EXECUTIVE SUMMARY

Scope of this work

This work covers activities related to mineral processing, tailings and the waste-rock management of ores that have the potential for a strong environmental impact that can be considered as examples of "good practice". The intention is to raise awareness of best practice across all activities in this sector.

The starting point for this document is the Communication from the European Commission COM(2000) 664 on the Safe Operation of Mining Activities. As a follow-up to the tailings dam bursts in Aznalcollar and Baia Mare this Communication proposes a follow-up action plan, which includes the elaboration of a BAT Reference Document based on an exchange of information between the European Union's Member States and the mining industry. This document is the result of this information exchange. It has been developed pursuant to Article 19(3) of the proposed Directive on the management of waste from the extractive industries[1].

The abovementioned bursts have brought public attention to the management of tailings ponds and tailings dams. However, it should not be forgotten that the collapse of tailings and waste-rock heaps can also cause severe damage. The dimensions of either type of facility can be enormous. Dams can be tens of metres high, heaps even more than 100 m high and several kilometres long possibly containing hundreds of millions of cubic metres of tailings or waste-rock. According to the Eurostat yearbook 2003 more than 300 million tonnes of mining and quarrying waste is estimated to be generated annually in the EU15.

The following metals are covered in this document on the basis that they are mined and/or processed in the European Union (EU-15), candidate countries and Turkey are covered, i.e.:

- aluminium
- cadmium
- chromium
- copper
- gold
- iron
- lead
- manganese
- mercury
- nickel
- silver
- tin
- tungsten
- zinc.

These metals are all covered in this document, irrespective of the amounts produced or the mineral processing method used (e.g. whether mechanical methods are used, such as flotation, or whether by chemical or hydrometallurgical methods such as leaching, etc.).

[1] COM(03)319

Coal and selected industrial minerals are also covered in this document, i.e.:

- barytes
- borate
- feldspar (if recovered by flotation)
- fluorspar
- kaolin (if recovered by flotation)
- limestone (if processed)
- phosphate
- potash
- strontium
- talc (if recovered by flotation).

Coal is only included when it is processed and there are tailings produced (thereby following the above-mentioned theme). Generally, this means that hard coal (or rock coal or black coal) is covered, whereas lignite (or brown coal), which is usually not processed, is not covered.

Oil shale is processed in Estonia and large amounts of tailings result, which need to be managed. Therefore, it was also decided to include this in the document. However, as no relevant information was provided on this subject, oil shale issues are not addressed in this document.
Also this document does not address:

- abandoned sites, however, some examples of recently closed sites are discussed
- the mining, processing and tailings management associated with the mining of gas and liquids (e.g. oil and salt from brine).

Vertical Scope
For all minerals defined in the previously mentioned scope the document:

- looks at waste-rock management
- includes topsoil and overburden if they are used in the management of tailings
- includes mineral processing relevant to tailings management (e.g. when the mineral processing influences the characteristics and behaviour of the tailings)
- focuses on tailings management, e.g. in ponds/dams, heaps or as backfill.

The mining industry

The purpose of mining is to meet the demand for metals and minerals resources to develop infrastructure etc. and to improve the quality of life of the population, as the extracted substances are in many cases the raw materials for the manufacture of many goods and materials. These include, for example, metalliferous minerals or metals, coal, or industrial minerals that can be used in the chemical sector or for construction purposes.

The products of the mining industry are sometimes used directly, but often are further refined, e.g. in smelters.

Typical process steps at any mining operation are extraction, followed by mineral processing and finally the shipment of the products and the management of the residues.

For most metalliferous ores, European production is small compared to overall world production (e.g. gold: 1 %, copper: 7 %), as is the similar case for coal mining (6 %). In contrast to the mostly declining production figures in the metal and coal mining sectors, the production of many industrial minerals has been expanding steadily on a European scale. In the case of most industrial minerals, the European production presents a major fraction of the world production (e.g. feldspar: 64 %, potash: 20 %).

Some parts of the mining industry, such as metal and coal mining within Europe, operate under severe economic conditions, mainly because the deposits can no longer compete on an international level. The EU metal sector is also struggling from the difficulty of trying to find new profitable ores in known geological regions. Hence the ability for the metal and coal mining sectors to invest in non-productive expenditures such as tailings and waste-rock management may be constrained. However, despite the reduced mine production in these areas, consumption is steadily increasing. Therefore, to meet this demand imports into Europe are on the increase.

The size of the companies involved in this sector varies significantly, from a handful of employees to several thousand per site. Ownership varies between international companies, industrial holding groups, stand-alone public companies and private companies.

The management of tailings and waste-rock

The management of the residues generated at mining operations, the topsoil, the overburden, and, of special concern in this document, the tailings and waste-rock typically presents an undesired financial burden on operators. Typically the mine and the mineral processing plant are designed to extract as much marketable product(s) as possible, and the residue and overall environmental management is then designed as a consequence of the applied process steps.

There are many options for managing tailings and waste-rock. The most common methods are:

- discarding slurried tailings into ponds
- dry-stacking of thickened tailings
- dumping more or less dry tailings or waste-rock onto heaps or hill sides
- backfilling tailings or waste-rock into underground mines or open pits or using them for the construction of tailings dams
- discarding tailings into surface water (e.g. sea, lake, river) or groundwater
- using the tailings and waste-rock as a product for land use, e.g. as aggregates, or for restoration.

Tailings and waste-rock management facilities vary vastly in size, e. g. from swimming-pool-sized tailings ponds to ponds of over 1000 ha, and from small tailings or waste-rock piles to waste-rock areas of several hundred hectares or tailings heaps over 200 m high.

The choice of the applied tailings and/or tailings management method depends mainly on an evaluation of three factors, namely:

- cost
- environmental performance
- risk.

Key environmental issues

The main environmental impacts from the management of tailings and waste-rock management facilities are the potential emissions of dust and effluents during operation or in the aftercare phase. Furthermore, bursts or collapses of tailings and/or waste-rock management facilities can cause severe environmental damage – and even loss of human life.

The bases for the successful management of tailings and waste-rock are a proper material characterisation, including an accurate prediction of our long-term behaviour, and a good choice of site location.

