found in 18.8 % of samples, the confidence interval was set from 0.31 to 3.17 μg l^{-1}. The highest concentrations of uranium were found at the border of district Olomouc, Přerov and Prostějov [5].

Many analytical procedures are commonly used for analysis of uranium in water samples. Procedures using chelation ion chromatography [6]), spectrophotometric determination with 4-(2-pyridylazo)resorcinol in Cetylpyridinium chloride [7], or reaction with the arzenazo III [8], or with *p*-carboxylchlorphosphatase in acid solution [9] are described in many publications. A number of physico-chemical methods, for example, "-radiation spectrometry, neutron activation analysis, laser-induced fluorescence or fluorescence spectrometry method can be used. Inductively coupled plasma optical emission spectrometry (ICP-OES) is a sensitive, fast and time-saving method for analysis of uranium. It can analyse samples mostly after ion exchange preconcentration [10] or less directly [4] depending on the uranium concentration. Especially, inductively coupled plasma mass spectrometry (ICP-MS) is a very interesting alternative to above mentioned methods. It enables direct detection of uranium at ng l^{-1} levels with small sample consumption and minimal spectral interferences [4,5].

The aim of this present study was to evaluate the efficiency of the recultivation and remedial measures taken by a state owned company — DIAMO in former mining site Licoměřice and its impact on the surrounding area.

Experimental

Samples

Sixty seven water samples were analysed. Forty seven samples originated from the polluted area of Licoměřice and surroundings, seventeen samples were from the unpolluted control areas in the East Bohemia and three samples from the control areas in the Northern Moravia. In the polluted area, the samples were taken from the mine water purifier, private wells of local people, from the watercourses of rivers Kurvice and Doubrava, from Lovětín's and Starkoč's streams and from garden ponds. Sampling sites are summarized in Table I and are also shown in Fig.1.

