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A review of uraniferous and other waste at mining and waste sites in CR

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1. INTRODUCTION

Uranium mining is currently stopped in the Czech Republic and there are no active mines in the Czech Republic. Nevertheless, these inactive mining complexes are a source of both pollution and potential strategic materials, especially heavy metals. These heavy metals are toxic in the environment and must be removed from the water. Therefore, water treatment technologies have been installed at all mines. All major uranium mining sites are managed by DIAMO, as are some other mineral mines. Within the framework of the project, sites were selected for initial sampling in cooperation with DIAMO experts.

During each sampling event, samples of mine water, samples from the various water treatment technologies, sludge, and biological samples (plants, roots, etc.) that could be contaminated with heavy metals were collected. The objective of this action was to complete the screening of mine waters, to describe the basic chemical parameters and to analyze the heavy metal concentrations in these waters.

Based on these analyses, a total of 6 sites were selected. Experiments have been initiated to recover these strategic materials and, where appropriate, improve existing technologies to help reduce the impact of contamination from mining activities.

Basic parameters measured at each site during water sampling were temperature (T), pH, oxygen concentration (O_2), oxidation-reduction potential (ORP) and conductivity (C). The sample designation is the abbreviation of the site, whether it is a water (W) or solid sample (SL), and the last number refers to the date of collection.

2. Zlaté Hory

The first references to panning and shallow gold mining date back to the 13th century, while from the 16th century onwards, deep mining of gold, Cu, Pb and Ag ores was developed, and at the end of the 19th century, mining of Fe ores also took place. The modern history began in 1952 with drilling exploration of the Zlaté Hory (hereinafter ZH)-South and ZH-Hornické skály copper deposits, the ZH-East Cu, Pb, Zn, Ag ore deposits and the ZH-West Cu, Pb, Zn, Au ore deposits. Mining began in 1965 at the ZH-South deposit, in 1981 at the ZH-Hornické skály deposit and in 1988 at the ZH-East polymetallic deposit.

Mining of the monometallic Cu deposits was terminated on 30 June 1990 and on the ZH-East deposit on 30 June 1992. Mining of the ZH-west polymetallic deposit (mainly Au, less Cu and Zn) was carried out in 1990-1993. A total of 7 184.4 kt of ore was extracted, of which 6 412.8 kt from the monometallic deposits, 127.9 kt from the ZH-east polymetallic deposit and 643.7 kt from the ZH-west polymetallic deposit. The deposits were opened by 4 pits, 14 adits, 4 decline pits and 11 chimneys. The area of the two mining areas was 3.1 km^2. The current area of the ZH-East mining area is 0.137 km^2. Mining was carried out by means of deep mining of non-ferrous metal ores and gold; the mining method - open chamber with a flat bottom. The ore was processed in a local flotation plant into concentrates.

In the years 1990-2005, liquidation works were carried out at the ZH-South and ZH-Hornice rocks monometallic deposits, followed by the liquidation of the ZH-East polymetallic deposit, the liquidation of the mine and the open pit area at the ZH-West polymetallic deposit and the liquidation of the Auxiliary and Mining Pits. Pit 3 remains unliquidated. The initial decline pit has been reopened for development activities.

Mine water is discharged into a dewatering gallery where lime milk is added to the surface and fed into a flocculation tank. The mine water is discharged from the mine water treatment plant into Zlaty Potok.

Table 1: Onsite analysis of Zlaté Hory samples

Sample	T [°C]	pH	O_2 [mg/l]	ORP [mV]	C [µS/cm]	Description
ZH-W1-230627	8,6	4,8	10,29	330,7	568	runoff from drainage shafts - mixture from mine shafts
ZH-W2-230627	9,2	9,1	10,01	105,6	660	runoff from the drainage shaft after mixing with lime - mixture from mine shafts
ZH-W3-230627	10,7	9,3	8,5	95	670	sludge from the flocculation tank
ZH-W4-230627	10,9	7,5	10,20	-37	218	water outflow from the tailings pond
ZH-SL4-230627	---	---	---	---	---	sludge from tailings
ZH-SL5-230627	---	---	---	---	---	boreholes from the tailings, two samples were taken: ZH03-04; ZH03-06,
ZH-W6-230816	8.8	7.4	10.58	154.7	1221	water dripping from the borehole in the tunnel ceiling forms a greenish precipitate (Cu) on the wall, Zlaté H. - East
ZH-W7-230816	7.6	7.7	10.75	282	325	water Bramborarka, pit 3, mixed water (Cu/Au)
ZH-W8-230816	8.1	4.6	9.59	375.5	403	Zlaté Hory - South
ZH-W9-230816		9.31	236.7	1351	3.07	Zlaté Hory - West