Emissions:
Effluents and dust emitted from tailings and waste-rock management facilities, controlled or uncontrolled, may be toxic in varying degrees to humans, animals and plants. The effluents can be acidic or alkaline, and may contain dissolved metals and/or soluble and entrained insoluble complex organic constituents from mineral processing, as well as possibly natural occurring organic substances such as humic and long-chain carboxylic acids from the mining operations. The substances in the emissions, together with their pH level, dissolved oxygen content, temperature and hardness may all be important aspects affecting their toxicity to the receiving environment.

The actual environmental impact of emissions to watercourses always depends on many factors, such as concentration, pH, temperature, water hardness etc.

The past two decades have increased the widespread awareness of an environmental problem in mining known as 'acid rock drainage' or ARD. Though difficult to reliably predict and quantify, ARD is associated with sulphide ore bodies mined for Pb, Zn, Cu, Au, and other minerals, including coal. While ARD can be generated from sulphide-bearing pit walls, and underground mines, only tailings and waste-rock management are considered in this document.

The key issues that are the root of these environmental problems are:
- tailings and/or waste-rock often contain metal sulphides
- sulphides oxidise when exposed to oxygen and water
- sulphide oxidation creates an acidic metal-laden leachate
- leachate generation over long periods of time.

Accidental bursts and collapses:
The collapse of any type of tailings or waste-rock management facility can have short-term and long-term effects. Typical short-term consequences include:
- flooding
- blanketing/suffocating
- crushing and destruction
- cut-off of infrastructure
- poisoning.

Potential long-term effects include:
- metal accumulation in plants and animals
- contamination of soil
- loss of animal life.

Site rehabilitation and aftercare:
When an operation comes to an end the site needs to be prepared for its subsequent use. Usually plans for closure and site clean-up will have been part of the permitting of the site, right from the planning stage onwards and should therefore have undergone regular updating with every change in the operation and in negotiations with the permitters and other stakeholders. In some cases the aim will be to leave as little a footprint as possible, whereas in other cases a complete change of landscape may be aimed for. The concept of 'design for closure' implies that the closure of the site is taken into account in the feasibility study of a new mine site and is then continuously monitored and updated during the life cycle of the mine. In every case, negative environmental impacts need to be kept to a minimum.

Common processes and techniques

Mining techniques:
The extraction of an ore (a process called mining), subsequent mineral processing and the management of tailings and waste-rock are in most cases considered to be a single operation. The ore extraction, the subsequent mineral processing techniques and the tailings and waste-rock management applied depend on the mining technique. Hence it is important to have an understanding of the most important mining methods.

For the mining of solids, there are four basic mining concepts:
(1) open pit
(2) underground mine
(3) quarry and
(4) solution mining.

The choice between these four alternatives depends on many factors, such as:
- value of the desired mineral(s)
- grade of the ore
- size, form and depth of the orebody
- environmental conditions of the surrounding area
- geological, hydrogeological and geomechanical conditions of the rock mass
- seismic conditions of the area
- site location of the orebody
- solubility of the orebody
- environmental impact of the operation
- surface constraints
- land availability.

Mineralogy:
Basically it is possible to differentiate between the mayor mineral types such as oxide, sulphide, silicate and carbonate minerals, which, through weathering and other alterations, can undergo fundamental chemical changes (e.g. weathering of sulphides to oxides). The mineralogy is set by nature and determines in many ways the subsequent recovery of the desired minerals and the subsequent tailings and waste-rock management.

Having a good knowledge of the mineralogy is an important precursor for:
- environmentally sound management (e.g. separate management of acid-generating and non-acid-generating tailings or waste-rock)
- a reduced need for end-of-pipe treatments (such as the lime treatment of acidified seepage water from a TMF)
- more possibilities for utilising tailings and/or waste-rock as aggregates.

Mineral processing techniques:
The purpose of mineral processing is to turn the raw ore from the mine into a marketable product. This is usually carried out on the mine site, the plant being referred to as a mineral processing plant (mill or concentrator). The essential purpose of the processing is to reduce the bulk of the ore, which must be transported to and processed by subsequent processes (e.g. smelting), by using methods to separate the valuable (desired) mineral(s) from the gangue. The marketable product of this is called concentrate, and the remaining material is called tailings.
Mineral processing includes various procedures that rely on the mineral's own physical characteristics (i.e. particle size, density, magnetic properties, colour) or physico-chemical properties (surface tension, hydrophobicity, wetability).

Typical techniques applied in mineral processing are:

- comminution
- screening
- gravity
- flotation
- sorting
- magnetic separation
- electrostatic separation
- leaching
- thickening
- filtration.

Some of these techniques require the use of reagents. In the case of flotation frothers, collectors and modifiers are necessary to achieve the desired separation.

The techniques used in mineral processing have an effect on the characteristics of the tailings.

Tailings and waste-rock management:
Some of the most important characteristics of materials in tailings and waste-rock management facilities are:

- shear strength
- particle size distribution
- density
- plasticity
- moisture content
- permeability.

Tailings dams are surface structures in which slurried tailings are managed. This type of TMF is typically used for tailings from wet processing. For each tailings impoundment, several activities need to be considered, including:

- dams to confine the tailings
- diversion systems for natural run-off around or through the dam
- tailings delivery from the mineral processing plant to the tailings dam
- deposition of the tailings within the dam
- evacuation of excess free water
- protection of the surrounding area from environmental impacts
- instrumentation and monitoring systems to enable surveillance of the dam
- long-term aspects (i.e. closure and after-care).

Some other techniques to manage tailings and waste-rock are backfilling, management on heaps, thickened tailings, and underwater management.

Usually a mine, together with the mineral processing plant and the tailings and waste-rock facilities, will only remain in operation for a few decades. Mine voids (not part of the scope of this work), tailings and waste-rock however, may remain behind long after the mining activity has ceased. Therefore special attention needs to be given to the proper closure, rehabilitation and after-care of these facilities.

The most important aspects in management of tailings and waste-rock are the consideration of failure modes of heaps and dams, the relationship between tailings characteristics and tailings behaviour and the acid rock drainage (ARD) potential.

