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CHE 5106 – MINING WASTE MANAGEMENT

Methods for the Characterisation of Mining Waste, Risk Assessment of Mining Waste Facilities including Old/Abandoned Mining Waste Facilities, Review of Techniques for the Prevention and Abatement of Pollution Generated by Mining Wastes, Examples of Decision Support Tool for Minimising the Impact of the Mining Industry on the Environment.

CONTENTS

1. INTRODUCTION

Mining waste is the high-volume material that originates from the processes of excavation, dressing and further physical and chemical processing of wide range of metalliferous and non-metalliferous minerals by opencast and deep shaft methods. It comprises overburden, run-of-mine rock as well as discard, slurry and tailings from the preparation/beneficiation or extraction plants. Wastes from mineral excavation both under US Resource Conservation and Recovery Act (RCRA, 1976 with further amendments) and EU regulations pursuant to Article 1 (a) of Council Directive 75/442/EEC (1975) on waste and article 1(4) of Directive 91/689/EEC (1991) on hazardous waste is considered non-hazardous, though many aspects related to its safe disposal and use with respect to the environmental behaviour and impact are applicable also to hazardous waste. Some types of wastes from physical and chemical processing of minerals are classified as hazardous in the European list of wastes (Commission Decisions 2000/532/EC and 2001/118/EC).

These wastes comprise: acid generating tailings from processing of sulfide ore (code 01 03 04*); other tailings containing dangerous substances (code 01 03 05*); other wastes containing dangerous substances from physical and chemical processing of metalliferous (code 01 03 07*) and non-metalliferous minerals (code 01 04 07"), as well as drilling muds and other drilling wastes containing oil (code 01 05 05*) and dangerous substances (code 01 05 06*). The kind of mining waste and its share in the total waste stream in the different countries highly depend on their natural resources, economic value of a mineral and market demand, and therefore ranges from almost none to the predominant proportion [Szczepafiska et al., 2004].

Unfortunately, due to the scarce statistical data, the information on the mining waste generated and disposed is not available for countries with the highest mining output, such as China, the USA, India, Australia, Russian Federation and South Africa.

In historic mining areas in Europe and elsewhere, mine closure and abandoned mines have grown a major concern for contamination, as reflected by the new EU Mine Waste Directive (Directive 2006/21/EC) requiring the risk-based inventory of closed and abandoned mine waste sites. Associated problems include, among others, the long-term release of contaminated acid mine drainage (AMD) effluents and accidental pollution by tailings dam failure. In addition to the environmental complexity of mine sites, problems of bridging the gap between detailed site-specific investigation and regional-scale assessment, identification of key parameters (indicators), long-term risk-based monitoring, application of existing geological information and harmonization of sampling, analysis and data processing methods have to be addressed. Contamination Risk Assessment (RA) studies the combined effect of the probability of contamination and the significance of toxic impacts along the contamination source-pathway-receptor chain. It is generally recognized that risk-based inventory of mine sites should enable the ranking of mine sites (identification of ‘hot spots') and it should follow a tiered approach proceeding from preliminary risk screening to more detailed site studies [SAFEMANMIN, 2009].

2. RELEVANT STANDARDS AND TECHNIQUES FOR MINING WASTE CHARACTERISATION

2.1. Introduction

Regardless of the large number of methods used for characterization of mining wastes, there is a clear tendency in most countries, including the New Member States of the European Union, to carry out this characterization in accordance with the existing international standards. Some of these methods are general for wastes, and do not always apply to mining wastes. Some of these wastes are highly toxic and their characterization requires additional specific tests, mainly connected with the assessment of the role played by the indigenous microflora under real field conditions. Most of these methods are, based on the determination of some essential physiological parameters of the individual members of this microflora. However, some methods are connected with determination of the microbial enzymatic activities and the genotypic changes of the relevant microorganisms as a result of their interactions with the environmental factors in the relevant mineral deposits or depositories for mining wastes. The final objective of the development of such methods is the creation of systems consisting of bioindicators for on-line characterization of the processes which take part in the different sites containing mining wastes (old and abandoned mines, dumps, tailings pond, etc). Such activity needs financial and technical support and close collaboration between the leaching institutions worldwide working in the field of extractive industries and environmental protection.

In the EU the technologies and methods applied in Bulgaria for characterization of mining wastes are similar to or even the same as those applied in most members of the European Union countries as well as countries with intensive mining activities (USA, Australia, Canada, South Africa). In most cases these technologies and methods are suitable and sufficient to achieve a real and pragmatic characterization of the mining wastes. However, some investigations are needed to give additional information especially on the leachability and toxicity of some mineral wastes under different and changing environmental conditions.

In Norwegian mining industry the majority of the standards quoted in the responses are, with few exceptions, English translations of the relevant EU standards. Where exceptions occur it is generally due to the lack of a specific European standard, and the companies concerned are therefore using the relevant ISO standards. Effluent monitoring provides information that is complimentary to waste characterisation testing, and in certain cases, could reveal more useful information than waste characterisation alone would provide. It is important to ensure that the mineral assemblages present in wastes are determined as this will have a considerable influence on the potential for release of environmental pollutants [Chuldjian et al., 2007].

2.2. Parameters

In most of the countries the mining activities have declined dramatically during the last 10 ?years, and most of the mines are now closed. In several lands the most critical environmental issues are caused by the old and abandoned mining sites, some of the problems to be mentioned being:

- mechanical instability of waste heaps,
- dust pollution and erosion,
- acid drainage, followed by contamination of soil and water,
- self ignition of coal waste heaps.
- habitat change/modification and biodiversity reduction

There are numerous examples showing that some of the existing standards are not very suitable with respect to the assessment of the environmental status of terrestrial and water ecosystems. Thus, the pollution of a given soil or water is characterized by the permissible levels for contents of the different pollutants. In the cases where these contents are lower than the relevant permissible levels, the tested soil or water are accepted as non-polluted. However, very often such soils and waters can be very toxic due to the joint cumulative effect of the pollutants, regardless of the fact that each of the pollutants is present at a concentration lower than the relevant permissible level.

Other examples include following: assessment of heavy metals contamination in soils using data on the total content of the individual heavy metals. These relevant permissible levels are connected only with the pH of the tested soil. However, much more important is the partitioning of the heavy metals into different components of the ecosystem and biomagnification/bioconcentration in the fauna and flora. [As a result of such determination, it is possible to find that a soil with a lower total content of a given metal, can be much more toxic than a soil with a higher total content but consisting mainly in fractions refractory to solubilization. In other words, solubility of contaminant/ pollutants is important in the overall effect of that pollutant on the environment]. The weak point here is that traditional mineralogical methods of identification fail in characterization of fine grained matters like those we find in tailing ponds or very old, eroded waste heaps. The situation with quantitative assessment of the mineral composition of such materials is even worse. It is obvious, that the development of proper methodology for quantitative mineralogical characterization of mining wastes is urgent.

The mining waste facilities must have an approved design to be authorized. The design has to consider at least these aspects:

- Size of the deposit (area and height)
- Geology of the site
- Aquifer vulnerability
- Surface water network
- Geotechnical and hydrogeological properties of the site
- Dump stability
- Surface water and groundwater monitoring network
- Kind of waste to be stored
- Waste characterization (physical and chemical characterization of solid phase; pH, Eh and ionic content in the liquid phase)
- Seismicity.
- Program of facility abandon and dismantling
- Biological diversity and conservation sensitivity of adjacent areas

The mining waste facilities must be controlled at least five years after their abandonment.

3. METHODS USED FOR THE CHARACTERISATION OF MINING WASTE ON A NATIONAL LEVEL IN DIFFERENT EUROPEAN COUNTRIES

3.1. Methods applied in Europe

The European countries are using landfill directive. On the other hand Austrian standards can be used to give more assistance to the management of contaminated sites as hereafter presented. A general outline for risk assessments is set by ÖNORM S 2088 part 1, part 2 and part 3, which also defines guideline values for contaminated land related to the protection of groundwater resources (ÖNORM S 2088-1) as well as the safe use of surface environments (ÖNORM S 2088-2) and for public asset air (ÖNORM S 2088-3). The Austrian standards can be considered for the sampling and characterisation of mining wastes; framework for preparing and using a sampling plan, and S2123-1: Sampling plans for waste – Part 1: Sampling of heaps, S 2123-2: Sampling plans for waste - Part 2: Sampling of solid waste from containers and transport vehicles, S 2123-3:

Sampling plans for waste - Part 3: Sampling of solid waste out of material streams, S 2123-4: Sampling plans for waste - Part 4: Sampling of liquid or paste-like waste, S 2123-5: Sampling plans for waste - Part 5: Sampling of lumpy waste, describe in great detail all the aspects of sampling of waste. In particular the examples of sampling (with an informative character) described in the annexes of this ÖNORMs (Part 1: annex D, E, F; Part 2: annex D, Part 3: annex C; Part 4: annex C) gives a very clear demonstration of practical sampling of waste material. The examples presented according to CEN/TC 292 "Characterisation of Waste" belong to the investigation steps basic characterisation (Level 1 testing according to the European landfill Directive) and compliance test (Level 2 testing according to the European landfill Directive).

If we take recommendations and methods for materials that are similar to mining wastes from composition and structural point of view, as for instance granular bulk materials, iron ores, old deposits etc. we can assume that secured samples can be taken also from mining wastes. In this respect it could be mentioned that all the necessary factors that have an impact on the sampling of solid materials are known. If the specifications given in the ÖNORMs S 2123-1 to 5 and EN 14899 (sampling plan, assessment of the homogeneity / heterogeneity, mass determination, appropriate sampling techniques and sampling procedures, observance of the minimum number of samples and minimum sample amount, setting of sampling points, sampling documentation, sampling report etc.) are carefully observed, these sampling strategies can be used also for mining purposes (mining waste), respectively for environmental geological purposes.

From the other reviewed ÖNORMs for raw materials geology, the specifications regarding the minimum number of samples and the required minimum sample amount for geological materials could be useful. Further a special importance should be given to the "visual sampling" on site, like it is described in the ÖNORMs with raw materials geological background. The sampler should be familiar with the regional geology and be able to acknowledge some material characteristics on site (e.g. efflorescence of sulphates, sulphide track etc.). This increases the assessment competence and the testing capacity during sampling. There is a lot experience acquired from the raw materials geology for the material analysis of deposits. This knowledge can surely be useful in the characterisation of mining wastes.

The sampling techniques and sampling strategies described in the ÖNORMs S 2123-1 to 5 and EN 14899 are appropriate for sampling of mining wastes. For very high mining waste heaps (20 meters and more) professional drilling and construction equipment is needed for sampling the soil on which the heap is located. This is also the main difference between sampling from mining waste heaps and landfills or other waste. For the mining activities of the last decades there are large areas and large volume deposits (mining heaps, mixed heaps from the fluid mechanical and fluid magnetic processing, flotation heaps, tailings ponds etc.) amounting more than 100.000 m^3, that have a long-term acid generation and contamination potential for the environment for several hundred years. A qualified and standard sampling, characterisation and analysis of such mining wastes can be technically done with corresponding sampling techniques and existing on site equipment. As it was mentioned in the study of RASEMANN & HERBST (1996) an extensive characterisation of mining wastes amounting more than 100.000 m^3 can only be financially justified in cases of actual environmental danger (soil, water etc.). Before such mining waste deposits are investigated, a geodetic survey might be necessary.

For the analysis of mine waters from the active mines as well as of acid leachate from mining wastes there are comprehensive standards, regulations and guidelines for monitoring and risk assessment of potentially contaminated sites and brownfields (e.g. LABO 2002). In this field there is also no need for additional or new standards for sampling, characterisation or analysis of such polluted mines or leachate from mining waste heaps.

With regard to analytical methods the following should be noted:

Within the international mineral industry as a whole, terminology and standard methods used are not mutually understandable to environmental engineers and scientists.

Pollutants are perceived differently depending on the particular branch of the mineral industry. For companies producing materials for the filler, glass or paper industries iron content is of great concern with regard to its' potentially detrimental impact on their products. Thus, analytical instruments and techniques will be optimised for the detection of iron. In ilmenite production calcium and magnesium are regarded as serious product pollutants, whilst for environmental purposes these elements are generally regarded as benign.

Where analytical methods and instruments are optimised for a particular element or set of elements this may affect the quality and/or treatment of samples for environmental analysis. The reason being that a standard sample analysis method would be designed to preserve those features of most interest. In such a case, the analysis of samples for environmental assessment would require the development of separate instrument-specific method programmes i.e. for spectroscopic analyses such as XRF, and ICP-based methods, while specific sample treatment procedures might need to be applied to the samples themselves.

As an example, if a standard sample was given to a number of mining companies for standard analysis by XRF it is likely that the results would exhibit greater variation than that which would be expected from external laboratories. This would not be because the mining companies have relaxed views regarding the environment but would instead reflect the fact that their analytical equipment is optimised to comply with the requirements of the industry that they are serving, which represents a huge range, from metal smelters, producers of paper, pharmaceuticals, plastics, petrochemicals, sandblasting etc. In some cases results from the mining companies will have better precision than commercial laboratories but this is precisely because their instruments are optimised for their products.