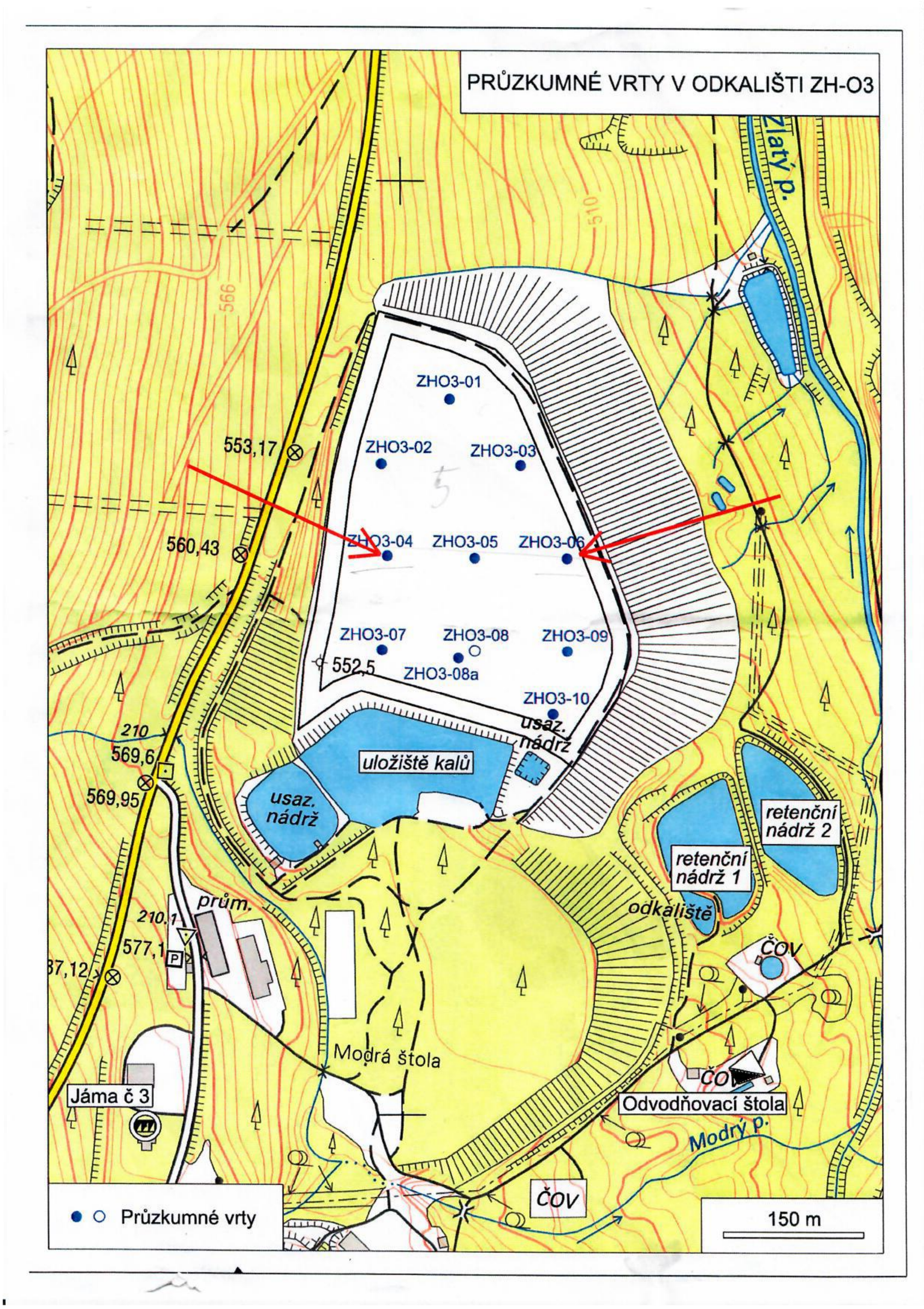

Figure 1: Zlate Hory tailings and surroundings