Table I List of samples

No.	Location	GPS
1	Stará Ves 185, Rakovi	49° 22' 38.981" N, 17° 29' 1.894" E
2	Karviná - Mizerov, Poutní 353/1, Buchtovi	49° 25' 15.979" N, 17° 43' 15.96" E
3	Loukov 227, Kučerovi	49° 25' 15.979" N, 17° 43' 15.96" E
4	Licoměřice, Sýkora's pond 1a	49° 54' 59.166" N, 15° 33' 22.913" E
5	Licoměřice, Sýkora's pond 2a	49° 54' 59.788" N, 15° 33' 24.851" E
6	Licoměřice, Sýkora's pond 3a	49° 54' 59.788" N, 15° 33' 24.851" E
7	Licoměřice, stream in a forest 1	49° 54' 56.402" N, 15° 33' 32.008" E
8	Licoměřice, stream in a forest 2	49° 54' 54.809" N, 15° 33' 40.013" E
9	Vápenka 1a	49° 55' 21.976" N, 15° 33' 46.547" E
10	Stream flowing from Vápenka 1	49° 55' 23.032" N, 15° 33' 42.547" E
11	Stream flowing from Vápenka 2	49° 55' 23.032" N, 15° 33' 42.547" E
12	Vápenka 1b	49° 55' 21.976" N, 15° 33' 46.547" E
13	Vápenka 2	49° 55' 21.976" N, 15° 33' 46.547" E
14	Licoměřice 39, Hanzlíkovi	49° 55' 6.022" N, 15° 33' 0.562" E
15	Licoměřice 30, Zumrovi 1	49° 55' 0.609" N, 15° 33' 14.609" E
16	Licoměřice 30, Zumrovi 2	49° 55' 0.609" N, 15° 33' 14.609" E
17	Licoměřice, before the gate of Mine water purifier	49° 54' 55.777" N, 15° 33' 10.488" E
18	Licoměřice 53, Vášovi	49° 54' 57.562" N, 15° 33' 17.661" E
19	Licoměřice, Sýkora's pond 3a	49° 54' 59.788" N, 15° 33' 24.851" E
20	Licoměřice, Sýkora's pond 3b	49° 54' 59.788" N, 15° 33' 24.851" E
21	Licoměřice 11, Jiráková	49° 54' 57.947" N, 15° 33' 23.852" E
22	Licoměřice, sedimentation tank No. 0a	49° 54' 55.638" N, 15° 33' 8.982" E
23	Licoměřice, sedimentation tank No. 0b	49° 54' 55.638" N, 15° 33' 8.982" E
24	Licoměřice, TJ 56, raw water 1	49° 54' 53.697" N, 15° 33' 5.35" E
25	Licoměřice, TJ 56, raw water 2	49° 54' 53.697" N, 15° 33' 5.35" E
26	Licoměřice, sedimentation tank No. 1	49° 54' 52.421" N, 15° 33' 4.583" E
27	Licoměřice, sedimentation tank No. 2	49° 54' 50.867" N, 15° 33' 1.131" E
28	Licoměřice, HVP 1	49° 54' 48.494" N, 15° 32' 59.775" E
29	Ronov nad Doubravou, Kurvice river	49° 53' 20.448" N, 15° 31' 19.567" E
30	Ronov nad Doubravou, Doubrava before Kurvice inflow	49° 53' 18.316" N, 15° 31' 18.366" E
31	Ronov nad Doubravou, Kurvice before outflow to Doubrava	49° 53' 18.625" N, 15° 31' 18.144" E
32	Ronov nad Doubravou, Doubrava 1	49° 53' 18.642" N, 15° 31' 17.944" E
33	Ronov nad Doubravou, Doubrava 2	49° 53' 18.642" N, 15° 31' 17.944" E
34	Ronov nad Doubravou, Lovětín's stream	49° 52' 59.581" N, 15° 33' 4.2" E
35	Ronov nad Doubravou, pond "Horní rybník" 1	49° 53' 1.006" N, 15° 33' 4.016" E
36	Ronov nad Doubravou, pond "Horní rybník" 2	49° 53' 1.006" N, 15° 33' 4.016" E
37	Tuchov, fire tank	49° 54' 29.761" N, 15° 32' 30.933" E
38	Tuchov, Kurvice HVP č.2a	49° 54' 28.191" N, 15° 32' 32.395" E
39	Tuchov, Kurvice HVP č. 2b	49° 54' 28.191" N, 15° 32' 32.395" E
40	Licoměřice, HVP1	49° 54' 48.494" N, 15° 32' 59.775" E
41	Licoměřice, drain to Kurvice river	49° 54' 48.462" N, 15° 32' 59.749" E
42	Licoměřice, Kurvice river	49° 54' 47.433" N, 15° 32' 58.133" E
43	Licoměřice, Sýkora's pond 1b	49° 54' 59.788" N, 15° 33' 24.851" E
44	Licoměřice, Sýkora's pond 2b	49° 55' 0.12" N, 15° 33' 26.384" E
45	Licoměřice 24, Popková 1	49° 54' 47.433" N, 15° 32' 58.133" E
46	Licoměřice, Sýkora's pond 1c	49° 54' 59.788" N, 15° 33' 24.851" E
47	Licoměřice, Sýkora's pond 2c (after the rain)	49° 55' 0.12" N, 15° 33' 26.384" E
48	Licoměřice, Sýkora's pond 2d (after the rain)	49° 55' 0.12" N, 15° 33' 26.384" E
49	Licoměřice, Sýkora's pond 3b (after the rain)	49° 54' 59.788" N, 15° 33' 24.851" E
50	Licoměřice 24, Popková 2	49° 54' 47.433" N, 15° 32' 58.133" E
51	Bystřec, Falta's pond	50° 0' 19.672" N, 16° 37' 45.08" E
52	Bystřec, Vávra's rock pond	50° 0' 55.367" N, 16° 37' 46.626" E
53	Dolní Čermná, pond	49° 58' 35.829" N, 16° 34' 5.274" E
54	Lanškroun, Pšenička's pond	49° 55' 38.331" N, 16° 34' 10.196" E
55	Pardubice, Na Ležánkách, breeding pond	50° 2' 41,85" N, 15° 47' 23,98" E

