Challenges of Water Management at the Uranium Mining Site Schlema-Alberoda of Wismut (Germany)

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Abstract

In 1991, Uranium mining at Schlema-Alberoda (Saxony) finally ceased. In 45 years of operation the mine produced some 80,000 tons of Uranium. Numerous waste rock dumps deposited in the immediate vicinity of residential area as well as a tailings pond subsequently shaped the townscape of Schlema. Since the end of Uranium mining, a number of remediation measures have been realised above and below ground, which minimise the environmental impact. The article indicates that the remediation measures were able to considerably reduce the pollutant load in the Zwickauer Mulde stream.

Keywords: Uranium mining, water management, sustainable remediation

Introduction

From 1946 through 1990, the SAG/SDAG Wismut Company mined uranium ore in the territories of Saxony and Thuringia of the reunified Germany. By the end of 1990, a total of about 216,000 tonnes of uranium had been produced at a number of sites in the southern part of East Germany (Schramm *et al*. 2013). The mining legacy included 1,500 km of open mine workings, 311 million m³ of waste rock and 160 million m³ of radioactive sludge (tailings) located in densely populated areas.

During the production phase from 1946 to 1990, the Schlema-Alberoda site in Saxony, produced approx. 80,000 tonnes of uranium. Remediation of the Schlema-Alberoda mine is a huge challenge as the underground workings on 60 levels were reaching down to −1,800 m. As a consequence, 21 waste rock dumps (WRD) with a total volume of about 47 million m³ deposited in the immediate vicinity of residential areas as well as a tailings pond subsequently determined the townscape of Schlema.

In 1991, Wismut GmbH, being the successor company to SDAG Wismut and restructured as a federally owned company, started to remediate the legacies left behind. Controlled flooding of the Schlema-Alberoda mine was initiated in 1991 accompanied by the gradual decommissioning of the underground mine dewatering system. The in situ remediation of the majority of the WRDs at the site started in 1992. This was the beginning of a series of remediation measures to avoid danger for the affected population, to reduce emitted pollutant loads and thus to improve the status of surface waters, especially in the Zwickauer Mulde stream.

Initial Situation and environmental impact at the remediation site

The Wismut Act regulating the remediation of Uranium mining in Saxony and Thuringia came into force in December 1991. This set the course for a federally financed remediation of the legacies of Uranium mining above and below ground. First, priority lists and remediation concepts for the Wismut sites were created with the participation of experts from Germany and abroad. Thus, work was initiated with the aim of reducing the risk potential for people and the environment.

At the Schlema-Alberoda site, the remediation concept included the following tasks:

- decommissioning and safekeeping of the mine Schlema-Alberoda in accordance with the rules of the Federal Mining Act and the Radiation protection regulations, while the safekeeping of the mine near the surface had special priority
- controlled flooding of the Schlema-Alberoda mine including an adapted

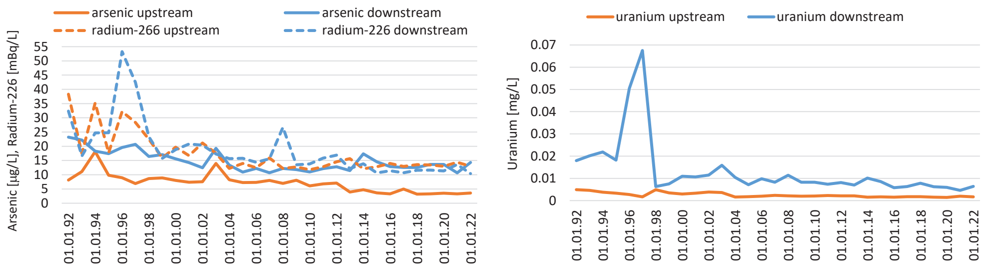

Figure 1 Uranium, radium-226 and arsenic concentration in the Zwickauer Mulde stream

monitoring (geomechanics, hydrogeology, radiation protection, mine ventilation, mining damage)

- remediation of WRDs, preferably in-situ, including profiling, covering, planting, hydraulic engineering and road construction
- remediation of the Borbachtal tailings pond by dry in-situ stabilisation and subsequent covering with waste rock material and mineral soil
- water treatment of contaminated mine and seepage water as well as the safe storage of the residues of water treatment
- long-term monitoring (soil, water, air, biosphere).

