RECLAMATION STRATEGY AT THE RONNEBURG URANIUM MINING SITE BEFORE FLOODING THE MINE

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ABSTRACT

The main long term radiation exposure potential to the public from the decommissioned uranium mines in eastern Germany will result from groundwater contamination. The most extensive of the decommissioned uranium mining sites in Germany is at Ronneburg. Here, the main sources of groundwater contamination are an open pit partly filled with waste rock material and an abandoned underground mining system. The open pit has a total volume of around 160 mio. m^3 and is planned to be filled completely with the material of the surrounding heaps. The underground mining system contains drifts having a total length of around 3,000 km and workings originally having a total void space of around 40 mio. m^3. The mining system is spread over an area of around 50 km^2 and reaches a depth of at maximum 940 m. The following reclamation options are presented:

- *backfilling hydraulically sensitive parts of the mining system;*
- *stabilizing drifts as an underground drainage system for the open pit;*
- *setting hydraulical barriers to separate different parts of the mine;*
- *possibilities of an in situ treatment of the acid mine water;*
- *possibilities of a controlled collection of (hopefully all) contaminated ground water;*
- *other reclamation options.*

The effectiveness of these options are investigated in numerical simulations using highly sophisticated models. The hydrogeological model is a 3D FE-model containing more than 660.000 elements and having a module especially for solving turbulent ground water flow in mining systems. In addition geochemical models are used to simulate the development of the ground water contamination. These models are discussed briefly. The reclamation options, most of which have already been realised, are discussed.

INTRODUCTION

The Ronneburg mining site in Thuringia is the most extensive WISMUT uranium mining site to be decommissioned (Figure 1). Between 1952 and 1990 approximately 125,000 mio. m^3 uranium ore (average U_3O_8 content 0.085 wt.%) were produced from underground and surface mines at Ronneburg totalling an uranium production of approx. 114,000 t.

The decommissioning of the Ronneburg mining site comprises the remediation of:

- an open pit, which had an original volume of about 160 mio. m^3 and was already partly backfilled with about 80 mio. m^3 waste rock material,
- an abandoned underground mining system, and
- 14 waste rock heaps resulting from surface and underground operations with an original total volume of approx. 190 mio. m^3.

It is planned to backfill the open pit completely with the material from the surrounding waste rock heaps. The underground workings covering an area of about 50 km^2 consist of approx. 3,000 km drifts reaching an average depth of around 600 m. Before the partial backfilling of the underground workings they originally comprised a total void space of around 40 mio. m^3. A detailed description of the site is given in Kögel (1991), Lange and Freyhoff (1991), Prokop et. al. (1991) and Barthel (1993).

GEOLOGICAL SETTING

The uranium ore at the Ronneburg mining site is hosted mainly in shales and carbonate rocks having ages ranging from Ordovician to Devonian, which were intensely folded during the Variscan orogeny. The ore mineralization consists of pitchblende and coffinite and is accompanied by sulphides (mainly pyrite) and some cobalt and nickel arsenides. The geological situation of the site is described in Lange, Mühlstedt, Freyhoff and Schröder (1991), Russe (1991) and Szurowski (1991).

The southern part of the mining area is located in the Variscan basement of the Ronneburg Horst, which is drained by three small creeks (Gessenbach, Wipse and Sprotte). The northeast boundary of the Ronneburg Horst is formed by an extensive NW-SE-striking fault zone (Crimmitschauer fault). North of this fault zone, the Variscan basement is overlain by platform sediments of Permian (Zechstein) and Triassic ages (Bunter). These platform sediments contain three aquifers, of which the uppermost is used for drinking water purposes. Figure 1 shows the Ronneburg mine site with the three creeks. In Figure 2 a schematic vertical cross section through the Crimmitschauer fault is shown.

