HEAP LEACHING TECHNIQUE in MINING
WITHIN THE CONTEXT OF
BEST AVAILABLE TECHNIQUES (BATs)

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The **primary objective of mining** is:

- to supply raw materials to downstream users,
- extracted from ore deposits in the earth's crust,
- using applicable excavation and ore enrichment processes with:
  - **economically feasible** and
  - **environmentally sound** engineering operations.

There are several mainframe ore preparation/beneficiation methods available in mining practice based on physical, chemical and smelting processes:

- **Concentration:** Gravity concentration heavy/dense media, Shaking tables, spiral separators, jigs), Electrostatic separation, Magnetic separation
- **Hydrometallurgy:** Leaching, Electrolysis, Precipitation (cementation)
- **Pyrometallurgy:** Calcining, Roasting, Smelting, Refining

All of these processes require **crushing and/or grinding/milling** of run-of-mine ores for liberation of mineral particles of interest for efficient application of appropriate processes of beneficiation.
SCHEMATIC ORE and WASTE MANAGEMENT in a typical mine operation

1. ORE EXCAVATION
   - Open Pit Mine
   - Underground Mine

2. ORE DRESSING & MINERAL PROCESSING
   - Ore Crushing
   - Ore Milling
   - Metal Recovery Smelting
   - Ore Dressing, Mineral Processing

3. WATER and WASTE MANAGEMENT
   - Surface Water Pond
   - Water Recovery & Reuse
   - Treated Water Discharge (If needed)

- Waste Rock Storage
- Tailings Pond
- Water Recovery & Reuse
- Processed Tailings
- Treated Water Discharge (If needed)
Selection of a mining/beneficiation technology is based on economic viability which is directly dependent on:
• ore type (namely, oxide or sulphide),
• mineral composition, matrix features of ore
• reserves and average grade (based on the “cut-off grade”) of the ore.

Lowering in cut-off grade of ores:
• increases asymptotically the quantity ore to be excavated and treated
• increases energy and chemical usage in pressure/tank leaching technologies,
• generating larger volumes of tailings to be managed;
• decreases profitability, making beneficiation processes uneconomical below certain grades.
In response to global increases in metal commodity prices
- the low grade base metal and precious metal ores (<1% Cu, <1g/ton Au, <0.5% Ni)
- previously considered uneconomical

became feasible with introduction of **HEAP LEACH TECHNOLOGY**.
Applicable Process Categories

*based on leach recovery versus gold ore grade*

(McNab, B., 2006)
Leaching is a physico-chemical process where minerals in rock masses go through dissolution under percolating water and anion/cation exchange reactions to generate metal salts in solute/colloid phase that migrate and accumulate under hydrological forces.

Depending on the presence of pyrite (FeS) and acidic/alkaline conditions, biological process of sulphur oxidation by certain natural bacteria may also be enhance the leaching process.

Lateritic ore deposits, the major resources of aluminum, nickel, platinum, cobalt and even gold, are clear evidence of ongoing natural leaching process through geological times.

Similarly, leaching is also a major natural process that occurs at depths in evolution of hydrothermal-origin ore deposits which are the products of complex chemical interaction processes involving hydrothermal fluids and gases with the host rocks; namely, a "natural high temperature and pressure leaching" followed by a cooling process on a geologic time scale.
Soaking colored minerals and soils in water and decanting the colored liquid for clothing/rug fiber dying is likely the oldest practice of leaching process used by humans.

The earliest written records of leaching as a mining technique can be found in V. Biringuccio’s book of “Pirotechnica” published in 1540 and Georgius Agricola’s book of “De Re Metallica” published in 1557 illustrating a heap leach for saltpeter (caliche-sodium/potassium nitrate) and alum (aluminium sulfate) recovery, respectively.

In the 16th century, the extraction of copper by dump/heap leaching was known to be practiced in the Harz mountains area in Germany and in Rio Tinto mines in Spain.

The first uses of pressure leaching of bauxite ores with Na$_2$CO$_3$ and Na(OH) were in France and St. Petersburgh in 1887 by L. LeChatelier and K.J. Bayer for recovery of Al(OH)$_3$ and Al$_2$O$_3$. The Bayer process is still used for Bauxite ore beneficiation. Pressure leaching has been in use since 1890’s for recovery of numerous metallic ores with advances in hydrometallurgy.

The first use of cyanide for leaching of gold and silver ores was in England in 1887 by J.S. MacArthur. Worldwide application of cyanidation process with heap and vat leaching and gold recovery processes increased greatly during the 1900-1920 period.

Heap leaching of gold ore started to gain prominence in the late 1960’s when it was applied on a large scale to low grade ores that were uneconomic to process by conventional tank leach methods.
LEACHING LIXIVIANTS USED IN MINING

The primary objective of leaching processes applied in mining are:

- **dissolution** of metals of interest in ores,
- **Segregation** of the loaded (pregnant) solution from solids, and
- **Recovery** of available metals either:
  - in **metal compounds** or
  - in **metallic forms**
    through further hydrometallurgical treatment.

**Lixiviants** are chemical solutions used in leach mining to enhance dissolution of metals in ores.
- **Sulphuric acid** and
- **Cyanide salts**

*are the most common demonstrated lixiviants used in heap or vat (tank) leaching processes applied under atmospheric conditions.*

**Thiourea and thiosulphate** are also known lixiviants for copper and gold ores; however, they are not used in world mining practice for their more complicated chemical management issues and environmental concerns.