Commercial analysis for standard test methods is of course available in Norway, typically from NIVA, NGI, NGU, the Universities and others. In addition, it is possible to secure specialised analyses from many smaller laboratories, though in this case, one normally requires some specialised knowledge in order to contact the relevant staff.

While Universities generally have the greatest analytical capability and the most advanced equipment, until recently, few had extensive procedures for serving industry. While this is changing it is still the case that each analytical contract must often be conducted as a free-standing project. However, Universities are now altering their focus and in the last 10 years have begun to develop procedures for environmental testing in areas where the Government has not done so. Compliance testing is, in some respects a relatively recent phenomenon in Norway but this is accelerating due partly to the Government's ambitious harbour remediation targets.

In Norway much work has been put into the design of test methods and justification for their use. However, while a compliance test can be very well designed what is missing is data on real materials. Several investigators may have compared different tests but this still cannot illustrate the effect of running a test with different materials, against what is known to be a problem, and what is deemed to be acceptable. This is far more time consuming as synthetic materials cannot be used and it is necessary to locate real sites with known conditions and environmental effects, requiring additional time and funding. It may initially be more valuable to ascertain what level of a pollutant is safe rather than what probable level a leaching test will supply. The latter will be of little value without adequate means of interpretation.

A criticism which may be made of the recently developed prediction test for the capping of polluted sediments is that the compliance limits were chosen arbitrarily. There should have been testing against real materials before final implementation of the test. However, since the test has now been implemented, it has already been used for deposition of tailings to the sea –for which the test was not designed. The determinative part required is the linking of tests to real situations.

Regardless of the large number of methods used for characterization of mining wastes, these is a clear tendency in most countries, including the New Member States of the European Union, to carry out this characterization in accordance with the existing international standards. Some of these methods are general for wastes, and do not always apply to mining wastes. Some of these wastes are highly toxic and their characterization requires additional specific tests, mainly such connected with the assessment of the role played by the indigenous microflora under real field conditions. Most of these methods are, based on the determination of some essential physiological parameters of the individual members of this microflora. However, some methods are connected with determination of the microbial enzymatic activities and the genotypic changes of the relevant microorganisms as a result of their interactions with the environmental factors in the relevant mineral deposits or depositories for mining wastes. The final objective of the development of such methods is the creation of systems consisting of bioindicators for on-line characterization of the processes which take part in the different sites containing mining wastes (old and abandoned mines, dumps, tailings pond, etc). Such activity needs financial and technical support and close collaboration between the leading institutions worldwide working in the field of extractive industries and environmental protection.

In general the methodologies and methods which are usually applied in Bulgaria for characterization of mining wastes are similar or even just the same to these applied in the most countries members of the European Union as well as in countries with intensive mining activities (USA, Australia, Canada, South Africa). In most cases these methodologies and methods are suitable and sufficient to achieve a real and pragmatic characterization of the mining wastes. However, some investigations are needed to give additional information especially on the leachability and toxicity of some mineral wastes under different and changing environmental conditions.

Effluent monitoring provides information that is complimentary to waste characterisation testing, and in certain cases, could reveal more useful information than waste characterisation alone would provide.

It is important to ensure that the mineral assemblages present in wastes are determined as this will have a considerable influence on the potential for release of environmental pollutants. In Romania there are no specific standards dealing with the mining waste characterization from the point of view of the environmental protection; hence we are not sure that the standards dedicated to soil or ores body characterization would be appropriate for these kinds of wastes and for this special purpose.

The adopted international standards for wastes, as has already been presented, refer generally to domestic wastes and to hazardous wastes, but we think that the mining wastes have many particularities and proprieties that should be taken into account when assessing their environmental impact.

No standards are available for the sampling of mining wastes and leachate. We are following some literature references in order to do the sampling. Solid samples are generally taken at 5-10 cm deep from the top after removing the superficial layer and the leachate is sampled from the peripheral channel of the mining tailing pond. We are not sure that the procedure is good and that the samples are totally representative.

In Romania the metal analysis is generally performed using atomic absorption spectrometers (flame, graphite furnace, hydride generation) or ICP-MS (especially in research works).

An extensive programme should be implemented for testing a wide range of wastes from the extractive industry against standard methods which are currently in use, or likely to be used with such wastes.

3.2. Recommendations

Two types of studies are to be additionally used in mining waste characterisation:

- **Mineralogical study:** Investigators are often satisfied by the results of the different types of chemical analyses (ICP AES, AAS, SCE etc.) which are easy, fast and relatively cheap and give high degree of detection of the elemental composition. Since the aim of the study is often defined as evaluation of the actual concentrations of chemical elements against the respective regulation limits, this approach looks satisfactory. However, it gives no indication about the speciation of these elements in the leachates, neither for the solid compounds yielding them.

The environmental behaviour of each compound (comprising one and the same element) can be dramatically different. For instance as, one of the most toxic elements in mining wastes, can be a constituent of more than 50 compounds (mineral species), where it can be represented by 5 possible chemical states. Just one of these 5 states is highly toxic and another one is moderately dangerous. This means that during risk assessment we need to know which state we have to deal with. Next important item of knowledge is the solubility of the available compounds in waters with different pH values. The pH of the leaching waters in its turn depends on the mineral composition of the waste, since it first reacts with its bulk components, which change its initial pH. Only then we can predict the environmental behaviour of the toxic elements and assess the environmental risk.

All these crucial bits of knowledge are only provided by the mineralogical studies. For the large particle (stone piece) wastes (dumps, piles) the classical methods of mineralogical investigation are easily applicable and the available data from the economic geological reports of the mine can also be used for reference. Tailing materials, on the contrary, represent a real problem because their grain sizes are below (often much below) 1 mm. Although some mineralogical methods can go far beyond this size, the grains of mineral species, representing chemical risk should be tracked between hundreds of particles of the bulk rocks. This approach is extremely time consuming and still does not guarantee exhaustive results.

Unfortunately, to the best of our knowledge, no effective methodology, for mineralogical characterisation of tailings exists. From my personal point of view, the successful approach for the solution of this problem should be a combination of separation procedures (based on physical properties) and polyphase X-ray determinations, with the use of sets of standard samples and consecutive X-ray curve deconvolution and fitting estimates.

For the successful mining waste characterisation, a new mineralogical determination method, especially adapted to the specific features of the tailing materials should be developed.

- **Chemical reactions in waste dumps:** Mineral phases in generic nature are stable in a narrow range of physico-chemical conditions, typical for their natural environment. Mining destroys this equilibrium and puts mineral phases in new, unnatural conditions, where they start reequilibrating.

This process passes through a series of chemical reactions, producing new mineral phases, not typical for the initial ores and rocks. They may produce highly unusual chemical compounds, especially in the case of ore dressing tailings or metallurgical wastes, where natural material is treated with chemical substances, unavailable in nature. Under such conditions, minerals usually regarded as insoluble can undergo solution and re-crystallisation as new compounds. Since some of these reactions can be exothermic (as in metallurgical waste, where coke residue is stored together with the waste) the temperature of the dump can be raised to several hundred degrees centigrade. This turns the dump into a real chemical reactor. In such conditions even highly insoluble silicates can be destroyed and extremely material can be mobilised and pollute surface and ground waters with toxic substances.

Waste dumps (especially tailings and metallurgical wastes) must be checked for ongoing chemical reactions (thermal effects observable on satellite images, gas emissions (smokes, especially after rainfalls), formation of recent minerals at water drainage outlets etc.). If found, much more complex mineral composition and leaching behaviour of the dump must be expected. This will instantly raise the risk category of the dump and more complex remediation would be required .

- It is necessary for the content of different elements in a sample of mining wastes to be supplemented by data about the different **mobility of fractions** of each individual elements related to the heavy metals and radionuclides or characterized by a very high toxicity, e.g. arsenic. The determination of the relevant bioavailable fractions is also essential (by means of leaching tests using, at least, EDTA, DTPA and H_2SO_4/HCl);

- The **toxicity** of mining wastes is directly correlated to their solubility. Some methods are very suitable to test this solubility because they are largely used in most countries and this allows a very efficient comparative assessment of different mining wastes. These methods are tas follows: Toxicity Characteristic Leaching Procedure (TCLP), Multiple Extraction Procedure (MEP) Method 1320, and Extraction Procedure (EP) Toxicity Test Method and Structural Integrity Test, Method 1310 A, all suggested by US EPA. This institution also suggested several toxicity tests methods using different organisms (microorganisms, protozoa, algae, terrestrial plants, invertebrates and vertebrates animals) (US EPA 712-C-96);

- Some **microbial leaching tests** are strongly recommended to achieve a detailed and more realistic characterization of mining wastes. This is connected with the fact that microorganisms are the most active agents participating in the solubilisation of these wastes.

The different mineral deposits and the wastes from the processing of the relevant mineral raw materials are characterized by indigenous microflora, which in some cases is quite specific. The information about this microflora is essential for the correct characterization of the relevant mining wastes. Apart from the different microbiological tests carried out under laboratory conditions, it is essential to test the microbial activity in situ. There are different tests in this respect, which are based on determination of the microbial respiration, CO_2 fixation ability of chemolithotrophic bacteria or microbial oxidation or reduction of different elements. Some tests are based on determination of parameters such as pH, Eh, content of oxygen, changes in temperature, etc, which provide information about the density of microbial population and its activity in situ. There are no standard acceptable methods for such determinations but the existing information is abundant and further studies in this field are strongly recommended;

Some methods based on determination of microbial enzymatic activities and of changes in the genotype of some indigenous microorganisms in response to changes in some environmental parameters are already available (8) but have only limited application for the characterization of mining wastes.

It is well known that the many standard test methods considered, or currently applied to wastes from the extractive industries have not been developed for this purpose. While these tests methods themselves have been developed with great care, many such standard methods were originally designed for use with municipal wastes. Where this is the case, there is often little, or no, extensive testing of these methods with wastes from the extractive industry. Thus there is a need for an extensive testing programme using real wastes from the extractive industry in order to identify norms, refine procedures if necessary and in particular to ensure that compliance limits are not set arbitrarily due to lack of the determinative linking of real samples with the test methods.

4. RISKS ASSESSMENT: ISSUES TO BE CONSIDERED

4.1. Methodologies applied in Europe

The general frame of risk assessment is divided into the following steps [BRGM, 2001] as presented in Figure 1.

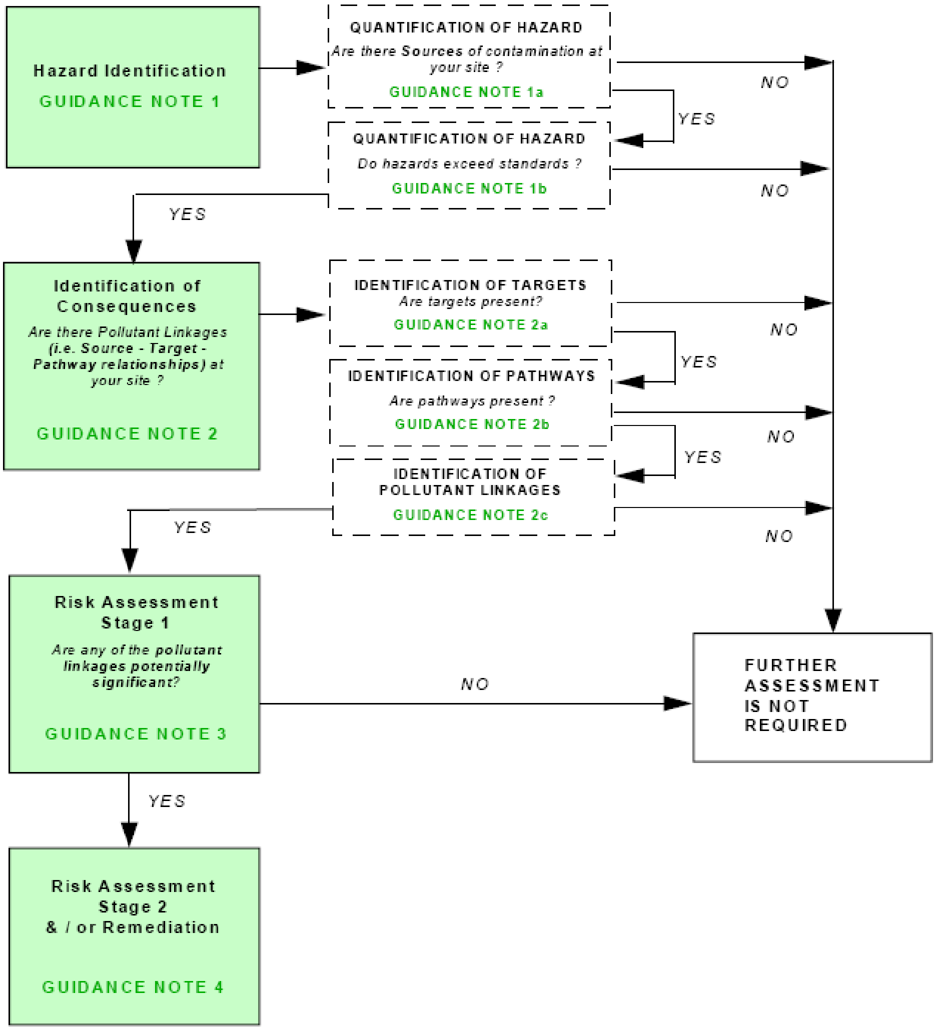

Figure 1. Risk Assessment – Methodology Guidance Notes [BRGM, 2001].