Table I – Continued

No.	Location	GPS
56	Pardubice, Na Ležánkách, pond Čičák	50° 2' 41,86" N, 15° 46' 56,14" E
57	Pardubice, Chrudimka near the junction with Labe	50° 2' 39,51" N, 15° 46' 42,10" E
58	Pardubice, Labe near the junction with Chrudimka	50° 2' 41,62" N, 15° 46' 40,75" E
59	Pardubice, Na Ležánkách, local stream	50° 2' 50,58" N, 15° 47' 13,36" E
60	Opatovice, pond	50° 9' 49.035" N, 15° 47' 27.438" E
61	Humburky, pond "Koláč"	50° 13' 50.908" N, 15° 30' 25.446" E
62	Pardubice, pond "Bajkal"	50° 2' 45.179" N, 15° 45' 56.346" E
63	Hrádek	50° 6' 19.465" N, 15° 42' 58.148" E
64	Vinice	50° 1' 43.625" N, 15° 47' 6.967" E
65	Matiční lake	50° 2' 7.419" N, 15° 47' 2.806" E
66	Nechanice	50° 14' 36.844" N, 15° 36' 58.896" E
67	pond in the roundabout Hradec Králové	50° 10' 46.782" N, 15° 46' 19.995" E

In the mine water purifier, the samples were taken from mine shaft (raw water), sedimentation tanks and from the draining point of river Kurvice. From river Kurvice, the samples were taken in several places — before the draining from mine water purifier, in the point of draining and in different distances from point of draining. In Sykora's pond the samples were taken under different climate conditions — before, during and after the rain.

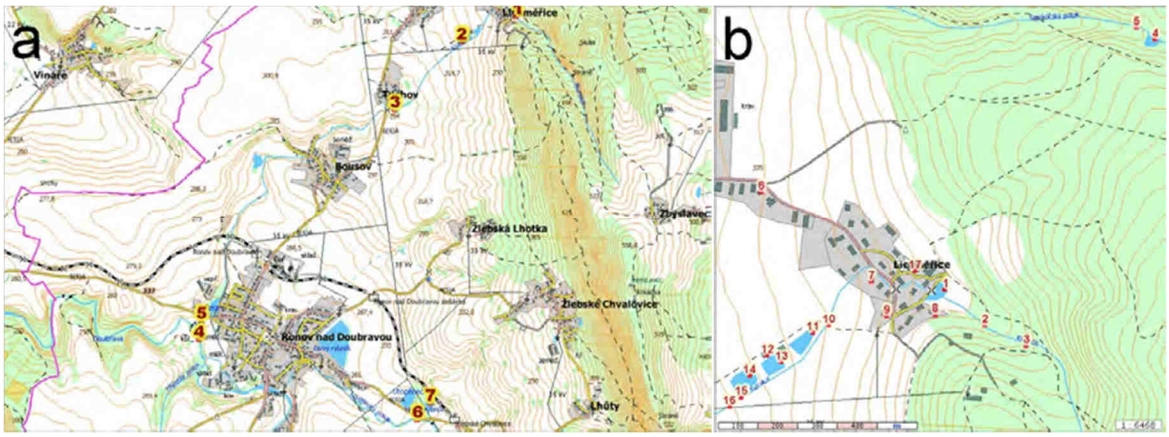

Fig. 1 Map of sampling places. a – Sampling belong the river Kurvice flowing: 1 – Sýkora's pond, 2 – mine water purifier, 3 – main draining profile 1, 4 – Doubrava river, 5 – Kurvice river, 6 – Lovětín's stream, 7 – Horní rybník; b – Sampling in Licoměřice: 1 – Sýkora's pond, 2, 3, 16 – Kurvice river, 4 – Vápenka, 5 – Starkoč's stream, 6, 7, 8, 9, 17 – private wells of local people, 10 – before the gate of mine water purifier, 11 – sedimentation tank No. 0, 12 – raw water, 13 – sedimentation tank No. 1, 14 – sedimentation tank No. 2, 15 – main draining profile 1