Applied processes and techniques, emission and consumption levels

In the following some examples of the most important factors in tailings management will be highlighted:

- The slurried tailings, called 'red mud' from the refining of alumina have an elevated pH and are either stored in conventional tailings pond/dam systems or are thickened to a degree that they can be 'dry-stacked'
- Tailings from base metal operations are mostly managed as slurries in large tailings ponds. Often base metals ores contain sulphides, so that the tailings have an acid-rock-drainage (ARD) potential. At one operation the tailings are discharged subaqueously to prevent ARD generation from the start. Some operations backfill part of the tailings underground. In several case the chosen closure method for the tailings pond is the 'wet' cover technique.
- The coarse tailings from iron ore operations are managed in heaps. The slurried tailings are managed in ponds
- Only the tailings from some gold mines have an ARD potential. When cyanide leaching is used to extract the gold, the cyanide is destroyed prior to discharge into the tailings pond.
- In the case of industrial minerals, several sites do not generate tailings at all or sell the tailings as aggregates.
- The borates operations first store the coarse tailings on heaps before they are backfilled
- One fluorspar operation discharges the tailings into the sea
- One kaolin operation first dewaters the fine tailings before they are transferred to heaps, this is also done in some limestone/calcium carbonate operations
- One limestone operation discards the slurried tailings into a former quarry
- Potash sites manage the solid tailings on heaps or backfilled. The liquid tailings are partially pumped into deep wells and partially led into surface waters. In one case there is marine discharge of the tailings.
- In coal operations backfilling is often not viable. The coarse tailings are managed on heaps or in former open pit operations. The slurried fines are either discarded into ponds or filtered. In some cases the filtered tailings are sold. In other cases they are put on heaps.
- Some of the measures applied to prevent accidents are monitoring routines, OSM manuals, independent audits, water balances, subsidence measurements, planning by external experts, the use of piezometers and inclometers and seismic monitoring.

In the following some examples of the most important factors in waste-rock management will be highlighted:

- In underground operation the waste-rock usually remains underground
- As with the tailings the waste-rock in base metals operations sometimes has an ARD potential. Some operations manage ARD and non-ARD waste-rock separately. Upon closure ARD generating waste-rock heaps are covered with engineered vegetative covers that aim at preventing ARD generation
- Waste-rock from one iron operation is managed on heaps with coarse the tailings
- Waste-rock from gold operations is managed on heaps, used for dam construction or backfilled into the open pit
- Some industrial minerals operations backfill the waste-rock or sell it as aggregate
- In many coal operations the waste-rock is managed in heaps with the filtered fine tailings. The final heap design is agreed on with the authorities and the communities with the aim of creating landscape integrated structures.

Emission and Consumption levels

Unless reagent built-up is an issue, most of the process water is returned from the tailings management facility to the mineral processing plant.

Due to the large variations in mineralogy, mining and mineral processing methods and in site conditions it is impossible to further summarise the emission and consumption levels. However many sites provided this information, which is included in Chapter 3. Typically the information includes data on the water consumption and the amount of process water re-use, the water balance, the reagent consumption, the dust emissions and information on the emissions to water.

Costs

In Chapter 3, some examples of costs for tailings and waste-rock management for operation and closure have been included.

Techniques to consider in the determination of BAT

Chapter 4 contains the detailed information used to determine BAT for the management of tailings and waste-rock in mining activities.

The aim was to include enough information to assess the applicability of the techniques in general or in specific cases. The information in this chapter is essential to the determination of BAT.

Those techniques which the are judged to be BAT, are also cross-referenced from chapter 5. Users of the document are thus directed to the discussion of the relevant techniques associated with the BAT conclusions, which can assist them when they are determining the BAT-based conditions of permits.

Some of the techniques in Chapter 4 are very technical whilst others are good operating practices, including management techniques. The techniques are grouped in the following order:

1. general principles: Good management principles, management strategies and risk assessment, all aimed at providing the general background for successfully managing tailings and waste-rock
2. life-cycle management: A reduction of .the risk of any failures can be assisted by a commitment of the operator to the adequate and enforced application of appropriate available engineering techniques for the design, operation and closure of tailings and waste-rock management facilities over the entire period of their operating life. Some tools elemental to good engineering are the establishment of an environmental baseline, the characterisation of tailings and waste-rock, the use of dam safety manuals and audits, as well applying planning for closure from the outset
3. emission prevention and control:
   - ARD management: There are a number of prevention, control and treatment options developed for potentially ARD generating tailings and waste-rock, applicable for the operational as well as the closure phases of the mine life
   - techniques to reduce reagent consumption: Several approaches are available to reduce the use of reagents, i.e. computer-based monitoring of feed quality, operational strategies to minimise cyanide addition and pre-sorting of the feed to the mineral processing plant
   - prevention of water erosion: Water erosion of tailings or waste-rock management facilities can be avoided by covering the slopes or encouraging particle binding
   - dust prevention: The main sources for dust emissions are the beaches of tailings ponds, the outer slopes of dams and heaps and the transport of tailings and waste-rock
   - techniques to reduce noise emissions: The most common sources for noise emissions are transport, dumping and spreading, when trucks and conveyor belts are used
   - progressive restoration/revegetation: Heaps and dams are often restored/revegetated during operation. Amongst other advantages, this allows a shorter closure period
   - water balances: Completing a detailed water balance is of importance for the design of any tailings pond, the mine site and for the post mining scenario. The water balance can

determine the discharge capacity of the pond and the required freeboard (if the water from the pond cannot be directly released into the recipient watercourse). Upon closure, the water balance is evaluated in order to implement the closure plans

- drainage of ponds: In impermeable ponds a drainage systems may be required to allow the re-use of process water and to reduce the required ponds size
- free water management: If the free water in the pond is not discharged directly into the natural watercourses, it is necessary to arrange the deposition such that all free water is returned to the plant or, in arid, hot climates, evaporated
- seepage management: A prerequisite for the design of seepage management systems is a thorough understanding of the hydrogeological background of the site. In some cases, seepage is prevented. In other scenarios, the seepage water is collected or, if of a good quality, allowed to seep into the groundwater
- techniques to reduce emissions to water: Emissions to water can be prevented by re-using the process water. If this is not possible the effluents may turn out to be acidic or alkaline, they may contain suspended solids, dissolved components or metals (e.g. arsenic) or process chemicals (e.g. cyanide). The treatment techniques that can be applied will differ for each compounds
- groundwater monitoring: Groundwater is usually monitored around all tailings and waste-rock areas. This includes the level of the water table and the water quality

