Mine Waste Pile Jazbec Latest View of Groundwater Findings

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Abstract

Zirovski Vrh Uranium Mine started ore production in 1982. The Government of the Republic of Slovenia ceased production activities by decree in 1990. During this short lifetime the mine produced 630,000 ton of ore with average uranium content of 850 gU_3O_8/ton and 40,000 ton of poor ore with average content from 150 to 280 gU_3O_8/ton.

All mine waste materials including building debris, contaminated equipment and soil will be stored at the central mine waste pile Jazbec, sited next to the main mine entrance P-11. There was a narrow branched out ravine, originally with small-branched torrent. Individual small torrents flowed into a concrete culvert on one side and into a PEHD pipeline on the other side. These flows were incorporated in one concrete tunnel of 2 m^2 cross section. Small springs and local swamps were drained into this tunnel. During the depositing of the mine waste uncaptured water was covered with material. During production these drainage features were damaged, especially plastic pipelines.

When remediated there will be 1.6 M tons of mine waste stored. The plan is to cover the pile with engineered multi-layer rock-soil cover to protect the material against erosion and to prevent leaching of the contaminants due to weathering.

This study shows numerous hydro-geological problems were met during remediation of the waste pile, including water inflows from the rock base into the pile. The water in waste pile forms separate polluted groundwater that partially inflows into the drainage tunnel and partially outflows into karstic channels beneath the pile and thereafter into the bottom of the Brebovscica valley. A strong karstic spring is polluted downstream which may be used as a as potential potable water source or for irrigation. Contaminants concentrations are lower due to dilution with water from other kar-

stic inflows into the monitored karstic channels system. This data is essential for long-term groundwater monitoring and system planning.

Introduction

The mine waste pile at Jazbec was constructed with the mine waste backfill of the Jazbec brook ravine. The Jazbec brook was before that captured and led into polyethylene pipes and further down into concrete culvert that dewaters two smaller torrents. The drainage pipes were connected to a concrete culvert with the purpose of removing ground water and protecting the waste pile body from the ground water. The mine waste was deposited in layers approximately 3 m thick; between two layers of red mud was deposited. The red mud was produced with neutralisation of acid raffinate during uranium concentrate production. From 1983 to 2003 1,716,000 ton of mine waste was deposited, 197,400 ton of poor ore and 48,000 ton of red mud. The area of the waste pile is 6.7 ha and has not been covered yet. The rainfall infiltrates into the pile without any hindrance. The mine waste pile was constructed with insufficient attention to the springs from the torrent banks and nearby hill slopes. Poor ore that was deposited on the bottom of the ravine also represents big problems; it is exposed to the impacts of the ground water now. Drainage pipes for groundwater removal and spring water removal as well were considerably damaged.

Hydrological Circumstances and Geological Description

The mine waste pile Jazbec is situated in the area of deep ravine of the Jazbec brook that flows in the northern part of the Zirovski Vrh ridge. The area is geologically disturbed; several thrusts, faults and different litho logical units are observed. This heterogeneity enabled formation of deep ravine that was cut into Upper Triassic limestone and dolomites. In the same area are present Carboniferous strata that are trusted onto Upper Triassic Rabelj formation Jul Tuval period and transitive strata than follows Main Dolomite that belongs to Norian period.

In the south side the mine waste covered part of Carboniferous strata, which are trusted onto Carnian limestone. Carbon strata are broken in the thrust zone. Weathered stratum thickness from three to six meters is typical for these. Carboniferous mudstones and sandstones among them are prevalent schist clays, which we classify into superposition unit c (Mlakar 1999). Flint and sericite prevail in mudstone strata (illite to muscovite). The quantity of quartz in lamellas varies and alternates with sericite. Presence of the carbonate is clear in the shape of dolomite with more or less iron, its presence in individual veins is big and we can talk about siderite. Among ore minerals we would like to call attention to pyrite, whose frequency varies and also its distribution is very irregular. We found pyrite in elongated nests in a shape of lumps and on the surface one can easily see cubic crystals of pyrite.

