THE WISMUT WASTE ROCK PILE REMEDIATION PROGRAM OF THE
RONNEBURG MINING DISTRICT, GERMANY

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The production of the East German SDAG Wismut during 1946 -1990 amounted to over 200,000 tonnes of uranium. An assessment of the environmental impact of these mining, milling and processing activities of the SDAG Wismut, after German reunification, led to the conclusion that a large scale remediation was urgently needed for the severely affected area of approximately 35 km². The remediation program is projected to take 15 to 20 years, with an estimated cost of DM 13 billion (approximately US $ 7 billion). The specific remediation goals are developed through remedial investigations/feasibility studies (Umweltbewertung) for each object and are measured individually. This paper focuses on the remediation/relocation of the waste rock piles at the Ronneburg site and those issues of acid rock drainage which are of significance for the optimization of the remedial measures.

There are 14 piles covering an area of 600 ha (1500 acres) with an original volume of approximately 190 Mm³ of waste rock in the district. Environmental problems arise due to the lack of an impermeable base liner under the waste rock piles and inadequate (or lack of) cover. The three remediation options considered for the waste rock pile were: (a) relocation into the open pit, (b) in situ remediation, and (c) do nothing except collect and treat seepage. Decision concerning remediation of individual piles was based on a multi attribute utility analysis (MAUA) considering, in addition to costs and risk reduction, the socio-economic factors. All the remediation options include water treatment. The seepage from the Nordhalde pile, from the backfilled pit and mine waters exhibit a similar high sulphate content and a joint central treatment plant is planned for the drainage. Drainage from the piles distant from the central plant, such as the Beerwalde/Drosen pile (non acidic discharge, high in Mg content) will be handled independently in accordance with the specific geochemistry of the pile. At the Ronneburg, site relocation into the mine pit is the optimal remedial solution for most of the waste rock piles. For a smaller number of piles in situ remediation by reshaping and capping is proposed. Significant optimization parameters in waste rock remediation are, the placement of the acid generating rock in the mine pit below the ground water table and the depth of atmospheric oxygen penetration in the waste rock above the ground water table. Optimization of the remediation measures at the Ronneburg mining district requires that the two key projects, the relocation of waste rock in the mine pit and the flooding of the underground mines (because of their hydrogeological interdependence) to be carried out in a coupled manner. Optimal reclamation of the site will have to consider the whole remediation cycle including water treatment and sludge management.

Keywords: uranium, remediation, waste rock, Germany
HISTORY, ORGANIZATION, AND LEGAL FRAMEWORK OF THE REMEDIATION

The Wismut mining districts under remediation are located in Eastern Germany and spread around the federal states of Saxony and Thuringia (Fig. 1). The uranium mining and processing activities of the Wismut SDAG occurred between 1946 and 1990. Over 200,000 tonnes of uranium were produced to which the Ronneburg district contributed with 113,000 tonnes of uranium. The extent of the area affected by the former mining and ore processing activities is approximately 35 km², of which 1,100 hectares (2,650 acres) are covered by waste rock piles, 700 hectares (1,700 acres) by tailings ponds and 3,480 hectares (8,352 acres) by the facilities. The remediation is projected to take 15 to 20 years, with an estimated cost of DM 13 billion (Mager, 1996).


The on-site work is organized by districts into four remedial operation units (consolidated from the original 9 mining districts): (1) Ronneburg, SBR, (2) Seelingstadt, SBS, (3) Königstein, SBK, and (4) Aue, SBA. The Wismut Head Office is located centrally in Chemnitz, Saxony. The management of specific remedial tasks lies with project managers located at the remedial operation units. Currently there are projects for: ‘Relocation of the waste rock piles in the mine pit’ and ‘Flooding of the mine’, Ronneburg, ‘Remediation of the tailings ponds’, Seelingstadt, ‘Flooding of the mine and water treatment’, Königstein, ‘Waste rock pile remediation’ and ‘Water treatment’, Aue.