Potential hazards (step 1) are typically identified during desk studies including mining data, e.g. literature reviews, historic map searches, and site visits.

Identified hazards (step 2) should be examined by field testing, sampling and laboratory testing, where the results obtained should be compared to the EU standards/guidelines. Ground contamination only becomes an issue of concern in relation to the risks it poses. For instance, the presence of measurable concentrations of chemicals in the ground does not automatically indicate that there is a contamination problem.

Risk associated (step 3) with contaminated land should always be assessed in terms of:

- Targets (the entity that could be harmed through contact with a hazard.
- Pathways (the route by which a hazard comes into contact with a target). Risk does not exist unless there is a plausible hazard-target-pathway relationship (the relationship between source, pathway and target is defined as pollutant linkage).
- Pollutant linkages identified should be assessed to ascertain whether they can be considered to be potentially significant (this means that linkage has an identified potential to result in harm to that target).

The interpretation of risk (step 4), in practice, risk is based largely on intuitive judgement and where uncertainty exists in the assessment, reference should be made to an experienced environmental scientist.

The final stage of a risk assessment (step 5) is complex and requires extensive data. Step 5 is necessary if required remedial works are expensive, or difficult to implement as in such a case, costs may only be justified by further assessment, such as a quantitative risk assessment. Step 5 may not be necessary if the source, pathway or target can be easily remediated at low cost; then, it may be appropriate at this stage to carry out such remedial works, without undertaking the second stage of the risk assessment, which includes a detailed study of these works. If the risks posed are very apparent and the need for remediation obvious, is not necessary to carry out the final stage of the risk assessment.

If step 5 is deemed necessary and is implemented, it will provide further information on the linkage and the significance of the risk. In its context, additional investigations will be performed in order to examine the pollutant pathways of (a) wind erosion, (b) direct contact with the risk source, (c) surface water and (d) groundwater. The specific kind of the risk assessment depends also on the site, raw material, extraction type, production line and end product.

4.2. Foundations and basic principles

The main objective of risk assessment is to keep under control all the risks related to one location and activity by identifying:

- the pollutants and major hazards;
- the major risks that may occur;
- the producers and acceptors that may be exposed to the risk;
- the mechanisms by which the risks is achieved (pathways between sources and potential receptors) the measures for risks mitigation to an “acceptable level”.

4.3. Methodology

Risk assessment methodologies can be classified broadly into two groups: deterministic and probabilistic/stochastic. The deterministic assessment uses point estimates, such as the main or 95th percentile, for each factor in the model in order to calculate a point to estimate of risk. This results in a single figure, which usually is labeled “typical” or “reasonable maximum” with no indication of the range of possible risks. In the probabilistic/stochastic assessments the point estimates are replaced by distributions of possible values for the factors. Results can be presented in the form of a distribution of possible risks within an exposed population, indicating maximal and minimal risks that might be experienced by different individuals, and the relative likelihood of intermediate risks between those two extremes [UK DOE, 1995].

Regulatory standards and actual exposures/risks from sources of population (such as mining wastes) in European countries are often calculated by means of mathematical models. Research in the different independent institutions across the European Union and elsewhere produces individual models, each with their own assumptions. The risk assessment in the mining and post-mining areas is directly connected with the characterization of mining wastes present in these areas as well as with sites and ways of their storage and/or deposition. The information on the mining wastes is necessary to be sufficiently comprehensive for a full and realistic evaluation of the risks connected with their presence. In the cases where a full sampling program and a full analytical suite have not been undertaken it is possible to assume that the samples collected are representative of material being sampled and the assessment will be based only on the parameters analyzed.

However, such approach has a negative effect on the character of the risk assessment. The hazard identification involves the characterization of the identified wastes, together with the collection of information on the wider environment. Testing of the wastes is undertaken to provide information on the presence, concentration and bioavailability of pollutants and the susceptibility of the wastes to leaching. The concentrations of pollutants are compared to typical levels of pollutants in soils to appropriate standards to assess whether the concentrations detected have the potential to cause a hazard.

The risk associated with mining should always be assessed in terms of pathways and targets, i.e. the route by which a hazard (source) comes into contact with the entity that could be harmed through contact with the hazard. The methodology for assessing this relationship is divided into the following three sub sections:

- Identification of targets,
- Identification of migration pathways, and
- Identification of pollutant linkages.

Consequence analysis is always a mixture of the quantitative and qualitative. Some components can be measured, estimated or projected with a relative precision but others will need to rely more on qualitative analysis. A wide range of analytical methods and tools are available for consequence analysis, including sophisticated mathematical modeling using computer programs and software packages. On the basis of the wide range of data, all plausible pollutant pathways are identified.

Typical examples of environmental hazards that might be encountered in mining industry operations include [Peppas et al., 2005]:

- clearing vegetation (loss of rare species or habitat)
- soil disturbance (wind and water erosion and dust)
- acid sulphate soils
- blasting (explosion, dust and vibration)
- mullock/waste rock and slag (instability, leachate and dust)
- subsidence (impacts on heritage items and natural and man-made structures)
- radioactive tailings
- potentially toxic tailings (acid leachate, heavy metal or saline)
- saline or other contaminated waters from mine workings
- contaminated stormwater runoff
- storage, handling and transport of fuels or process chemicals (spillage, fire, explosions etc.) and/or containers
- disruption of surface or groundwater flows (including collection for use, diversion and increased runoff)
- storage and handling of explosives (unintended explosions)
- exotic species and plant, animal or human pathogens (introduction through transportation operations or rehabilitation planting etc. or change to habitat)
- bushfires (increased frequency from more ignition sources)
- processing, storage, handling and transport of mined material and processed material (fire, explosion, spillage, dust etc.)
- continuous/intended emissions to air or water (e.g. smelter emissions, dust discharges)
- containment and service structures (e.g. tailings dams or water supply dams, product or supply

pipelines, conveyor belts)

- inadequate security—sabotage etc., mechanical failure (e.g. burst pipes, ruptured liners) human error (e.g. poor or careless bund management), accident (e.g. vehicle collisions, roll over)
- creation of stagnant pools of water that may serve as breeding places for pathogens and vectors of diseases.
- Conversion of agricultural land into some useless contaminated pools of water and waste heaps/tailings.

The above list is representative, not exhaustive, and should not be used as a checklist. Factors will change from site to site. As can be seen from the listed items there are links and interactions between them and an event causing a hazard of one type might lead to one or more other hazards e.g. subsidence followed by a dam failure and tailings release. Various methods are available to identify and evaluate hazards. There are also different ways to present the information. When word diagrams are used, explanatory text is generally added to expand relevant aspects.

For each possible pollutant pathway identified, a risk assessment is undertaken, involving:

1) *Assessing the probability of a consequence, i.e. that an identified hazard (e.g. a pollutant) will reach a target.*

The probability that a pollutant will reach a target in sufficient concentration (or exposure) to cause harm usually is assessed according to a qualitative scale [UK DUE, 1995]:

High Probability → Certain or near certain to occur

Medium Probability → Reasonably likely to occur

Low Probability → Seldom likely to occur
Negligible Probability → Never likely to occur

2) Assessing the magnitude of a consequence, I.e. predicting the significance of an impact in terms of its magnitude should the hazard (e.g. pollutant) reach the target.

The magnitude of the harm from the predicted concentration/exposure at the target is assessed according to a qualitative scale [UK DOE, 1995]:

Severe → Human fatality, major injury or illness causing long term disability; a significant change in number or eradication of one or more species including beneficial, endangered or key species; irreparable damage to non-living structures.
Moderate → Human injury or illness causing short term disability; a significant change in species population densities but not total eradication of a species (no effect on endangered or beneficial species); damage to structures which are present in limited numbers (e.g. monuments and buildings with historical and/or cultural significance)
Mild → Other human injury or illness, some change in species population densities with no negative effects on ecosystem function; damage to commonplace present day structures which could be repaired
Negligible → Nuisance rather than harm to humans, no significant changes in any species populations or in any ecosystem functions; very slight damage to structures.

3) Assessing the risk

The risk associated with each pollutant pathway is estimated based on the consideration of the magnitude and the probability of the consequences of the hazard (Table 1) [UK DUE, 1995]:

Table 1. Risk assessment; level of probability of consequences.

Probability of consequence	Magnitude of Consequences			
	Severe	Moderate	Mild	Negligible
High	High	High	Medium/ Low	Near zero
Medium	High	Medium	Low	Near zero
Low	High/ Medium	Medium/ Low	Low	Near zero
Negligible	High/ Medium	Medium/ Low	Low	Near zero

4) Recommendation for additional data collection

Recommendations are provided for the collection of additional data which would allow the risk to be more accurately assessed. Once recognized and analyzed, there are a range of possible responses to risk. These can include [Peppas et al., 2005]:

- accepting the risk
- eliminating the hazard or avoiding the risk
- reducing the consequences
- reducing the likelihood
- risk transfer

A framework of objectives or criteria can provide a rational and consistent basis for evaluating the responses. While criteria are thus important, it is equally important that the risk analysis and risk management processes do not become exercises in passing 'tests' rather than achieving real improvements in safety and environment protection.

The fundamental notion underlying the adoption of risk criteria is that as all risk cannot be eliminated; some level of risk must be regarded as acceptable or tolerable. The acceptability or tolerability of a risk varies with the benefits that flow from the risk generating activity and the distribution of those benefits and risk costs.

The appropriate criteria and objectives will depend on the purpose of the analysis. Criteria may be specified by regulatory requirements, company policy, national or international standards or by particular political or community imperatives. Alternatively, they may be driven by case-specific research or considerations.

The assessment process at its simplest is comparing risk results with criteria or objectives. In practice, some interpretation is necessary and the conclusions may need to be qualified. Where risk levels do not meet criteria it may be appropriate to revisit the analysis and refine it, particularly for sensitivity to conservative assumptions. It is likely that the requirements for a high standard of environment management will increase in the near future. For that reason, the environment risk management will play a bigger role in the environmental management of mining, including that of the mining wastes. A greater experience with using risk management in mining will promote further development and refinement of tools, especially those for capping with the consequences of releasing toxic pollutants to the aquatic environment. Risk criteria are likely to be progressively developed, refined and standardized. The basic principles of the methodologies which are currently used for the risk assessment in connection with mining wastes are shown in Table 2.

Table 2. Methodology for risk assessment- a general structure.

Stage	Method
Hazard identification and assessment	Identify whether a plausible source-pathway- target relationship exist (i.e. the identification of a hazards source migrating along a pathway and causing harm to a target)
Risk assessment	Once a plausible pollutant has been established, the risk is defined by assessing the probability that the hazard will reach the target and the significance of the impact should the hazard reach the target.
Recommendations for further data collection	Recommendation for additional data collection in order to further define the risk.
Risk management	Use the assessed risk to identify appropriate controls.

4.4. Content of a Risk Assessment Report

The risk assessment report should include, at least, the following chapters:

- Abstract of the report (initial situation, present state of knowledge, purpose of investigations, essential results, recommendation and justification of following measures).
- Introduction (reason and contract, aims of the project, chronology of the several operations).
- Characterization of the site conditions (area and location, geology and hydrogeology, subject of protection).
- Detailed research program (results, justification of determined methods of exploration and investigations, sampling locations and analytical parameters).
- Methods of investigations and results have to be described in detail (e.g. sampling, laboratory analysis, hydraulic parameters, map of the area, representation of the pollutant concentration variation in time, correlation of data).
- Basic principles of assessment (e.g. guideline value, limit value, standards, toxicological information, chemical / physical information for an individual substance, safety-related information, ecotoxicological information (e.g. No-observable-effect-concentration (NOEC), toxicity for fish (GF), biodegradability).
- Assessment of the results (comparison with ambient pollution, comparison with toxicological information from literature, exceedance of guideline value and limit value, limitation of impacted areas, pollutant dispersion, actually determined contamination).
- Complete assessment with regard to necessity of safeguard- and remediation measures.
- Recommendation for further measures to avert acute risks.
- Recommendations for further investigations and measures of safeguard and remediation.
- Literature review.
- Annexes (timetable, map of the area including old deposits and contaminated sites, site plan of

sampling points, groundwater hydrograph curve, copy of laboratory report, diagram of measurements and analytical results, spatiotemporal design of measurements with tables and graphics, geological survey map, soil layers)

Groundwater studies always include an assessment of the geology and hydrogeology of the site and its surroundings with regard to the possible migration of hazardous substances, including identification of relevant pathways and geological and hydrogeological barriers. Assessing the dispersal of hazardous substances in groundwater focuses on the degree to which waste deposit or a contaminated site causes, or could cause, changes in groundwater quality.

5. MINING WASTE MANAGEMENT IN THE DEVELOPING WORLD

5.1. Current status

DC often seek to exploit mineral resources as a way of providing much needed revenue. According to some, mineral wealth is part of a nation’s natural capital and the more capital a nation possesses the richer it becomes. In spite of the difficulties, the economic and social impact of small-scale mining is far from small, particularly in high-value product areas such as gold, silver, diamonds or gemstones.