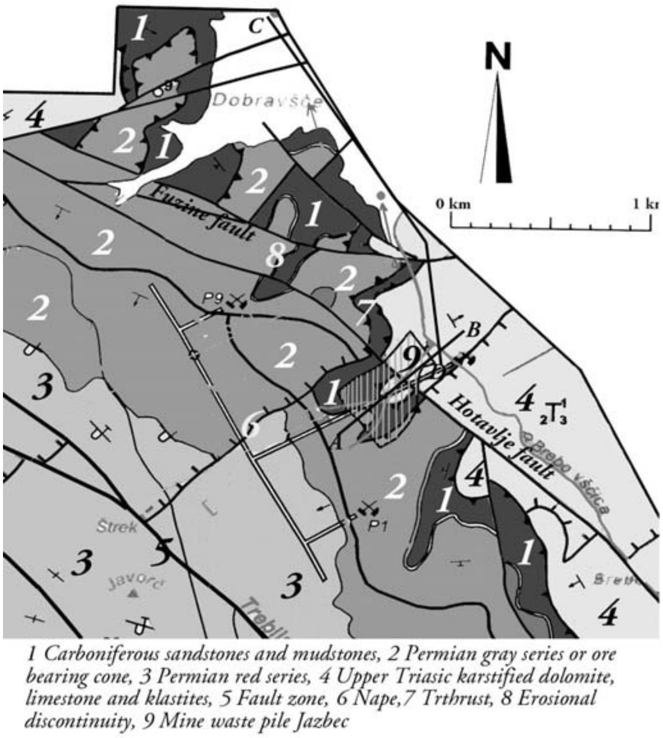
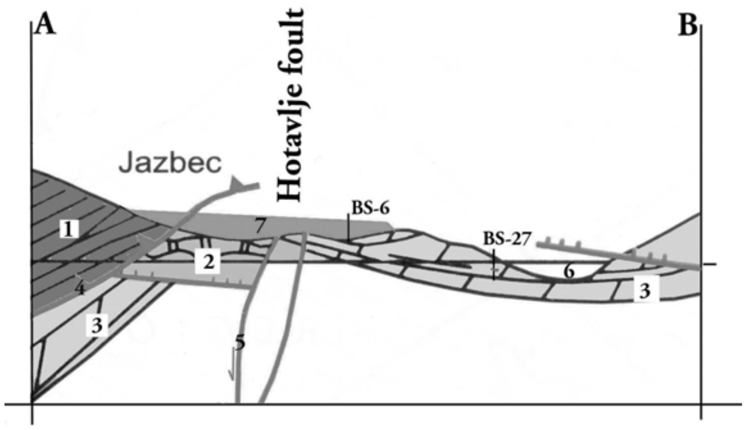


Fig. 1. Geological map of the mine waste pile Jazbec area (Mlakar 1999)

It is suggested that the fresh tectonic undamaged and un-weathered carboniferous schist are not water conductive (Novak 1977). However, our measurements of water permeability in fresh, undamaged rock show that the schist has low water permeability k = 1 10^{-7} to 1 10^{-9} m/s. With shallow boreholes and excavations in the upper part of the mine waste area it was found that carboniferous schist is very weathered, with thickness from 3 to 6 m. In this zone there exists connected groundwater with a stable level, which feeds numerous small springs, and marshes, which had been covered with mine waste backfill. Water bearing strata in weathered carboniferous schist contributes the largest water quantity that flows into mine waste pile in dry period.

The boundary among carboniferous strata, Upper Triassic clastites and limestone represents the trust zone. Right on this contact several springs and marshes were observed in the past. Between the trust of Carboniferous strata and Hotavlje fault in the rock base of the mine waste lie Carnian strata that are represented mainly by megalontide limestone carnian clastites above them we observe a stratum of carnian clastites. Grey megalontide limestone contains abundance of organic matter and it is demolished near Hotavlje fault. Carnian clastites are represented here in a shape of sandstone with jaspers. Carnian clastites have low water permeability and in them we can observe only crack porosity. Limestone has very good water permeability due to karstification. In them smaller karstic caves and springs in tectonic crushed zone near Hotavlje fault appears.