The specific remediation goals follow from the legal requirements under applicable radiation protection and/or water resources laws and regulations. Although remediation of the sites affected by mining and processing activities is stipulated by the German mining law, the remediation of the Wismut properties is frequently based on environmental reasoning. Most commonly, due to the radioactive nature of most of the Wismut waste, the Atomic Safety and Radiation Protection Ordinance applies. The Ordinance requires any remediation measures to be: (i) justified, (ii) optimized, and (iii) the dose to the reference persons limited. For remedial intervention the Ordinance recommends that the estimated individual dose caused by the remediation object, on the long term, not to exceed 1 mSv/a.

The assessment of the effect of the contaminant release and efficiency of the remedial measures is done by means of remedial investigation/feasibility studies, RI/FS (“Umweltbewertung”) preceding every implemented measure. The assessment compares the impact of the source ‘in the existing state’ on the potential target with the ‘expected improvement’ due to remedial measures. The assessment comprises the evaluation of the conditions along the pathways relevant for the specific source and estimation of the potential exposure of the target. Whenever the complexity of the situation so requires the RI/FS is supplemented by a detailed probabilistic risk assessment and/or decision analysis.

The derivation of the requirements and remediation goals for treatment of aquatic discharges is based on the Water Resources Act which provides for the preservation of the aquatic community and protection of the drinking water resource. In contrast to the Ordinance, the explicit evaluation of the exposure is not requested and the water quality standards prescribe the permissible concentrations of heavy metals and other contaminants for the effluent directly.
Due to the fact that not all mine waters qualify as waste waters under the Water Resources Act and the Effluent regulations do not contain any specific regulation applicable to decommissioning of uranium mines, the regulators' decisions on effluent standards are usually guided by requirements from other industrial sectors. In addition, consideration is given to indirect and long term, cumulative effects of the discharge. The consideration of the cumulative effects is required because the contaminant load in the liquid discharges of Wismut amount typically to several tons of uranium and arsenic as well as several giga-Bequerels of radium per year which could have a considerable impact in a densely populated area.

THE WASTE ROCK PILES OF WISMUT.

The most visible consequences of mining activities are the 64 waste rock piles spread over the Wismut property. The physical dimensions of the waste rock piles given in Table 1 provide the extent of the remediation effort needed:

Table 1: Waste Rock Piles Of Wismut GmbH (Feb. 1, 1996)

<table>
<thead>
<tr>
<th>Site</th>
<th>Number of piles</th>
<th>Volume (10^5 m³)</th>
<th>Base area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aue (Schlema/Alberoda and Pöhla)</td>
<td>42</td>
<td>47</td>
<td>345</td>
</tr>
<tr>
<td>Königstein (incl. Gittersee)</td>
<td>3</td>
<td>5</td>
<td>38</td>
</tr>
<tr>
<td>Ronneburg (without the open pit)</td>
<td>14</td>
<td>125</td>
<td>460</td>
</tr>
<tr>
<td>Seelingstädt (incl. Crossen)</td>
<td>5*</td>
<td>51</td>
<td>237</td>
</tr>
<tr>
<td>Total</td>
<td>64</td>
<td>228</td>
<td>1,080</td>
</tr>
</tbody>
</table>

* Only the self-standing waste rock piles are considered.

The pile with the smallest base area is less than 1 ha while the largest is approximately 225 ha. The corresponding volumes vary from less than 0.1 to 66 M m³. The thickness of the piles range from a few meters to 50 m in Schlema-Alberoda and to about 100 m for the conical piles at Ronneburg. The size and form of the piles vary widely due to the differences in the rock type, methods of mining, mucking and dumping. Morphologically, the piles were built as self-standing bodies at Ronneburg and Königstein, commonly used as tailings impoundment at Seelingstädt and dumped in the valleys or on the mountain slopes in the mountainous countryside of Schlema-Alberoda. In Schlema-Alberoda, the individual piles commonly develop into continuous rock pile chains extending up to 2 km. The most extensive waste rock piles remediation projects are at the Schlema-Alberoda and Ronneburg sites (Table 1). The environmental concern at Schlema-Alberoda is the radon exhalation from the piles in narrow and deep valleys of the Erzgebirge. At Ronneburg, in addition to radon exhalation, acid generation is of environmental concern. The principal focus of the paper is the remediation of the waste rock piles at the Ronneburg site.
THE RONNEBURG SITE: GEOLOGY, UNDERGROUND MINE AND MINE PIT