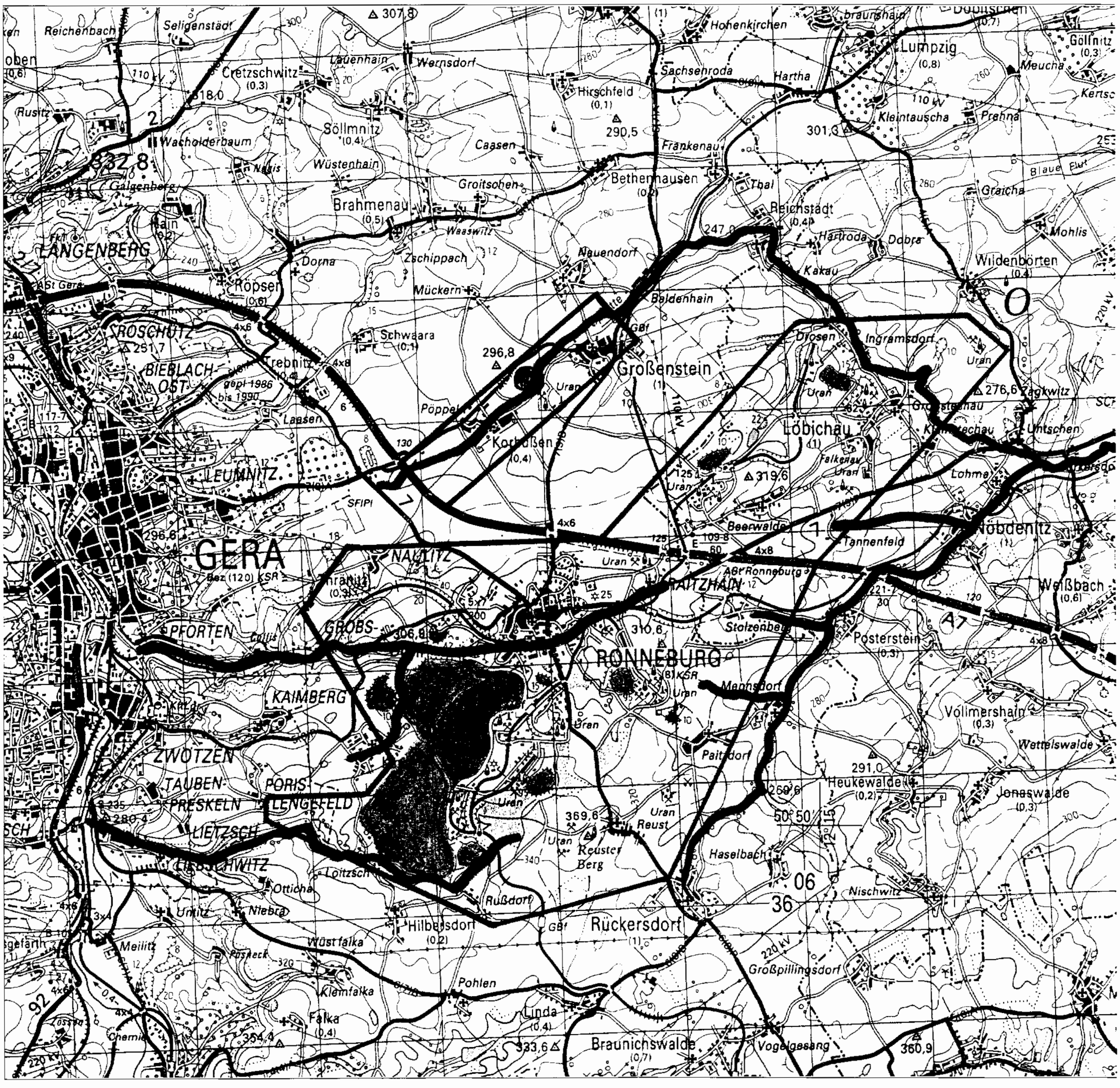

Figure 1. Ronneburg mining site with the three creeks draining the mining area; the shaded area indicates the mining system; distance between grid lines is 2 km.