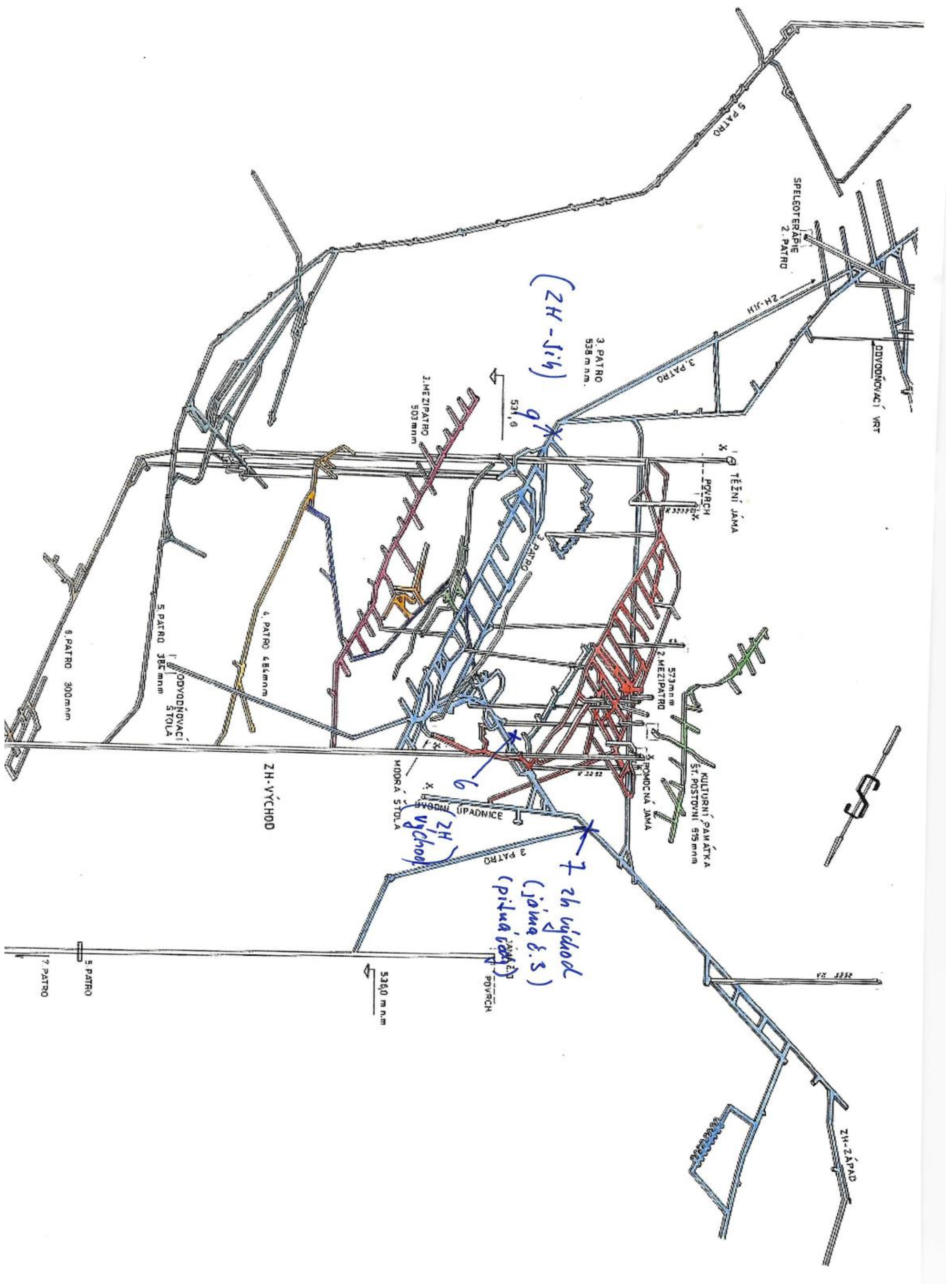

Figure 2: Scheme of Zlate Hory sampling sites (part 1)