In the Ronneburg mining district the uranium body is present as lenses and stockworks within a package of slates and limestones, approximately 250 m thick, reaching from upper Ordovician to lower Devonian with an average uranium content of less than 0.1 percent. Uranium is present as pitchblende with carbonates and sporadically with Pb-, Zn- and Cu-sulfids or Co- and Ni-arsenids.

The exploitation of the Ronneburg ore body commenced as cut and fill mining in Schmirchau in the early fifties. This was succeeded in 1959 by surface mining south of the city of Ronneburg (the Lichtenberg mine pit). The southern parts of the mine pit reached a depth of 260 m below the surface. The northern part of the mine pit, which was mined later, reached a depth of 180 m below the surface. Surface mining terminated in 1976. A total of 160 million $m^3$ ore and rock were removed from the surface mine creating a pit of 1.6 km by 900 m and extending over 160 ha. In 1978 underground mining resumed in the walls and below the pit frequently intersecting the mine pit and creating interconnections. A total of 5 underground mines exist in the district with workings between 30 m to 940 m in depth. The location of the various mining facilities in the Ronneburg mining district is shown in Figure 2. The waste rock from the mine pit forms the two biggest piles on the site: The Nordhalde (North Dump) to the west and the Absetzerhalde to the south of the mine pit. Due to partial backfilling during the ‘operational phase the volume of the mine pit decreased from the original 160 million $m^3$ to 80 million $m^3$ before the remediation activities commenced.

Hydrogeologically the region is controlled by the fractured Silurian aquifer. On the site the aquifer is confined by the impermeable Ordovician and Devonian layers. A hydrogeological connection exists between the mine pit and underground workings. Presently, due to continuous pumping from the underground mine, the mine pit lies in the dewatered cone of a ground water depression.

WASTE ROCK CHARACTERIZATION, ACID GENERATION, CONTAMINANTS MOBILIZATION AND SEEPAGE

The environmental problems at Ronneburg result from the considerable pyrite and marcasite content in the mine and in much of the waste rock, lack of an impermeable base liner under the piles and from the inadequate (or lack of) cover on the piles thus allowing infiltration, leaching and seepage through the piles. A first assessment of the contamination potential and associated (health) risk of the waste rock piles indicates that these correlate with the (a) physical dimensions of the pile, (b) quantity and quality of the potential contaminants present in the pile and (c) ease of mobilization of contaminants and availability of pathways out of the pile.

The physical characteristics of the piles at the Ronneburg site are summarized in table 2.
An initial indication of the geochemical characteristics of the piles was derived from the geological origin of the waste rock. The waste rock piles of Ronneburg are composed of approximately 40% Devonian limestones and slates, 30% of ochre limestone, 20% of Silurian siliceous and alum slates, 5% Ordovician leather slates and 5% diabase. U mineralization is highest in the leather slates. Although a pyrite and marcasite content of 0.5 to 7% is characteristic for the rock, the content varies widely and the largest of the piles, the Absetzerhalde, can have a local pyrite content of up to 17%. In the four conical piles, which visually dominate the Ronneburg site, the leather slate is the most common rock and the carbonates can reach 35%. Some of the waste rock can have an organic matter and carbon content of 0.5 to 10%.

The historical data on the waste rock piles turned out to be insufficient for characterization of the waste rock distribution according to their acid generation/neutralizing potential and contaminant content within the piles. An extensive investigative research program, including test pits and boreholes on the waste dumps, was carried out to obtain the necessary geochemical characterization data. In some cases, such as for the Nordhalde, the investigations basically confirmed the distribution of the rock types within the pile expected from the historical data and geological judgment. But, for the majority of the piles geostatistical methods had to be used for characterization of the material units. For example, the distribution of the material classes in the largest pile, in the Absetzerhalde, had to be estimated by krigging based on the results of the characterization program. Geostatistical methods proved to be sufficiently accurate to plan the sequence of waste rock units relocation to specific placement levels in the mine pit, assessed to be geochemically optimal for placement of waste rock classes with a specific acid generating potential. Details of the waste rock pile characterization can be found in Hockley et al, 1997.