Table II The working parameters of the O-TOF ICP MS analysis

Parameter	Value	Parameter	Value
Ion optics		Pulse shaping	
Skimmer	–1 200 V	Fill	–35 V
Extraction	–950 V	Fill bias	0 V
Z1	–850 V	Fill grid	0 V
Y mean	–245 V	Pushout grid	–445 V
Y deflection	0 V	Pushout plate	565 V
Z lens mean	–1150 V	Blanker	200 V
Z lens deflection	0 V	Spectral frequency	33 kHz
Lens body	–165 V	Reflectron	690 V
Detection		Plasma	
Multiplier gain	2400 V	Plasma power	1 200 W
Ion threshold	8.4 mV	Nebulizer gas flow	0.75 l min^{-1}
Integration window	Auto	Plasma gas flow	10 l min^{-1}
Measurement	Pulse	Auxiliary gas flow	0.8 l min^{-1}
Mode	Counting/analog	Sample flow rate	1.5 ml min^{-1}
Measurement		Mode	Peak area
Acquisition	5 s	Replicates	10

Materials and Methods

Immediately after sampling, samples were acidified — 1 ml concentrated HNO_3 was added to each 100 ml of sample in order to stabilize analytes. Samples were filtered (nitrocellulose filter 0.22 μm, Millipore, Merck, Germany) and the internal standard Rh was added. Samples with a higher content of uranium expected (e.g., raw water) were diluted. Analysis of sample was performed using the oTOF-ICP-MS spectrometer (Optimass 8000, GBC, and Australia). For calibration standards preparation, the single element stock solution of uranium in concentration of 10 ± 0.02 g l^{-1} (SCP Science, Canada) and demineralised water were used. Calibration range was from 0.5 to 20 μg l^{-1}, each calibration standard was stabilised by

subboiled concentrated HNO_3 (1 ml to the final volume of 100 ml). Rh was used as an internal standard at the concentration level of 5 μg l^{-1} (diluted form 1 ± 0.002 g l^{-1}, SCP Science, Canada).

ICP-MS method

The operating conditions of the ICP-MS analysis (Table II) were adjusted to compromise a sensitivity and resolution of the instrument for ^{238}U as well as to obtain the minimal LaO^+/La^+ and UO^+/U^+ ratios. The sensitivity of 40000 counts s^{-1} for 1 μg l^{-1} (mass integrated peak) and resolution of 1500 was reached for ^{139}La. For ^{238}U (1 μg l^{-1}), the intensity 50000 counts s^{-1} and resolution 1600 was obtained. The mass calibration was achieved using responses from ^{7}Li, ^{114}In and ^{238}U. The peak area mode, 5 s data acquisition time and 10 replicates were used for measurement.

The most abundant isotope ^{238}U and the sum of isotopes were used for measuring using the ICP-MS method. As the internal standard, the isotope ^{103}Rh (5 μg l^{-1}) was used. The limit of detection was evaluated as a concentration of triple standard deviation of the signal obtained by measuring of blank, and its value was 0.009 μg l^{-1}. During analysis, the control sample (the uranium standard 5 μg l^{-1}) was used after each 5 samples to check quality of analysis. The normalisation of the method was carried out after each 20 analyses.

Results and Discussion

The above-mentioned method was used for uranium determination in 67 samples of water. Forty seven samples originated from the polluted area of Licoměřice and surroundings, 20 samples were from the unpolluted control areas in the East Bohemia and the Northern Moravia.