Figure 3: Scheme of Zlate Hory sampling sites (part 2)

Table 2: Chemical analysis of Zlaté Hory water samples

Element [mg/l]	ZH-W1-230627	ZH-W2-230627	ZH-W3-230627	ZH-W4-230627	ZH-W6-230627	ZH-W7-230627	ZH-W8-230627	ZH-W9-230627
Cd	0.029	0.028	0.633	0.003	0.022	0.002	0.061	0.016
Be	0.000	0.000	0.006	0.000	0.000	0.000	0.001	0.000
Se	0.065	0.033	0.105	0.109	0.013	0.001	0.002	0.015
As	0.085	0.061	0.245	0.058	0.009	0.000	0.006	0.025
Cu	3.343	3.047	104.652	0.026	0.774	0.004	1.33	18.7
Cr	0.000	0.000	0.106	0.000	0.000	0.000	0.005	0.020
Ni	0.064	0.047	1.396	0.011	0.010	0.003	0.060	0.147
Pb	0.007	0.001	0.340	0.012	0.023	0.010	0.049	0.073
Fe	4.552	4.144	145.434	33.231	0.594	0.012	13.0	34.4
Sb	0.015	0.026	0.065	0.026	0.000	0.002	0.001	0.006
Mg	24.206	21.950	125.433	47.835	28.0	6.78	13.3	33.8
Ca	76.043	139.667	748.489	174.693	113	32.0	28.9	80.1
Na	12.454	10.252	29.299	8.543	94.3	15.5	2.62	3.74
Mn	3.695	3.701	58.655	8.156	0.738	0.002	1.79	7.56
Al	5.067	4.994	168.534	0.125	0.785	0.020	10.0	26.5
Ag	0.001	0.001	2.279	0.002	0.000	0.000	0.003	0.006
Ti	0.000	0.012	0.239	0.000	0.00	0.00	0.00	0.00
V	0.003	0.004	0.009	0.000	0.001	0.000	0.001	0.002
Co	0.093	0.085	2.136	0.027	0.013	0.000	0.030	0.256
Zn	7.006	6.327	192.563	0.298	5.10	0.306	15.4	2.90
Mo	0.007	0.002	0.012	0.000	0.00	0.00	0.00	0.00
Tl	0.001	0.006	0.000	0.026	0.00	0.00	0.00	0.00
Sn	0.140	0.024	0.128	0.110	0.00	0.00	0.00	0.00
Sr	0.218	0.227	0.575	0.359	0.00	0.00	0.00	0.00
Ba	0.052	0.043	0.198	0.040	0.00	0.00	0.00	0.00
K	1.744	2.590	4.071	3.663	2.42	0.826	1.29	0.941

Table 3: Chemical analysis of Zlaté Hory solid samples

Element [mg/kg]	ZH-SL5-230628	ZH-SL4-230628
Cd	8.8	33.9
As	63.1	147.7
Cr	662.1	2669.5
Pb	21.6	9.9
Fe	25.2	--
Mg	549.5	2584.2
Ca	39646.4	66702.9
Na	8771.4	5694.2
Mn	8688.2	11388.3
Al	844.3	765.6
Zn	9657.8	5024.3
K	14.4	--

3. Stráž pod Ralskem

Mining took place between 1968 and 1996. Chemical uranium mining was carried out on the deposit - the method of underground leaching of uranium ore by drilling from the surface - acid leaching (leaching agent: H_2SO_4, oxidizing agent: HNO_3). A total of 37 leaching fields were established on an area of 745.1 ha. The area of the leach pad is 27.3 km^2. A total of 15 861.8 t of uranium was extracted during the period of chemical mining. The uranium ore deposit is located at a depth of around 220 m below the surface. During the mining 4.1 million tonnes of H_2SO_4, 320 thousand tonnes of HNO_3, 112 thousand tonnes of NH_3, 26 thousand tonnes of HF and 1.5 thousand tonnes of HCl were injected underground. A large number of technologies are used to remediate mine water. For example, the flow of contaminated water through the ionic exchanger, where uranium is removed from the water and then deposited in the form of a yellow cake. Yet the water that flows out of the nearly 30-metre columns is still full of metal ions.