The acid generation in the piles and backfilled open pit is due to their exposure to atmospheric air and the resulting oxidation of the sulfides in the waste rock, which creates the acidity for potential release. Under the partly saturated conditions of the piles and backfilled...
Fig. 2  LOCATION OF THE MINING FACILITIES  
AT THE RONNEBURG SITE
mine pit the oxygen can be derived from both atmospheric or dissolved oxygen in water. The rate of sulfide oxidation (and continued sulfide degradation) can be expected to be controlled by oxidation of ferrous iron to ferric iron by molecular oxygen. Sulphides in the waste rock not exposed to atmospheric oxygen, e.g. placed below the ground water table, will not generate acid seepage. The oxidation of pyrite by ferric iron is not expected to become dominant at Ronneburg because the solubility of ferric iron is too low in sulfate-containing environments at pH > 2.5, which are typical for the site.

Beyond the described processes, electrochemical reactions and bacterial activity may influence the kinetics and direction of pyrite dissolution and promote generation of acidic discharge. Instead of individually specifying each of these processes, an integral assessment of the collective processes was selected for the Ronneburg waste rock assessment. A series of saturated and unsaturated column tests were carried out with representative waste rock samples and the leachate composition monitored. The observed composition of the leachate represents the integral result of all the relevant mobilization processes. These tests provided the bases for the empirical assessment of the acid generating/neutralizing potential of the waste rock types (Hockley et al, 1997).

In Rormeburg the waste rock containing carbonates, ochre limestones and calcareous slates and are lumped together with slates and alum slates containing pyrite and carbon thus creating geochemical inhomogeneities in the piles. The acid generation in the pile, therefore, depends on the locally prevailing mineral content. The resulting geochemical conditions affect the mobilization of the other elements.

In piles where carbonates prevail over the sulphide content, the acidic waters produced in one place are neutralized by carbonates present in an other. Because the dissolution rate of calcite is comparable to the oxidation rate of pyrite, under these conditions the contaminant transport through the pile takes place as a succession of dissolution and precipitation steps with a considerable retardation. In this case the acidic release of uranium and iron is retarded as well.

In waste rock with lack of carbonates a different transportation mechanism can be expected. Because the dissolution rate of primary pitchblende is slow compared to oxidation of pyrite it can be assumed that the uranium leached out in one place will be carried along channels of preferred percolation where the oxidation of pyrite by the percolating water (the oxygen saturation in water is 10 ppm) has already generated acidic conditions.

An additional consequence to the mobilization of the heavy metals, due to sulphuric acid generation, is the increased inorganic salts content causing high hardness of the waters seeping from the piles. For example the Beerwalde dump, where the acid consuming carbonates prevail over the acid generating minerals, an almost neutral pH with low heavy metal content is characteristic of the seepage. On the other hand, the low heavy metal content in the seepage is accompanied by elevated magnesium and sulfate concentrations, causing high hardness and an unacceptable water quality for discharge.

The observed water quality of seepage at the Ronneburg site is summarized in table 3.
Table 3
Composition Of Typical Mine And Seepage Waters Of The Ronneburg Site.

