EUROPEAN COMMISSION

Reference Document on
Best Available Techniques for

Management of Tailings and Waste-Rock in Mining Activities

January 2009

This document is one from the series of documents as listed below, which have to be reviewed:

Reference Document on Best Available Techniques . . .	**Code**
Large Combustion Plants	LCP
Mineral Oil and Gas Refineries	REF
Production of Iron and Steel	I&S
Ferrous Metals Processing Industry	FMP
Non Ferrous Metals Industries	NFM
Smitheries and Foundries Industry	SF
Surface Treatment of Metals and Plastics	STM
Cement, Lime and Magnesium Oxide Manufacturing Industries	CLM
Glass Manufacturing Industry	GLS
Ceramic Manufacturing Industry	CER
Large Volume Organic Chemical Industry	LVOC
Manufacture of Organic Fine Chemicals	OFC
Production of Polymers	POL
Chlor - Alkali Manufacturing Industry	CAK
Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers Industries	LVIC-AAF
Large Volume Inorganic Chemicals – Solid and Others industry	LVIC-S
Production of Speciality Inorganic Chemicals	SIC
Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector	CWW
Waste Treatments Industries	WT
Waste Incineration	WI
Management of Tailings and Waste-Rock in Mining Activities	*MTWR*
Pulp and Paper Industry	PP
Textiles Industry	TXT
Tanning of Hides and Skins	TAN
Slaughterhouses and Animals By-products Industries	SA
Food, Drink and Milk Industries	FDM
Intensive Rearing of Poultry and Pigs	IRPP
Surface Treatment Using Organic Solvents	STS
Industrial Cooling Systems	ICS
Emissions from Storage	EFS
Energy Efficiency	ENE
Reference Document . . .	
General Principles of Monitoring	MON
Economics and Cross-Media Effects	ECM

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EXECUTIVE SUMMARY

Scope of this work

This work covers activities related to tailings and waste-rock management of ores that have the potential for a significant environmental impact. In particular the work sought out activities that can be considered as examples of "good practice". Mining techniques and mineral processing are only covered as relevant to tailings and waste-rock management. The intention is to raise awareness of such practices and promote their use across all activities in this sector.

The starting point for the work and the actual development of 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 proposed a follow-up action plan to be taken, 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 as a Commission initiative and in anticipation of the proposed Directive on the management of waste from extractive industries[1].

The above-mentioned failures 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 environmental 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[2] more than 300 million tonnes of mining and quarrying waste is estimated to be generated annually in the EU-15.

The following metals are covered in this document on the basis that they are mined and/or processed in the European Union (EU-15), the acceding countries, the candidate countries and Turkey, 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, flotation, chemical, or hydrometallurgical methods such as leaching).

[1]) COM(2003) 319 final, 2.6.2003. The proposed Directive includes references to BAT in its articles 4(2), 19(2) and 19(3)
[2]) Eurostat yearbook 2003, A statistical guide to Europe, 8th Edition, Eurostat, the Statistical Office of the European Communities, Luxembourg

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

For all minerals defined in the previously mentioned scope, the document:

- looks at waste-rock management
- 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
- includes topsoil and overburden if they are used in the management of tailings.

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 used in the chemical sector or for construction purposes, etc.

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 shipment of the products and management of the residues.

For most metalliferous ores, European mining production is small compared to the overall world production (e.g. gold: 1 %, copper: 7 %), and similarly 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. 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, 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
- backfilling tailings or waste-rock into underground mines or open pits or using them for the construction of tailings dams
- dumping more or less dry tailings or waste-rock onto heaps or hill sides
- using the tailings and waste-rock as a product for land use, e.g. as aggregates, or for restoration
- dry-stacking of thickened tailings
- discarding tailings into surface water (e.g. sea, lake, river) or groundwater.

Tailings and waste-rock management facilities vary vastly in size, e.g. from swimming-pool-sized tailings ponds to ponds of over 1000 hectares, 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 waste-rock management method depends mainly on an evaluation of three factors, namely:

- cost
- environmental performance
- risk of failure.