Table 4: Onsite analysis of Stráž pod Ralskem samples

Sample	T [°C]	pH	O2 [mg/l]	ORP [mV]	C [µS/cm]	Description
SR-W1-230808	15.30	2.16	8	371	21.9	Outflow from the SKLR column
SR-W2-230808	15.1	2.53	8.3	358	12.5	Outflow from the NDS column

Table 5: Chemical analysis of Stráž pod Ralskem samples

Element [mg/l]	SR-W1-230808	SR-W2-230808
Ag	0.00	0.00
Al	5331.45	2648.02
As	4.73	2.70
Ba	0.02	0.02
Be	0.85	0.45
Ca	216.86	148.24
Cd	0.41	0.29
Co	9.79	5.04
Cr	11.15	5.35
Cu	0.57	0.10
Fe	1665.33	632.02
K	57.82	34.24
Mg	65.05	47.22
Mn	28.56	10.04
Mo	0.16	0.08
Na	32.45	14.39
Ni	25.63	14.14
Pb	0.12	0.14
Sb	0.01	0.00
Se	0.05	0.02
Sn	0.01	0.01
Sr	14.47	11.34
Ti	2.87	1.30
Tl	1.15	0.63
V	14.40	7.77
Zn	67.56	41.92

4. Kutná hora - Kaňk

The origins of mining in this locality date back to the second half of the 13th century. Previously, the mines in this locality were the main source of silver - up to 14.56 tonnes per year. Silver mining continued here until the 19th century. Later, mining of other ores such as sphalerite and chalcopyrite became more prevalent. Modern mining was resumed after 1945 and ceased in 1991. The main mining and hauling pits were the Turkaňk pit, the Pánská pit, the initial pit of 14 Helpers and the Skalecká pit. In the period 1958-1991, a total of 2,230.7 kt of ore with a metallic grade of 2.0% Zn (44,624.98 t Zn) was mined. The deposit has recorded non-bilant reserves of polymetallic ore of 861 kt of Zn. The mine was liquidated, the underground flooded and the surface partially reclaimed. Removal of redundant buildings and rehabilitation of the site is ongoing. Mine water is pumped through boreholes at the Turkaňk pit to the surface, where a mine water treatment plant is operated on site. Highly contaminated and acidic mine water is pumped to the mine water treatment plant, which contains aeration tanks, retention tanks for mixing with lime milk and flocculation tanks. Leachate from the Skalka adit is also discharged to the Šífovka River, and from the 14. Pomocníků adit to the Beránek River.

Table 6: Onsite analysis of Kaňk samples

Sample	T [°C]	pH	O_2 [mg/l]	ORP [mV]	C [µS/cm]	Description
KH-W1-230628	16.8	4.0	4.68	251.3	6070	Inlet to the aeration tank
KH-W2-230628	28.2	5.5	6.93	96.5	5790	The first retention tank
KH-W3-230628						Second retention tank
KH-W4-230628	19.2	9.1	7.17	45.6	5510	Outlet from the purifier
KH-SL5-230628	---	---	---	---	---	Compressed sludge

Table 7: Chemical analysis of Kaňk samples

Element [mg/l]	KH-W1-230628	KH-W1-230628	KH-W4-230628
Cd	0.16	0.09	0.00
Be	0.01	0.01	0.00
Se	0.16	0.20	0.21
As	45.80	49.48	0.38
Cu	0.10	0.05	0.02
Cr	0.03	0.03	0.00
Ni	0.03	0.04	0.00
Pb	3.30	3.23	0.03
Fe	1502	1502	11.9
Sb	0.04	0.01	0.01
Mg	201	197	119
Ca	478	904	966
Na	104	101	101
Mn	32.15	31.34	0.40
Al	4.12	4.05	0.24
Ag	0.31	0.31	0.00
Ti	0.00	0.02	0.01
V	0.03	0.03	0.00
Co	0.02	0.02	0.00
Zn	116	107	0.78
Mo	0.07	0.07	0.00
Tl	0.06	0.02	0.04
Sn	0.05	0.09	0.06
Sr	0.85	1.06	0.87
Ba	0.03	0.04	0.01
K	15.79	15.88	15.74