Due to the geological situation, the release of the accumulated weathering products by the mine flooding and the discharge behaviour at the site, the focus of environmentally relevant emissions is at uranium, radium and arsenic. Figure 1 shows the concentrations of uranium, radium-226 and arsenic at a measuring point before (upstream) and after the Wismut mining area (downstream) in the Zwickauer Mulde stream. The loads can be calculated based on the concentration differences between the two measuring points and using the official flow rates assigned to river gauges. In the case of arsenic, the background concentration of the Zwickauer Mulde stream is already increased by the historical ore mining and ore processing in the Schneeberg mining area (not under responsibility of Wismut GmbH) and is additionally influenced by the mine water and seepage water of Wismut uranium mining.

For the period from 1992 to 1998, before the water treatment plant (WTP) Schlema-Alberoda was put into operation, a mean annual load increment of approx. 9,200 kg uranium, approx. 2,600 MBq radium-226 and approx. 3,800 kg arsenic was calculated as input between the two measuring points using this balancing method. With the effects of the remediation measures described below, it was possible to reduce the mean annual load increment in the period 2016 to 2022 to approx. 1,400 kg uranium and approx. 2,800 kg arsenic. The current analysis result of radium-226 is often below the limit of quantification, particularly at the downstream measuring point. This clearly limits the evaluation using this balance sheet method. Theoretically, no load increase for radium-226 can be detected in the remediation area for the current period. Balance uncertainties are primarily due to measurement error in stream flow measurement.

Chronology of remediation measures

The main surface and underground remediation measures at the Schlema-Alberoda uranium mining site are described below in chronological order.

Mine Flooding and water treatment

The dense network of working levels between the shafts extends up to 1.8 km below valley level and acts as an intensive water drainage. The Schlema-Alberoda mine has a floodable cavity of 36.5 million m³. The mine workings represent a complex system of linear mining cavities that are spatially connected to each other. Between 1991 and 1997, the pumping stations in the Schlema-Alberoda mine, which had been staggered over the depth, were gradually liquidated. The mine cavities were flooded step by step. At the same time other measures were realised to secure the long-term success of this mine remediation (prevention of surface subsidence by safekeeping of mine cavities, ventilation of open levels). By the end of 2000, the influx of some 32 million m³ had filled approximately 87% of the open mine volume. By reaching the level -120 m level (212 m a.s.l. – above sea level), the dynamic part of the mine flooding at the Schlema-Alberoda site was completed.

In 1999, after detailed planning, the new WTP went into operation. With the commissioning of the WTP, the mine flooding could be continued in a controlled manner. Two years later, the treatment capacity was expanded to a maximum of 1,150 m³/h with a second sub-system. Until 2007, the remaining flooding took place step by step to the-30 m level, where a working and buffer storage of the WTP Schlema-Alberoda will be operated for the long term (0.52 million m³). The mining containment work at a level of up to 300 m a.s.l. was completed in 2007.

Since 2009, the collected seepage water (WRD 371/I) with the highest loads has been treated for the main purpose of separating uranium. A separate ion exchange treatment was set up and put into operation. Although this was operated as intended, various procedural deficiencies occurred. The ion exchange process caused a much higher manual support effort than planned. Therefore an alternative procedure had been discussed with the authorities. After approval the alternative approach, hydrotechnical reconnection work was carried out in 2014 to discharge the seepage water into the underground mine where it was included into the treatment at the WTP. For some less significant seepage streams at the site, a discharge into the mine was also realized in connection with the remediation of the assigned dump objects.

