Mine closure: From cleaning up the failures of the past to integrated mine closure policy and planning

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“One of the strongest business drivers for progressive mine rehabilitation and systematic closure management is the well-documented knowledge of the enormous cost incurred if mining operations are not closed correctly.”

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1Leading Practice Sustainable Development Program for the Mining Industry, September 2016, Australian Government
The Wismut-Project

1946 - 1990, SDAG Wismut:
- Main uranium producer of the former Eastern bloc
- Massive devastations and environmental damage

according to a decision of the Federal Constitutional Court from 02.12.1999:
“………………because uranium mining in the German Democratic Republic has left damage of singular extent……………….”
After completion of mining activities:

- 5 mines, 1,500 km mine openings, 56 shafts, 1 opencast mine
- 37 km² production facilities with contaminated buildings/infrastructure
- 48 heaps with 325 Mio m³ stockpile material
- 4 large tailing ponds
- 2 processing plants for uranium ore

Former mine site in Berlin, Germany: company headquarters and processing plant.
Increasing pressure from civil society:

1989/1990 Downfall of the GDR – public protests and political pressure from NGOs

• Stop of radioactive emissions from uranium production
• Remediation of destroyed landscapes

03.10.1990: Reunification – West Germany assumes the GDR-share of SDAG Wismut (50%).

01.01.1991: End of uranium production

16.05.1991: Agreement on the termination of activities of SDAG Wismut between the USSR and Germany

12.12.1991 Wismut-Law
A new beginning – developing mine closure concepts from scratch:

• Development of rolling concepts specifying general remediation targets

• Step by step implementation

• Plans for emergency measures

• Base line monitoring. Development and/or refinement of waste material inventory

• Controlled transition to regular remediation activities based on environmental impact assessments, economic feasibility studies and remediation criteria
Mine closure activities of Wismut GmbH

- Plant decommissioning and site rehabilitation
- Remediation of heaps and tailings ponds
  - concentration, conditioning, covering & revegetation
- Backfilling of mines and shafts; mine flooding
- Construction and operation of water treatment plants, including accompanying infrastructure (water supply, treatment waste disposal)
- Environmental monitoring, real estate management
Wismut: mine closure in a nut shell:
“The future of the mining industry is dependent on the legacy it leaves. As access to resources becomes tied to industry and corporate reputation, effective closure processes and satisfactory mine relinquishment become critical to a company’s ability to develop new projects.”

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In-situ Recovery (ISR) Mine Closure
Beverley and Beverley North – Frome Basin, SA

- Most advanced ISR mine in the world (also due to the excellent teamwork between Heathgate (Australia) and UIT (Germany))
(Proactive) Mine closure as immanent part of ISR mine development

Database

- Exploration (geophysical surveys/drilling) → Reserve estimate
- Delineation drilling/logging 3D model of deposit → Reserve definition
- Wellfield planning
- Wellfield installation (injectors/extractors/infrastructure)
- Wellfield operation/in-situ recovery (phases) → Reconciliation
  Recovery

Regulatory/approval procedures

- Mineralogical/geochemical/hydrogeological studies
- ISR performance model and economic model
- Monitoring (environment) and process control
- Monitoring (environment)

Post-mining measures incl. wellfield rehabilitation
Applying the ISR reactive-transport model extended to neutral pH – combined with testwork/monitoring

Environmental conditions/Impact by mining (on aquifer mainly)

- Active treatment
- ENA
- NA

**METALLOGENETIC EPOCHES**

- Mesozoic
- Cenozoic

Geological time scale [million years]

- 100
- 10
- 1

Mining phase (~10a) Post-mining phase (~10-100a ?)

Reference level?