Table 8: Chemical analysis of KH-SL5-230628 sample

Element [mg/kg]	KH-SL5-230628
Cd	7.3
As	6875.1
Cr	5.5
Pb	404.6
Fe	216776.0
Mg	12073.9
Ca	94098.9
Na	332.8
Mn	4312.9
Al	1170.7
Zn	14623.7
K	162.5

5. Jáchymov

Silver mining took place in the area as early as the 16th century and lasted until the 19th century. In the 20th century a large amount of uranium was mined here (the third largest deposit in the Czech Republic). The entire deposit is located on the southeastern slope of the Ore Mountains. The Jáchymov uranium deposit is a set of eight deposit sections: the Abertamy section, the Barbora - Eva section, the Rovnost - Eduard - Eliáš section, the Nikolaj - Klement section, the Svornost section, the Panorama - Mariánská section, the Bratrství - Plavno section and the Popov section. The deposit is a hydrothermal medium-temperature uranium ore deposit. A large part also contains a deposit of the five-element formation (U, Ag, Bi, Ni, Co). In total, 2.270 million tonnes of ore have been mined in the Jáchymov area of 29.79 km^2, of which 7,950 tonnes of uranium have been extracted through the deposition of uranium ore gravity tailings. The sealing of the deposit took place between 1964 and 1965. Today, most of the pits are covered with reinforced concrete slabs and possibly backfilled with unsorted rubble from the tailings. In addition, the Svornost pit is used for spa purposes or the Št-2 adit is used as a radioactive waste repository.

The mine water discharge is now stabilized and the water is discharged without treatment, but is monitored regularly.

Table 9: Onsite analysis of Jachymov samples

Sample	T [°C]	pH	O_2 [mg/l]	ORP [mV]	C [µS/cm]	Description
JZ-W1-230726	11.6	7.1	10.25	169.5	230	drainage system (cascade) from the tailings. Drainage from Elias + seepage
JZ-W2-230726	9.2	7.6	10.37	44.5	518	Inflow to the drainage system

Table 10: Chemical analysis of Jachymov samples

Element [mg/l]	JZ-W1-230726	JZ-W2-230726
Cd	0.00	0.00
Be	0.00	0.00
Se	0.01	0.02
As	0.02	0.10
Cu	0.01	0.01
Cr	0.00	0.00
Ni	0.01	0.01
Pb	0.00	0.00
Fe	0.06	1.17
Sb	0.00	0.00
Mg	4.02	16.66
Ca	11.79	76.39
Na	5.68	5.66
Mn	0.01	0.49
Al	0.03	0.03
Ag	0.00	0.00
Ti	0.00	0.00
V	0.00	0.00
Co	0.00	0.00
Zn	0.12	0.07
Mo	0.00	0.00

Tl	0.01	0.01
Sn	0.00	0.00
Sr	0.08	0.30
Ba	0.02	0.02
K	1.10	3.73

6. Zadní Chodov

The history of the area dates back to the 15th century, where there were deposits of silver, lead and copper ores. A uranium deposit was discovered here in 1952 and mining began in the same year. The mine was closed in 1992 and subsequently flooded uncontrollably in 1995. The mines are located at an altitude of 550 - 650 m above sea level. The deposit area covers an area of 7.16 km^2 and 1990 thousand tonnes of ore with a total quantity of 4150 tonnes of uranium were extracted by deep uranium mining - the method of outcrop mining with its own base and descending caving to the cave under an artificial ceiling.

Mine water is treated by the standard process: barium chloride precipitation, sedimentation, filtration and uranium sorption on ion exchange. Since 2012, a wetland has been constructed for biological treatment.