Legend to the figure: 1 Carboniferous schist and sandstone 2 Carnian limestone and clastites, 3 Norian karstificated dolomite, 4 Nape, 5 Fault, 6 Impermeable aluvial deposits, 7 Mine waste pile, 8 Weathered carboniferous schist, 9 Polluted water in the pile body

Fig. 2. Geological profile cross the mine waste pile (Mlakar 1999)

Transition from carnian strata into Norian dolomites is gradual. We put the boundary between Carnian and Norian strata in dolomite where we cannot observe inserted pieces of mudstone among dolomite strata. With regard to this we can attribute Upper Carnian considerable part of dolomite in the Northern part of Hotavlje fault that were observed in the tunnel P-10 (Mlakar 1999). The valley of the Brebovscica creek is built of Norian dolomites, in them we observe inter strata karstic channels, which interconnect into branched karstic channels parallel to the valley and are filled with water. The bottom of the valley of the Brebovscica creek is filled up with rough sands and gravel alluvial sediments.

Mine Waste Pile Jazbec

Water permeability coefficients of the mine waste were determined by Infiltration tests in the range from 2.4 10^{-4} to 3 10^{-5} m/s (Begus et al. 1992). Red mud exhibits permeability coefficients from 1 10^{-7} to 1 10^{-8} m/s. The lower part of the mine waste pile has low water permeability close by the rock base. This fact causes water to stagnate, which increases its contamination (Cades 1996).
In the mine waste pile and downstream in the valley of the Brebovscica brook we have continually observed groundwater since the year 1996 (Gantar 1996).

Table 1. Chemical composition of the mine waste and the poor ore

Element	Unit	Maximum	Minimum	Medium
Uranium	ppm	249	2	79
Thorium	ppm	40	5	13
Vanadium	ppm	98	11	31
Manganese	ppm	6670	50	795
Arsenic	ppm	89	1	13
Lead	ppm	2300	45	348
Zinc	ppm	10450	30	220
Cupper	ppm	688	20	111
Mercury	ppm	3	Traces	0.6
Cadnium	ppm	2.8	0.8	1.8
Silver	ppm	0.3	Traces	0.2
Chromium	ppm	350	> 100	203
Nickel	ppm	147	7	71
Cobalt	ppm	7.1	1.2	3
Selenium	ppm	43	7	31
Bismuth	ppm	10	> 10	> 10
Strontium	ppm	135	75	105
Molibdenum	ppm	21	0.2	3.2

The rainfall waters directly infiltrate into the mine waste pile from the waste's surface, rainfall water inflows into the mine waste pile from the slope areas around the waste pile and waters inflow from the springs and marshes which have been covered by the waste material (Brencic 2002). Total water outflow from the concrete drainage culvert was 200,000 m^3/a in year 2003 with average uranium concentration 503 mgU/m^3. Infiltrated rainfall waters flow into the waste pile where they are impeded and/or redirected by red mud layers. Due to that these waters flow longer toward the bottom of the pile and have higher uranium concentrations.