The results were statistically evaluated (Statistica 10, Statsoft CR, Czech Republic). In total, 67 samples were analysed. The minimal concentration found is given by the limit of the detection, i.e., 0.009 μg l^{-1}. The maximal amount of uranium was found in the sample from a sedimentation tank in the mine water purifier, and this concentration reached 6080 μg l^{-1}. The mean value was 139, median 0.075 and modus 0.009 μg l^{-1}. The standard deviation was found 772 μg l^{-1}. The skewness 7.256 and kurtosis 55.42 significantly differed from values typical for the normal distribution. The concentrations of uranium found for all samples are summarized in the Table III with the exception of samples No. 51-76 from unpolluted areas in the Eastern Bohemia where the uranium was undetectable.

The results were compared with the legislation in force as discussed below

Table III Concentrations of uranium found

No.	Location	c*, μg l^{-1}
1	Stará Ves 185, Rakovi	2.53 ± 0.15
2	Karviná - Mizerov, Poutní 353/1, Buchtovi	0.0750 ± 0.0056
3	Loukov 227, Kučerovi	0.334 ± 0.028
4	Licoměřice, Sýkora's pond 1a	0.0640 ± 0.0055
5	Licoměřice, Sýkora's pond 2a	0.009**
6	Licoměřice, Sýkora's pond 3a	1.60 ± 0.11
7	Licoměřice, stream in a forest 1	2.54 ± 0.19
8	Licoměřice, stream in a forest 2	0.0540 ± 0.0042
9	Vápenka 1a	0.151 ± 0.010
10	Stream flowing from Vápenka 1	0.395 ± 0.029
11	Stream flowing from Vápenka 2	1.82 ± 0.11
12	Vápenka 1b	0.243 ± 0.18
13	Vápenka 2	0.009**
14	Licoměřice 39, Hanzlíkovi	0.009**
15	Licoměřice 30, Zumrovi 1	0.009**
16	Licoměřice 30, Zumrovi 2	0.009**
17	Licoměřice, before the gate of Mine water purifier	0.170 ± 0.0092
18	Licoměřice 53, Vášovi	0.009**
19	Licoměřice, Sýkora's pond 3a	0.625 ± 0.049
20	Licoměřice, Sýkora's pond 3b	0.009**
21	Licoměřice 11, Jiráková	0.009**
22	Licoměřice, sedimentation tank No. 0a	60804 ± 357
23	Licoměřice, sedimentation tank No. 0b	1690 ± 93
24	Licoměřice, TJ 56, raw water 1	268 ± 12
25	Licoměřice, TJ 56, raw water 2	412 ± 22
26	Licoměřice, sedimentation tank No. 1	738 ±39
27	Licoměřice, sedimentation tank No. 2	0.009**
28	Licoměřice, HVP 1	0.009**
29	Ronov nad Doubravou, Kurvice river	0.009**
30	Ronov nad Doubravou, Doubrava before Kurvice inflow	0.009**
31	Ronov nad Doubravou, Kurvice before outflow to Doubrava	5.24 ± 0.39
32	Ronov nad Doubravou, Doubrava 1	3.08 ± 0.13
33	Ronov nad Doubravou, Doubrava 2	0.217 ± 0.018
34	Ronov nad Doubravou, Lovětín's stream	0.251 ± 0.014
35	Ronov nad Doubravou, pond "Horní rybník" 1	0.208 ± 0.012
36	Ronov nad Doubravou, pond "Horní rybník" 2	0.166 ± 0.0089
37	Tuchov, fire tank	18.7 ± 1.2
38	Tuchov, Kurvice HVP č.2a	7.82 ± 0.52
39	Tuchov, Kurvice HVP č. 2b	10.2 ± 0.51
40	Licoměřice, HVP1	15.2 ± 0.70
41	Licoměřice, drain to Kurvice river	10.4 ± 0.48
42	Licoměřice, Kurvice river	23.5 ± 0.99
43	Licoměřice, Sýkora's pond 1b	3.69 ± 0.14
44	Licoměřice, Sýkora's pond 2b	0.732 ± 0.030
45	Licoměřice 24, Popková 1	0.262 ± 0.010
46	Licoměřice, Sýkora's pond 1c	0.787 ± 0.032
47	Licoměřice, Sýkora's pond 2c (after the rain)	0.768 ± 0.040
48	Licoměřice, Sýkora's pond 2d (after the rain)	0.009**
49	Licoměřice, Sýkora's pond 3b (after the rain)	0.721
50	Licoměřice 24, Popková 2	0.009**

