Characterisation of final mine flooding at the Schlema-Alberoda site of WISMUT GmbH with particular emphasis on flooding water quality evolution

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Abstract. Controlled flooding of the Schlema-Alberoda uranium mining site comprising ca. 38 million m^3 of voids and reaching down to a depth of 1,800 m began in 1991 under the mine closure program. The flooding progress is monitored for its environmental effects in terms of geomechanics, radiology and hydrochemistry. By mid-2001 ca. 93 % of the floodable voids at the site were filled up and the flood water level rose to some 100 m below the natural spillover to the Zwickauer Mulde river. This was accompanied by a slowdown in the continuous rapid rise and the transition to a discontinued, step-by-step flooding progress. Flooding of the remaining near-surface-voids will have to be closely monitored with a view to ensuring targeted control of flooding impacts on this densely populated area. Slowed down final flooding is a good prospect for getting first-hand information from the analysis of contaminated flood water and for establishing detailed prognoses of long-term water characteristics. In the medium term, such prognosis will help optimise cost-intensive operation of the water treatment plant which came on line in 1999. Current trends in water quality are characterised by predominantly stagnating and/or downward concentrations of major components in a neutral and reducing hydrochemical environment. Convection-driven transfer of constituents still continues in the flooded mine.

State of mine flooding

Details regarding mine characteristics and implementation of the flooding process have already been published (Meyer et al. 1998, 2000). This paper will focus on current results.

Initiated in 1991, flooding of the mine relies essentially on mine water inflow. In hydraulic terms, flooding is well advanced. By June 2001, the flood level had reached the maximum elevation of 135 m a.s.l. (above sea level) corresponding to the -120-m mine level. The natural spillover from the flooded mine workings to the Zwickauer Mulde river is at 223 m a.s.l., the greatest mine depth at 1475 m below sea level. The flood water level is to a large extent uniform across the entire mine field.

Flood progress is controlled for a number of reasons, e.g. the precipitation-dependent volume of water inflow into the mine, completion of work to ensure safe mine closure and control of geomechanical effects of flooding. Partial pumping of flood water is the main control feature since late 1999. Prior to discharge into the receiving stream, the pumped flood water passes through a conventional water treatment plant (WTP) of 1000 m^3/h design capacity. The multi-stage process removes U, Ra, As, Fe, and Mn down to acceptable residual concentrations.

Annual flooding progress was in the order of 1.2 to 5.2 million m^3 of flooded mine voids. By mid-2001, the cumulative flood water volume amounted to ca. 33 million m^3. Yet, there is no indication of major additional cavities.

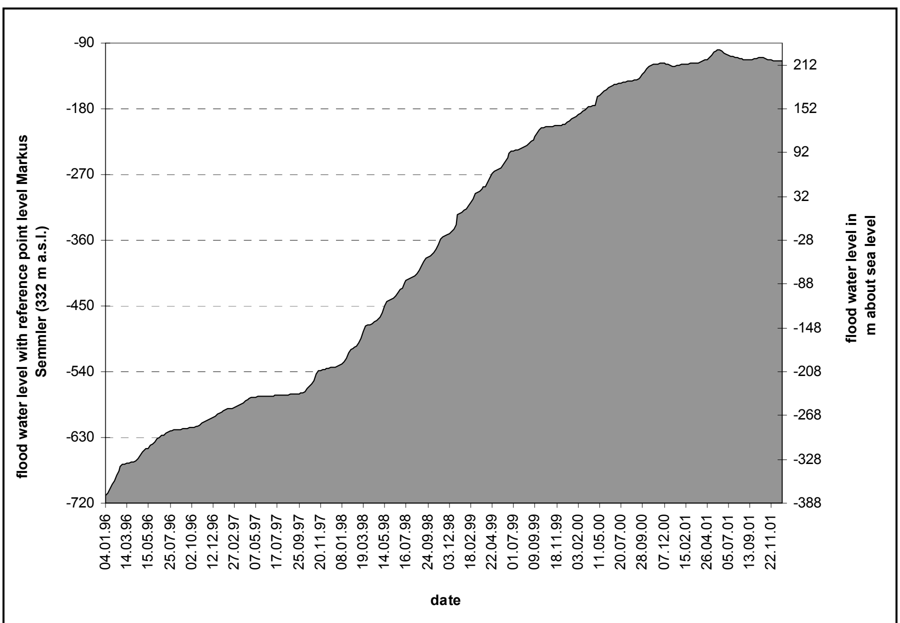

Fig. 1. Development of flood water level in Schlema-Alberoda-Mine since 1996

Total annual inflow into the mine varies from 5.9 to 9.5 million m^3. Short-term inflow may peak at 1200 m^3/h. Until now, there is no flood-induced decline in inflow volume as was found at other mine floodings. This is mainly due to the dominance of near-surface inflow over inflow from deep-seated aquifers.