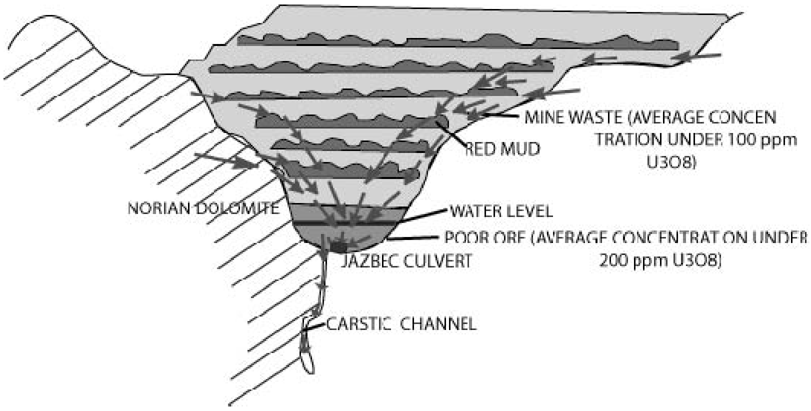


Fig. 3. Sketch of the mine waste pile Jazbec with water flows

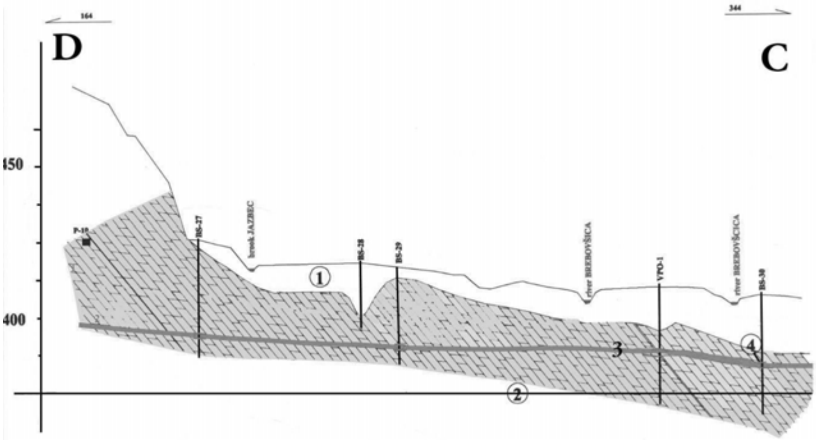
Table 2. Chemical composition of the red mud

Constituent	Unit	Value	Constituent	Unit	Value
Uranium	ppm	25	CO2	%	3.0
Thorium-230	Bq/kg	57500	Arsenic	ppm	1010
Protactinium-231	Bq/kg	1120	Cadmium	ppm	10
Radium-226	Bq/kg	490	Cobalt	ppm	200
Aluminium	%	2.3	Cupper	ppm	910
Calcium	%	17.6	Chromium	ppm	210
Kalium	%	0.1	Lead	ppm	470
Magnesium	%	2.0	Manganesse	ppm	6110
Potasium	%	0.5	Molibdenum	ppm	< 10
Iron	%	5.5	Nickel	ppm	117
Quartz	%	5.4	P2O5	ppm	8340
Sulphate	%	48.0	Strontium	ppm	517
CaCO3	%	6.3	Zink	ppm	1430
MgCO3	%	0.5	Vanadium	ppm	71

Six piezometers were used to monitor the levels within the waste pile until the end of 2003, namely: BS-6, BS-15, BS-16, BS-17 and BS-18. No significant change in lelvels within these piezometers was found. Groundwater was present at the bottom of the ravine; at a height of 5 m above the rock base in the lower part and only 2 m high at the higher part of the waste pile (Begus et al. 1997). Therefore the groundwater outflows from the waste pile in two ways.

Groundwater in the karstic water basin

A part of the groundwater inflows into the karstic cracks in the dolomite in the northern side of the Hotavlje fault. The connection between groundwater in the waste pile and the groundwater of the karstic water basin is proved only in the piezometer BS-27 that is situated in the Brebovscica brook valley. While drilling in the dolomite base a 2 m channel was found at a depth of 22 m. We found down water in piezometers BS-29, VPO-1 and BS-30 in similar depth a karstic channel with similar channel height except the piezometer BS-30. The karst channel is higher in BS-30 than in other piezometers, and it is filled with considerable quantities of cave clay. This system of karst channels is evidently a part of bigger karst channel system that leaks in the karst spring Mrzlek. Exploration boreholes were drilled for explosive storage place at the western slope near the mine waste pile Jazbec. They found numerous dry caverns in dolomite that are connected to the crushed and demolished zones of the Hotavlje fault.