Generally the amount of waste produced depends on the type of mineral extracted, as well as the size of the mine. Gold and silver are among the most wasteful metals, with more than 99 % of ore extracted ending up as waste. By contrast, iron mining is less wasteful, with approximately 60 % of the ore extracted processed as waste [WRI, 2004]. Mining wastes is of some significance in many DC where extraction and processing of minerals are important economic activities.

Papua New Guinea receives almost two thirds of its export earnings from mineral deposits whereas diamond mining accounts for approximately one third of Botswana’s GDP and three quarters of its export earnings [WRI, 2004].Small-scale mines account for as much as 80- 100% of gold, diamond or gemstone production in Burkina Faso, Cuba, Guyana, Mozambique, Myanmar and Niger and more than 50% in Bolivia, Mexico, the Philippines and Tanzania. Depending on the size of deposits, the economic significance of small-scale mining can be considerable, particularly for communities lacking any alternative sources of employment or income [ILO, 1999].

Small-scale gold miners, who by some estimates number as many as 10 million individuals in DC, have a significant environmental impact, primarily due to their use of mercury for gold amalgamation. In terms of the world’s largest gold producers, Figure 2 shows that the production of gold among the top 10 producers is relatively well balanced across a wide range of developing and developed countries.

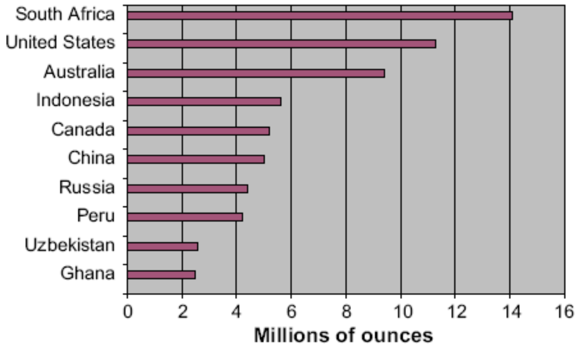

Figure 2. World’s largest primary gold producers.

Some mining operations use environmentally friendly storage options, others use less environmentally friendly ones; mining companies in DC sometimes dump mining waste directly into rivers or other bodies of water as a method of disposal as legislative requirements tend to be more permissive than in industrialized countries.

South Africa is by far the largest producer of gold and there is no question that gold mining has contributed enormously to the country's development where technological advancement and accelerated gold are combined. Gold is so rare that the share of ore representing usable metal is 0.00033% compared to 0.91% for copper, 2.5% for lead, 19% for aluminum, and up to 40% for iron. Therefore, to have profitable extraction in great quantities, there was a need to be able to extract such minute quantities. This innovation came in the form of the cyanidation process which was developed and applied specifically in South African gold mines in the later part of the nineteenth century and led to a much larger market for gold production. Gold production in South Africa rose from less than a ton in 1886, when the first discoveries were made, to 14 tons in 1889 and around 120 tons by 1898. Over exploitation, however, led to much more intensive mining and hence far greater environmental stresses. From an engineering perspective, economically viable and chemically efficient alternatives to cyanidation are arguably close to development but cyanidation continues to be the major means of industrial gold operations. While the cyanidation process has been refined considerably since its initial use, and industry has certain environmental safety protocols for cyanide, there remains tremendous resource usage for large-scale gold mining.

Figures 3 and 4 present the current mining sites for Sierra Leone and Mauritius (Africa) and Papua New Guinea (Pacific).

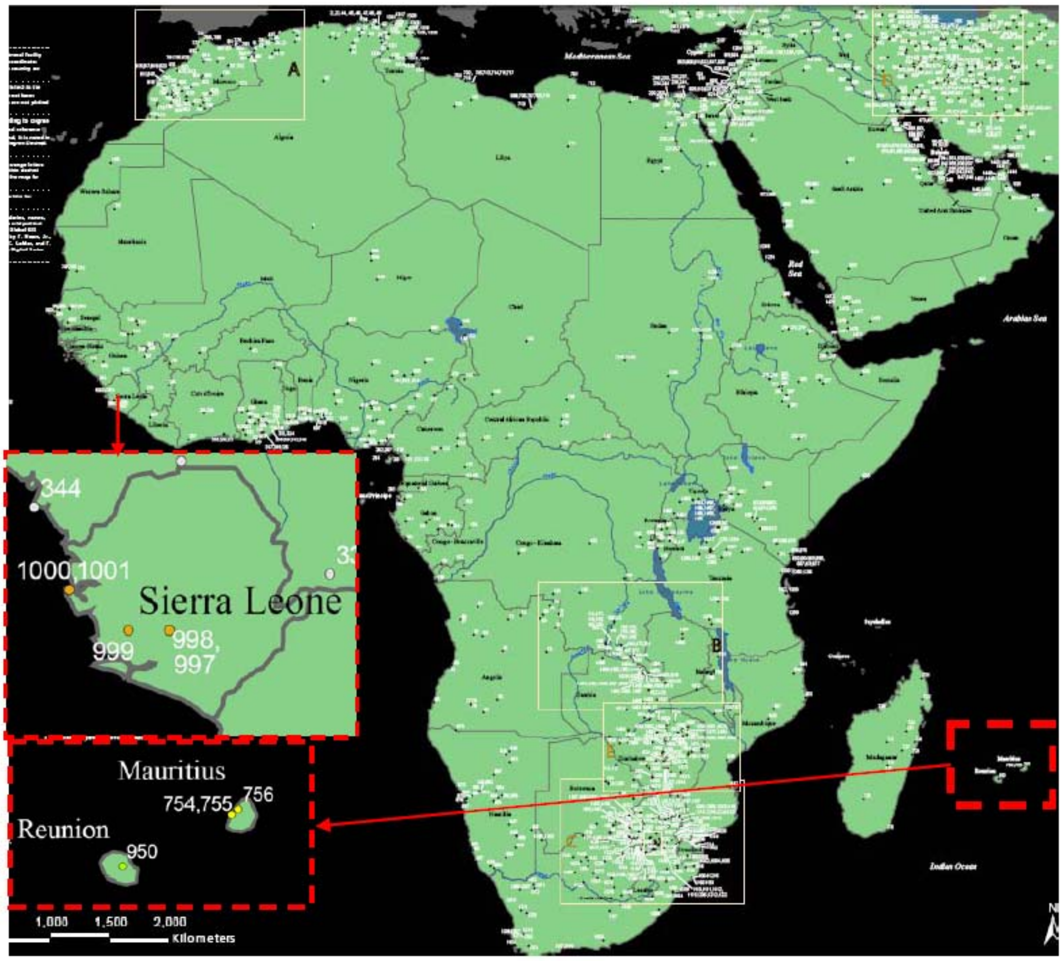

Figure 3. Mining sites and quantities of mining products in Africa; on the left the Sierra Leone and Mauritius status are presented [USGS, 2006].

Figure 4. Mining sites in Papua New Guinea.

Given the shared responsibility for gold consumption patterns, the responsibility for addressing environmental impacts should be shared between policy makers and corporations in both developed and DC. Consumption campaigns should thus reflect this shared responsibility. There is a plausible case to be made for channelling current gold consumption through controlled recycling of existing reserves, and/or through small-scale miners, provided they comply with the same level of environmental and social responsibility that mining corporations are held accountable for [Saleem, 2006].

5.2. Health and safety issues

Historically, the mines, required inexpensive labor that was in ample supply in colonized Africa, where miners to this day work as far down as 12,000 feet shafts at temperatures as high as 130°F. According to an estimate, to produce one ounce of gold from industrial mines requires "*thirty-eight man hours, 1400 gallons of water, electricity to run a large house for ten days, 282 to 565 cubic feet of air under straining pressure*" [Saleem, 2006].

Small-scale mining is expanding rapidly and often uncontrollably in many developing countries, employing large numbers of women and children in dangerous conditions and generating a workplace fatality rate up to

90 times higher than mines in industrialized countries, says a report by the International Labour Office (ILO) [ILO, 1999b].

Work in small-scale mines tends to be low-paid, seasonal and highly precarious, but provides direct employment, though often at a subsistence level, for up to 13 million workers whose labour generates an estimated 15-20 % of world production of precious metals, gems, building materials and (mostly) non-fuel minerals, according to the ILO survey.

As many as 80-100 million people worldwide depend for their livelihoods on the often scant proceeds of small-scale mining, roughly the same amount as for the more visible, large-scale mining sector, but most small-scale miners gain a very meagre living, some selling as little as US$1 worth of gold at a time. Less than 10 % of the workforce in small-scale mines are likely to have any formal training skills.

Women in Africa are actively involved in processing of raw materials, including crushing, grinding, sieving, washing and transporting of minerals. In some mining centres, these activities are even dominated by women who undertake these activities in the home, exposing entire families to high risks from silicosis and mercury poisoning. Although women rarely work underground, they can be found panning for gold or raking the surface of deposits in search of small amounts of raw material. In Ghana, women and children as young as 14 have been diagnosed with advanced stages of silicosis from grinding gold-bearing ore at home. But the almost total lack of access to health care makes it impossible to gauge the extent of occupational diseases, especially silicosis and mercury poisoning [ILO, 1999a].

The World Bank estimates that tens of thousands of residents may be affected by high levels of lead in the soil, some of which results from the impact of smelting and mining operations. Runoff and leakage from tailings dams and existing waste rock dams pollute streams flowing out of the mining area, causing widespread damage downstream. As farmers and fishermen, poor people's livelihoods often depend ''directly on goods and services provided by ecosystems and the quality of, and their access to, natural resources''. Such dependence obviously exacerbates their vulnerability to mining-induced environmental degradation [Pegg, 2006].

Similarly, for artisanal miners, the alternatives to mercury usage for amalgamation appear to be equally elusive. While technologies have been developed and proposed, even the United Nations Industrial Development Organizaton (UNIDO) believes that mercury usage will continue for this purpose in the foreseeable future. The focus of UNIDO's efforts is thus reducing miners' exposure to mercury by providing retorts to capture noxious vapors during gold recovery [Saleem, 2006].

An evaluation to the potential for acid drainage at new mines in developing countries proved [GIM, 2006]:

- lack of sufficient data, time, or budget;
- impatient mine developers;
- indifferent or non-technical regulators;
- political realities; and
- pre-existing contamination from artesanal miners.

To this direction it is suggested to take measures which include [GIM, 2006]:

- use of professionals;
- extrapolation of databases from other mines in other countries;
- clear communication of risks; and
- caution in decision making

5.3. Environmental impact issues

Evaluation of all the environmental impacts that are likely to arise from mining and mineral exploitation is now required, by almost all developed, and increasing number of DC, in the form of detailed Environmental Impact Assessments, before the authorities will grant the licence to proceed with new mining/processing operations [Dybowska et al., 2006].

An important component of sound environmental legislation is the ability to hold polluters accountable. This may be accomplished through a requirement to post a reclamation bond, which is held until the company has satisfactorily complied with government standards for closure and remediation of a mine site. There are no set international standards for the amount that should be retained in reclamation bonds, and estimates of potential environmental damages are often provided by the companies, which have an incentive to underestimate true costs. Seventeen mines have recently closed in the Philippines, many of which did not have the resources to implement post-closure measures. In 1999, 5.7 million cubic meters of acidic waste were discharged from the abandoned Atlas mine on the island of Cebu (in Phillipines). The resulting impact to the marine environment, including an extensive fish kill, was considered one of the country's top 10 recent environmental disasters. The environmental impacts of mining projects can also increase the vulnerability of the poor. A corporate sponsored review of the Ok Tedi mine in Papua New Guinea pointed out that even if mining at Ok Tedi were to cease immediately, the problems downstream would continue to increase due to the sheer volume of tailings already in the river and ongoing erosion from waste rock dumps adjacent to the mine in the mountains. The 1300 km^2 of rain forest along the river which is already dead or under severe stress is expected to eventually increase to as much as 2040 km^2. In Zambia, copper smelters emit 300,000 to 700,000 t per year of sulfur dioxide into the air. This contributes to soil contamination, as the sulfur dioxide emissions from the smelter are converted to sulfuric acid and induce vegetation loss downwind from the smelter stack emissions [Pegg, 2006].

Countries may also pass legislation that establishes fines and punishment for those found guilty of polluting. However, most countries lack any kind of legislation making polluters liable for clean-up. Where fines are collected, they are often low. Since 1977, the Mines and Geosciences Bureau in the Philippines has collected a flat-rate "mine waste and tailings fee" of $0.001 per ton, which is set aside to compensate for negative impacts caused by mining. As this rate has remained flat since 1977, environmental liability is capped at a relatively low level, providing an incentive for companies to surreptitiously discharge tailings rather than pay for more costly environmental remediation measures.

Although many countries have legislation requiring mitigation of environmental and social impacts of mining and oil development, the ability to enforce laws and monitor performance is largely lacking. Even in the United States, a lack of resources and staff means that many mines are not frequently inspected. A survey by the Mineral Policy Center revealed that eight western states have less than one inspector per 100 active mine sites. Table 3 highlights the lack of monitoring and enforcement in a select group of developed and DC.