4. accident prevention:
    - tailings or waste-rock management in a pit: In order to prevent the collapse of dams or heaps, the best possible place to construct a tailings or waste-rock management facility is a suitable nearby pit, since in this case dam/heap stability is not an issue
    - diversion of natural run-off: A diversion system is critical to the safety of a tailings dam. Failure of any part can lead to the impoundment receiving floods for which it was not designed with the possibility of overtopping, leading to a total failure of the dam
    - preparation of the natural ground below the dam: The natural ground below the retaining dam is usually stripped of all vegetation and huminous soils, in order to provide an adequate ‘foundation’ for the structure
    - dam construction material: The prime consideration for choosing the dam construction material is that the materials should be fit for the purpose and must not weaken under operational or climatic conditions
    - tailings deposition: Proper deposition of tailings, particularly in a wet state, will always be critical to the stability of the structure. Typically, the wet tailings are discharged off the crest of the dam in as even a distribution as possible around the dam, in order to create a "beach" of tailings against the inner face of the retaining dam
    - techniques to construct and raise dams: Tailings dams used to be constructed of the coarse tailings fraction and indeed this can still be a very appropriate way of retaining the tailings slurry. However, over the life of the mine the qualities of the ore can change and the processing method can change and therefore the characteristics of the tailings may also change. Hence quality management is a tricky issue over the entire lifespan of an operation. Therefore there is a trend to construct the initial starter dam, and often also the raises, with borrow material, whose quality can be more easily monitored during the construction of the dam. However not only is the type of material used to construct tailings dams important but so is the placing and compaction of suitable construction material, to ensure long-term stability. The basic dam types used are conventional dams or dams constructed using the upstream, downstream or centreline method
    - free water management, freeboard, emergency discharge and design flood determination: Techniques for the removal of free water include spillways, open channels, decant towers and decant wells. Together with maintaining an adequate freeboard and emergency discharge systems, this is an essential tool for the prevention of accidents, such as dam overflows
    - drainage of dams: Permeable dams are based on the principle that seepage through the dam should be drawn down well below the toe of the outer slope. This can be achieved by an internal drainage system, with the drainage zone being located in the inner section of the dam. Non-permeable dams have similar drainage systems, with the aim being to

stop the seepage flow through the core from eroding the core and the outer slope of the dam
- monitoring of seepage: Controlled seepage occurs through the dam and ensures the stability by lowering the pore pressure over the dam. However, it is essential that the seepage is well controlled and managed both with respect to the day to day environmental performance, as well as from an accident prevention point of view
- dam and heap stability: An important measure of the stability of heaps and dams is the safety factor, i.e. the ratio of the available shear strength to the shear stress
- techniques to monitor stability of dams and heaps: The basis for all monitoring is the development of a monitoring plan. The monitoring consists of a list of measurements carried out in certain intervals. The overall monitoring plan typically also includes the plans for inspections and audits/reviews. A further factor influencing the stability of dams and heaps is the stability of the supporting strata, i.e. the ground on which the dams and heaps are built
- cyanide management: In addition to the treatment of cyanide leaching, the management of CN in general also involves a large number of security measures taken to prevent accidents. The design of the plant also includes several technical solutions aimed at the prevention of accidents
- dewatering of tailings: The main disadvantage of dealing with slurried tailings is their mobility. If the containment structure (i.e. the dam) were to collapse, they could liquefy and then cause considerable damage due to their physical and chemical characteristics. To avoid this problem two alternatives have been developed: dry tailings and thickened tailings managment

5. reduction of footprint: An efficient way to reduce the footprint of tailings and waste-rock management facilities is to backfill all or part of these materials. Other options include the underwater management of tailings, i.e. discharge into the sea, or finding other uses of the tailings and waste-rock
6. mitigation of accidents: Two tools for the mitigation of accidents are emergency planning and the evaluation and follow-up of incidents
7. environmental management tools: Environmental management systems are a useful tool to aid the prevention of pollution from industrial activities in general.

BAT for the management of tailings and waste-rock in mining activities

The BAT chapter (Chapter 5) identifies those techniques that are considered to be BAT, based upon the information in Chapter 4 and taking into account the definition of "best available techniques" and the considerations listed in Annex IV of the IPPC Directive (see Preface).

The BAT chapter is divided into a generic part, applicable to all sites managing tailings and waste-rock, and a specific part for specific minerals.

For completion, all BAT conclusions are shown here.

<u>Generic BAT</u>
BAT is to:
- apply the general principles set out in Section 4.1
- apply a life cycle management approach as described in Section 4.2.

Life cycle management covers all the phases of a site's life, including:

- the design phase (Section 4.2.1):
  - environmental baseline (Section 4.2.1.1)
  - characterisation of tailings and waste-rock (Section 4.2.1.2)
  - TMF studies and plans (Section 4.2.1.3), which cover the following aspects:
    - site selection documentation
    - environmental impact assessment

    - risk assessment
    - emergency preparedness plan
    - deposition plan
    - water balance and management plan and
    - decommissioning and closure plan
  - TMF and associated structures design (Section 4.2.1.4)
  - control and monitoring (Section 4.2.1.5)
- the construction phase (Section 4.2.2)
- the operational phase (Section 4.2.3), with the elements:
  - OSM manuals (Section 4.2.3.1)
  - auditing (Section 4.2.3.2)
- the closure and after-care phase (Section 4.2.4), with the elements:
  - long-term closure objectives (Section 4.2.4.1)
  - specific closure issues (Section 4.2.4.2) for
    - heaps
    - ponds, including
      - water covered ponds
      - dewatered ponds
      - water management facilities

Furthermore, BAT is to:

- reduce reagent consumption (Section 4.3.2)
- prevent water erosion (Section 4.3.3)
- prevent dusting (Section 4.3.4)
- carry out a water balance (Section 4.3.7) and to use the results to develop a water management plan (Section 4.2.1.3)
- apply free water management (Section 4.3.9)
- monitor groundwater around all tailings and waste-rock areas (Section 4.3.12).

ARD management

The characterisation of tailings and waste-rock (Section 4.2.1.2 in combination with Annex 4) includes the determination of the acid-forming potential of tailings and/or waste-rock. If an acid-forming potential exists it is BAT to firstly prevent the generation of ARD (Section 4.3.1.2), and if the generation of ARD cannot be prevented, to control ARD impact (Section 4.3.1.3) or to apply treatment options (Section 4.3.1.4). Often a combination is used (Section 4.3.1.6).

All prevention, control and treatment options can be applied to existing and new installations. However, the best closure results will be obtained when plans are developed for the site closure right at the outset (design stage) of the operation (cradle-to-grave philosophy).

The applicability of the options depends mainly on the conditions present at the site. Factors such as:

- water balance
- availability of possible cover material
- groundwater level.