Currently, there is no demonstrated application with success on an industrial scale that can be considered within the context of Best Available Tecniques (BATs).
Techniques employed in modern leaching technologies *mimic the naturally occurring leaching processes under optimized operational conditions* for improved productivity.

**Dump Leaching**: is a technique used in historical and early modern times; where, generally run-of-mine sulfidic copper ore dumps are wetted with water and/or sulphuric acid as a lixiviant to leach copper salts.

**Heap Leaching**: is a technique where crushed (>5 mm) and/or agglomerated ores are stacked over an engineered impermeable pad, wetted with lixiviant (solvent) chemicals under atmospheric conditions and leachate (metal loaded solutions) are collected for metal recovery processes.

**Tank Leaching**: is a technique where ground ores are chemically treated in open tanks under atmospheric pressure conditions to extract metal salts from the ore in an accelerated rate.

**Pressure Leaching**: is a technique where ground ores are chemically treated in reactors (otoclavs) under high pressure and temperature conditions to extract metal salts from the ore in an accelerated rate.

**In-Situ Leaching**: is a technique used recovery of salt/trona and uranium ores in appropriate hydrogeological settings.

Primary factors in selection of applicable/appropriate leaching technique and lixiviant chemicals are:

- **mineralogical composition/matrix features of the ore**, and
- **economical feasibility** based on
- **head grade and reserve** of the ore deposit,
- **forecasted commodity market prices** and
- **magnitude of capital investment required** for the project.
Operational units in a mine utilizing ORE LEACHING TECHNOLOGIES

- Metal Salts for further refinement
- HEAP LEACHING TECHNOLOGY
- VAT/PRESSURE LEACHING TECHNOLOGY
- Ore Excavation
- Waste Rock Storage
- Ore Staging
- Ore Crushing
- Ore Milling
- Leach Solution Chemical Treatment
- Metal Salts for further refinement
- Electro/Pyrolitic Metal Recovery
- Vat Leaching (CIP/CIL), Pressure Leaching
- Tailings Disposal Pond
The objective of “heap leaching process” is to chemically dissolve the metals out of:

- gravel/pebble-size crushed ore
- stacked on an impermeable lined pad
- By applying lixiviant solutions onto the heaped ore into a solution where metals are recovered through further chemical processing.
IED Objectives for Mining Operations:
- ENVIRONMENTAL PROTECTION
  - Noise, Vibrations, Dust
  - Air Quality
  - Water Quality (Surface/Groundwater-ARD)
  - Soil Quality-Erosion Protection/Prevention
- ACCIDENT MITIGATION
  - IED
- ECONOMIC BENEFIT
  - Site Rehabilitation
  - Economic Benefit
  - Social Responsibility
  - BATs
The Directive 2006/21/EC on Management of Waste from Extractive Industries (Mining Waste Directive) requires that measures taken to achieve the objective of preventing or reducing environmental impacts are based, inter alia on,


As per the European Union Directive 2008/1/EC, emission limit values were to be based on the best available techniques, as described in item #18 stated as:

"whereas emission limit values, parameters or equivalent technical measures should be based on:
- the best available techniques,
- without prescribing the use of one specific technique or technology,

and taking into consideration:
- the technical characteristics of the installation concerned,
- its geographical location and
- local environmental conditions;

"whereas in all cases, the authorization conditions will lay down provisions on:
- minimizing long-distance or transfrontier pollution and
- ensure a high level of protection for the environment as a whole."
Framework Concept for Evaluation of a Technique in Consideration as a BAT:

is to identify:
• available techniques \textit{that are developed}
  • on a scale which allows \textit{implementation in the relevant industrial sector}
  • under \textit{economically and technically viable conditions},
  • taking into consideration \textit{the costs and advantages, in order to}:
    • to prevent or reduce emissions \textit{and}
    • to prevent or mitigate accidents

in accordance with Section 6.3 of the EU Communication - \textit{COM(2000)664}.

The Directive 2008/1/EC includes a definition of best available techniques in article 2.12, where:

	extit{"Best Available Techniques" mean:}

the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally \textit{to reduce emissions and the impact on the environment as a whole}:

• \textit{"Techniques"} shall include both the technology used and the way in \textit{which the installation is designed, built, maintained, operated and decommissioned},
• \textit{"available techniques"} means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, \textit{whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator},
• \textit{"Best"} means most effective in \textit{achieving a high general level of protection of the environment as a whole}. 
EU Directive 2008/1/EC STATES:

.... "whereas emission limit values, parameters or equivalent technical measures should be based on:

• the best available techniques,
• without prescribing the use of one specific technique or technology.

7.1 Annex IV of the Directive 2008/1/EC

Considerations to be taken into account generally or in specific cases when determining best available techniques, as defined in Article 2(12), bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention:

• the use of low-waste technology;
• the use of less hazardous substances;
• the furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate;
• comparable processes, facilities or methods of operation which have been tried with success on an industrial scale;
• technological advances and changes in scientific knowledge and understanding;
• the nature, effects and volume of the emissions concerned;
• the commissioning dates for new or existing installations;
• the length of time needed to introduce the best available technique;
• the consumption and nature of raw materials (including water) used in the process and energy efficiency;
• the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it;
• the need to prevent accidents and to minimise the consequences for the environment;
• the information published by the Commission pursuant to Article 17(2), second subparagraph, or by international organisations.
According to article 4 par. 3 of the **Mining Waste Directive**, •“emission limit values, parameters or equivalent technical measures should be based on **BAT**
•*without prescribing the use of one specific technique or technology*.