Another remediation measure was the mining expansion of a new connecting adit ("Südumbruch") to the historical Markus Semmler adit in the Oberschlema deformation area to ensure the free drainage of mine water from the neighbouring former Schneeberg ore mine (initial operation autumn 2018). With the implementation of this measure, a probable overloading of the WTP Schlema-Alberoda by the contaminated water from the Schneeberg historical ore mine is excluded in the future.

Since 2008, the mined cavity between 300 and 316 m a.s.l. has been used as an internal mine storage to buffer high inflow rates or reduced capacity due to maintenance at the WTP. This internal storage has been expanded to 287 up to 316 m a.s.l. due to different reasons. These include shaft safekeeping, as well as risk preparedness during the pandemic (staff shortages) and a possible response to shortages of treatment chemical supply. Regarding the supply shortages for treatment chemicals, the discharge of seepage from WRD 371/I was stopped in October 2022 in order to reduce the treatment volume.

The amount of water to be treated annually at WTP Schlema-Alberoda varies between 4.3 and 9.5 million m³. Uranium, radium, arsenic, iron, and manganese have to be removed from the water rising from the Schlema-Alberoda mine site to reach compliance with regulatory standards prior to discharge into the Zwickauer Mulde stream. The water is pumped from the mine and fed to the WTP Schlema-Alberoda for treatment. The plant consists of two nearly identical treatment lines and includes several process stages for the physical-chemical precipitation of the pollutants. It has been technically expanded and optimised several times.

Water treatment residues are immobilised and the resulting crumbly product is then disposed into an engineered storage cell at WRD 371. Treatment of the mine water will have to continue until contaminant levels will be below regulatory standards to allow direct discharge into the receiving stream. Until 2011, the flooding was controlled with the pump system in shaft 208, which tapped the flooding water from the depth range below 500 m. After that, the flooding was controlled via the new pumping system in the investigation cavity UG 212 as near-surface tapping from the -60 m level (270 m a.s.l.). Depending on the development of the concentration of the flooding water, the treatment will have to be continued in the medium to long term until the treatment goals are reached. In Figure 2, the flooding process was illustrated graphically and linked in time to the development of the concentrations in the flooding water and to the progress of the remediation of the dump objects.

Remediation of WRDs

Beside flooding and water treatment, another important task of Wismut is to remediate numerous WRDs. Remediation by covering of WRDs has to meet several criteria: Cover systems have to safely contain the waste rocks, control direct radiation and emissions, control percolation through the cover and offer good conditions for projected vegetation type (Schramm *et al*. 2013). The design of the two-layer-cover at Schlema-Alberoda site was optimised considering site-specific boundary conditions and remediation objectives. The primary objective of the cover system was not to control the cover percolation rate and thus oxygen ingress but to reduce radon emission. Secondary, the interaction of cover and vegetation shall increase the evapotranspiration as main component of the water balance (Schramm *et al*. 2015).

The largest waste rock dumps in the Schlema-Alberoda mining area were left in place to be rehabilitated in situ (without a base sealing). This involves regrading of the slopes. Finally, they are capped with a one-metre-thick cover consisting of a sealing/storage layer and a humus-rich topsoil to enhance vegetation growth. Comprehensive work was done with regard to the construction of trails and in terms of hydraulic engineering work. As the last step the WRDs were vegetated (initial with grass, later planted with trees). In some cases, concepts for subsequent use have been implemented on the WRDs, such as the construction of a golf course or model airfield.

For preserving and maintaining the remedial performance, maintenance and environmental monitoring will have to be conducted for several years. At the moment, 98% of the WRDs at the Schlema-Alberoda site have been rehabilitated. The WRD 371/I with the depository of the residues from the water treatment is considered to be the last project of the WRD rehabilitation. However, storage of residues from the WTP will remain in operation in the long term.