Influence the options applicable at a given site. Section 4.3.1.5 provides a tool for deciding on the most suitable closure option.

Seepage management (Section 4.3.10)

Preferably the location of a tailings or waste-rock management facility will be chosen in a way that a liner is not necessary. However, if this is not possible and the seepage quality is detrimental and/or the seepage flow rate is high, then seepage needs to be prevented, reduced (Section 4.3.10.1) or controlled (Section 4.3.10.2) (listed in order of preference). Often a combination of these measures is applied.

Emissions to water

BAT is to:

- re-use process water (see Section 4.3.11.1)
- mix process water with other effluents containing dissolved metals (see Section 4.3.11.3)
- install sedimentation ponds to capture eroded fines (see Section 4.3.11.4.1).
- remove suspended solids and dissolved metals prior to discharge of the effluent to receiving watercourses (Section 4.3.11.4)
- neutralise alkaline effluents with sulphuric acid or carbon dioxide (Section 4.3.11.6)
- remove arsenic from mining effluents by the addition of ferric salts (Section 4.3.11.7).

The following techniques are BAT for treating acid effluents (Section 4.3.11.5):

- active treatments:
  - addition of limestone (calcium carbonate), hydrated lime or quicklime
  - addition of caustic soda for ARD with a high manganese content
- passive treatment:
  - constructed wetlands
  - open limestone channels/anoxic limestone drains
  - diversion wells.

Passive treatment systems are merely a long-term solution after the decommissioning of a site, when used as a polishing step combined with other (preventive) measures.

Noise emissions (Section 4.3.5)

BAT is to:

- use continuous working systems (e.g. conveyor belts, piplelines)
- encapsulate belt drives in areas where the noise is a local issue
- first create the outer slope of a heap and transfer ramps and working benches into the heap's inner area as far as possible.

Dam design

In addition to the measures in Section 4.1 and Section 4.2, during the **design** phase (Section 4.2.1) of a **tailings dam**, BAT is to:

- use the once in a 100-year flood as the design flood for the sizing of the emergency discharge capacity of a low hazard dam
- use the once in a 5000 – 10000-year flood as the design flood for the sizing of the emergency discharge capacity of a high hazard dam.

Dam construction

In addition to the measures in Section 4.1 and Section 4.2, during the **constructional** phase (Section 4.2.2) of a **tailings dam**, BAT is to:

- strip the natural ground below the retaining dam of all vegetation and huminous soils (Section 4.4.3)
- choose a dam construction material that is fit for the purpose and which will not weaken under operational or climatic conditions (Section 4.4.4).

Raising dams

In addition to the measures in Section 4.1 and Section 4.2, during the **constructional** and **operational** phases (Sections 4.2.2 and 4.2.3) of a **tailings dam**, BAT is to:

- evaluate the risk of too high pore pressure and monitor the pore pressure before and during each raise
- use conventional type dams (Section 4.4.6.1), under the following conditions, when:
  - the tailings are not suitable for dam construction
  - the impoundment is required for the storage of water
  - the tailings management site is in a remote and inaccessible location
  - retention of the tailings water is needed over an extended period for the degradation of a toxic element (e.g. cyanide)

  - the natural inflow into the impoundment is large or subject to high variations and water storage is needed for its control
- use the upstream method of construction (Section 4.4.6.2), under the following conditions, when:
  - there is very low seismic risk
  - tailings are used for the construction of the dam: at least 40 – 60 % material with a particle size between 0.075 and 4 mm in whole tailings (does not apply for thickened tailings)
  - the dam is not used to store water
- use the downstream method of construction (Section 4.4.6.3), under the following conditions, when:
  - sufficient amounts of dam construction material are available (e.g. tailings or waste-rock)
- use the centreline method of construction (Section 4.4.6.4), under the following conditions, when:
  - the pond will not be used for permanent storage
  - the seismic risk is low.

Dam operation

In addition to the measures in Section 4.1 and Section 4.2, during the **operational phase** (Section 4.2.3) of a **tailings pond**, BAT is to:

- monitor stability as further specified below
- foresee provisions for diverting any discharge into the pond away from the pond in the event of difficulties
- provide alternative discharge, possibly into another impoundment
- provide second decant facilities (e.g. emergency overflow, Section 4.4.9) and/or standby pump barges for emergencies, if the level of the free water in the pond reaches the pre-determined minimum freeboard (Section 4.4.8)
- measure ground movements with deep inclometers and have a knowledge of the pore pressure conditions
- provide adequate drainage (Section 4.4.10)
- maintain records of design and construction and any updates/changes in the design/construction
- maintain a dam safety manual as described in Section 4.2.3.1 in combination with independent audits as mentioned in Section 4.2.3.2
- educate staff and provide adequate training for staff.

Removal of free water from the pond (Section 4.4.7.1)

BAT is to:

- use a spillway in natural ground for valley site and off valley site ponds
- use a decant tower:
  - in cold climates with a positive water balance
  - for paddock-style ponds
- use a decant well:
  - in warm climates with a negative water balance
  - for paddock-style ponds
  - if a high operating freeboard is maintained.

Dewatering of tailings (Section 4.4.16)

The choice of method (slurried, thickened or dry tailings) depends mainly on an evaluation of three factors, namely:

- cost
- environmental performance
- risk.

BAT is to apply:

- dry tailings (Section 4.4.16.1)
- thickened tailings (Section 4.4.16.2) and
- slurried tailings (Section 4.4.16.3) management.

There are many factors that influence the choice of the appropriate techniques for a given site. Some of these factors are:

- mineralogy of the ore
- ore value
- particle size distribution
- availability of process water
- climatic conditions
- available space of tailings management.

Tailings and waste-rock management facility operation

In addition to the measures in Section 4.1 and Section 4.2, during the **operational phase** (Section 4.2.3) of **any tailings and waste-rock management facility**, BAT is to:

- divert natural external run-off (Section 4.4.1)
- manage tailings or waste-rock in pits (Section 4.4.1). In this case heap/dam slope stability is not an issue
- apply a safety factor of at least 1.3 to all heaps and dams during operation (Section 4.4.13.1)
- carry out progressive restoration/revegetation (Section 4.3.6).