**THEREFORE**, the Mining Waste Directive and the BATs **do not impose or ban** any available technology.
BREF on Management of Tailings and Waste-Rock in Mining Activities

EU Directive 2008/1/EC also states that, if there is a BAT described in the applicable BREF and the project or operation decides not to adopt it for technological reasons, then the project or operation will have to justify why the proposed choice of technology is BAT.

A revised BREF document on “Management of Tailings and Waste-Rock in Mining Activities” adopted in January 2009 provides information on mining techniques and mineral processing relevant to tailings and waste rock management including BATs for tank leaching techniques.

Heap leaching techniques were not explicitly covered in this version of the BREF document.

HOWEVER: if the Operational Activities of Heap Leaching are evaluated in terms of:
• prevention or reduction of emissions and
• prevention or mitigation of accidents
use of Heap Leaching Technology also fulfills the general intent of a BAT as summarized in the following BREF criteria.
## Framework BAT Criteria for Mining Operations in the Current IPPC-BREF Document

<table>
<thead>
<tr>
<th>BAT is to:</th>
<th>BREF Section (*)</th>
<th>Criterion/Action Item</th>
<th>BREF Section (*)</th>
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</thead>
<tbody>
<tr>
<td>• apply the general principles to assure that tailings and waste-rock management decisions are based on:</td>
<td>Sect. 4.1</td>
<td>• environmental performance, risk, and economic viability with risk being a site specific factor.</td>
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<tr>
<td>• apply a life cycle management approach</td>
<td>Sect. 4.2.1</td>
<td>• environmental baseline</td>
<td>Sect. 4.2.1.1</td>
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<td></td>
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<td>• characterisation of tailings and waste-rock</td>
<td>Sect. 4.2.1.2</td>
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<td>• TMF studies and plans which cover the following aspects:</td>
<td>Sect. 4.2.1.3</td>
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<td></td>
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<td>• site selection documentation</td>
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<td>• environmental impact assessment</td>
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<td>• risk assessment</td>
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<td>• emergency preparedness plan</td>
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<td>• deposition plan</td>
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<td>• water balance and management plan</td>
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<td>• decommissioning and closure plan</td>
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<td>• TMF and associated structures design</td>
<td>Sect. 4.2.1.4</td>
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<td>• control and monitoring</td>
<td>Sect. 4.2.1.5</td>
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<td>• the construction phase</td>
<td>Sect. 4.2.2</td>
<td>• “as built” drawings and “actual” procedure and test work records are maintained, construction is supervised by an independent qualified engineering/geo-technical specialist</td>
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<td>• the operational phase</td>
<td>Sect. 4.2.3</td>
<td>• OSM manuals</td>
<td>Sect. 4.2.3.1</td>
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<td></td>
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<td>• auditing</td>
<td>Sect. 4.2.3.2</td>
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<td>• the closure and after-care phase</td>
<td>Sect. 4.2.4</td>
<td>• long-term closure objectives</td>
<td>Sect. 4.2.4.1</td>
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<td>• specific closure issues for heaps</td>
<td>Sect. 4.2.4.2</td>
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<td>• ponds, including:</td>
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<td>• water covered ponds</td>
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<td>• dewatered ponds</td>
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<td>• water management facilities</td>
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<td>• reduce reagent consumption</td>
<td>Sect. 4.3.2</td>
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<td>• prevent water erosion</td>
<td>Sect. 4.3.3</td>
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<td>• prevent dusting</td>
<td>Sect. 4.3.4</td>
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<td>• carry out a water balance</td>
<td>Sect. 4.3.7</td>
<td>• water management plan</td>
<td>Sect. 4.2.1.3</td>
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<td>• apply free water management</td>
<td>Sect. 4.3.9</td>
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<tr>
<td>• monitor groundwater around all tailings and waste-rock</td>
<td>Sect. 4.3.12</td>
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</tbody>
</table>