Table 3. Capacity to Monitor and Enforce Laws [WRI, 2004].

Country or State	Number of Inspectors	Number of Mines	Ratio of Inspectors to Mines
Zimbabwe	4	300	1:75
Venezuela	3	400*	1:133
Arizona, USA	13	538	1:41
Colorado, USA	15	1,944	1:129
Idaho, USA	6	65	1:11
Montana, USA	20	11,00[1]	1:55
Nevada, USA	13	225	1:17

New Mexico, USA	7	185	1:26
Utah, USA	4	766[2]	1:191

** Includes exploratory concessions*

[1] Includes 1,000 "notice mines" (5 acres or less).

[2] Includes 334 "notice mines" and 326 mining exploration projects.

Variability of the waste materials and the fact that they may contain soluble substances which may leach out and cause damage to the structure or pollute water courses and kill fishes, are some other limiting factors against using mining and quarrying wastes. Another factor is that in using colliery spoil in embankments there is the danger of spontaneous combustion of the unburnt waste. There is also the possibility that pyrite present in the shale may oxidize forming jarosite or gypsum which may cause heave. Again, there may be health hazards in the use of mining and quarrying wastes for construction purposes. Wastes containing heavy metals for example may result in toxic contamination of any water which leaches through it or the heavy metals may be concentrated to toxic levels by plants grown on the waste [Hammond, 1988].

In the Philippines, each regional office of the Mines and Geosciences Bureau is staffed with roughly the same number of technical inspectors without taking into consideration the hectares of the mining areas[*]. Lack of funding, staffing and training are common constraints in many countries:

- inspectors rely on companies to provide access and additional resources, eliminating the element of spontaneity required for auditing (in Philippines).
- due to the lack of available resources for monitoring the performance of mines (in Papua New Guinea), the government relies on company reports rather than conducting periodic site visits to determine compliance with standards set in the mine contract.

5.4. Mining waste use

The benefits of using mining and quarrying wastes have been sufficiently summarized as conservation of natural resources, savings of energy and reduction of environmental pollution. In the developing world, especially, infrastructure is a pre-condition for development. There is therefore a correspondingly high demand for building materials such as sand, crushed stones, bricks and cement in large quantities in order to provide these facilities. This has led in some areas to local depletion of the naturally available materials which traditionally are used for construction. At the same time, there are in the same areas heaps of mining and quarrying wastes which cannot be disposed of in an economically and environmentally acceptable manner. These can be profitably used if they satisfy the basic requirements of the purpose they will serve. Also if the wastes are cleared, the land can be put to industrial, agricultural or residential use. Against these benefits are the problems associated with the transportation of the waste materials. Haulage costs are usually a function of the quantity of materials and the haulage distance. They bear no relationship to the value of the material that is being carried. Besides, in many countries tax incentive and freight rates do not favour the use of waste materials. Transporting the waste from one area to another by road may create environmental nuisance such as noise, vibration, traffic congestion, odour or dust. These are disadvantages in using the waste [Hammond, 1988].

This has led in some areas to local depletion of the naturally available materials which traditionally are used for construction. At the same time, there are in the same areas heaps of mining and quarrying wastes which

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[*] *e.g. a certain area has more than 72,000 hectares of approved mining areas, which amounts to approximately 400 hectares per person and on the other hand nine of the other 15 regions have less than 5,000 hectares of approved mining areas, resulting in a more manageable monitoring target of approximately 30 hectares per person.*

cannot be disposed of in an economically and environmentally acceptable manner. These can be profitably used if they satisfy the basic requirements of the purpose they will serve. Also if the wastes are cleared, the land can be put to industrial, agricultural or residential use. However some mining waste from phosphate or uranium may be sufficiently radioactive to be hazardous. There is also the lack of specification for using most waste materials. This makes it difficult for engineers who are understandably conservative to use the waste materials for construction. Patent rights and existence of monopolies also militate against the use of mining and quarrying waste [Hammond, 1988].

6. TECHNIQUES FOR PREVENTION AND ABATEMENT OF POLLUTION GENERATED BY MINING WASTES

6.1. Review of the techniques used to minimize the amount of mining wastes

Different mining methods and techniques are used to minimize the amount of mining wastes generated during commercial scale operations. Some of these methods and techniques are related to the “classical” open pit and underground mining activities but others are quite specific.

An efficient method to minimize the waste generation during the open pit mining is to construct the waste dump inside the void formed by the exploitation of the useful substances (coal or ore).

The sterile rock generated by the underground mining activities can be used in the stowing process for backfilling the remaining voids after coal or ore extraction.

The specific mining techniques are quite varied. In order to exploit deposits of coal and non-metallic minerals with low thickness and declivity that outcrop large areas a method consisting in digging a preparatory trench or half-trench towards the deposit or outcrop, with the level below the bottom of the deposit, is applied. The ore extraction is carried out through drilling holes or with mining shearers.

A large number of methods are based on the dissolution of the useful components. An efficient extraction of salt through boreholes by injecting fresh water was achieved in this way. The melting exploitation method is used since a long time for sulphur recovery. Water with 140 – 165 ^{o}C and 10 – 15 atmosphere pressure is used as leach solution. This solution goes inside the cracks and melts the sulphur. Hot air is also introduced under pressure to facilitate the formation of emulsion of the melted sulphur and water. The biggest disadvantage of this method is the high sulphur loss. Some improvements have been introduced recently to decrease these losses. These improvements are connected with the construction of impermeable clay layers covering the undesirable cracks in the boreholes.

The exploitation of sand deposits with boreholes using the air-lift methods for sand evacuation is used for banded sand deposits with 10 – 20 m thickness, with horizontal or with low declivity located at 80 – 150 m depth without tectonic influences and completely flooded with pressurized water.

The sublimation exploitation method is based on turning the solid substances into vapours, which are condensed afterwards. The method is particularly efficient for minerals such as mercury sulphide, auripigment, antimonite and tellurite.

The underground coal gasification is based on the immediate transformation of the coal into combustible gas products and their transport to the surface. This is achieved by injecting air or water vapours, or by using an artificial combination between oxygenized air, air vapours and oxygenized vapours, depending on the type of the gas intended as a final product.

The chemical and bacterial leaching of non-ferrous precious and rare metals and uranium from different mineral raw materials by means of dump, heap, in situ and reactor techniques are largely used worldwide. Most of these methods are environmentally friendly but the in situ underground leaching is connected with specific geotechnical conditions which limit its application (cf. Figure 5).

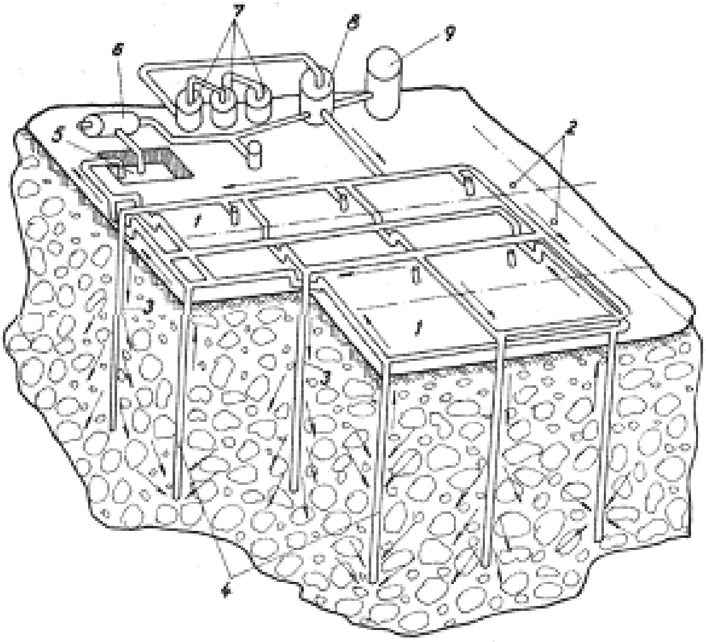


Figure 5. The chemical – bacterial leaching of low depth metal ore (1- exploitation panels; 2- monitoring boreholes; 3- boreholes for solution infiltration; 4- boreholes for solution collecting; 5 – decanting reservoir; 6 – pump; 7 – bacterial reservoir; 8 – central reservoir; 9 – collecting reservoir)

A very efficient approach to minimize the amount of mining wastes is to find suitable utilization of the secondary raw products (clay, sand, gravel, slag etc.) obtained during the mining and mineral processing operations. Some of these products are used as construction materials or as additives in agriculture but some still contain sufficient amounts of valuable metals, which can be recovered by appropriate methods, e.g. by bacterial or chemical leaching.

6.2. Review of the techniques used to prevent the generation of polluted mine drainage

The acid mine drainage is considered to be the major environmental problem associated with mining activities. This phenomenon is connected with the oxidation of pyrite and other sulphide minerals as a result of which acidic waters containing sulphuric acid, dissolved heavy metals and solid iron precipitates are released to the environment. The oxidation is a result of several chemical, electrochemical and biological reactions occurring in the presence of molecular oxygen, water and some acidophilic chemolithotrophic bacteria possessing iron- and sulphur-oxidizing abilities. These bacteria played the most essential role in the AMD generation process. In most cases the oxidation of sulphides is carried out by mesophilic microbial consortia containing *Acidithiobacillus ferrooxidans, At. thiooxidans* and *Leptospirillum ferrooxidans* as well as some acidophilic facultatively autotrophic bacteria as dominating species. However, in some very rich-in-pyrite parts of the relevant mineral leach areas with temperatures well exceeding 40 ^{0}C the sulphide oxidation is carried out by different thermophilic bacteria related to the genera *Acidimicrobium, Ferromicrobium*, and *Sulfobacillus*.

The main sources for acid mine drainage are open-pit and underground mining works, waste rock and low-grade ore dumps, processing tailings, temporary stockpiles of sulphide concentrates as well as rich-in-pyrite coal and uranium mines. The acid mine drainage from the uranium mines contain, apart from the iron and other heavy metals, also radioactive elements such as uranium and radium. Toxic elements such as arsenic and antimony are also essential components of the AMD released from mineral raw materials containing these elements.

Predicting and preventing acid mine drainage is important in order to avoid a remedial treatment which is usually capital intensive. Several methods to prevent the generation of AMD are known:

- Application of mining techniques connected with a minimal output of mining wastes. Such techniques are well known but their application, apart from the ecological, depends also on many other factors which can prevent such application. In some cases considerable amounts of mining wastes are used as stowing material in discontinued underground mining workings. But, despite these activities, the deposition of mining waste on dumps will remain unavoidable.

- Establishing a water table above the disposed waste as a barrier that limits transport of oxygen into the waste. The water cover is not only efficient but in most cases is cost effective compared to a dry cover.

- Isolation of the mining waste from water and/or air by means of different dry covers consisting of impermeable artificial or natural materials. The impermeable material must connect with the sealed boundary ditches to collect the rainwaters running from the covered mining wastes. Such sealing barriers can also be installed in the interior of the waste dumps during their construction, by means of layer-by-layer deposition of mining wastes, followed in each case by sealing.

- An advanced soil cover includes a compacted sealing layer with low hydraulic conductivity, such as clay or clayey till, placed between the tailings and the till cover to act as a protective layer; the required thickness of the protective layer depends on the local climatic conditions and on the local flora and fauna, i.e. with respect to root penetration depth, digging animals, etc. and the characteristics of the available protective materials.

- Treatment of wastes in order to alter their chemical and physical properties and to make them unsuitable for the growth and activity of the acidophilic chemolithotrophic bacteria. Water-saturated organic covers in combination with crushed limestone are very efficient to create system with anoxic conditions and high pH levels.

- Suitable handlings during operation or treatment. During operation, the simplest way is to deposit reactive and non-reactive tailings or waste-rock separately to reduce the cost of decommissioning the non-reactive part. During treatment, separation of pyrite by flotation permits less extensive decommissioning measures for the depyritisated wastes. However, in some cases is possible to mix in suitable ratios acid-generating sulphide wastes with wastes presenting high positive net neutralization potential. The applicability of these techniques is ruled by the geology of the deposit, the mining and processing methods applied, and the geochemical properties of the ore and wastes.

- Application of suitable bactericides to inhibit the acidophilic chemolithotrophic bacteria. It has been found that sodium dodecylsulphate and isothiazolinone have some negative effect on this bacteria but it is far from being quantitative.

- Joint application of two or more of the above-mentioned methods.

6.3. Review of the techniques used for storage of hazardous mining wastes

The discrimination between hazardous and non-hazardous waste in the EU is based on a system for the classification and labelling of dangerous substances and preparations, which ensures the application of similar principles over their entire life cycle. The properties which render waste as hazardous are laid down in the Directive 91/689/EEC and are further specified by the Waste List Decision 2000/532/EC as last amended by Decision 2001/573/EC.

Council Directive 91/689/EEC on hazardous waste (last amended by 2001/118/EEC) codifies all waste types according to the generation source, waste composition, and other criteria. The European Waste Catalogue (EWC) lists 23 types of wastes resulting from exploration, mining, and treatment of minerals. Six of these wastes are classified as hazardous.