Monitoring stability

BAT is to:

- monitor in a tailings pond/dam (Section 4.4.14.2):
  - the water level
  - the quality and quantity of seepage flow through the dam (also Section 4.4.12)
  - position of phreatic surface
  - pore pressure
  - movement of dam crest and tailings
  - seismicity, to ensure stability of the dam and the supporting strata (also Section 4.4.14.4)
  - dynamic pore pressure and liquefaction
  - soil mechanics
  - tailings placement procedures
- monitor in a heap (Section 4.4.14.2):
  - bench/slope geometry
  - sub-tip drainage
  - pore pressure
- also carry out:
  - in the case of a tailings pond/dam:
    - visual inspections (Section 4.4.14.3)
    - annual reviews (Section 4.4.14.3)
    - independent audits (Section 4.2.3.2 and Section 4.4.14.3)
    - safety evaluations of existing dams (SEED) (Section 4.4.14.3)
  - in the case of a heap:
    - visual inspections (Section 4.4.14.3)
    - geotechnical reviews (Section 4.4.14.3)
    - independent geotechnical audits (Section 4.4.14.3).

Reduction of footprint
BAT is to:

- if possible, prevent the generation of tailings/waste-rock
- backfill tailings (Section 4.5.1), under the following conditions, when:
  - backfill is required as part of the mining method (Section 4.5.1.1)
  - the additional cost for backfilling is at least compensated for by the higher ore recovery
  - in open pit mining, if the tailings easily dewater (i.e. evaporation and drainage, filtration) and thereby a TMF can be avoided or reduced in size (Sections 4.5.1.2, 4.5.1.3, 4.5.1.4, 4.4.1)
  - nearby mined out open pits are available for backfilling (Section 4.5.1.5)
  - backfilling of large stopes in underground mines (Section 4.5.1.6). Stopes backfilled with slurried tailings will require drainage (Section 4.5.1.9). Binders may also need to be added to increase the stability (Section 4.5.1.8)
- backfill tailings in the form of paste fill (Section 4.5.1.10), if the conditions to apply backfill are met and if:
  - there is a need for a competent backfill
  - the tailings are very fine, so that little material would be available for hydraulic backfill. In this case, the large amount of fines sent to the pond would dewater very slowly
  - it is desirable to keep water out of the mine or where it is costly to pump the water draining from the tailings (i.e. over a large distance)
- backfill waste-rock, under the following conditions (Section 4.5.2), when:
  - it can be backfilled within an underground mine
  - one or more mined out open pits are nearby (this is sometimes referred to as ‘transfer mining’)
  - the open pit operation is carried out in such a way that it is possible to backfill the waste-rock without inhibiting the mining operation
- investigate possible uses of tailings and waste-rock (Section 4.5.3).

Closure and after-care
In addition to the measures in Section 4.1 and Section 4.2, during the **closure and after-care phase** (Section 4.2.4) of **any tailings and waste-rock management facility,** BAT is to:

- develop closure and after-care plans during the planning phase of an operation, including cost estimates, and then to update them over time (Section 4.2.4). However, the requirements for rehabilitation develop throughout the lifetime of an operation and can first be considered in precise detail in the closure phase of a TMF
- apply a safety factor of 1.3 for dams and heaps after closure (Section 4.2.4 and 4.4.13.1).

For the closure and after-care phase of tailings ponds BAT is to construct the dams so that they stay stable in the long term if a water cover solution is chosen for the closure (Section 4.2.4.2).

Gold leaching using cyanide
In addtion to the generic measures for all sites applying gold leaching using cyanide, BAT is to do the following:

- reduce the use of CN by applying:
  - operational strategies to minimise cyanide addition 4.3.2.2
  - automatic cyanide control 4.3.2.2.1
  - if applicable, peroxide pre-treatment 4.3.2.2.2
- destroy the remaining free CN prior to discharge in the pond (Section 4.3.11.8). Table 4.13 shows examples of CN levels achieved at some European sites
- apply the following safety measures (Section 4.4.15):
  - size the cyanide destruction circuit with a capacity twice the actual requirement
  - install a back-up system for lime addition
  - install backup power generators.

Aluminium

In addition to the generic measures for all alumina refineries, BAT is to do the following:

- during operation:
  - avoid discharging effluents into surface waters. This is achieved by re-using process water in the refinery (Section 4.3.11.1 or, in dry climates, by evaporation
- in the after-care phase (Section 4.3.13.1):
  - treat the surface run-off from TMFs prior to discharge, until the chemical conditions have reached acceptable concentrations for discharge into surface waters
  - maintain access roads, drainage systems and the vegetative cover (including re-vegetation if necessary)
  - continue groundwater quality sampling.

Potash

In addition to the generic measures for all potash sites, BAT is to do the following:

- if the natural soil is not impermeable, make the ground under the TMF impermeable (Section 4.3.10.3)
- reduce dust emissions from conveyor belt transport (Section 4.3.4.3.1)
- seal/line the toe of the heaps outside the impermeable core zone and collect the run-off (Section 4.3.11.4.1)
- backfill large stopes with dry and/or slurried tailings (Section 4.5.1.6).

Coal

In addition to the generic measures for all coal sites, BAT is to do the following:

- prevent seepage (Section 4.3.10.4)
- dewater fine tailings < 0.5 mm from flotation (Section 4.4.16.3).

Environmental management

A number of environmental management techniques are determined as BAT. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

BAT is to implement and adhere to an Environmental Management System (EMS) that incorporates, as appropriate to individual circumstances, the following features: (see Chapter 4)

- definition of an environmental policy for the installation by top management (commitment of the top management is regarded as a precondition for a successful application of other features of the EMS)
- planning and establishing the necessary procedures
- implementation of the procedures, paying particular attention to
  - structure and responsibility
  - training, awareness and competence
  - communication
  - employee involvement
  - documentation
  - efficient process control
  - maintenance programme
  - emergency preparedness and response
  - safeguarding compliance with environmental legislation
- checking performance and taking corrective action, paying particular attention to
  - monitoring and measurement (see also the Reference document on Monitoring of Emissions)
  - corrective and preventive action

  - maintenance of records
  - independent (where practicable) internal auditing in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained
- review by top management.

Three further features, which can complement the above stepwise, are considered as supporting measures. However, their absence is generally not inconsistent with BAT. These three additional steps are:
- having the management system and audit procedure examined and validated by an accredited certification body or an external EMS verifier
- preparation and publication (and possibly external validation) of a regular environmental statement describing all the significant environmental aspects of the installation, allowing for year-by-year comparison against environmental objectives and targets as well as with sector benchmarks as appropriate
- implementation and adherence to an internationally accepted voluntary system such as EMAS and EN ISO 14001:1996. This voluntary step could give higher credibility to the EMS. In particular EMAS, which embodies all the above-mentioned features, gives higher credibility. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.