CONTAMINATION POTENTIAL

The main sources of groundwater contamination at the Ronneburg mining site are the open pit, that is backfilled with heap material which will drain into the surrounding underground mining system, and the older parts of the underground mine. In contrast to the younger workings, in these older areas the hanging walls of the mined out stopes were blasted to prevent uncontrolled collapses. This mining method lead to highly fractured rocks easily accessible for oxygen and water resulting in enhanced sulphide oxidation. The high content of pyrite and organic carbon in the black shales lead to underground fires resulting in high amounts of stored oxidation products. During the flooding contaminants (e.g. acidity, sulphate, iron, heavy metals, etc.) stored in easily soluble secondary minerals will be released when coming in contact with the flooding water.

The main long-term potential radiation exposure to the public from the decommissioned mining site will result from groundwater water contamination. In the southern and the northern part of the mine site different contamination pathways have to be taken into account:

- In the southern part contaminated ground waters (i.e. mine waters) will discharge directly into the creeks that are close by and hydraulically connected to the underground mining system.
- In the northern part, the contamination of the aquifers in the platform sediments by rising mine water during the flooding process has to be considered.

The ground water situation after flooding the mine can be predicted and effects of possible reclamation measures can be assessed using highly sophisticated models for groundwater flow and contaminant release and transport described in the following chapter.

MODEL DESCRIPTION

For the mathematical modelling of groundwater flow and contaminant transport during and after flooding of the Ronneburg mine two different types of water flow have to be taken into account:

- slow groundwater flow through porous media and fractured rocks, and
- turbulent water flow through drifts and open underground excavations.

Groundwater flow through porous media is modelled using DARCY's law

$$\underline{v}_D = -\underline{K}_f \bullet \text{grad } h \quad \text{(Eq. 1)}$$

where $\underline{K}_f$ is the tensor of hydraulic conductivity, h the hydraulic potential, and $\underline{v}_D$ the "Darcy velocity". For the numerical solution of flow equation (Eq. 1) a finite element algorithm was used.

Turbulent water flow through open drifts was assessed in the model by using an empirical approach (Rössert, 1992) given in the following equation

$$|\nabla| = v^2 / (a\ R^{4/3}) \quad \text{(Eq. 2)}$$

where h is the hydraulic potential, v the mean velocity across the cross-section of the drift in m/s, R the radius of the drift in m, and a an empirically determined constant in the range of approx. 1,000. The system of non-linear equations evolving from equation (Eq. 2) is solved using the method of finite differences.