↔ Use category

Future time scale
Beverley North Groundwater – Baseline Conditions

- **Groundwater quality parameters within mining and attenuation zone:**
  - Salinity (TDS): 2-12 g/L
  - Uranium: up to 1 mg/L
  - Radium: up to 500 Bq/L
  - Fluor: up to 20 mg/L
- **According to ANZECC limits, not suitable for**
  - Potable use
  - Irrigation use
  - Stock use

- **No use category!**
  (refers to both Beverley and Beverley North)
Regulatory guidelines for ISR in Australia:

– Developed by Geoscience Australia (2010)
– Best practice means:
  ➢ Application of technologies that will achieve the remediation targets in an agreed timeframe with minimum environmental impact
  ➢ Balancing active treatment options (and involved consequences regarding infrastructure, energy consumption and waste stream generation) versus natural attenuation (NA) and additional in-situ measures to enhance it (ENA), e.g. groundwater sweep, in-situ treatment with reductants, bioremediation)

• Every ISR mine operation/restoration is unique, i.e. to be optimized with reference to the above principles

• Challenge:
  Quantify both efficiency and time dependence of NA/ENA within mining/attenuation zone to be defined as part of the application documents (PER – available on internet)

• Application case: Beverley North (second one after Four Mile)
Hydrogeology at Beverley North

Slow-moving groundwater (~10-25 m/yr)

Model-space for (E)NA scenarios

Slow-moving groundwater (~15 m/yr)

Stagnant groundwater in a confined mining aquifer (isolated "bathtub" aquifer)
Chemical/Microbial Factors in (Acidic) ISR

- Attenuation mechanisms in acid ISR
  - Rock-water interactions
    - Neutralization
      - (Fast) dissolution of calcareous minerals
      - (Long-term) dissolution of clays, feldspars a.o.
      - Effect of cation exchange capacity of clay minerals
      - Surface complexation on clays, organic matter, etc.
  - Chemical reduction by
    - Sulfide minerals
    - Organics

- Microbial effects
  (e.g. sulfate reducing bacteria)

- Quantification of model parameters
  - Lab tests (batch and column)
  - Parameter adjustment vs. operational data by simulation of active ISR
    (where attenuation effects apply obviously)
  - Monitoring data (from monitoring wells around the wellfields)

Clear evidence of NA

3D reactive-transport model
Modeling Approach to Control ISR and Mine Closure
(Simplified)

Exploration/delineation

3D structural modeling
- Regional scale
- Ore body

Major data categories
- Stratigraphy
- Ore outline/grade
- Geophysics/hydrology
- Mineralogy
  (reactive minerals mainly)

3D hydrological modeling
- Regional scale (groundwater flow conditions)
  \(\rightarrow\) Regulatory process

1D-3D reactive-transport modeling
- ISR wellfields embedded in regional-scale groundwater flow model
  \(\rightarrow\) ISR control and optimization

1D-3D reactive-transport modeling of post-mining scenarios
- 3D hydrological flow of mine-water plumes
- 1D-3D reactive transport to simulate natural attenuation in space and time
- Assessment against long-term monitoring
- Enhanced NA as required

ISR wellfield – 1 a timeframe

Post-ISR – 100 a timeframe
NA in Space and Time from Calibrated Model (Reactive Transport)

Example 1: Neutralisation of post-mining fluid (left)

Example 2: Immobilisation of dissolved metal (caused by both neutralisation and chemical reduction)
ISR mine closure and rehabilitation:

- Minimum surface disturbance, no waste rock heaps, no tailings, most radioactivity kept underground.

- Attenuation forces to be overcome during active leaching are identical to drivers of (E)NA → consistent understanding.

- Mine closure: integrative part of ISR mine development and approval from the very beginning / prevention vs. remediation.
It is essential that extensive investigations be carried out during the feasibility and planning and design phases to identify, determine and, if possible, quantify the following:

• an initial benchmarked baseline evaluation of the water resource at the operation.
1994: Approval of the mine closure plan with the goal of flooding of the pit; Ancillary provision: Contamination of the 3rd aquifer (GWL) shall be excluded.