Specifically for the management of tailings and waste-rock, it is BAT to apply an integrated risk/safety and environmental management system. Therefore environmental management has to be developed and carried out jointly with the risk assessment/management described in Section 4.2.1 and the operation, supervision and maintenance management described in Section 4.2.3.1.

The following list gives some examples of environmental management systems applied in Europe:
- all Kaolin operations in the UK and the Lisheen mine in Ireland have an ISO 14001 certification
- all permits in Ireland require some sort of EMS
- the Global Mining Initiative and the associated Minerals Mining & Sustainable Development forums advocate EMS.

Emerging techniques

Chapter 6 includes six ‘emerging’ techniques that have not yet been commercially applied and that are still in the research or development phase. They are:
- co-disposal of iron ore tailings and waste-rock
- inhibiting progress of ARD
- recycling of cyanide using membrane technology
- lines cells
- utilisation of red mud to remediate problems of ARD and metals pollution
- combination of SO_2/air and hydrogen peroxide to destroy cyanide.

They have been included here to raise awareness for any future revision of this document.

Concluding remarks

Information exchange

Many documents were provided by industry and by permitting authorities as a basis for the information to be included in this document. Bulletins from the ‘International Commission on Large Dams’ (ICOLD) concerning tailings management, the Canadian ‘Guide to the management of tailings facilities' document and the Finnish 'Dam safety code of practice' may be considered as the cornerstone documents for this BREF.

The amount and quality of the data in this document shows an imbalance, in that little information was provided on actual consumption and emission levels of industrial minerals tailings and waste-rock management facilities.

Emission data for metal operations is based on single facilities. No correlation could be developed between the applied techniques and the available emission data. Therefore BAT conclusions with an associated emissions level were not possible.

Degree of consensus reached

The conclusions of the work were agreed at the final plenary meeting in November 2003, with a high level of consensus being achieved. There is one split view concerning the safety factor for long-term stable dams having a 'wet' cover.

Recommendations for future work

The result of this information exchange, i.e. this document, presents an important step forward in reducing everyday pollution and preventing accidents from tailings and waste-rock management facilities. On a few topics, however, the information is incomplete and did not allow BAT conclusions to be reached. Future work could usefully focus on collecting information on the following topics:

- expansion of the scope to address all types of mining waste and to include examples and techniques from other minerals
- more detailed information on the generation of tailings and waste-rock
- BAT associated emission levels for effluent treatment and for cyanide destruction
- underwater tailings management in seawater
- economic data for many of the techniques presented in Chapter 4
- characterisation of tailings and waste-rock:
  - to include more international and national standards in Annex 4
  - to develop a standard methodology for the characterisation waste-rock and tailings
- more performance data for the thickened tailings technique
- new cyanide remediation techniques.

Suggested topics for future research and development projects

The information exchange has also exposed some areas where additional useful knowledge could be gained from Research and Development projects. These relate to the following subjects:

- life-cycle management: Applying full life-cycle management is essential for a site to achieve a high level of safety and environmental performance. However, economic data showing that it is economically effective to manage a mining operation with the entire life-cycle model is currently missing. Research in this area is needed to investigate any existing case studies, to determine the economics of applying integrated life-cycle management for assessing short-term projects (e. g. to assess the maximum profit during operation)
- cyanide decomposition products toxicity: The toxicity of cyanide itself is a well investigated subject. However, it seems that some decomposition products may also be of toxicological importance. In view of the impact of spills from sites using cyanide to leach gold, there is a need for research on the toxicity of cyanide decomposition products.

7 CONCLUDING REMARKS

Timing of the work

The first plenary meeting of the TWG took place in June 2001. The first draft of the document was then sent out to the Technical Working Group (TWG) for consultation in September 2002. The comments were assessed and integrated into the document and a second draft, including proposals for BAT conclusions was sent out in May 2003. The final plenary meeting on the TWG was organised in November 2003. After the meeting there was a short consultation of the concluding remarks and executive summary chapters before the final version of the document was produced.

Sources of information

Many documents were provided by industry and authorities as a basis for the information to be included in this document. Bulletins from the International Commission on Large Dams' (ICOLD) concerning tailings management, the Canadian "Guide to the management of tailings facilities" document and the Finnish "Dam safety code of practice" may be considered as cornerstone documents for this BAT document. Valuable information on specific operations and the techniques applied were provided by the metal, industrial minerals and coal mining industries. These were supplemented by information provided by Ireland, Sweden, Spain, Portugal, Finland, Greece, Italy, Austria and Germany. Site visits were carried out in Ireland, Germany, Austria and Poland. The consultation rounds on each draft document provided specific feedback from operators, remarks on applicability and implementation of some techniques and additional operational and cost data. Throughout the project, special attention was given to the involvement of the new Accession Countries that have important mining activities. This resulted in the active participation of Poland, the Czech Republic and Hungary.

In order to promote the exchange of information, workshops were organised in Sweden, Ireland, Poland and Bulgaria. Furthermore subgroup meetings were held in Austria and, repeatedly throughout the process, in Brussels. All these events provided additional operational data and useful technical information.

Gaps and weaknesses

At the kick-off meeting it was decided to include information on the management of tailings and waste-rock from oil-shale mining in Estonia. Unfortunately no relevant information was provided on this subject.

Initially most contributions focussed on mineral processing and the general management of tailings and waste-rock. Request for further detailed information did provide the desired degree of detail for the techniques applied, but the time delay in incorporated this request resulted in a delay in the compilation and distribution of the first draft.

The amount and quality of the data in this document shows an imbalance, in that little information was provided on actual consumption and emission levels of industrial minerals tailings and waste-rock management facilities.

Emission data for metal operations is based on single facilities. No correlation could be developed between the applied techniques and the available emission data. Therefore BAT conclusions with an associated emissions level were not possible.

Very little information was provided by the TWG on the mitigation of accidents.

Degree of consensus reached

The conclusions of the work were agreed at the final plenary meeting in November 2003, with a high level of consensus being achieved.

The main issues for discussion at the final meeting concerned:

- the amounts of tailings and waste-rock generated
- BAT associated emission levels for effluent treatment and for cyanide destruction
- methods for covering tailings ponds upon closure
- safety factors for heaps and dams
- the monitoring of dams and heaps
- methods for dewatering tailings slurries
- methods for constructing and raising tailings dams.