To the extent where it can be monitored by measurements, the flooded mine space shows a largely homogeneous composition of water. Relatively intensive convective water exchange within the hydraulically well connected mine workings accounts for that phenomenon.

Final flooding approach

The final flooding volume of ca. 3,5 million m^3 will remain suspended until completion of all closure operations in the floodable near-surface area. These operations are to ensure:

- geomechanical stability of the mine site environs
- ventilation of the non-floodable near-surface mine space (for radiation protection purposes)
- sustained flood water feed to water treatment plant/spillover point

Furthermore, cost-effective operation of the cost-intensive water treatment process together with residue disposal (operational optimisation) have to be implemented. In accordance with current estimates, water treatment may be required for up to 30 years.

The final flooding will require ongoing control and monitoring for a number of environmental aspects. With this in mind, the final flooding is designed to proceed in a step-by-step manner with relatively small annual progress. Current considerations are based on the need for a hydraulic storage facility of the WTP in the near-surface mine area. Such a buffer storage would compensate peak inflow exceeding 1000 m^3/h and a possible WTP failure.

For the overall flooding project, the year 2001 marks a fundamental transition from rapid to slowed down or even stagnating flooding.

Retrospective development of flood water condition

Development

The rising flood water was routinely monitored by sampling/analyses and a number of in situ measurements. In view of the above-mentioned flood water homogenisation and despite objectively limited measurement possibilities, the observed data are of sufficiently good quality.

Quality development was characterised by continuous trends. Major discontinuities occurred essentially during the period before 1994.

The chemical environment of the flood water (and of the inflow as well) is in general characterised by neutral pH conditions. Redox conditions are intermediary to reducing. The inflow, in contrast, shows oxidising to intermediate redox conditions. Temperature of the flood water shows a downward trend and had fallen to approx. 30 °C in late 2001.

Total mineralisation had increased to ca. 4.5 g/l by 1999 and then started to recede. Principal components are cationic Ca, Mg, Na, also K and anionic SO_4, HCO_3, also Cl. Development of those parameters is similar to that of overall mineralisation. For some parameters, however, stagnation was observed following the end of concentration rise or before the onset of recession.

The redox sensitive parameters Fe and Mn show on the whole ascending to stagnating concentrations at a low level (together < 20 mg/l).

Parameters U, As and Ra-226 show environmentally relevant concentrations. Other nuclides and heavy metals are scarcely mobilised. Steady increase was noted for U until 1998, followed by stagnation (8 mg/l), and since 2000 there is a clear-cut recession. As for Ra, the increase came to an end as early as 1997 to be followed by several years of stagnation (4 Bq/l) and a decrease from 2000 onwards. Arsenic concentration peaked already in 1993 (at 8 mg/l) and then decreased until 2000. Current signs point to stagnation.

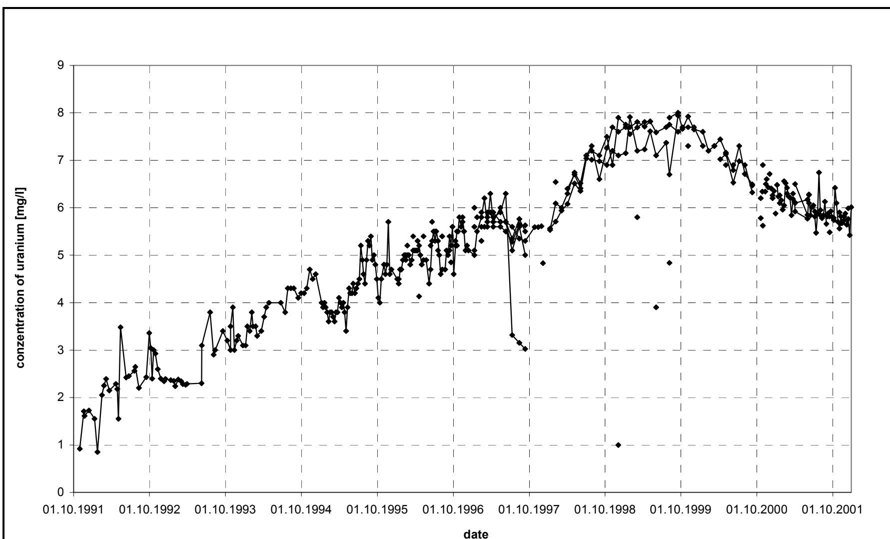

Fig. 2. Concentration of uranium in Schlema-Alberoda-Mine

For the most part, flood water is free of solids. Parameters which are environmentally relevant and redox sensitive occur predominantly in dissolved and partly also in colloidal form.