2000-2013:
• Flooding of subsection I (up to 140 m NN)
• Section II (up to 190 m NN) not approved.
• Water authority failed to agree
• Wismut filed a protest in 2013
• Dispute over Uranium baseline in the 3rd aquifer ongoing
• Deadlock since January 2013. Total costs until today: 12 Mio. € (7500 €/Day)

In-situ Recovery (ISR) Mine Closure Königstein, Saxony

• Conventional uranium mining started in 1967 (Reserves 30,000 tonnes)
• Deposit was developed across an area of approx. 6 km².
• In 1984 underground uranium mining was switched to chemical leaching.
• Leach solution was injected via boreholes into prepared sandstone blocks or blasted chambers.

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Unfortunately, in some sectors of the mining industry, the appetite for closure planning and progressive rehabilitation can change rapidly as the financial viability of operations changes.

1Leading Practice Sustainable Development Program for the Mining Industry, September 2016, Australian Government
Mount Polley mine, B. C., Canada, 4. Aug. 2014

- Open pit copper and gold mine (with an underground component)
- Commenced operations in 1997
- Area of 19,601 hectares
- Water abundant – but apparently too abundant………….
Mount Polley disaster (10 Mio. m³ water / 4.5 Mio. m³ slurry), B. C., Canada, 4. Aug. 2014

- Shear failure of dam foundation materials (glacial till)
- Increased loading imposed by the growing dam
- Failure occurred rapidly and without precursors

- Dam raising proceeded incrementally, one year at a time.
- More reactive than anticipatory,
- No long-term planning or execution.

- Absence of an adequate water management or water treatment strategy
- Absence of a well-developed tailings beach (fundamental of the design as a tailings dam)

Source: http://commonsensecanadian.ca/mount-polley-spill-may-far-bigger-initially-revealed/
Wismut, Germany - Uranium mining legacy tailing pond – when things don’t go wrong…….

- Embankment stable according to GDR-design
- Longterm embankment stability questioned in the early 90ties (no acute risk - even though level of unreleasable contaminated water increased in the early nineties).

Immediate measures:
- Water treatment plant,
- Removal of uncontaminated surfacewaters,
- Release of untreated seepage water, operation of drainage wells,
- Building an upstream protecting embankment.
Mineral resource legacy framework\textsuperscript{1}:
- Stakeholder relationships in the discovery and utilisation of minerals -

\textsuperscript{1}Leading Practice Sustainable Development Program for the Mining Industry, September 2016, Australian Government
Essential elements of mine closure

• Recognise and address the closure issues that the mining operation needs to consider in its planning for closure through to relinquishment.

• Developing a risk management approach to mine closure planning that applies from mine concept to post-closure and is integrated with whole-life of-mine planning.

• Perform the closure activities associated with each step in the LoM cycle and integrate them into business practice via the progressive implementation of a closure system.

• Understand the processes and tools that can assist the mining operation to achieve leading practice in mine closure and relinquishment.

• Understand the need for engagement with communities and regulators in establishing and implementing leading practice closure, as the community inherits the resource legacy.

• Collect quality baseline data and develop a high-quality knowledge base that is easily accessible.

\(^1\text{Leading Practice Sustainable Development Program for the Mining Industry, September 2016, Australian Government}\)
Essential elements of mine closure – continued:

- Develop closure objectives and completion criteria in the planning phase of the mine, in consultation with key stakeholders, and then regularly review them as research, monitoring and progressive rehabilitation is undertaken.

- Recognise that the physical, chemical and geochemical characterisation of soils and mine waste is an important component of engineered landform design and construction.

- Recognise that mine tailings rehabilitation and closure requires a unique focus.

- Recognise that water management and its interaction with the mine landforms is a critical closure element.

- Consider mine closure planning and associated financial provisioning across all phases of the LoM, developing estimates for provisioning, regulatory reporting and long-term LoM planning and budgeting.

- Be aware that the pre-decommissioning and closure planning stage is critical and requires a focus on liability, planning, assets, divestment, remediation, legacy infrastructure and post-closure monitoring and management.

- Use advanced and careful planning to ensure that the transition to post-mining land use and relinquishment is as smooth as possible.