Directive 1999/31/EEC on landfilling of waste intends to prevent or reduce the adverse effects of the landfill of waste on the environment and defines the different categories of waste, i.e. municipal, non-hazardous, hazardous and inert. It also specifies design characteristics of the three main landfill classes, namely for hazardous, non-hazardous and inert waste.

The US-EPA has classified most of the extraction and beneficiation of wastes from mining of metallic ores and phosphate rock, together with 20 specific mineral processing wastes, as “special wastes”, which are under special control and their disposal on land is a practice of particular concern.

Both in the European and in the US legislation, land disposal units, such as landfills for hazardous waste should comply with stringent requirements for liners, leak detection systems, and groundwater monitoring.

This study summarizes general requirements and construction characteristics of the main liners and systems that constitute a landfill for hazardous wastes.

The soil liners are widely used in such landfills. Clay is the most important component of soil liners because the clay fraction of the soil ensures low hydraulic conductivity. The soil liners differ with respect to some compaction variables such as soil water content, type of compaction, compactive effort, size of soil clods, and bonding between lifts.

The flexible membrane liners constitute the main interceptive layer against the percolation of leachate. They differ with respect to their chemical comparability, manufacturing considerations, stress-strain characteristics, survivability, and permeability.

The composite liner systems allow much less leakage than a clay liner acting alone, because the area of flow through the clay liner is much smaller. The flexible membrane liner must be placed on top of the clay, so that the liquid does not spread along the interface between it and the clay and move downward through the entire area of the clay liner.

Drainage and geosynthetic materials play an essential role in the liquid management systems.

Biogas collection systems in hazardous waste landfills are often installed but, in the case of hazardous mining wastes, their amounts are negligible due to the small amounts of fermentable materials in these wastes.

The storage of wastes from the mining and processing of different mineral raw materials such as hard coal, lignite, ores of non-ferrous metals and sulphur is characterized by a specific approach based on the chemical and mineralogical composition, particle size, and geotechnical characteristics of the relevant wastes have to be applied. Such approach, together with the current legislation and the diversity of the existing materials, provides the ability of development of the most suitable design of facilities for storage of hazardous wastes.

6.4. Review of the techniques used to clean up the polluted mine drainage

A large number of methods for treatment of acid mine drainage (AMD) are known, and some of them have been widely applied under real commercial or field scale conditions. This application is necessary to avoid the hazardous effect of these waters on the environment and its inhabitants, and to some extent is connected with the practical difficulties to prevent the generation of AMD at source. Several classifications of the methods for treatment of such waters exist but currently the most popular is that which divides these methods and the relevant technologies into “active” and “passive”. The active technologies are connected with the construction of more sophisticated equipments which are operated at a permanent control by the staff and by a permanent consumption of energy as a result of a direct or indirect human activity. The application of some of these technologies can result in a very efficient cleanup of heavily polluted waters at relatively short residence times. However, these efficient technologies are quite expensive due to the high investment and operational costs. The passive technologies are based mainly on natural processes which are occuring in relatively simple installations, similar to the relevant natural ecosystems.

These processes proceed at a periodic human control and without a permanent input of energy from outside. For these reasons, the technologies of this type are relatively inexpensive and environmental friendly.

Another important classification divides the technologies for water cleanup into those that rely on biological activities and those that do not. Within these major groups, there are processes that may be described as either “active” or “passive”.

Several efficient technologies of different types are currently available for the treatment of AMD. The choice of the most appropriate technology for a given case is dictated by a number of economical and environmental factors, such as the level of investment and operational costs, the sustainability of the relevant technology, the possibility to combine the water cleanup with the production of some valuable products, the impact on the environment and its inhabitants, the type and the amount of waste and the possibilities for safe disposal, the inclusion of the water cleanup operation in the overall strategy for remediation and further development of the relevant area.

A typical tendency of the current development in this field is the large inclusion of different biological processes in systems for treatment of AMD. The microbial dissimilatory sulphate reduction, the biosorption and the oxidation or reduction of some elements are the most important processes of this type. In most cases they are applied in combination with different chemical processes.

The microbial sulphate reduction is very efficient for removal of radionuclides, heavy metals, arsenic and sulphate from AMD. The production of alkalinity, the generation of relatively small amounts of stable sludge consisting of insoluble metal sulphides as well as the possibility for utilization of some cheaper sources of carbon and energy by the sulphate-reducing bacteria are other positive properties of this process. The sulphate reduction can be applied in both active and passive treatment systems.

One of the most important tasks in this field is the isolation and selection of strains able to perform sulphate reduction at low pH values (at about 3.0 – 3.5).

The biosorption by both alive and dead plant and microbial biomass is also an essential process for water cleanup. Important tasks for further improvement of this process are the production of relatively cheap biomass possessing a high metal sorption capacity and ability for selective metal binding, as well as the development of effective desorption methods and technologies based on the recycling of desorbents and repeated use of biomass. The biosorption of pollutants plays a very essential role in the passive systems, especially during the cold winter months, when the growth and activity of microorganisms are strongly or even completely inhibited.

There are efficient biotechnologies for removal of iron, manganese and arsenic based on the bacterial oxidation of these metals. The microbial reduction of uranium and chromium is applied for treatment of waters polluted with these elements.

The active treatment systems based on the application of effective bioreactors can treat huge amounts of polluted waters for short residence times. The water cleanup by these systems can be combined with the production of valuable products such as elemental sulphur, sulphidic concentrates, biogas and iron pigments.

Most of the innovations in the technologies for cleanup of AMD are connected with different passive systems. The constructed wetlands, the permeable reactive multibarriers and especially the different composite systems involving two ore more components (RAPS, ARUM and some others) prove to be very efficient for the treatment of strongly acidic and metal-rich AMD.

Some abiotic methods as chemical neutralization of AMD followed by precipitation of metals mainly as hydroxides, the sorption of metals by various inorganic sorbents as clays, natural and modified zeolites, apatites, iron hydroxides and activated carbon, as well as different membranes methods (electrodialysis, filtration and reverse osmosis) are also efficient for the treatment of such waters. The chemical neutralization is still the most widely applied method for the treatment of AMD. Some recent innovations have been suggested to improve this traditional method, e.g. the stepwise neutralization by the consecutive addition of small amounts of alkalizing agents (limestone or lime) as well as the addition of sandstone to the limestone in the alkalizing drains to reduce the armoring of limestone. Different inorganic sorbents are largely used not only for water cleanup but mainly for recovering valuable metals from pregnant solutions from different operations for chemical and biological leaching of ores, concentrates and wastes. Currently, membrane technologies are used for obtaining very pure permeates, including drinking water by treatment of sea water.

An important tendency of the current development in the field of AMD treatment is also the combinations between various biological and abiotic methods present as active and/or passive systems. Several important achievement have been made in the engineering of various novel (bio)reactors, filters, separators and other facilities which are used in the water treatment.

Numerous studies are carried out on the isolation, biology, genetic improvement and selection of microorganisms which are or can be used for the treatment of AMD.

6.5. Review of the techniques used to clean up soils polluted as a result of the mining activities

Soil contaminants can be characterized according to of different criteria. The chemical nature of the pollutants is the most suitable criterion with respect to the selection of methods for soil remediation.

The heavy metals, radionuclides, substances increasing the soil salinity or changing the acid-base properties are the most important pollutants in the soils polluted as a result of mining activity.

The heavy metals are present in the soil solutions mainly as free ions or as cations adsorbed by the minerals and organic components of the soil. They can be also present in forms of salts with different solubility (such as oxides, carbonates, sulphides and sulphates) as well as impurities in the structures of some soil minerals.

The radionuclides including isotopes of both light (Cs, Cr) and heavy (U, Ra, Th) metals are a very specific group of pollutants. Their emissions of ionizing radiation require the application of special techniques for soil remediation.

The pollutants causing salinity, acidification or alkalization of the soils are a very diverse group.

They are present mainly as non-metallic anions (such as chlorides and sulphates) and as ions of some light metals (Na, K, Mg, Ca).

Most of the physical methods for soil remediation do not change the physico-chemical properties of pollutants. The removal of polluted soil and its replacement by non-polluted soil (of the same type) is the simpliest method of this group. However, such treatment is connected with the problem of storage and cleanup of the removed polluted soils. In some cases, e.g. with soils polluted with radionuclides, it is possible to isolate in situ these soils by means of impermeable barriers. In any case, these isolation techniques are only a temporary solution.

Electroremediation and vitrification are regarded as more innovative physical methods but they are still in the stage of advanced studies and development, because the relevant processes are not under strict control and the side effects can be negative with respect to the soil quality, e.g. changes of the physico-chemical properties of the soil and destruction of the normal soil microflora.

The application of some inorganic sorbents such as natural and synthetic zeolites is the most widely applied physical method for soil remediation. The selective sorption abilities of zeolites with respect to some heavy metals as well as the improvement of the physico-mechanical properties of the soil are the main advantages of this group of methods. However, it is necessary to maintain a proper soil humidity during such treatment.

The chemical methods for soil remediation are also a very large group. Some of these methods are connected with the immobilization of pollutants as insoluble non-toxic forms. In some cases this is achieved by adding substances, e.g. cement, which bond and completely block pollutants in the soil.

Such treatment is applied mainly in the cases when heavily polluted soil must be removed from the place of origin and its storage is connected with a high environmental risk. In some other cases the immobilization is due to processes such as neutralization, oxidation and reduction which result in precipitation of the pollutants in insoluble compounds. Some of these processes are carried out by adding suitable chemical reagents to the soil.

However, in some other cases the processes are carried out by the indigenous soil microorganisms, e.g. precipitation of the heavy metals and arsenic as the relevant insoluble sulphides as a result of the process of microbial dissimilatory sulphate reduction. The microbial activity in situ is stimulated by suitable changes in the levels of some essential environmental factors such as pH and oxygen, water and nutrient contents of the soil. Both chemical and biological methods of pollutant immobilization are, as a whole, relatively not expensive, well accepted by the local communities and do not create real environmental and health hazard.

The soil washing and flushing are the most efficient methods for treatment of soils polluted with heavy metals. These methods are very suitable for in situ application. They are based on the solubilization of pollutants as a result of chemical and/or biological action, transport and removal of the dissolved pollutants form the soil profile via drainage waters with a composition suitable to maintain the pollutants in the relevant soluble forms. The cleanup of the pregnant soil effluents is an essential problem connected with these methods. However, a recent innovation consists in the precipitation of the dissolved pollutants in the deeply located soil layers in the forms of the relevant insoluble sulphides by stimulating the in situ activity of the sulphate reducing bacteria inhabiting these soil layers. It must be noted also that the in situ precipitation of the soil washing and flushing methods is possible only under suitable geologic and hydrogeologic conditions.

The phytoremediation methods are based on the ability of some plant species to accumulate heavy metals and/or other toxic substances from soil through their root systems. The pollutant-rich plant biomass is then mechanically removed and burned to ash. Regardless, of some positive results, these methods are still in the stage of further development connected with the selection of very active plant accumulators and with their symbiosis with the local indigenous microflora.

6.6. Review of the techniques for closure of mines and remediation of post-mining areas

The closure of mines and the remediation of the post-mining areas is an important activity with respect to the environmental protection.

This activity involves application of techniques for prevention and treatment of polluted mine drainage, land shaping and revegetation.

The treatment of polluted mine drainage, especially of such with a low pH, can be arranged by means of different active and/or passive techniques. The treatment by active techniques is applied usually at operating mines where appropriate space, control and security are feasible. However, these operations would be prohibitively expensive at abandoned sites where the mining infrastructure has been dismantled. A recent tendency consists in the combination of water treatment with recovery of some valuable components such as non-ferrous metals and uranium by means of ion exchange, sorption, cementation or other appropriate methods. In some cases even solid mineral wastes, e.g. dumps consisting of low-grade ores and rock mass, flotation tailings, slags, clinkers and other wastes from metallurgy and mineral processing, are subjected to treatment for recovering the residual amounts of valuable components. Such treatment usually is carried out by advanced technologies of different types – biological and chemical leaching, flotation, gravimetric separation. In such ways, the hazardous wastes are turned into valuable mineral raw materials, and the new operations make acceptable the application of active techniques for water treatment. On the other side, these resumed activities put some problems with respect to the land shaping and revegetation of the old post-mining areas.

In the cases when the mineral wastes are not regarded as sources of valuable components, the treatment of polluted drainage waters can be done by using different passive systems such as constructed wetlands, permeable reactive barriers and reactive in situ zones (cf. Figure 6).