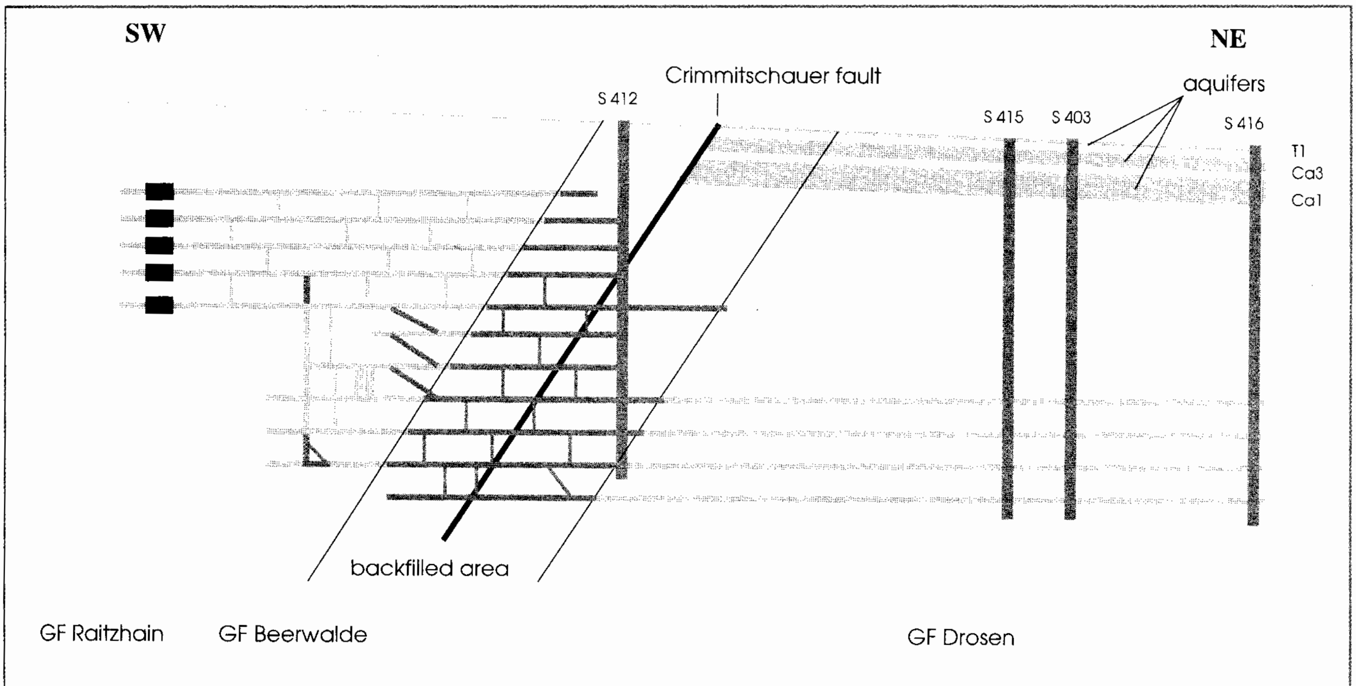

Figure 2. Schematic vertical cross section through the mining site in the neighbourhood of the Crimmitschauer fault: Hydraulical separation of the northern and the southern parts of the mining system is carried out by backfilling.

The applied hydrological model MINE WATER is characterised by the following features:

- Ground water flow through porous and/or fractured rocks is modelled using a 3-dimensional FEM-program. The grid consists of approx. 660,000 elements distributed on 33 grid layers with approx. 20,000 elements each.
- Turbulent flow of mine water through drifts is modelled using a network.
- Both water flows are coupled at the nodes of the FEM-grid using source/sink terms.
- Various material types are assigned to the individual finite elements; each material type is characterized by a set of parameters describing its hydraulic properties, which can be adjusted according to local variations. At present 26 different types of material are used in the model such as
  - * different rock types (e.g. black shale, shale, limestone, diabase, etc.),
  - * different heap materials (partly compacted, partly uncompacted) backfilled in the open pit, and
  - * different types of backfill in the underground mine.
- Furthermore the increased hydraulic conductivity of some rocks due to weathering processes at or close to the surface, and due to underground and surface mining and blasting has been taken into account.
- A preferred spatial orientation of small fractures in the rocks can be taken into account by using an anisotropic tensor for their hydraulic conductivity.
- Fault zones having higher hydraulic conductivities can be modelled explicitly.
- The uppermost layer in the model is represented by the digitized topography of the mining area; thus the discharge points of the ground water after flooding can be modelled directly without further assumptions.
- Coupling the results of the hydrogeologicial modelling with a geochemical compartment model allows the long-term prediction of mine water quality in different mining areas during and after flooding. The development of the geochemical model and the predictive calculations were performed by SENES.

The hydrogeological model was calibrated using measurements of the actual groundwater table and the results of pump tests in the flooded part of the mining system as well as in the surrounding rocks.

The geochemical model was calibrated using geochemical analyses of the mine water and leaching experiments on waste rocks from the Ronneburg mine.

MODELING RESULTS

The main results of the hydrogeological model with regard to the ground water regime after flooding of the underground workings at Ronneburg are as follows:

- After flooding, the hydraulic potential in the mining system will be more or less the same in most parts of the mine leading to a flat water table in an area of approx. 30 km^2 ("underground sea"). The separation of different mining areas by underground dams would lead to the formation of separate "underground seas" having different flooding levels.
- Without additional reclamation measures, the ground water level in the mining region would be significantly lower than before mining activities started. As a consequence, significant parts of the backfilled open pit and the surrounding rock weakened by the mining activities would remain unsaturated. This would lead to a higher level of long term oxidation processes and contaminant release.
- After flooding the water tables of the creeks in the southern part of the mining area will change with respect to the pre-mining situation. Mine water from this area will mainly discharge into the Gessenbach.
- The backfilled open pit will be drained by the surrounding drifts. As a consequence, the groundwater flow through the open pit will be reduced. Groundwater flow through the open pit will be preferable in vertical direction (due to infiltration) whereas the horizontal flow will be comparably small.
- Without additional reclamation measures, after flooding contaminated mine water would flow from the southern part into the less contaminated northern part, where it could contaminate the deepest aquifer.