* concentration is expressed as a mean value ± standard deviation

** LOD – the limit of detection 0.009 ng l^{-1}

in the next part belonging to individual sampling places. According to the Government resolution No. 23/2011, the imission limit allowed for the contami- nation with uranium in surface water is 40 μg l^{-1} [11]. Emission limits for uranium are specified in the resolution of the State office for nuclear safety [12]. The limit of the detection for the method is 0.009 μg l^{-1}. This value is deeply bellow legislative restrictions.

Control Samples

The control samples from the unpolluted areas in the Eastern Bohemia were analysed as a natural background in the Czech Republic. All these samples (No. 51-67) contained no detectable amount of uranium, i.e., less than 9 ng l^{-1}. For comparison, three locations were sampled in the Moravia. Sample No. 1 from Stará Ves near Přerov contained 2.53, the sample No. 2 from a private well in Karviná 0.0750 and the sample No. 3 a from private well in Loukov near Kroměříž 0.334 μg l^{-1} of uranium. This pollution may be caused by inhomogeneous subsoil in the area, by an industrial and anthropogenic load and mining industry in this area or by using fertilizers close to sources of drinking water. These results correspond with the study of Halata *et al.* dealing with uranium in drinking water in the Olomouc region [5].

Content of Uranium in Direction of Water Flow

The highest concentrations of uranium were found in the samples from the mine water purifier in Licoměřice. The sample No. 22 was taken from the sedimentation tank No. 0 in the mine water purifier in Licoměřice and contained 6080 μg l^{-1} of uranium. The value of the emergency level in Licoměřice given by the resolution of the State Office for Nuclear Safety is 0.300 mg l^{-1} [12]. Therefore, the mentioned sample exceeded the emergency level more than 20 times. The sample No. 23 taken in the same sedimentation tank on the other side than the sample No. 22 contained significantly lower concentration (1690 μg l^{-1}). This sample also exceeded the emergency level more than 5 times. It is important that these values are not troublesome because they correspond to the uranium decontamination process. The sedimentation tank No. 0 has not been in operation since 2000 when the new decontamination station was turned on. The samples No. 24 and 25 came from the mineshaft in the decontamination station of the mine water purifier. The sample No. 25 contained 412 μg l^{-1} of uranium and exceeded emergency level. The sample No. 24 contained 268 μg l^{-1} of uranium and exceeded the investigation level 110 μg l^{-1}[12]. The Sample No. 26 was taken in the next step of the cleaning process, in the decontamination tank No. 1 of the mine water purifier in Licoměřice. It contained 738 μg l^{-1} of uranium and exceeded the emergency level

more than two times [12]. In other samples, which were taken in the area of the mine water purifier gradually during cleaning process, lower concentrations of uranium were found.