1 Alluvial sediments; 2 Triassic (Norian) dolomite; 3 Groundwater; 4 Proven karstic channels

Fig. 4. Profile of the karstic water basin along piezometers in the Brebovscica river valley (Tavcar et al. 2003)

Groundwater contamination

The groundwater in the waste pile is contaminated due to dissolution of the pollutants from the mine waste, poor ore and red mud. The waste pile is mainly in unsaturated zone, permanently is flooded only the shallow part at the bottom of the valley, where we observe permanent groundwater. Secondary uranium minerals permanently originate due to presence of the oxygen and moisture. Secondary minerals are easily soluble in the pore water and rainfall waters, which wash them into the groundwater. Due to transfusion of the spring waters that do not flow by the shortest way through the pile, but are partially diverted by red mud, they also wash out uranium. Considerable problem of uranium leaching represents also stagnant groundwater at the bottom of the waste pile due to filling of the drainage pipes and karstic cracks as well. Additional contamination contributes poor ore that was backfilled at the bottom.

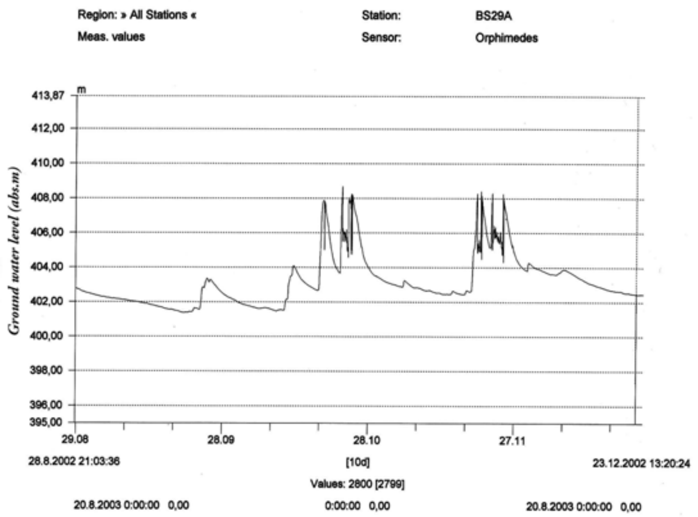


Fig. 5. Changes of the groundwater levels in piezometer BS-29

Diagram in the figure 6 shows increasing of uranium concentration in the body of the waste pile from piezometer BS-15 toward BS-6. Piezometer BS-15 is located in the shallowest part of the waste pile. With this piezometer we monitor the groundwater in carboniferous schist, which is under impact of waters from waste pile that are primarily waters from spring and marshes. Concentration of uranium is proportionally high. Groundwater in carboniferous layers is not contaminated with uranium. High concentration of sulphates can be assigned to the nearby concrete plant. Sulphate also came from carboniferous schist. In piezometer BS-16, which is located in the middle of the waste pile, uranium concentration increases, and sulphate concentration decreases to the level of sulphate concentrations in carboniferous schist. Piezometer BS-6 was built in the uttermost northern part of the waste pile at it is the deepest part close to the waste pile foot. With it we follow the groundwater that stagnates in the pile ant outflows into operating drainage pipes and into the karstic water basin.