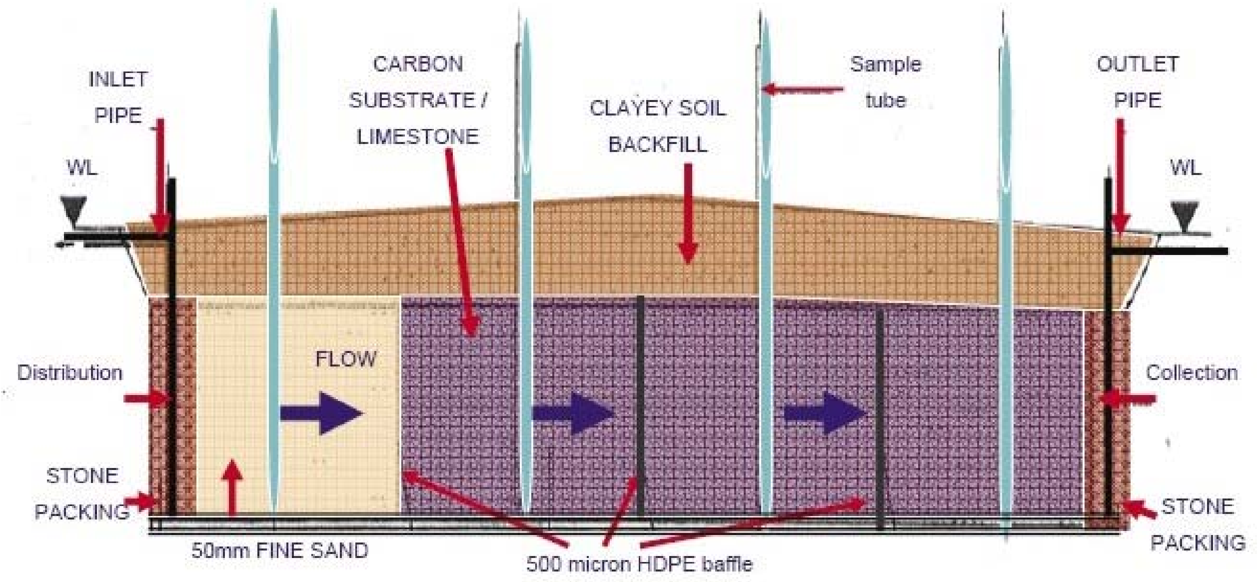


Figure 6. A diagrammatic presentation of Permeable Reactive Barriers (PRB).

The technology to prevent acid mine drainage from developing at mining sites has not been widely applied until quite recently and the projects of this type are connected with mines which are still in operation or have only recently been closed.

The reclamation of the post-mining areas usually starts with land shaping. It is necessary to contour aesthetically pleasing landforms, which blend with the surrounding area. The shapes and slopes of these landforms must be with slope angles suitable to minimize erosion and to provide stability for post-mining development. This development is necessary to be consistent with the subsequent use planned for the relevant site.

The appropriate land shaping is essential for increasing the revegetation success. Revegetation is the final stage in the site reclamation and there are several factors which make difficult its proper establishment. Most of these factors are climatic but some others are connected with the land shaping and structure. Mine sites generally offer harsh conditions to the plants. However, if some fertile soil is used as a top cover of the landforms and some appropriate melioration techniques such as ploughing, irrigation and addition of fertilizers are applied, the plant growth starts even when the climatic conditions are not very favourable. An essential point in this activity is the proper selection of plants which are the best suited for the relevant conditions. Test plots can be used to determine which species will be successful, whereas areas in which plants fail to establish can be reseeded with more appropriate vegetation. In any case, the revegetation early in the reclamation process is critical because it may take several seasons to establish a widespread and healthy vegetation.

In some cases different wastes from the metallurgy and mineral processing are used in the reclamation of post-mining areas, e.g. fly ashes to improve physico-chemical conditions in reclamated hard coal wastes; hard coal mining wastes to prevent the wind erosion of fine fly ashes or to create a stable and environmentally safe top layer on tailing ponds containing flotation wastes.

It must be noted, however, that the new national or EU legislation do not favour such solutions. It concerns especially the wastes classified as dangerous wastes, e.g. flotation tailings from the processing or fly ashes.

In many cases it is impossible to provide large amounts of fertile soil for reclamation of post-mining areas. A recent tendency in these cases is to apply various innovative techniques for improving the quality of barren soils or even to enhance the soil-forming processes on rock and clay minerals.

These techniques use different chemical and microbial fertilizers, mycorrhizal fungi which stimulate the growth of plants used for revegetation, reagents improving the physico-chemical properties of the mineral mass, solid biodegradable organic substrates (cow manure, plant compost, straw) which are sources of carbon and energy for the microbial consortia, as well as appropriate melioration techniques such as ploughing, liming, irrigation, grassing and moulching.

The underground spaces, including the underground mines, offer the possibility to new development without a further deterioration of the surface environment and ecosystems. These spaces are used mainly for storage of different products and wastes such as petroleum, oils and lubricants, natural gas, industrial and food products, mine tailings, metallurgical and construction wastes, etc. However, some more advanced applications includes recreational facilities, balneotherapy sanatoriums and religious facilities. The application depends on several factors, the most important of them being the type of the mineral matter recovered during the mining activities and the type of the host rock, as well as the location with respect to other civil or industrial structures.

6.7. Review of monitoring systems in connection with the mining operations

The monitoring systems are an essential part of any environmental management system. They provide the basis for effective decision making and development of strategies for management connected with environmental protection and remediation. The monitoring systems are designed and implemented for collecting data on ambient air, water, soil and biomass quality and on releases of pollutants of concern from different sources. The modern monitoring systems also involve parameters reflecting the environmental effect on the health and safety of the humans inhabiting and/or working in the relevant ecosystems.

The elements of a typical monitoring system normally include:

- the selection of the parameters of concern and the control parameters according to the monitored phenomenon;
- the methods of collection and handling of samples, with information on the location, type and quantity of samples, as well as on the sampling frequency and equipment;
- the methods of sample analysis or on-line monitoring;
- informational volume processing;
- decisional analysis;
- recommendations of actions intended to prevent a negative impact on the environment and/or to

restore the normal environmental status.

It is known that mining and mineral processing are among the human activities which have a strong negative impact and cause the largest destructions of the environment. These activities are connected with the generation of large amounts of wastes, most of which are hazardous to the environment.

The monitoring systems applied in mining operations are focussed on the polluted effluents, quality of surface and groundwaters, stability of mining wastes, air and soil pollution, and level of noise standards. The monitoring approach is changed with the progress within the development of mining operations and the life cycle of the mining wastes. The monitoring systems can be related to three different groups with this respect:

- a basic monitoring to study the parameters which characterize the current situation and their development on site,
- a remedial monitoring to characterize the impact of remedial measures during the time of their implementation, and
- a post-remedial monitoring which covers a long period of time to demonstrate the success of remediation.

It is possible to say that in most countries the general development in mining over the last decades has in many ways a less negative impact as far as health, safety and environment. The higher levels of mechanisation and automation have increased the production intensity with a consequent raise in the quantities of air pollutants produced per time unit. The new ventilation methods, improved blasting agents and technologies, cleaner diesel engines and fuels have exerted a positive effect on the exposure and safety situation of the workers. However, the increased mechanisation and automation have increased the level of psychological stress.

Noise is probably the individual factor that causes most injuries at work. Whole body vibration and poor lighting are also important and may cause personal injury and accidents. Some rock-blasting activities still remain a reason for health problems due to noise, mineral dust and vibration.

Modern mining requires competent planning to achieve maximum safety for workers and, at the same time, to maintain the production efficiency with the chosen working methods. All safety aspects must be addressed during the early stages of the planning process. The transfer of knowledge and the understanding of new information are essential factors for the development of a working environment, with improved the health and safety conditions.

7. A NOVEL DECISION SUPPORT TOOL FOR THE MANAGEMENT OF MINING WASTE AND WASTE FACILITIES, WITH EMPHASIS IN NEW EU MEMBER STATES

Mining generates one of the largest waste streams in the European Union; it is responsible for 29% of the overall waste generation. Mining has an impact on all elements of the environment, as the associated generated point- and diffuse-source pollution presents catchment-scale and transboundary impacts [Hamor , 2004]. Abandoned mining waste heaps and excavation spaces result in long-lasting, often historical impacts.

Wastes from extractive operations (i.e. extraction and processing of mineral resources) constitute one of the largest waste streams in the EU. They involve materials that must be removed to gain access to the mineral resource, such as topsoil, overburden and waste rock, as well as tailings remaining after minerals have been largely extracted from the ore. Specifically, every year, some 1.2 billion Mg of waste, including also particularly hazardous waste, are produced in EU Member States and this figure is rising steadily, whereas the European mining industry having an annual production of over 400 Mt of waste, thus accounts for nearly 30% of all waste generated in the EU. These materials may have lasting environmental and socio-economic impacts and can be extremely difficult and costly to address through remedial measures. Mining waste is often produced in large quantities and storing it can be hazardous, either because of the use of defective techniques or the emission of polluting substances, such as heavy metals or cyanide [EUROPA, 2009(a)]. Wastes from extractive industries have therefore to be properly managed in order to ensure in particular the long-term stability of disposal facilities and to prevent or minimise any water and soil pollution arising from acid or alkaline drainage, as well as leaching of heavy metals [EUROPA, 2009(b)].

A comprehensive framework for the safe management of waste from extractive industries at EU level is now in place comprising:

- Directive 2006/21/EC on the management of waste from the extractive industries (the mining waste directive) [EUROPA, 2009(c)]; and
- A Best Available Techniques reference document for the management of tailings and waste-rock in mining activities [EUROPA, 2009(d)].

Directive 2006/12/EC (Waste Framework Directive) on waste has been revised in order to modernise and streamline its provisions. The revised Directive 2008/98/EC sets the basic concepts and definitions related to waste management and lays down waste management principles such as the "polluter pays principle" or the "waste hierarchy". Waste resulting from prospecting, extraction, treatment and storage of mineral resources and the working of quarries covered by Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries is excluded from the scope of Waste Framework Directive [EUROPA, 2009(e)].

In general, wastes from the extractive industries are not being systematically tested and there is no specific methodology for their characterisation. The methods in use are European and international standards for waste, soil, construction or raw materials, but also local standards in some cases. These methods have not particularly been developed for mining wastes and might be inappropriate in some cases; this is why an extensive testing programme might be required before recommending a methodology. For good prediction of the leaching behaviour of mining waste and a realistic assessment of the environmental impact, a very good knowledge of the testing methods is required, as well as of the characteristics of the material to be tested. In addition to this, the natural conditions in which the waste is stored and the involved microbiological influences are also essential.

There are always various reasons why one standard is preferred to another in mining area. In Italy, for instance, the use of local standards is required by law. Usually European standards are used if available, and if not local, international, American or British standards, according to the characteristics of the waste and the available equipment. As far as the New EU Member States are concerned, a special notice should be made for Bulgaria where considerable experience in the characterisation of mining wastes has been acquired. Also in Romania, some special standards for rational analysis have been developed that to our knowledge have no equivalent in international standards, and might be helpful for the characterisation of mining wastes.

7.1. Risk Assessment of Mining Waste Facilities

In historic mining areas in Europe and elsewhere, mine closure and abandoned mines have grown a major concern for contamination, as reflected by the new EU Mine Waste Directive (Directive 2006/21/EC) requiring the risk-based inventory of closed and abandoned mine waste sites. Associated problems include, among others, the long-term release of contaminated acid mine drainage (AMD) effluents and accidental pollution by tailings dam failure.

Contamination Risk Assessment (RA) studies the combined effect of the probability of contamination and the significance of toxic impacts along the contamination source-pathway-receptor chain. It is generally recognized that risk-based inventory of mine sites should enable the ranking of mine sites (identification of 'hot spots') and it should follow a tiered approach proceeding from preliminary risk screening to more detailed site studies [UK DoE, 1995].

In principle, the main environmental risks related to old or abandoned mining waste facilities are connected with accidental spillages of tailings (mainly due to dam failures) or to an inadequate design or management of the facilities (causing the slow seepage of polluted leachates to groundwater or surface water). According to the information compiled and analysed, in several countries there is no specific regulation of risk assessment for mining waste facilities and it would be necessary to rapidly establish such a methodology, in order to avoid human and environmental accidents.

From an environmental point of view, the methodology should consider as the main risks [Peppas et al., 2005]:

- Risks of failure.
- Environmental Risks: impacts on soil, surface water, groundwater and air.
- Special ecosystems protection.

The methodology also should consider the way to establish the maximum acceptable amount of each potential pollutant for each potential receptor (humans, air, soils and freshwater ecosystems in the area). Likewise, the methodology should establish the means of prioritisation for old mining waste facilities that require further remedial actions.

In general, tailing ponds and waste dumps are the vulnerable waste facilities. Seismic movements, strong winds or heavy rainfall could affect their stability and contribute to the risk of failure. In both cases, an inadequate storage capacity as well as construction problems or poor drainage designs, could be the potential reasons for a collapse. In addition, dams are usually built of material available at the mine site. Therefore, they can show inconsistencies in their quality, which can lead to seepage that can weaken the pond structurally. For this reason, the preparation of Contingency Plans in case of accident should be a prerequisite for the approval and permit issuing of any extracting activity.

7.2. Review of pollution prevention and abatement techniques

7.2.1. Techniques used to minimize the amount of mining wastes

Different mining methods and techniques are used to minimize the amount of mining wastes generated during commercial-scale operations. Some of these methods and techniques are related to the "classical" open pit and underground mining activities but others are quite specific.

Specific mining techniques are quite varied. In order to exploit deposits of coal and non-metallic minerals with low thickness and declivity that outcrop over large areas, a method consisting of digging a preparatory trench or half-trench towards the deposit or outcrop, with the level below the bottom of the deposit, is applied. Ore extraction is carried out through drilling holes or with mining shearers.