Load Balancing

The main part of the liquid discharges into the Zwickauer Mulde at the Schlema-Alberoda site comes from the Schlema-Alberoda uranium mine. The focus of contamination is uranium, followed by arsenic and radium-226. Further pollution comes from the WRDs, where long-term weathering processes and leaching by the infiltrating waters result in a contaminant release. The comparison of the loads caused by uranium mining at the beginning of the remediation (1990 – 1999) with those of the last ten years (2013 – 2022) shows a distinct reduction of loads, especially for uranium and radium (Table 1). In the case

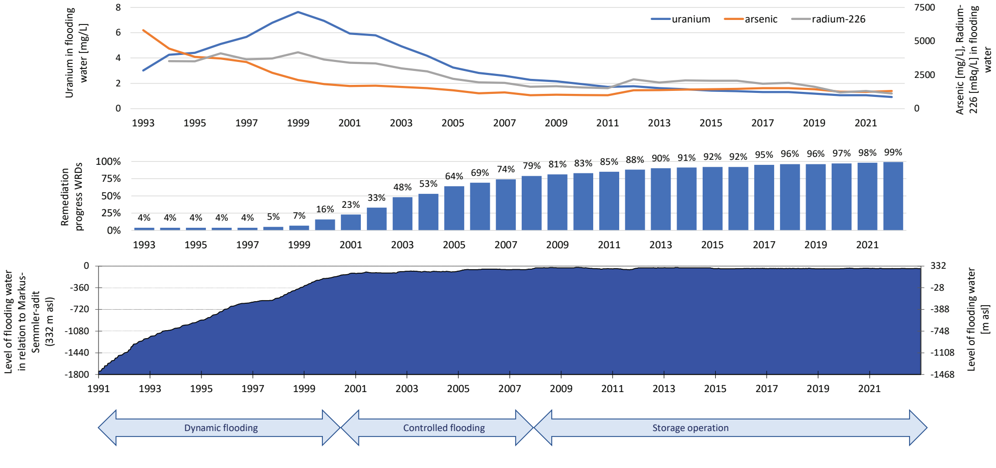

Figure 2 *Chronological classification of the remedial measures: flooding process, development of concentrations in flooding water and progress of dump remediation*

Table 1 Liquid discharges from Wismut remediation objects at the Schlema-Alberoda site

Years	Uranium [kg/year]	Radium-226 [MBq/year]	Arsenic [kg/year]
1990–1999	5120	1460	850
2013–022	1190	180	410

of arsenic, a high level of mobilization in the upstream of the Wismut remediation area is visible. There are a number of diffuse sources that are related to the historical ore mining/processing in the Schneeberg mining area.

The primary loads in the remediation area, which are caused by uranium mining, would be significantly higher (uranium: approx. factor 7, arsenic: approx. factor 15 to 20) without taking into account the water treatment of mine water and the collection and treatment of contaminated seepage water. These data underline the effectiveness of the complex and overlapping rehabilitation measures between 1990 and the present day.

Irrespective of this, the contribution of the mine water of uranium mine Schlema-Alberoda to the total load at the site remains dominant. With regard to the share of loads from dump objects, only uranium is relevant. The highest loads come from WRD 371, from the Borbach valley and from WRD 382 West. Figure 3 shows the load contributions for the period 2014 to 2021 including the load contribution from the Schneeberg mining area. The load balance is based on regular quantity and concentration measurements at the marked measuring points (reliable results).