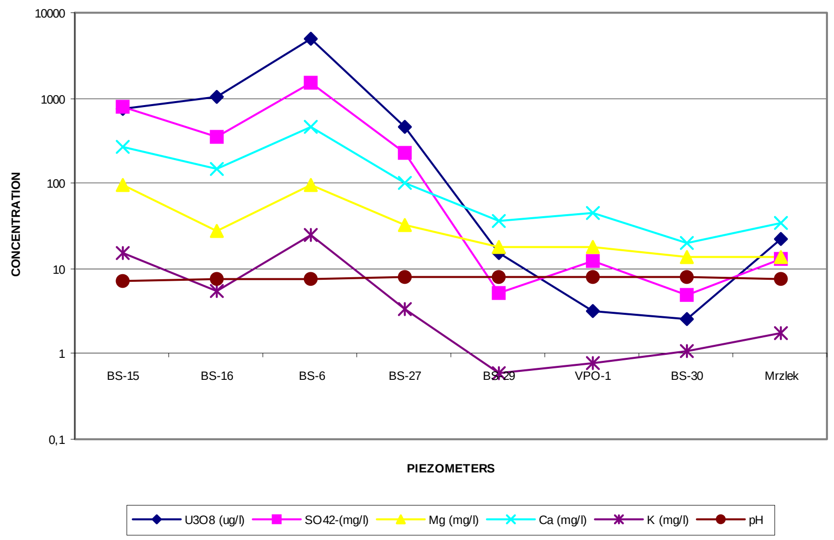


Fig. 6. Chemical parameters in the karstic water basin

We can observe the groundwater contamination in the karstic water basin with piezometer BS-27, which is located close to the waste pile in the valley of the Brebovscica creek. Uranium concentrations and other radionuclides as well noticeable drop between piezometers BS-6 and BS-27 in the distance of 100 m. This fact shows the waters leak into the karstic water basin and are hardly diluted by waters that flow in the main karstic channel. Pollutants are likely to be adsorbed on the cave clays that act as a kind of chemical barrier. We observed very low concentrations of uranium and other radionuclides in piezometer BS-29, which is located about 100 m downstream. It is not likely that only one karstic channel exists there, but on such a short distance we cannot expect that another karstic channel would join the channel we observe. Probably, it is the same channel because of the similar height of the channel we have found out with drilling the piezometer. Such a fast drop in the concentration of radionuclides in the karstic channel can be assigned to adsorption on the cave clays and in a smaller degree to dilution. We have another two piezometers VPO-1 and BS-30 downstream. With them we observe groundwater in karstic channel.

Table 3. Concentration of the pollutants in the waste pile body and in the karstic water basin in August 2003.

Piezometer	U_3O_8	SO^{-2}_4	Mg	Ca	K	pH
	μg/L	mg/L	mg/L	mg/L	mg/L	
BS-15	740	771	98	262	15	7,3
BS-16	1030	359	28	147	5.6	7,7
BS-6	4930	1488	97	463	25	7.5
BS-27	461	231	32	103	3.4	7.9
BS-29	15	5.2	18	37	0.6	7.8
VPO-1	3.1	12	18	44	0.8	7.9
BS-30	2.6	4.8	14	20	1.1	8.1
Mrzlek Spring	22	13	14	35	1.8	7.5

We follow the contamination in the Mrzlek spring two km downstream from BS-30. We believe this is the main outflow of the karstic water basin in this area. Concentration of uranium in it increases and is almost 10 times bigger than in the piezometer BS-30. Such an increase is ascribed to the fact that the western slope of the hill, where the mine waste pile is located, is built of karstified Upper Triassic dolomites. Probably, the karstic channels that lead through this hill inflow into the main karstic channel. Karstic channels, which we do not observe with piezometers,

Table 4. Concentrations of the radionuclides in the mine waste pile and in the karstic water basin [Tavcar et al 2003]

Piezometer	U_3O_8	Th-230	Ra-230	Po-210	Pb-210
	ppm	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3
BS-6	4930	69	148	17	31
BS-27	461	5	10	0.7	2.7
BS-29	15	0.3	8	2.5	3
VPO-1	3.1	<0.2	4.7	<0.6	<1
BS-30	2.6	0.2	3.6	0.9	<1
Mrzlek Spring	22	<0.2	4.8	1.4	2.5