The additional consideration of mobilised mass quantities, basically, shows mainly a pattern that is analogous to that of mass concentrations.

Tentative Interpretation

The flooding process triggered a significant mobilisation of macro chemical and micro chemical substances into inflowing and rising flood waters, respectively. Sources of mobilisation include rocks and minerals in the area of the deposit, in particular backfilled stopes and fine-grained mine sludges as well as propping, supporting and lining materials. These sources were already subject to natural weathering during the decades of exploitation.

Lack of sufficient geochemical data does not allow quantification of relevant contaminants and weathered products, respectively, for the various mine sections. Information on vertical distribution is available only for uranium, the resource exploited. Independently of the data situation, it may be assumed as plausible that weathering was more intense in near-surface, humid areas of the mine that in deep-seated dry areas.

The rising flood water level mobilises weathered products in dissolved, partly colloidal and only marginally in solid form. In modelling terms, one may assume the formation of a contaminant wave in the top section of the rising flood water column. As a result of the convective exchange, the mobilised substances are distributed across the entire flooded space (homogenisation).

Concentration of substances in the flood water was governed by the available quantities of soluble substances and the specific flood water solubility. With regard to solid phases of gypsum and a number of carbonates, there are temporarily specific solubility limits for SO_4 and HCO_3 as the quantitatively dominating parameters. With regard to partial atmospheric pressure, the flood water is definitely oversaturated with CO_2.

On the analogy of the above, rapid release of uranium from mine-related weathered rock is evident (carbonato complexes). Given the prevailing chemical conditions, further mobilisation from primary mineralisations might be of minor importance only. As for As it is assumed that mobilisation is controlled by kinetics and hence only a small portion of the theoretically available mass potential will be released.

Due to pH-neutral conditions of the flood water, mobilisation of environmentally relevant metals is not stimulated by free acids. Their chemical neutralisation occurs at a number of carbonate, oxidic, and silicate substances contained in the mine rock and the flood water, respectively.

Intermediate to reducing conditions trigger the mobilisation of Fe and Mn. For the time being, there is no definite indication of uranium being chemically reduced, as was learnt from other mine flooding projects. Occurrence of such a demobilisation is thought possible.

The decline in some parameters which was first noticed in 1999/2000 is at first sight caused by the pumping of flood water to the WTP which began in 1999 and was stepped up in 2001 as well as by natural dilution of water in the flooded space by the inflow of low mineralised and low polluted water.

Water quality prognosis/conclusions

It is anticipated that stable hydraulic and hydrochemical conditions will develop as early as the final flooding stage is under way. In the mid-term however, there will be continued flood control in accordance with the flooding concept (e.g. deep-seated flood water pick-up, buffer storage operation).

As for the future chemical environment of the flood water, one has to assume the continuance of pH-neutral conditions and the stabilisation of reducing redox conditions. It is therefore anticipated for the final flooding stage that there will be only limited mobilisation from the newly flooded mine areas.

According to current knowledge, convective exchange will diminish and continue in mid- and long-term. Further flood monitoring and specific in-situ measurements shall document to what extent the flood water will trend towards stratification.

In terms of exponential time functions, continued pumping of flood water to feed the water treatment plant will therefore ensure continued fall in most contaminant concentrations. Mid-term monitoring will provide data for more detailed quantification to be completed in late 2003. Tentative deduction will show the extent to which mere dilution or more complex chemical processes will be involved for the various parameters.

Operation of the water treatment plant will have to be adjusted/optimised in the light of changing water quality.

These monitoring data should also allow to further improve understanding of the chemical interactions in the flooded mine space. In that context, search shall also be continued with a view to identify ways for in-situ flood water treatment. In case of positive results, this may lead to measures that would supplement conventional water treatment by a more rapid demobilisation of environmentally relevant substances.

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