(* Numbers refer to the “Section Numbers” in the IPPC BREF Document on “Management of Tailings and Waste-Rock in Mining Activities” (European IPPC Bureau, 2009).
<table>
<thead>
<tr>
<th>Specific ISSUE:</th>
<th>BAT is to:</th>
<th>BREF Section (*)</th>
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<tbody>
<tr>
<td>Acid Rock Drainage (ARD) Management</td>
<td>If an acid-forming potential exists:</td>
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<td>- to finally prevent the generation of ARD</td>
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<td>- if the generation of ARD cannot be prevented</td>
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<td>- to control ARD impact</td>
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<td>- to apply treatment options</td>
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<td>- closure plans to be developed for the site (design stage of the</td>
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<td>operation determining the most suitable closure option)</td>
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<td>Seepage management</td>
<td>- seepage needs to be prevented, reduced and controlled</td>
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<td></td>
<td>- re-use process water</td>
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<td>- mix process water with other effluents containing dissolved metals</td>
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<td>- install sedimentation ponds to capture effluents</td>
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<td>- remove suspended solids and dissolved metals prior to discharge of the</td>
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<td>effluent to receiving watercourses</td>
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<td>- neutralise alkaline effluents with sulphuric acid or CO₂</td>
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<td>- remove As from mining effluents by the addition of ferric salts</td>
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<td>Emissions to water</td>
<td>General:</td>
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<td></td>
<td>- active treatments</td>
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<td>- addition of lime to create alkaline environment</td>
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<td>- addition of coagulants for ARD with high Mg content</td>
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<td>- passive treatment</td>
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<td></td>
<td>- constructed wetlands</td>
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<td></td>
<td>- open limestone channels around lime rock</td>
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<td></td>
<td>- diversion cells</td>
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<td>Noise emissions</td>
<td>use continuous working systems (conveyor belts, pipelines)</td>
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<td></td>
<td>divert natural external run-off</td>
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<td></td>
<td>enclose contaminated areas where risks are a local issues</td>
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<td>Tailings and waste-rock management</td>
<td>in addition the measures during the operational phases (Section 4.3.2)</td>
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<td>facility operation</td>
<td>of any tailings and waste-rock management facility</td>
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<td></td>
<td>- monitor in a heap</td>
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<td>- bench slope geometry</td>
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<td>- sub-top drainage</td>
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<td>- prevent rock slide</td>
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<td>Monitoring stability</td>
<td>in the case of a heap</td>
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<td></td>
<td>- visual inspections</td>
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<td>- geotechnical reviews</td>
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<td>- independent geological audits</td>
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<td></td>
<td>- carry out emergency planning</td>
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<td></td>
<td>- carry out progressive restoration reclamation</td>
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<td>Mitigation of accidents</td>
<td>evaluate and follow-up incidents</td>
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<td>monitor the pipelines</td>
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<td>Reduction of footprint</td>
<td>if possible, prevent and/or reduce the generation of tailings and waste-rock</td>
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<td>under the following conditions:</td>
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<td>- it can be backfilled within an underground mine</td>
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<td>- lined-out open pits are readily available</td>
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<td>- the open-pit operation can be carried out without inhibiting the mining operation</td>
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<td></td>
<td>- investigate possible uses of tailings and waste-rock</td>
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<td>Closure and after-care</td>
<td>in addition to the measures described the closure and after-care phases</td>
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<td>(Section 4.3.4) of any tailings and waste-rock management facility</td>
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<td></td>
<td>- develop closure and after-care plans during the planning phase</td>
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<td>(including cost estimates, and then update them over time. However, the requirements for rehabilitation develop throughout the lifetime of operation and can first be considered in precise detail in the closure phase of a TUF)</td>
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<td>- apply a safety factor of at least 1.5 for dams and heaps after closure</td>
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<td>- construct the dam(s) so that they stay stable in the long term if a</td>
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<td>water cover solution is chosen for the closure</td>
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</table>

(*) Numbers refer to the “Section Numbers” in the IPPC BREF Document on “Management of Tailings and Waste-Rock in Mining Activities”
In Summary

Heap leaching technology has been successfully applied to very low grade base metal (copper, zinc, nickel and cobalt) and precious metal (gold and silver) ores since 1969.

Techniques developed in the world and in EU Member States during the last several decades demonstrated that heap leaching is a viable process that can be applied in a manner:

• to address all of the regulatory issues identified in the BREF on “Management of Tailings and Waste-Rock in Mining Activities” and
• to ensure a high level of protection for the environment as a whole within the context of Best Available Techniques (BAT) identified in the EU Acquies.

Kisladag and Copler gold mines in Turkey are current examples of environmentally sound, operational heap leach mining facilities in Europe.
KISLADAG Gold Mine, Turkey
(In operation since 2006)
Alacer Gold - COPLER Mine, Turkey
(http://www.anatoliaminerals.com/downloads/presentations/asr_p20110815.pdf/)
(In operation since 2010)
CONCLUSIONS

Currently, there are many copper, nickel and precious metal heap leach mining projects in design and permitting phase in Europe suffer from the fact that Heap Leaching Techniques were not explicitly described by the 2009 version of the BREF document on Management of Tailings and Waste-Rock in Mining Activities.

Therefore,

Inclusion of the Heap Leach Mining Process as a BAT in the next revision of the BREF document on “Management of Tailings and Waste-Rock in Mining Activities” would increase the consistency of the regulatory framework and ease the permitting of the current and upcoming EU mining projects planning to use the heap leach technology.
Reference document is available at:


Thank you for your Attention..
Caner ZANBAK, PhD.

Dr. Zanbak, is a 1971 graduate of Istanbul Technical University, has completed his Ph.D. at the University of Illinois, USA. His academic experience includes Istanbul Technical University until 1981, Kent State University, Ohio, South Dakota School of Mines, Rapid City, South Dakota as an associate professor until 1984 and at Illinois Institute of Technology, Chicago, Illinois as an adjunct full professor until 1994.

Dr. Zanbak has worked as a consultant to the USEPA and numerous industry facilities on hazardous waste management, remedial investigations, feasibility studies and remedial design for Superfund projects during the 1984-1994 period.


Since 1994, Dr. Zanbak is the coordinator of the Responsible Care© Program of the Turkish Chemical Manufacturers Association and provides consultancy to the mining sector on geotechnical design, regulatory and environmental management issues. He regularly lectures on environmental management, industrial waste management and environmental policy topics at numerous universities in Turkey.