The TWG was not able to provide information on the amounts of tailings and waste-rock generated by mining activities. Therefore only general data from the yearly Eurostat report was included in Chapter 1.

Concerning effluent treatment and cyanide destruction, as mentioned above regarding gold leaching operations the TWG could not agree on BAT associated emission levels.

It was decided in the final plenary meeting that both the 'dry' cover technique and 'wet' cover technique are methods that allow the prevention of ARD generation when closing a tailings pond. Additional data and text was provided by Sweden to support this argument. Hence both techniques are considered BAT for the prevention of ARD.

The TWG agreed on a safety factor for dams and heaps during operation and upon closure of 1.3 as BAT. However there was a split view concerning the safety factor for long-term stable dams having a 'wet' cover. One Member State and some industry working group members proposed a value of at least 1.3. This proposal was supported by arguments that it is not practical to change the safety factor from 1.3 during operation to 1.5 upon closure of the tailings pond, and that furthermore 1.3 was considered to be 'safe enough' and in accordance with current legislation. However the other Members States and some industry working group members proposed a value of 1.5, arguing that by applying a factor of 1.5 the monitoring in the after-care phase could be reduced. Furthermore the International commission on large dams (ICOLD) recommends the value of 1.5. Therefore there was no BAT decision on the safety factor for long-term stable dams having a 'wet' cover.

Concerning the monitoring of heaps and dams, the TWG described the range of monitoring frequencies and agreed on BAT for the type of monitoring to be carried out to guarantee the stability of heaps and dams.

The TWG decided that drying tailings, thickening tailings as well as the deposition of slurried tailings are all BAT, depending on many factors (e.g. grain size, climate, etc.).

As for the methods for constructing and raising tailings dams, the TWG agreed on the applicability for the upstream method based on information available in this document and further information provided in the final meeting. Conventional dams as well as the upstream, downstream and centreline methods are considered BAT under specific conditions.

Recommendations for future work

The result of this information exchange, i.e. this document, presents an important step forward in reducing everyday pollution and preventing accidents from tailings and waste-rock management facilities. On a few topics, however, the information is incomplete and did not allow BAT conclusions to be reached. The main issues have been presented in Section 7.2 and 7.3 (insert cross-reference).

Future work could usefully focus on collecting the following information:

- expansion of the scope: In the kick-off meeting the TWG decided to limit the scope to an appropriate extent so that this document could be developed in the given time-scale. Any future revision should seek to expand the scope in two directions: (1) the list of minerals covered should be expanded, and (2) the management of other residues, i.e. topsoil and overburden should be addressed
- generation of tailings and waste-rock: There is a lack of information in the document on the amounts of tailings and waste-rock generated in Europe. Ideally this information should be included for all of the minerals discussed in this document. This information needs to be collected by industry and Member States from ongoing projects
- BAT associated emission levels for effluent treatment and for cyanide destruction: There is a lack of information on emission levels for effluent treatment and cyanide destruction. This data should be gathered from current operations and then, analysed and compared with the information already included in Chapter 3 in such a way that it is possible to agree the BAT associated emission levels. For cyanide destruction, there are few example sites in Europe. Therefore information should be gathered from operations outside of Europe, especially Australia, Canada and the US where there is greater experience in this subject. An information exchange with industry and authorities from these countries should be established in order to gather the information necessary to establish BAT associated emission levels
- underwater tailings management in seawater: This technique was introduced following a comment on the 2nd draft. During the final plenary meeting, the TWG concluded that further information about this technique is required to decide whether it is BAT. Currently a clearer description of the technique and information on the applicability, cross-media effects and the economics of this technique are missing. This information needs to be collected by industry and Member States from ongoing projects before it is possible to fully assess whether it is BAT
- economic data: There is a lack of economic information for many of the techniques presented in Chapter 4. This information needs to be collected by industry and Member States from ongoing projects
- characterisation of tailings and waste-rock:
    - in Annex 4 some standards are shown which can be used to characterise tailings and waste-rock. However these are mainly BS and ASTM standards. There is a need to include more international and national standards in order to facilitate the use of the methods in different Member States
    - Annex 4 lists and describes many methods for the characterisation of tailings and waste-rock. A standard methodology needs to be developed that can be generally applied and accepted within Europe, in order to allow a relevant level of characterisation of all waste-rock and tailings to be achieved
- thickened tailings: The current document describes techniques to dewater slurried tailings as well as for the management of slurried tailings in ponds. There is relatively little information in the document on the thickened tailings technique, since this technique has only been recently introduced in the mining area. It is expected that this technique will be more broadly applied in the future. Once more, if performance data is available it needs to be incorporated into the document. This would allow a more precise description of the applicability of this technique
- phytoremediation of cyanide emissions: In the case of gold mining, environmental risks nowadays originate from the use of cyanide solutions, highly toxic for animals and plants. One possible route for minimising the environmental impact of emissions from mining may be wastewater treatment with constructed wetlands, i.e. wetland-phytoremediation. Phytoremediation is the use of green plants to stabilise or remove contaminants from soils, sediments or water. Previous studies on phytoremediation of heavy metals and organic

contaminants have proven the general ability of plants to take up substances from soil or water. The goal of an ongoing research project is to find high biomass plants that combine a sufficiently high uptake of cyanide with low susceptibility towards cyanide as well as towards toxic metals. After laboratory studies the aim is to establish field scale experiments in model wetlands in order to develop a bioremediation technology for industrial use. The results of this research project should be included in a future revision of this document.

Suggested topics for future research and development projects

The information exchange has also exposed some areas where additional useful knowledge could be gained from Research and Development projects. These relate to the following subjects:

- life-cycle management: The TWG recognised that applying full life-cycle management would be essential for a site to achieve a high level of safety and environmental performance. However, economic data showing that it is economically effective to manage a mining operation with the entire life-cycle model is currently missing. Research in this area is needed to investigate any existing case studies, to determine the economics of applying integrated life-cycle management compared to the conventional approach (i.e. maximum profit during operation)
- cyanide decomposition products toxicity: The toxicity of cyanide itself is a well investigated subject. However, it seems that some decomposition products may also be of toxicological importance. In view of the impact of spills from sites using cyanide to leach gold there is a need for research on the toxicity of cyanide decomposition products.