<table>
<thead>
<tr>
<th>Type</th>
<th>pH</th>
<th>U mg/L</th>
<th>Ra-226 mBq/L</th>
<th>Hardness °dH</th>
<th>SO₄ mg/L</th>
<th>Fe₉₀₀ mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine water Central section (Measuring point e-567)</td>
<td>3.8</td>
<td>0.1</td>
<td>150</td>
<td>123</td>
<td>2,272</td>
<td>69</td>
</tr>
<tr>
<td>Mine water Central section, influenced by open pit mine and dumps (Measuring point e-480)</td>
<td>2.9</td>
<td>4.4</td>
<td>384</td>
<td>587</td>
<td>10,290</td>
<td>218</td>
</tr>
<tr>
<td>Mine water, SE-section of deposit (Measuring point MW 435/2)</td>
<td>7</td>
<td>1.7</td>
<td>192</td>
<td>297</td>
<td>4,865</td>
<td>6</td>
</tr>
<tr>
<td>Seepage Absetzerhalde dump (Measuring point e-440)</td>
<td>2.8</td>
<td>7.2</td>
<td>&lt;10</td>
<td>500</td>
<td>16,000</td>
<td>1,300</td>
</tr>
<tr>
<td>Seepage Beerwalde dump site (Measuring point s-611)</td>
<td>7.6</td>
<td>5.2</td>
<td>136</td>
<td>1,840</td>
<td>32,000</td>
<td>1</td>
</tr>
</tbody>
</table>

Finally, because the Ronneburg piles are unsaturated, the mobilization and transport of heavy metals and salts in the waste rock is substantially affected by the infiltration-wetting-drying cycles leading to precipitation of a number of U compounds, various iron hydroxides, oxyhydroxides and sulphates and creation of secondary minerals which may be released into solution. An analytical prediction of the geochemical behavior of secondary minerals at the Ronneburg site is very complex (they may act as sinks in the piles but may serve as a source in the flooded underground workings) and the modeling of quantitative predictions of the water quality in the seepage are notoriously unreliable. For this reason, geochemical models at Wismut are used mainly to test the plausibility of the remediation concepts and to test the model assumptions with observed values, rather than predict the concentration of contaminants in the seepage.

The modeling approach for assessment of the mine drainage at Ronneburg used by the regulator's expert Brenk Systemplanung is presented in Kistinger, 1997.

WASTE ROCK PILE REMEDIATION OPTIONS

At the Ronneburg site the principle remediation objectives, control of radon exhalation, acidic drainage and contaminant release from the dumps can be achieved both by relocating the waste rock into the mine pit or in situ remediation involving reshaping, capping and vegetating as well as capturing and treating the drainage from the piles.

The remediation option for each pile was derived by searching for an optimum between rehabilitation costs, acceptable risks and socio-economic impact on the area. From a cost perspective one can assume in a first approximation that for in situ remediation the specific unit
costs increase with the surface to volume ratio of the rock pile while for relocation the costs increase directly with the volume of the pile. From a risk minimization point of view the obvious candidates for relocation are the piles having the greatest environmental impact. The selection of the optimal remediation option was based on a multi-attribute utility analysis (MAUA) which considered besides remediation costs, environmental and health benefits (risk reduction), socio-economic factors, such as job creation and potential land use. The options considered for each of the piles at Ronneburg were: (1) relocation into the open pit, (2) in situ remediation and (3) do nothing but collect and treat the seepage, with the latter serving as a reference. Linear utility functions were employed to normalize the consequences of cost, health risk and socio-economic factors and tradeoffs made among the various consequences using relative weighting factors.

All remediation options involve water treatment. The two sources of contaminated water at the site are: (1) the mine water, which is expected to overflow after flooding of underground workings and (2) the contaminated seepage from the waste rock piles. It is assumed that flooding will take at least 12 years to complete after which a rate of mine water drainage of approximately 250 m³/h is expected through the Silurian outcrop in the Gessental valley. The seepage from the Nordhalde pile, from the backfilled pit and mine waters exhibit a similar high sulphate content and a joint treatment is planned. Drainage from the piles distant from the central plant, such as the Beerwalde/Drosen pile will be handled independently in accordance with the specific geochemistry of the pile (a non acidic discharge high in Mg content). In order to develop long term solutions for waste rock seepage treatment the feasibility of using wetlands is being investigated.

For most of the piles the MAUA analysis showed a preference for relocation into the pit. An important advantage of the relocation option is the containment of the acid generating material presently scattered across the entire Ronneburg site in one place. After relocation, the area taken up by waste dumps will be reduced from 600 to 160 ha (the extent of the mine pit) or 250 ha, resp. depending on whether the Nordhalde will be relocated or remediated in situ. The reclaimed land can then be released for other uses. An added benefit of backfilling the mine pit is the stabilization of the pit walls without special geotechnical measures.