Table 11: Onsite analysis of Zadní Chodov samples

Sample	T [°C]	pH	O_2 [mg/l]	ORP [mV]	C [µS/cm]	Description
ZC-W1-230726	17.3	7	3.4	-61.1	662	Runoff from boreholes from flooded shafts
ZC-W2-230726	17.8	7.6	7.7	67	649	Drainage from an artificially created wetland to remove pollutants

Table 12: Chemical analysis of Zadní Chodov samples

Element [mg/l]	ZC-W1-230726	ZC-W2-230726
Cd	0.00	0.00
Be	0.00	0.00
Se	0.02	0.01
As	0.02	0.02
Cu	0.01	0.00
Cr	0.00	0.00
Ni	0.00	0.00

Pb	0.01	0.01
Fe	1.36	0.26
Sb	0.00	0.00
Mg	28.25	27.57
Ca	72.57	70.45
Na	36.94	39.18
Mn	2.01	0.39
Al	0.02	0.06
Ag	0.00	0.00
Ti	0.00	0.00
V	0.00	0.00
Co	0.00	0.00
Zn	0.00	0.00
Mo	0.00	0.00
Tl	0.02	0.01
Sn	0.02	0.01
Sr	0.48	0.47
Ba	0.03	0.02
K	3.82	3.91

7. Horní Slavkov

Mining activity in this area dates back to the 13th century, when tin deposits were discovered here. After the Second World War, uranium deposits were found here and were mined until 1962. Horní Slavkov is a collection of nine sections: Nadlesí, Vlčí, Bošířany, Pichtova Hora, Zdař Bůh, Barbora, Leznice, Svatopluk and Krásná. There were 26 pits, 33 adits and 2 spoil heaps. The area of the mining area covered 21.7 km². 2,668.3 t of uranium was extracted by means of deep uranium mining - the outcrop method with its own base. The ore was processed at the Eliáš gravity treatment plant, Bratrství and at the chemical treatment plant in Nejdek.

A drainage system was built to drain contaminated mine water, which is fed to a treatment plant that begins with aeration tanks and the addition of calcium hydroxide suspensions. After aeration, the water is fed into rapid mixing sumps where a solution of barium chloride and flocculating agent is added. The water then enters the slow mixing sumps from where it overflows into the settling tanks. The technology removes suspended solids, Ra, U, heavy metals and metallic elements from the water. The treated water is monitored and discharged into a watercourse.

Table 13: Onsite analysis of Horní Slavkov samples

Sample	T [°C]	pH	O_2 [mg/l]	ORP [mV]	C [µS/cm]	Description
HS-W2-230726	11.5	6.3	4.23	39	442	outflow from adit 13
HS-W3-230726	15.4	6.6	8.47	147	1133	outflow from the tailings pond
HS-W4-230726	12.4	6.5	7.6	26	469	Barbora Mine - drainage tunnel. collection from all shafts. inflow to wastewater treatment plant

Table 14: Chemical analysis of Horní Slavkov samples

Element [mg/l]	HS-W2-230726	HS-W3-230726	HS-W4-230726
Cd	0.00	0.13	0.00
Be	0.00	0.01	0.00
Se	0.00	0.02	0.00
As	0.06	0.01	0.10
Cu	0.01	0.13	0.00
Cr	0.00	0.00	0.00
Ni	0.00	0.14	0.01
Pb	0.01	0.01	0.02
Fe	5.88	0.72	11.32
Sb	0.00	0.00	0.00
Mg	12.69	42.34	19.08
Ca	27.65	143.21	43.40
Na	13.61	13.41	15.69
Mn	0.91	16.54	2.02
Al	0.02	2.93	0.07
Ag	0.00	0.00	0.00
Ti	0.00	0.00	0.00
V	0.00	0.00	0.00
Co	0.00	0.26	0.00
Zn	0.01	41.81	0.20
Mo	0.00	0.00	0.00

Tl	0.01	0.00	0.01
Sn	0.01	0.01	0.02
Sr	0.19	0.54	0.28
Ba	0.04	0.04	0.03
K	3.70	14.89	5.04
Li	0.06	0.45	0.11

8. CONCLUSION

The analyses carried out showed interesting contents of the monitored elements at the six selected sites. These localities became the subject of further research using the proposed methods.