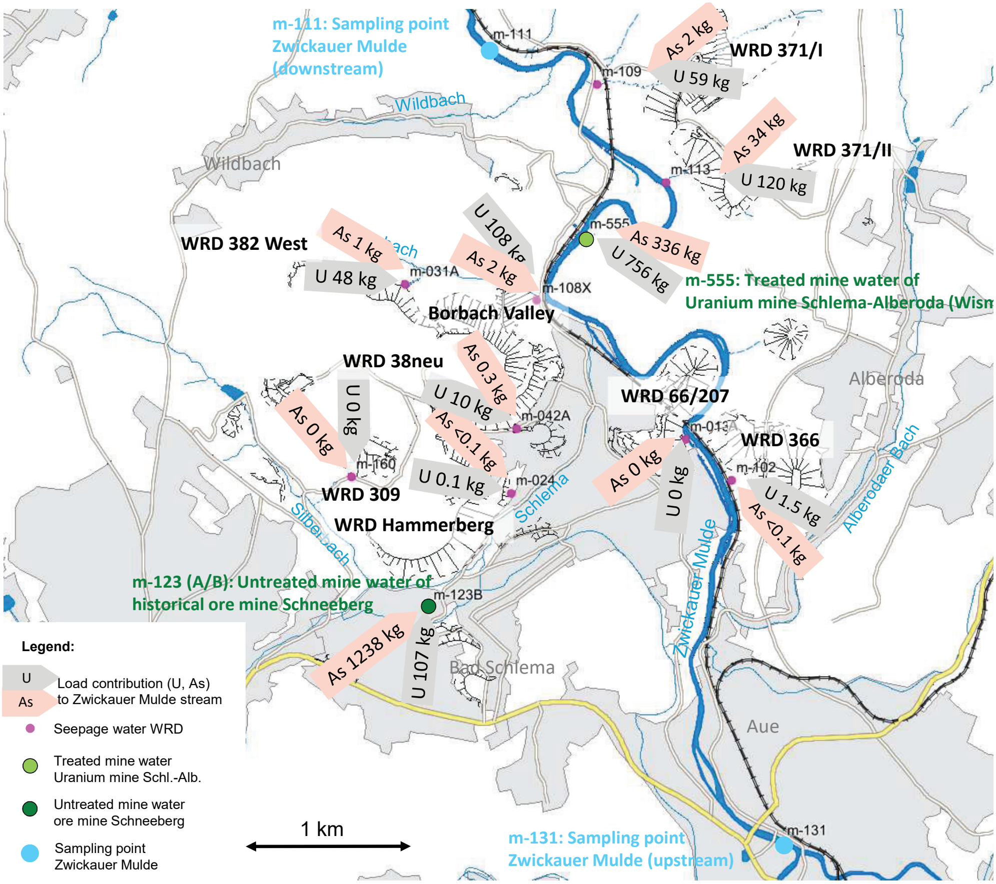

Figure 3 Real uranium and arsenic loads at Schlema-Alberoda site (period 2014–2021)

Conclusions

The target reduction of liquid contaminant loads at the Schlema-Alberoda site caused by uranium mining through the complex remediation measures described above has been successful. The most effective remediation measure is the treatment of contaminated mine water as the largest source of the uranium mining site Schlema-Alberoda. One of the current challenges in water management is the modernisation of the Schlema-Alberoda water treatment plant. The operation of the treatment plant has to be adapted to the changing conditions in the long term, e.g. with regard to the water quantities to be treated, the raw water qualities as well as the requirements on the plant performance (Paul *et al*. 2015). At the same time, immobilisation must be optimised.

The costs of water treatment, which have currently risen to approx. 1.3 €/m³ (mine water inlet, treatment, storage of residues, personnel, analysis), and monitoring costs of approx. 567,000 €/year (analysis, personnel, sampling and maintenance for groundwater and surface water monitoring) must also be taken into account. Both optimisation of procedures/processes and reduction of the scope of analysis are to be reviewed regularly.

A further gradual reduction of load inputs (especially uranium) to Zwickauer Mulde stream, is expected due to the implemented remediation measures. In the medium term, the completion and effect of the dump remediation and the long-term flooding of the mine including the water treatment will have a positive effect. With the targeted remediation of the mining area at Schlema-Alberoda site, Wismut meets the current objectives of the legislator for the gradual and sustainable improvement of water quality in accordance with the European Water Framework Directive.

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