Currently, he is a standing member of the following organizations:

- **Environmental Advisor**, Turkish Chemical Manufacturers Association,
- **Environmental Coordinator**, Turkish Miners Association,
- **Vice-Chairman, Environmental Affairs Commission** of the Istanbul Chamber of Industry,
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Heap leaching technique in mining within the context of best available techniques (BATs)

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ABSTRACT

The objective of the Directive 2006/31/EC on the management of waste from extractive industries is to prevent or reduce as far as possible any adverse effects on the environment or on human health brought about as a result of the management of waste from the extractive industries. It requires that measures taken to achieve its objective are based laterally on Best Available Techniques (BAT), as defined by Directive 96/61/EC concerning integrated pollution prevention and control, later codified by Directive 2008/1/EC. Directive 2008/1/EC will be repealed in January 2014 by Directive 2010/75/EU which provides for a similar definition of BAT.

A revised Reference Document (BREF) on the “Management of Tailings and Waste-Rock in Mining Activities”, published in January 2009, provides information on mining techniques and mineral processing relevant to tailings and waste rock management including BAT for tank leaching techniques. Heap leaching techniques are briefly addressed in this revised BREF document but not sufficiently described.

Heap leaching process has been successfully applied to very low grade base metal (copper, zinc, nickel and cobalt) and precious metal (gold and silver) ores since late 1960s. Techniques developed during the last decades demonstrated that it is a viable process which can be applied in a manner to address all the regulatory issues identified in the above-mentioned BREF and to ensure a high level of environmental protection.

In response to global increases in metal commodity prices, the low grade base metal and precious metal ores (<1% copper, <1% gold, <0.5% nickel) previously considered uneconomical, became feasible with introduction of heap leaching technologies (Marsden, 2009).

A generalized diagram showing applicable ore beneficitation technologies for oxide/sulphide ores versus ore grade is given in Figure 2.

1. LOW-GRADE ORE BENEFICIATION METHODS IN MINING

Selection of an ore beneficitation technology is based on economic viability which is directly dependent on:
- ore type (namely, oxide or sulphide);
- mineral composition, matrix features of ore;
- mineral reserves and average grade (based on the "cut-off grade") of the ore.

Figure 1. Relationship Between Excavation Quantity and Average Grade of Mixed Ore as a function of "cut-off grade" (modified from McNab, 2006).

It should be borne in mind that lowering in cut-off grade of ores:
- increases asymptotically the quantity ore to be excavated and treated (Fig. 1);
- increases energy and chemical usage in pressure/tank leaching generating larger volumes of tailings to be managed;
- decreases profitability, making beneficitation process uneconomical below certain grades.

2. LEACHING IN THE NATURE

Leaching is a physico-chemical process where minerals in rock masses go through dissolution under percolating water and ion/cation exchange reactions to generate metal salts in solution/colloid phase that migrate and accumulate under hydrological forces.

Depending on the presence of pyrite (FeS) and acidic/alkaline conditions, biological process of sulphur oxidation by certain natural bacteria may also be coupled in the leaching process.

Lateral ore deposits, the major resources of aluminum, nickel, platinum, cobalt and even gold, are clear evidence of ongoing natural leaching process. Leaching is the second fundamental step following physical alteration in the rock-to-soil weathering cycle taking place in nature under atmospheric pressure conditions.

Similarly, leaching is also a natural process that occurs at depths in evolution of hydrothermal fluids and gases with the host rocks; namely, a "natural high temperature and pressure leaching" followed by a cooling process on a geologic time scale.

3. LEACH LIxivIANTS IN MINING

The primary objective of leaching processes applied in mining is the dissolution of metals of interest in ores, separate the loaded solution from solids and recover available metals either in metal compounds or in metallic forms through further hydrometallurgical treatment.

Lixivants are chemical solutions used in leach mining to enhance dissolution of metals in ores. Sulphuric acid and cyanide salts are the most common demonstrated lixivants used in heap or vat (tank) leaching processes applied under atmospheric conditions.

Thiourate and thiosulphate are also known lixivants for copper and gold ores; however, they are not used in world mining practice for their more complicated chemical management issues and environmental concerns.

4. BASIC EFFICIENCY FACTORS IN HEAP LEACH PROCESS

Recovery rate of metals (in percentage of the ore grade) is an indicator of leaching effectiveness. In practice, recovery rate is characterised by the dissolution kinetics of metals, namely: percentage of metal of interest in ore transferred into the leach solution, and time required for metal dissolution.

Dissolution of metals in heap leaching process is controlled mainly by:
a. Degree of mineral liberation – crushed ore particle size: Ore is crushed to a certain particle size prior to stacking. Certain portions of a “run-of-mine” ore material can be placed directly on the leach pad.

b. Leaching solution with mineral grains: Percolation rate of the fluids should be slow enough to provide good contact of the leaching solution with the ore. Therefore, achieving a uniform leachability of the ore is required for optimal flow of leach fluids. In cases where fine particles are present, agglomeration techniques are used for optimization of leach permeability.

c. Dissolution potential of the metal/mineral composition – Leach Kinetics: The major factors affecting the dissolution rate of metals of interest are leachant concentration, temperature, pH, dissolved oxygen, presence of other metals and ions in the solution. Leach recovery rates generally increase with higher leachant concentrations, temperature and dissolved oxygen and higher pH (>9) for cyanide leach and lower pH (<2) for acid leach conditions.