In-situ remediation was shown to be the optimal solution for the Beerwalde/Drosen and Nordhalde piles. It is planned to present the Wismut-Ronneburg Site Remediation and specifically the combined, in situ remediated Beerwalde/Drosen pile as an exhibition object for the upcoming World Exposition, EXPO 2000.

OPTIMIZATION OF THE REMEDIAL MEASURES

In view of the fact that oxidation processes govern the acid generation and mobilization of the contaminants in the waste rock, the adjustment of the remedial measures to the redox conditions existing or achievable in the underground mine, open pit and piles is an important optimization parameter. In case of the flooded pit and mine the position of the redox interface is well defined by the position of the ground water level, which functions as a diffusion and convection boundary for the atmospheric air.
Under anoxic conditions, below the ground water table and in the oxygen depleted zone, the pyrite is stable and uranium dissolution will be controlled by sulphide equilibria. Accordingly, the degradation of the primary sulphide can be expected to remain limited both in the flooded mine and in the Zone A of the mine pit (Figure 3).

Less well defined, but of great significance for capping of the piles and backfilled pit, is the depth of oxidation in the unsaturated C/B waste rock zones. Because of the oxygen consumption by the waste rock in the upper part of the pit and piles, anoxic conditions will exist in those parts of the pile receiving only oxygen depleted air. Under these conditions the sulphides can be expected to remain stable as well. For this reason it was decided to determine the oxygen flux and depth of penetration of atmospheric oxygen into waste rock piles. Eight instrumented boreholes were installed in the Nordhalde and depth dependent measurements made of the barometric fluctuation, oxygen content, temperature and other relevant parameters. The preliminary observations indicate that the depth penetration of oxygen varies with the barometric pressure fluctuation (in dependence on the compaction of the pile), reactivity of the waste rock material and air convection in the pile. Furthermore, the observations (Figure 4) indicate that the oxygen penetration increases with the thickness of the dump and decreases with the acid generation (hence oxidation) characteristics of the waste rock. For example in the 20 m deep borehole no. 36 in a low sulphide content acid generating waste rock, (material class A - high sulphide) the oxygen penetration is about 5.5 m before it is consumed, while in the deeper (40 m) borehole no. 37 the penetration is greater (10 to 24 m) over the same period.

In addition, the oxygen concentration response to barometric pressure changes is superimposed by oxygen input due to thermally induced air flow, which is a function of the ambient air temperature, thus subject to seasonal change.

Finally, the temperature distribution in the pile is affected by the oxidation (and neutralization) heat generated by the chemical reactions in the waste. Well defined thermal gradients have been observed in the measured temperature profiles allowing estimates of the rate of heat transfer out of the pile. Since this heat transfer reflects the total heat generation by chemical processes in the pile, which is in the Nordhalde primarily due to sulphide oxidation, it
allows the backcalculation of the oxidation rate and net oxygen flux into the pile. The calculation of the oxidation rate relevant for the dump makes estimates of the total oxygen consumption capacity of the aeration zone possible, and hence the design of the C Zone and cover possible. The pile heat balance calculations also offer the possibility of verification of the results of complex modeling of oxygen transfer into the pile.

An independent estimate of the time delay of commencement of the acid drainage and contaminant mobilization from the waste rock piles can be derived from the observation that the decrease of pH and increase of iron and uranium contents in the seepage from the piles at Ronneburg started in the mid 80s, i.e. 20 to 30 years after mining started. Obviously, the development of acidic conditions and mobilization of contaminants in the waste rock piles require several decades under central European climatic conditions.

A detailed modeling of the conditions and processes in the oxidized zone is given in Pollmer et al, 1997.