In the samples originating from river Kurvice immediately behind the mine water purifier, in the mine draining profile No. 1, uranium content exceeded the recording level. For example, the sample No. 17 was taken in river Kurvice before the gate of the mine water purifier. It contained 0.170 μg l^{-1} of uranium. The sample No. 42, which was taken in river Kurvice behind the mine water purifier contained 23.5 μg l^{-1} of uranium and exceeded the above-mentioned recording level. This fact shows the possible loading of the aquatic ecosystem of the river Kurvice by the mine water purifier. Other samples were taken in the next village Tuchov remote about 2 km from the main draining profile No. 1 (the sample No. 38) and in the mine draining profile No. 2 (the sample No. 39). The samples contained 7.82 and 10.2 μg l^{-1} of uranium [12]. In village Tuchov, the sample No. 37 was taken. It should not be influenced by the mine water purifier, but it also contained a trace amount of uranium exceeding the recording level. The sample No. 31 was taken from river Kurvice right before it flows into river Doubrava in Ronov nad Doubravou. Uranium content in this sample was lower than the legislation limit. No measurable amount of uranium was detected in the sample, which was taken in the junction of rivers Kurvice and Doubrava. The sample No. 32 was taken about 3 m from this junction, from river Doubrava and this sample contained only 3.08 μg l^{-1} of uranium. The last sample from the journey of river Kurvice from mine water purifier was taken in river Doubrava about 20 m from the confluence with Kurvice and contained rapidly lower concentration of uranium, namely, 0.217 μg l^{-1}. Most of these places are regularly monitored by the state enterprise DIAMO. None of the analysed samples exceeded the limit 40 μg l^{-1} [11].

Sýkora's Pond

Next samples were taken in the Sýkora's pond used as a fish farming pond: No. 43 and 44 during rain, samples No. 47, 48 and 49 after the rain and other samples were taken in the period without rain. The highest amount of uranium, 3.69 μg l^{-1} was found in the sample No. 43. The content of uranium in all samples from Sýkora's pond did not exceed the legislation limit 40 μg l^{-1} [11]. It can be concluded that this location is not significantly affected with the nearby former contamination from the uranium mining. Some low content of uranium is a natural part of water in this area and corresponds with geological subsoil. One of the important facts is that uranium can be accumulated in sediments and bodies of water animals. Therefore, it would be appropriate to reconsider fish farming activities in this pond with the view of evaluate potential health risks of consumers.

Water in Licoměřice

In the area of Licoměřice, samples from wells of local people, from garden ponds and from public water supply were also taken. The only measurable content of uranium was in the sample from public water supply (0.262 μg l^{-1}). The public water supply is managed by the company Water and sanitation, Chrudim. It will be appropriate to consider an implementation of any additional monitoring of the uranium content in the public water supply in Licoměřice, although the Announcement No. 252/2004 does not define the immission limit for the uranium content in drinking water. The Binding Recommendation of Public Health Chief is only in force in the Czech Republic now.

Conclusion

In comparison with the analytical procedures for the determination of uranium discussed in literature, the method achieves considerably higher sensitivity and detection capabilities (0.009 μg l^{-1}). It also has less demand on preparation of the sample for analysis, which leads to a significant reduction of the entire analytical procedure. In terms of monitoring the concentration of uranium in the area, the research provides interesting information.

The highest concentration of uranium was found in water samples taken in the mine water purifier in Licoměřice. These values are not alarming, because the samples were taken in the sedimentation tanks during the process of decontamination. According to the Resolution of The State Office for Nuclear Safety there are three levels of immission limits for the uranium content in water: the recording level (10 μg l^{-1}), the investigation level (110 μg l^{-1}) and the emergency level (300 μg l^{-1}) [12]. Ten samples exceeded the recording level, five samples exceeded the investigation level and four samples were above the emergency level. According to the Government resolution No. 23/2011, only samples, which were taken in grounds of the mine water purifier in Licoměřice exceeded the permissible limit value of pollution of the surface water with uranium (40 μg l^{-1}) [11]. Samples from Sýkora's pond meet all the requirements of imission limits, nevertheless we can express the assumption that the uranium content in Kurvice river and associated flows is affected by recultivated uranium ore and also by the mine water purifier. There can also be observed some dilution mechanisms, in terms of uranium content in the river Kurvice and Doubrava.

Due to the uranium concentration in the downstream flow found under the imission limit and the decreasing trend of uranium concentration in water samples taken during the cleaning process in mine water purifier, it can be concluded that the recultivation and remedial measures of the state enterprise DIAMO in the former uranium mine are successful. However, there is a scope for further

monitoring of the uranium content in water, especially in the Kurvice river and river basin and Sýkora's pond.

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