A comparative leach kinetics (dissolution rate) of oxide, secondary and primary copper sulphide ores and oxide, transitional and sulphide gold ores in heap leaching is presented in Figure 4 (Robertson et al., 2005) and Figure 5, respectively.

d. Bacterial Activity on metal sulphides – Leach Kinetics: Presence of metal sulphides (mostly, pyrite) in the ore heaps initiate bacterial activity, especially for copper, nickel and zinc sulphide minerals. Bacterial activity can be utilised to catalyse the oxidation of iron in sulphides (ferro to ferric state) which improve the leach kinetics.

Figure 4. Comparative leach kinetics of oxide, secondary and primary copper sulphide ores in heap leaching (Robertson et al., 2005).

Figure 5. Comparative leach kinetics of transitional, oxide and sulphide gold ores in heap leaching (Taprogre Gold Co., Kaldag Gold Mine, Turkey).

In all ore leaching processes the gangue (unbenefited) metals consume lixiviants along with the metals of interest: copper, zinc, iron in gold ore leaching; iron, manganese, calcium and potassium in copper and nickel ore leaching, to name a few. Also, pre-precipitation products of some of these gangue minerals (gypsum, jarosite, silicate) have potential negative effects on leach permeability by plugging up the pores in the heap.

5. LEACHING TECHNIQUES IN MINING

Comprehension of the natural leaching mechanism has led the way to developments in the hydrometallurgical techniques for low-grade ores. Techniques employed in modern leaching technologies mimic the naturally occurring leaching processes under optimized operational conditions for improved productivity, namely:

- Dump Leaching: a technique used in historical and early modern times; where, generally run-of-mine sulphide copper ore dumps with no composite pad liner are wetted with water and/or sulphuric acid as a lixiviant to leach copper salts. Currently, the use of this technique is limited to a few sites due to environmental concerns and inefficiencies in copper solution recovery.

- Heap Leaching: a technique where crushed (>5 mm) and/or agglomerated ores are stacked on an impermeable pad, wetted with lixiviant, leached under atmospheric conditions and leached (metal loaded solutions) are collected for metal recovery. Because solutioning process is realized under atmospheric conditions by percolation of the lixiviant solution, completion of metal recovery requires longer time periods (weeks to months) for each pad loading sequence compared to tank leaching (hours to days).

Upon completion of heap leaching, the barren ore is stacked. The solutionized in place; therefore, this technique does not require use of tailings disposal facility.

- Tank Leaching: a technique where ground ores are chemically treated in open tanks under atmospheric pressure conditions to extract metal salts from the ore in an accelerated manner. This technique, requires handling and grinding and all run-of-mine ores and disposal of treated materials in tailings ponds/dams.

Pressure Leaching: is a technique where ground ores are chemically treated in reactors (autoclaves) under high pressure and temperature conditions to extract metal salts from the ore in an accelerated rate. This technique also requires grinding of all run-of-mine ores and disposal of treated materials (tailings) in tailings ponds/dams.

- In-Situ Leaching: is a technique used recovery of salt/shortened uranium ores in appropriate hydrogeological settings. Primary factors in selection of applicable/ appropriate leaching techniques and lixiviant chemicals are:

- mineralogical composition/matrix features of the ore, and - economical feasibility based on head grade and recovery of the ore deposit, forecasted commodity market prices and magnitudes of capital investment required for the project.

5.1 Historical Leaching

The earliest written records of leaching as a technique can be found in V. Biringuccio’s book of “Protechnia” published in 1540 describing leaching of salt peter from decayed nitried organic manure and in G. Agricola’s “De Re Metallica” published in 1557 illustrating a heap leach to recover alum (aluminunium sulphate) (Habashi, 2005; Kappe, 2002).

In the 16th century, the extraction of copper by dumpheap leaching was known to be practiced in the Haan mines area in Germany and in the Ibito mines in Japan. The first uses of pressure leaching of bauxite ores were in France and St. Petersburg in 1889 by L. LeChatelier and K.J. Bayer for recovery of alumina. The Bayer process is still used for bauxite ore beneficiation (Habashi, 2005).

The first use of cyanide for leaching of gold and silver ores was in England by J.S. MacArthur in 1877. Worldwide application of cyanidation process with heap and vat leaching increased greatly during the 1900-1920 period. Heap leaching of gold ore started to gain prominence in the late 1960’s when it was applied on a large scale to low grade ores that were uneconomic to process by conventional tank leach methods.

5.2 Modern Day Leach Mining

In mining operation flowcharts, leaching processes follows ore crushing, where:

- ore is directly stacked on leach pads - Heap Leaching,
- ore is further ground/milled and treated in vessels - Pressure Tank Leaching (Fig. 6).

There are two tank leaching processes where activated carbon is used for adsorption of cyanided gold; namely, carbon in pulp (CIP) and carbon in column (CIL). Another process, carbon in column (CIC), is used in gold recovery from heap leach solutions. Currently, 60-65% of world production of mined gold is realized using leaching techniques.

A special heap leaching technique is used on certain types of sulphide copper ores where copper sulphides are converted into sulphates in a two-step leaching process with the help of natural iron oxidising bacteria with sulphuric acid (bioheap-leaching). Since 2000, application of the heap leaching technique, using sulphuric acid as the lixiviant, gained wide acceptance for recovery of nickel/cobalt from very low grade (< 0.5%) laterite ores, where pressure leaching has not been feasible.
6. DESIGN COMPONENTS OF A HEAP LEACH UNIT

The objective of "heap leaching process" is to chemically dissolve the metals out of gravel/pebble-size crushed ore, stacked on an impermeable lined pad, into a solution where metals are recovered through further chemical processing (Fig. 7).