Because of the hydrogeological connection between the underground mine and mine pit and the significant environmental effect of the ground water level on the geochemical processes in the backfilled pit, the environmental benefits of the optimized relocation and placement of the waste rock will only be realized after flooding of the underground mines is complete. After flooding, the final water table in the pit is expected to reach 260 m asl, thus creating anoxic conditions below this elevation. Waste rock with acid generating potential, therefore, is placed in the mine pit below the final ground water level. Waste rock with balanced acid generating and neutralizing potential is placed above 260 m asl. in Zone B. Waste rock with an overabundance of neutralizing potential is placed closest to the surface in Zone C.

Hydrogeological coupling exists between the waste rock piles and the underground mine. Most of the waste rock piles are located above the underground workings, and a considerable portion of the seepage from the piles drains directly into the underground mine and appears as part of the mine water. Although the volume of this drainage amounts to only 9% of the total mine water discharge, it represents approximately 46% of sulphate, 83% of iron and 24% of uranium loading and contributes 39% to the water hardness. The reduction of the mine water treatment costs resulting from capping of the in situ remediated piles is yet to be evaluated.

The existing hydrogeological couplings make it necessary to handle the two projects at Ronneburg, the relocation/remediation of the waste rock piles and the flooding of the underground mine in a closely coordinated manner. An optimal reclamation of the site will require the additional consideration of the whole remediation cycle including water treatment and sludge management.
STATE OF REMEDIATION AND CONCLUSIONS

Since commencement of the remediation the original volume of approximately 190 million m$^3$ waste rock has been substantially reduced. A total of approximately 17 million m$^3$ waste rock had been placed in the open pit by April 1997. An open volume of approximately 65 million m$^3$ remains in the mine pit.

The relocation of the Gessenhalde dump was completed in October 1993. A rapid relocation of this pile was required because approximately 6 million m$^3$ of low grade ore in this former heap leach pile had to be contained urgently. The relocation of the Absetzerhalde into the pit is in progress. The mining units are planned, relocated and placed according to the waste rock characteristics. To prevent future acid generation and contaminant release at source, the waste rock is blended with lime in a ratio required to neutralize pore waters in the flooded waste rock (1 : 150 to 1 : 600). The waste rock is placed in 60 or 120 cm lifts, and compacted by haul trucks. As a result field hydraulic conductivities of $10^{-7}$ to $10^{-5}$ m/s are being achieved in the backfill and future settlement is expected to be reduced to approximately 15%.

Waste rock remediation at the other sites include relocation of a pile in Schlema/Alberoda (pile no. 250) and partial capping of the Gittersee dump in Künigstein-Gittersee. The results of the depth dependent monitoring of the barometric pressure and oxygen in the Nordhalde will help in the design and optimization of waste rock cover in the mine pit. In general, the Wismut design of the waste rock pile cover systems is adjusted to the specific conditions required for limitation of radon exhalation and infiltration prevention: For capping the Beerwalde/Drosen pile at the Ronneburg site a three-layer cover system consisting of approximately 0.4 meter of dense soil, 0.8 meter of mineral soil acting as a moisture storage layer and 0.2 meter of top soil is planned. For remediation of the piles at the Schlema-Alberoda site a 1 meter thick cover consisting of 0.8 meter mineral soil and 0.2 meter top soil is forseen. The cover design resembles the natural soil structure of the area.

An important aspect of remediation management is the consideration of the interdependencies of the individual projects and optimization on a multi-project bases. The reasons for coupling of the Ronneburg mine flooding and waste rock relocation projects were demonstrated. The integration of the long term remediation requirements into the remediation projects is a key issue, because most of the remediation activities lead to the long term generation of large volumes of contaminated water, the treatment of which and management of residues, in the long run, dominates the remediation costs.

The experience gained during five years of remediation taught us that there are no fast and easy rules for transfer of remediation technology from one site to another and the solutions have to be tailored to the specific conditions at the object and site. A pragmatic combination of experience, theoretical knowledge and interactive observation of the work progress is the only guarantee of a successful remediation project. Of prime importance is to maintain the right balance between permitting requirements and costs as well as quality of engineering and promptness of remedial measures (Gatzweiler et al, 1996).
REFERENCES