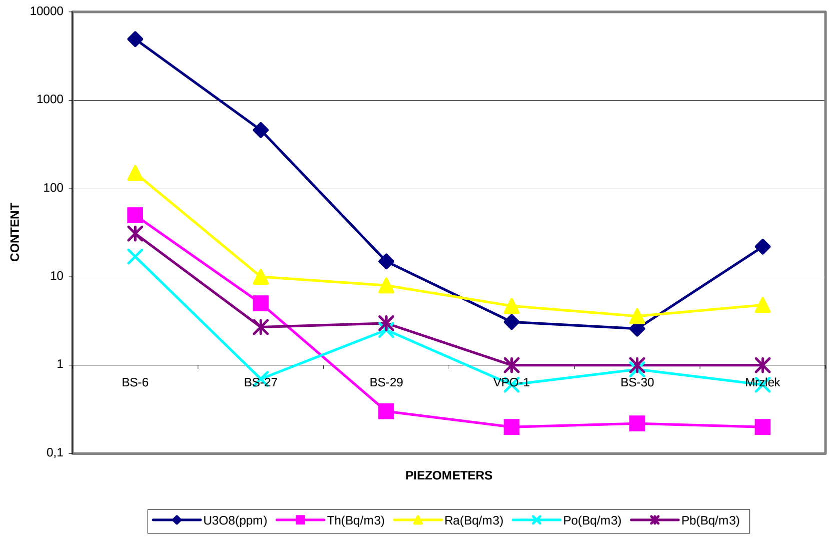


Fig. 7. Concentrations of the radionuclides in the groundwater of karstic basin.

contribute to the fact that concentrations of uranium in the Mrzlek spring increase. The spring water flow is an average 50 L/s in dry season with uranium concentration of 22 μgU/L.

Findings and Conclusions

The waters inflows into the mine waste pile are mainly from the carboniferous water basin that has a big charging area. The waters do not get dry, not even in the time of extreme draught. Regardless of the rainfall quantity that was extremely small in 2003 when the rain practically failed to come for six months, we observed outflow from the drainage culvert, which did not drop under 1.8 L/s and contained 0.84 μgU_3O_8 /L. Referring to the experiences of the karstic experts, at least equal quantity of contaminated water inflows from the waste pile into the karstic water basin. We gather from this that from the springs and marshes of the carboniferous water basin the waters inflow into waste pile with the flow at least 3.5 L/s. The water is enriched with sulphates and leaches uranium oxides that originate in the incompact and unsaturated waste. Lenses of red mud inside the waste pile change the courses of waters on longer course and enable waters to leach more uranium; at the same time the red mud is the source of thorium and other radionuclides as well. Waters that inflow into the karstic water basin at the bottom of the pile mix with other unpolluted waters and due to dilution and adsorption on the cave clays downstream from the waste pile we do not observe bigger contamination that decreases from waste pile toward piezometer BS-30. Between piezometer BS-30 and the Mrzlek spring inflows contaminated waters from the karstic channels that connects waste pile with the Mrzlek spring into the main karstic channel under the bottom of the valley. Karstic channels follow the general direction of the Hotavlje fault. With regard to that the Mrzlek spring is the main outflow of the karstic water basin in this area it should outflow at least yearly equal mass of uranium as it outflows from the culvert Jazbec, but this quantity is considerably smaller that we assign to cave clays.

There are two alternatives for the cover. The first is more complicated and expensive and the second is less complicated and cheaper. The first would permit less than 5 % of the rainfall to penetrate into the waste pile; the second would permit less than 40 % of the rainfall to penetrate into the waste pile. Considering the findings that considerable quantities of the water inflow into the waste pile, which we cannot prevent, it is logical that the second alternative was accepted. The rainfall water percolation into the waste pile is negligible compared to big water inflow from hinterland and therefore its small quantities have small impact. However, there is a dense grid of piezometers required to control groundwater in carboniferous water basin. Chemical changes should be monitored in the groundwater because yet a small change in the water chemistry can cause the remobilisation of radionuclides from the cave clays, where they are adsorbed now.

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