Figure 7. Generalized Flowsheet of a Heap Leach Unit

Basic components of a heap leaching unit are:
- Leach pad and liner system,
- Heaped ore,
- Ponds,
- Lixiviant solution application.

6.1 Leach Pads

Leach pads are a general term for the overall foundation of the heap (ore stack). Design objectives of a leach pad are to provide:
- Stable foundation for the ore heap,
- Collection of leachate (pregnant solution),
- Environmental Protection (soil and groundwater quality).

Depending on land availability, the pads are constructed either on large, relatively flat surfaces or in topographical valleys (Fig. 8).

Figure 8. Heap Leach Pad Types

Typical components of a leach pad are contoured natural ground surface and overlying liner system (Fig. 9).

6.4 Ore Heap

Crushed and/or agglomerated ore can be stacked on the heap leach pad by either truck dumping or via telescopic/grasshopper conveyor belts with travelling bridges in sequential lifts. Segregation of fines from coarse material during ore stacking is a common problem observed in heaps creating excessive concentration of fines in the center causing different pockets of permeability. Therefore, special care is needed for even distribution of crushed/agglomerated ore in order to obtain uniform permeability in heap leaches.

Conveyor stacking, especially for agglomerated ore cases are commonly used for handling of crushed material for its ease/mobility, more homogeneous grain distribution in the heaps and its favorable economics (Kappus 2002). Ore Stacking may proceed in the up or down slope direction provided the advancing face is stable. It is more usual to stack in uphill direction for increased slope stability (top sketch in Fig. 10).

6.3 Ponds

Ponds are integral part of a heap leaching technology to collect and contain the leaching solutions. Ponds are sized to have sufficient capacities to optimize processing of pregnant solution and safely manage the liquids in cases of power outages and major rainstorm events. Common design practice is to have the following ponds, located downslope of the heap:
- Pregnant solution pond (for heap leachate),
- Barren solution pond (for containment of processed pregnant solutions),
- Intermediate solution pond (for recycling of leachates from the older heaps to the newer heaps to build up the solution metal grade),
- Overflow/Stormwater Pond (standby for emergency).

Considering that the pregnant solution is the main valuable asset of the mine operation, current design practice for the process liquid ponds is to install double layer composite liner system fitted with leak detection pipes and pumps.

6.5 Lixiviant Solution Application and Pregnant Solution Collection

The objective of lixiviant application is to achieve uniform and complete wetting of ore through continuous percolation of liquids between the ore particles. Lixiviant solutions are applied on the top surface of the heaps using either irrigation sprays or drip irrigation techniques. Selection of spraying or drip irrigation is generally based on the climatic conditions of the site taking into account the evaporation rate and freezing potential. Currently, drip irrigation is more commonly applied technique in mining practice.

Cyanide (generally NaCN) and sulphuric acid are the most commonly used lixiviant chemicals in gold/silver and copper/nickel leach mining, respectively. Lixiviant chemical concentrations in the leach solution and feed application rates on the heaps are dependent on site-specific factors of:
- permeability of the heap,
- chemical depletion rate (chemical consumption by all metals in the heap) and,
- climatic conditions (evaporation, rain) which needs to be determined by bench/pilot-scale testworks on representative heap samples and optimized during the heap leach operations. The pregnant solution is drained into the pregnant ponds for chemical stripping of dissolved metal salts in the pregnant solution, where resultant water is sent to barren pond and pumped to the lixiviant solution dosing unit for reuse in the leaching cycle.

6.6 Heap Rinsing and Pad Closure

At the end of heap leaching cycle, the heap material is subjected to rinsing of lixiviant chemical with water circulation. During closure of pads, the solution management of heaps is conducted in three phases:
- residual metal recovery - where metal recovery continues via recirculation of solutions without the addition of lixiviant;
- inventory disposal - drained solution is evaporated and/or treated and discharged;
- drainage - where drainage of residual solutions continues passively.

Decisions for completion of heap rinsing process is based on depletion of free lixiviant chemical draining from the heap as demonstrated with continuous monitoring of the return water. Excessive rinsing with water is to be avoided to prevent generation of acid mine drainage in the sulphide ore heaps. Upon application of a cover layer on the heap to stop potential for entry of rain water, the heap
material is left for gravitational draindown of residual water. Any water drained from the heap is treated with active or passive treatment methods prior to release into the receiving media. Protocols for monitoring and treating of drainage from closed heap pads are to be developed on a case-by-case basis for each pad.

7. Regulatory definition of “best available techniques - BAT”

The Directive 2006/21/EC on the management of waste from extractive industries (Mining Waste Directive) requires that measures taken to achieve the above-mentioned objective of preventing or reducing environmental impacts are based inter alia on Best Available Techniques (BAT), as defined by Directive 96/61/EC concerning integrated pollution prevention and control, later codified by Directive 2008/1/EC. The Directive 2008/1/EC will be repealed in January 2014 by Directive 2010/75/EU providing for a similar definition of BAT, which reads as follows:

“BAT” means the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole.”