Key environmental issues

The main environmental impacts from tailings and waste-rock management facilities are impacts associated with the site location and relative land take as well as the potential emissions of dust and effluents during operation or in the after-care 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 their 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 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 past two decades have increased the widespread awareness of an environmental problem in mining known as 'acid rock drainage' or ARD. 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
- where there is defficiency of acid buffering minerals.

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 human and/or animal life.

Site rehabilitation and aftercare:
When an operation comes to an end, the site needs to be prepared for its subsequent use. Usually, at least for the past few decades, 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, adverse 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 major 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 and hydro-cycloning
- gravity concentration
- 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
- porosity.

Tailings dams are surface structures in which slurried tailings are managed. This type of tailings management facility (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
- removal of excess free water
- protection of the adverse surrounding area from environmental impacts
- instrumentation and monitoring systems to enable inspection 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, underwater management and finding other uses.

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, despite the choice of the site locations, 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 list some examples of the most important issues in tailings management are highlighted, including:

- slurried tailings, called ‘red mud’ from the refining of alumina have an elevated pH and are either stored in conventional tailings pond/dam systems, are thickened to a degree that they can be ‘dry-stacked’, or discharged into the sea
- tailings from base metal operations are mostly managed as slurries in large tailings ponds. Often base metals ores contain sulphides (in a quantity higher than the contained buffering minerals), so that the tailings have an acid-rock-drainage (ARD) potential. At one operation the tailings are discharged subaqueously to prevent ARD generation right from the start. Some operations backfill part of the tailings underground. In several cases, the chosen closure method for the tailings pond is the ‘wet’ cover technique, in other cases dry covers are applied
- coarse tailings from iron ore operations are managed in heaps. The slurried tailings are managed in ponds
- some of the gold mines operated in Europe have a net ARD potential. When cyanide leaching is used to extract the gold, the cyanide is destroyed prior to discharge into the tailings pond.
- For industrial minerals, several sites do not generate tailings at all or sell the tailings as aggregates
- borates operations first store the coarse tailings on heaps before they are backfilled
- one fluorspar operation described in this document discharges the tailings into the sea
- one kaolin operation described in this document first dewaters the fine tailings before they are transferred to heaps, this is also done in some limestone/calcium carbonate operations
- one limestone operation described in this document 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 described in this document there is marine discharge of the tailings
- in coal operations, the coarse tailings are usually 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 as well as the coarse tailings are sold. In other cases they are put on heaps. Backfilling is often not viable
- some of the measures applied to prevent accidents include: monitoring routines, operation, supervision and maintenance (OSM) manuals, independent audits, water balances, subsidence measurements, review of planning by external experts, the use of piezometers and inclometers and seismic monitoring.

In the following list some examples of the most important issues in waste-rock management are highlighted, including:

- in underground operation the waste-rock usually remains underground
- as in the case with tailings, waste-rock in base metals operations sometimes has an ARD potential. Some operations manage ARD and non-ARD waste-rock separately. Non-ARD generating waste-rock is either used as aggregate, used for construction of dams or roads at the site or managed on heaps. Upon closure ARD generating waste-rock heaps are covered with engineered dry covers that aim at preventing ARD generation
- waste-rock from one iron operation is managed on heaps with the coarse 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

Most of the process water is returned from the tailings management facility to the mineral processing plant, but reagent built-up is an issue to be aware of.

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 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 of a technical nature whilst others are good operating practices, including management techniques. The techniques are grouped in the following order:

- general principles: Good management principles, management strategies and risk assessment, all aimed at providing the general background for successfully managing tailings and waste-rock
- life-cycle management: A reduction of the risk of any failures can be assisted by a commitment of the operator to the adequate and rigorous 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 as applying planning for closure from the outset
- emission prevention and control:
  - ARD management: There are a number of prevention, control and treatment options (e.g. covers, addition of buffering minerals, active/passive treatment) 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. One technique to prevent dusting is to keep beaches in tailings ponds and other slopes wet