RECLAMATION MEASURES

To reduce the predicted contaminant release, the underground reclamation measures have the following objectives:

- protection of aquifers in the northern part of the mining area,
- concentration of the discharge of contaminated groundwater on one location in the southern part of the mining area, the Gessenbach valley, and
- minimizing the long-term release of contaminants.

The crucial point of the reclamation measures is the hydraulic separation of the southern and the northern parts of the underground workings. For this purpose, over a period of 4 years approx. 1 Mio. m^3 of backfill were used to fill drifts and stopes in the neighbourhood of the fault zone that separates the northern from the southern part of the mining area (see Figure 2).

From geological maps and investigation of those locations, where at present (before flooding) ground water enters into the northern mining system, the hydraulic connections between the mining system and the aquifers in the platform sediments are known. To minimise the amount of mine water entering the Zechstein aquifers after flooding, selected parts of the northern mining system were backfilled.

To elevate the final flooding level, parts of the drifts directly under the valley of the Gessenbach, which will be the main area of mine water discharge, have been backfilled. This measure leads to an increase in the hydraulic resistance for the discharging waters and therefore to an increase in the final water level in the backfilled open pit and the surrounding rocks that are weakened by mining activities. The elevation of the flooding level reduces the fraction of material that remains unsaturated and thus leads to a decrease in long term oxidation processes and the future contaminant release.

To avoid (or at least to minimise) an uncontrolled discharge of contaminated groundwater into the Wipse, the stopes and drifts near the Wipse valley have been backfilled.

Underground barriers will be built to subdivide different areas in the mining system to attain one or more of the following objectives:

- Protection of mining areas (GF) having a good water quality (barriers in GF Korbußen, GF Rückersdorf and GF Lichtenberg-West).
- Support of the hydraulic decoupling of the northern and the southern parts of the mining system (barriers in GF Beerwalde).
- Increasing the contact time of mine water with surrounding rocks and alkaline backfill to increase contaminant retardation underground (all barriers).
- Decreasing the velocity of water flow through drifts to support the formation of mine water stratification by gravitational settling due to different densities (barriers in GF Lichtenberg-Alt and GF Reust).
- Minimizing the amount of mine water discharging into the Gessenbach to reduce the amount of contaminated water that has to be treated in a water treatment plant (barriers in GF Rückersdorf).

As mentioned above, the model calculations show clearly the "drainage"-effect of the mining system in the vicinity of the open pit. To reduce the groundwater flow through the open pit, which is as a major source of contaminants, it is planned to deviate the mine water around the backfilled pit. For this purpose, selected drifts in the vicinity of the open pit were stabilised to avoid caving in and allow a continuous water flow through these drifts.

In the first years of the flooding process, the water infiltrating the southern part of the mining system will be (partly) highly contaminated by seepage from the local waste rock heaps. Due to the ongoing reclamation of these heaps, the quality of the infiltration water entering the mine will continuously improve. For the interim period, a station could be installed, which allows the injection of lime milk into those parts of the mine where the flooding water is most contaminated by the seepage from the heaps. The actual quality of this water is characterised by pH $\approx$ 3, $[Fe^{3+}]$ $\approx$ 0,3 g/l, and $[SO_4^{2-}]$ > 10 g/l. The injection of lime milk allows to neutralise the most acidic part of the flooding water. The decision not to use it has been made on the basis of a cost benefit calculation.

The effect of the various reclamation measures can be assessed by employing the models described above.

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