“Techniques” includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned

7.1 BREF on Management of Tailings and Waste-Rock in Mining Activities

The European IPPC Bureau, one of the scientific institutes of the European Commission’s Joint Research Centre (JRC), produces reference documents on Available Techniques, called BREFs. These reference documents are used by competent authorities in Member States to issue operating permits for the relevant industrial installations. It is important to note that, according to article 4 par. 6 of the Mining Waste Directive, “emission limit values, parameters or equivalent technical measures should be based on BAT without prescribing the use of one specific technique or technology”. Therefore, the Mining Waste Directive does not impose or ban the use of any available technology. As a consequence, if a project or operation decides not to adopt – for various reasons linked to technical characteristics or geographical location – a technology that is considered as BAT under the BREF document on “Management of Tailings and Waste-Rock in Mining Activities”, it will have to justify why the proposed technological choice is the most suitable technique to be implemented. A revised BREF document on “Management of Tailings and Waste-Rock in Mining Activities” adopted in January 2009 provides information on mining techniques and mineral processing relevant to tailings and waste rock management including BAT for tank leaching techniques. Heap leaching techniques are briefly addressed in this revised BREF document but not sufficiently described.

7.1 Framework concept for evaluation of a technique in consideration as a BAT

Framework concept of a BAT is to identify available techniques that are developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator.

“Best” means most effective in achieving a high general level of protection of the environment as a whole.

Chapter 4 of the Mining Waste BREF and the relevant environmental management issues as reviewed in a recent document supported by Euromines, which is available on Euromines’ website (Zanbak, 2012).

8. Conclusions

In response to ever increasing prices of base metals, “heap leaching” has become a major beneficiation technique used for low grade ores which cannot be economically processed through conventional leaching or any other available techniques.

Heap leaching process has been successfully applied to very low grade base metal (copper, zinc, nickel and cobalt) and precious metal (gold and silver) ores since 1969. Techniques developed in the world and in EU Member States during the last several decades demonstrated that heap leaching is a viable process that can be applied:

- to address all of the regulatory issues identified in the BREF on “Management of Tailings and Waste-Rock in Mining Activities”
- to ensure a high level of demonstrated protection for the environment as a whole.

Currently, there are numerous copper, nickel and precious metal heap leach mining projects in operation in the world and in Europe. However, there are many projects in design and permitting phase in Europe that suffer from the fact that heap leaching techniques were not sufficiently described by the 2009 version of the BREF on Management of Tailings and Waste-Rock in Mining Activities. Therefore, it is the opinion of the author that inclusion of the heap leach mining process as a BAT in the next revision of the BREF document would increase the consistency of the regulatory framework and ease the permitting of current and upcoming EU responsible mining projects planning to use modern heap leach technology.

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For current POPULARITY (??) of the Cyanide Ban Issue....

Back-up Info on status of CN ban issues in the EU....
YEAR 2005 - EU Commission's Response to an inquiry about
“the use of Cyanide Leaching Technique in Gold Mining and Processing in the EU”

There is no EU legislation explicitly allowing or prohibiting the use of this technique.

Your fax of 6 January 2005 enquiring about the use of the cyanide leaching technique in
gold extraction and processing in the EU was transmitted to my services.

There is no EU legislation explicitly allowing or prohibiting the use of this technique.
The proposed directive on the management of waste from extractive industries
(COM(2003)319 final, 2.6.2003) contains provisions relating to the concentration limit
values of cyanide in tailings ponds. This proposal is currently in the co-decision process.

The Commission does not keep a formal record of mining sites in the EU. However,
relevant information can be found in a Study on the Costs of Improving the Management
mining/index.htm. Furthermore, the recently finalised Reference Document on Best
Available Techniques for Management of Tailings and Waste-Rock in Mining Activities,
available at http://ec.europa.eu/energy/nature/best_activities.htm, lists a total of seven gold mining
sites (see page 198 of the document).

Actually, there is NO PROHIBITION on USE of ANY CHEMICAL in ANY industrial process
in the WORLD,
as long as the requirements of Human Health, Safety
and Environmental Protection regulations are fulfilled!!
Year 2010 - EU Commission's Response to a Parliamentary Question on
“Complete ban on the use of cyanide mining technologies in the EU”

Parliamentary Question - 14 May 2010
WRITTEN QUESTION by Csaba Sándor Tabajdi (S&D) to the Commission
Subject: Complete ban on the use of cyanide mining technologies in the European Union

Answer given by Mr Potočnik on behalf of the Commission, 23 June 2010, P-3589/2010

The resolution of the Parliament calling for a general ban on the use of cyanide mining technologies in the European Union has received the full attention of the Commission.

After an in depth analysis of the issue, the Commission considers that a general ban of cyanide in mining activities is not justified from environmental and health point of views. Existing legislation notably on the management of extractive waste (Directive 2006/21/EC) includes precise and strict requirements ensuring an appropriate safety level of the mining waste facilities. The limit values for cyanide storage as defined in the directive are the most stringent possible and implies in practice a destruction step of cyanide used before its storage. Due to the lack of better (in the sense of causing less impact on the environment) alternative technologies, a general ban on cyanide use would imply the closure of existing mines operating in safe conditions. This would be detrimental to employment without additional environmental and health added value.

The Commission intends to continue to closely follow the possible technological developments in this sector in order to ensure that ‘best available techniques’ are applied in practice as required by the directive.

In addition, the Commission considers that the priority should be set on ensuring full application of the directive by the Member States. As guardian of the Treaty, the Commission intends to take all necessary measures within its remit to ensure that the directive is fully and correctly applied in practice.