A very efficient approach to minimize the amount of mining wastes is to find a suitable utilization for the secondary raw products (clay, sand, gravel, slag etc.) obtained during the mining and mineral processing operations [EPA, 2005].

7.2.2. Techniques used to prevent the generation of polluted mine drainage

Acid mine drainage is considered to be the major environmental problem associated with mining activities. This phenomenon is connected with the oxidation of pyrite and other sulphide minerals as a result of which acidic waters containing sulphuric acid, dissolved heavy metals and solid iron precipitates are released to the environment. The oxidation is a result of several chemical, electrochemical and biological reactions occurring in the presence of molecular oxygen, water and some acidophilic chemolithotrophic bacteria possessing iron and sulphur-oxidizing abilities.

The main sources for acid mine drainage (AMD) are open-pit and underground mining works, waste rock and low-grade ore dumps, processing tailings, temporary stockpiles of sulphide concentrates as well as pyrite rich coal and uranium mines.

Predicting and preventing acid mine drainage is important in order to avoid a remedial treatment which is usually capital intensive. Several methods for prevention of AMD generation are known [Elander et al., 1998]:

- Application of mining techniques connected with a minimal output of mining wastes.
- Establishing a water table above the disposed waste as a barrier that limits the transport of oxygen into the waste.
- Isolation of the mining waste from water and/or air by means of different dry covers consisting of impermeable artificial or natural materials.
- Treatment of wastes in order to alter their chemical and physical properties and to make them unsuitable for the growth and activity of the acidophilic chemolithotrophic bacteria.
- Suitable handling during operation or treatment.
- Application of suitable bactericides to inhibit the acidophilic chemolithotrophic bacteria.
- Joint application of two or more of the above-mentioned methods.

7.2.3. Techniques used for storage of hazardous mining wastes

Stockpiling waste is not a viable solution and disposing it is unsatisfactory due to the resulting emissions and highly concentrated, polluting residues. The best solution is, as always, to prevent the production of such waste, reintroducing it into the product cycle by recycling its components where there are ecologically and economically viable methods of doing so. The current legislation in combination with the diversity of the existing materials provides the ability of variant and optimized landfill design for many wastes.

Flexible membrane liners constitute the main interceptive layer against the percolation of leachate. They differ with respect to their chemical compatibility, manufacturing considerations, stress-strain characteristics, survivability, and permeability. Composite liner systems allow much less leakage than a clay liner acting alone, because the area of flow through the clay liner is much smaller. The flexible membrane liner must be placed on top of the clay, so that the liquid does not spread along the interface between it and the clay and move downward through the entire area of the clay liner. Drainage and geosynthetic materials play an essential role in the liquid management systems.

The storage of wastes from the mining and processing of different mineral raw materials such as hard coal, lignite, ores of non-ferrous metals and sulphur is characterized by a specific approach based on the chemical and mineralogical composition, particle size, and geotechnical characteristics of the relevant wastes that have to be applied. Such an approach, together with the current legislation and the diversity of the existing materials, provides the means of development for the most suitable design of facilities for storage of hazardous wastes.

7.2.4. Techniques used to clean up the polluted mine drainage

A large number of methods for treatment of AMD are known, and some of them have been widely applied under real commercial or field scale conditions. This application is necessary to avoid the hazardous effect of these waters on the environment and its inhabitants, and is to some extent connected with the practical difficulties of preventing AMD generation at source. Several classifications of the methods for the treatment of such waters exist but currently the most popular is that which divides these methods and the relevant technologies into “active” and “passive” [Groudev et al., 2008].

The active technologies require more sophisticated equipment which is operated at a permanent control by the staff and require a permanent consumption of energy as a result of a direct or indirect human activity. The application of some of these technologies can result in a very efficient cleanup of heavily polluted waters at relatively short residence times. However, these efficient technologies are quite expensive due to the high investment and operational costs.

The passive technologies are based mainly on natural processes which occur in relatively simple installations, similar to the relevant natural ecosystems. These processes require regular human control but no permanent external input of energy. For these reasons, technologies of this type are relatively inexpensive and environmentally friendly.

Another important classification divides the technologies for water cleanup to such that rely on biological activities and such that do not. Within these major groups, there are processes that may be described as either “active” or “passive” (Figure 7) [Johnson et al., 2005].

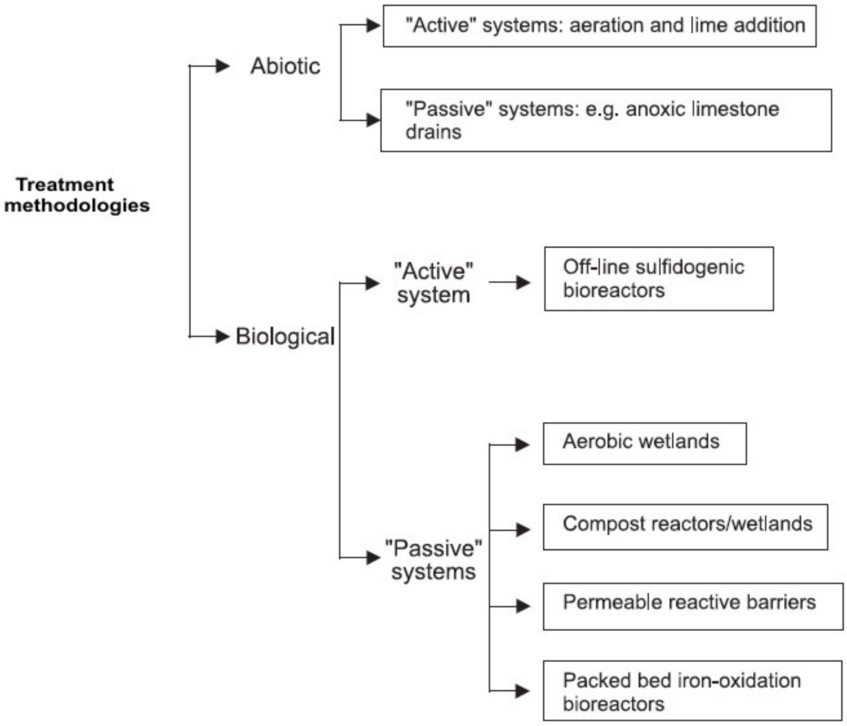


Figure 7. Biological and abiotic strategies for remediating and acid mine drainage waters [Johnson et al., 2005].

7.2.5. Techniques for closure of mines and remediation of post-mining areas

The closure of mines and the remediation of the post-mining areas is an important activity with respect to environmental protection. This activity involves the application of techniques for prevention and treatment of polluted mine drainage, land shaping and revegetation.

The treatment of polluted mine drainage, especially of that with a low pH, can be achieved by means of different active and/or passive techniques. Treatment by active techniques is usually applied at mines operating where appropriate space, control and security are feasible. However, these operations would be prohibitively expensive at abandoned sites where the mining infrastructure has been dismantled.

In some cases solid mineral wastes, e.g. dumps consisting of low-grade ores and rock masses, flotation tailings, slags, clinkers and other wastes from metallurgical and mineral processing, are subjected to treatment for recovering the residual amounts of valuable components. At the same time, these resumed activities must be coordinated with respect to the land shaping and revegetation of the old post-mining areas to prevent conflict with site remediation aims (Figure 8).

7.3. A Decision Support Tool for Minimising the Impact of the Mining Industry on the Environment

In order to make it easier for the people dealing with mining wastes to find their way through the large amount of information available in this field, a Decision Support Tool (DST) has been developed, by means of which the user can quickly identify the relevant options he/she requires (Figure 9).

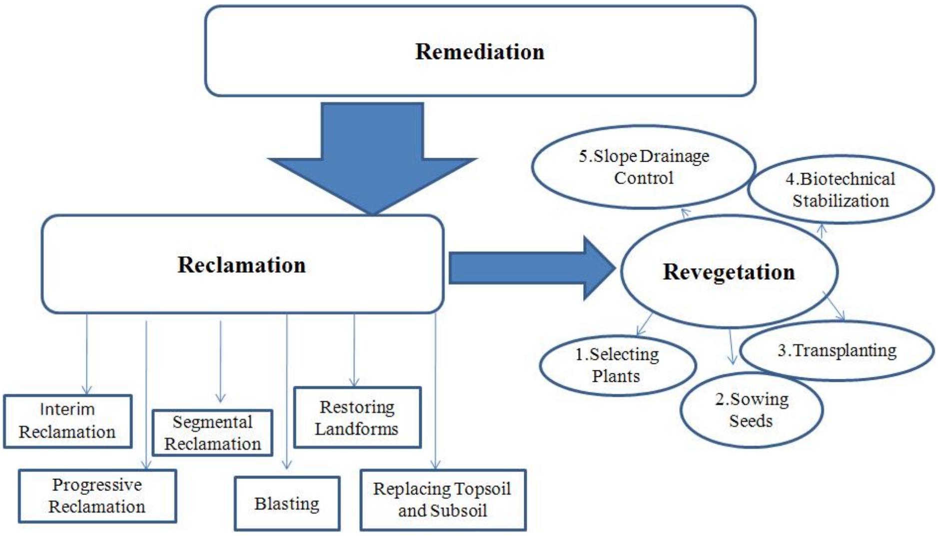
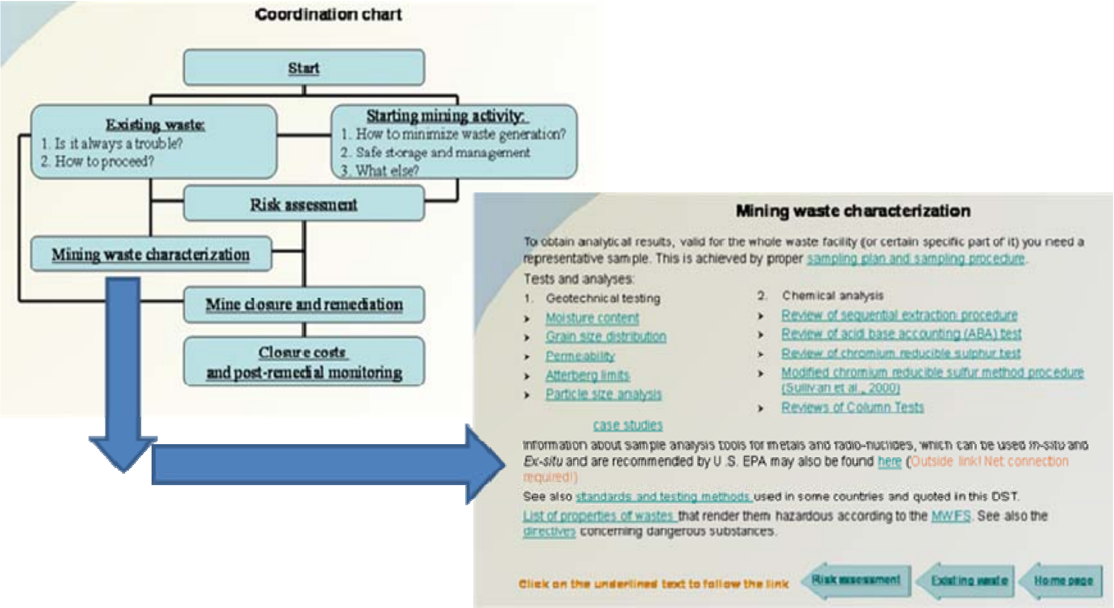


Figure 8: Remediation of the post-mining areas.



Mining waste characterization

To obtain analytical results, valid for the whole waste facility (or certain specific part of it) you need a representative sample. This is achieved by proper sampling plan and sampling procedure.

Tests and analyses:

1. Geotechnical testing
   - Moisture content
   - Grain size distribution
   - Permeability
   - Atterberg limits
   - Particle size analysis
2. Chemical analysis
   - Review of sequential extraction procedure
   - Review of acid base accounting (ABA) test
   - Review of chromium reducible sulphur test
   - Modified chromium reducible sulfur method procedure (Sullivan et al., 2000)
   - Reviews of Column Tests

case studies

Information about sample analysis tools for metals and radio-nuclides, which can be used *in-situ* and *Ex-situ* and are recommended by U.S. EPA may also be found here (Outside link! Net connection required!)

See also standards and testing methods used in some countries and quoted in this DST.

List of properties of wastes that render them hazardous according to the MWFS. See also the directives concerning dangerous substances.

Click on the underlined text to follow the link

Figure 9. Coordination chart of the decision support tool (DST) for the management of mining waste and waste facilities.

Because of the great variety of situations that can occur in this field, the end decision is of course the responsibility of the specialist in charge, but this tool gives a good overview of the aspects that he/she needs to consider.

The tool is based on a powerpoint presentation where the user can easily navigate between the slides and choose to open the different files that are linked to them, providing more extensive information on a certain topic. The presented DST gives a good overview of the state of the art regarding the practices related to the management of mining wastes in Europe, and can be a very useful tool for the environmental authorities in the implementation of the Mining Waste Directive (MWD), as well as a good information source for operators, consultants, scientists and other stakeholders.

As a whole, DST will contribute of reaching consensus on the sensitive issues of characterization of mining waste and the assessment of the risk related to mining waste facilities, laying down the basis for a common approach in mining area.

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