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# CYANIDE MANAGEMENT IN MINING: AN INTEGRATED OCCUPATIONAL - ENVIRONMENTAL APPROACH

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**ABSTRACT.** For over 100 years, cyanide has been the leach reagent of choice in gold mining because of its high gold recoveries, robustness and relatively low costs, but it is a dangerous chemical that must always be used with caution. The environmental damages resulting from its mismanagement, however, have initiated widespread research aimed at identifying and developing less toxic leaching agents. Best practice environmental management means using cyanide responsibility, to minimise the chance that workers or the environment will be harmed. The aim of this paper is to outline principles and procedures of cyanide management use so that it is used effectively, safely, economically and with no adverse effects on the environment. Safety for workers and responsible use of cyanide in mining are closely related, as discussed in the paper. Implementing best practice in the workplace will inevitably have a positive effect on the community perception, which will in turn influence views on the potential impact of cyanide use in mining on the environment.

**УПРАВЛЕНИЕ НА ЦИАНИДА В МИННОТО ДЕЛО: ИНТЕГРАЦИОНЕН ПРОФЕСИОНАЛНО-ЕКОЛОГИЧЕН ПОДХОД**

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**РЕЗЮМЕ:** Повече от 100 години цианидът е бил използван като излужващ реагент при добива на злато поради високия коефициент на извличане, здравина и ниска цена. Същевременно той е извънредно опасен химикал и би трябвало да се използва внимателно. Екологичните последици от неправилното му използване предизвикват множество проучвания с оглед откриване и разработване на по- малко токсични реагенти. Доброто практическо използване и управление на цианида предполага отговорното му приложение с цел минимизиране на опасното му въздействие върху работниците и околната среда. Целта на настоящата разработка е да се очертаят принципите и технологиите при използване и управление на приложението на цианида така, че той да се прилага ефективно, безопасно, икономично и безвредно върху околната среда. Както показват изследванията, безопасността на работниците и отговорното изпозване на цианид в минното дело са тясно свързани. Внедрявайки най- добрите практики на работното място, положителния ефект е неминуем и върху обществеността, което води до нов тласък върху използването на цианида в минното дело без въздействие върху околната среда.

## Introduction

At first "sustainable mining" could be perceived as a paradox-minerals are widely held to be finite resources with rising consumption causing pressure on known resources. The true sustainability of mineral resources, however, is a much more complex picture and involves exploration, technology, economics, social and environmental issues, and advancing scientific knowledge-predicting future sustainability is therefore not a simple task (Mudder and Smith, 1994).

Just as the application of technology in mining processes can cause pollution, it can also be harnessed to minimize, and sometimes eliminate, mine-related (Deacons, 1997) contaminants.

Waste minimization can be achieved through decreased waste production, waste collection, waste recycling, and the neutralization of pollutants into detoxified forms (Botz, 1995).

Cyanide is a widely used and valuable industrial chemical. It is probably best known for its use in mining as a lixiviant for removing gold and silver from ore, but only about 13 % of man-made cyanide is used in mining. The rest is used in many other industrial processes such as steel hardening, plastics production, and manufacture of goods such as adhesives, computer electronics, fire retardants, cosmetics, dyes, nylon, paints, pharmaceuticals, rocket propellant and road and table salts (Hartung, 1982; Richardson, 1992).

Cyanide is also a very common naturally occurring compound, which is formed, excreted and degraded naturally by thousands of animals, plants, insects, fungi and bacteria. It is common in many foodstuffs consumed by humans such as almonds, apricots, bamboo shoots, bean sprouts, cassava, cashews, cherries, lentils, olives, potatoes, sorghum and soya beans (Pesce, 1993).

Although it is a common compound essential to nature, it is widely regarded as a highly dangerous substance.

In spite of the increasing level of knowledge about cyanide and its proper management in mining, significant environmental impacts, particularly on rivers and streams, continue to occur as a result of poor management of cyanide at a number of mines around the world. These incidents attract concern from regulators and the public about the capacity of the mining industry to act responsibly, and have led in some quarters to calls for cyanide use in mining to be banned. In some jurisdictions, legislation relevant to cyanide use and waste disposal in mining has been reviewed and licensing tightened to improve levels of environmental protection. Best practice environmental management means using cyanide responsibly to minimise the chance that workers or the environment will be harmed. This includes correctly managing transport, storage, handling and emergency procedures.

## Cyanide ecotoxicology basics

Cyanide is present in the environment but generally at low levels. More elevated levels may be found in certain plants and animals (many plant and insect species contain cyanogenic glycosides) or near certain industrial sources. It is a rapidly-acting highly potent poison to people, animals and plants when exposed to high levels and increasing concerns are being raised about the effects of repeat low doses to animals.

Cyanide poisoning may occur due to inhalation of cyanide gas (hydrogen cyanide), dusts or mists, absorption through skin following skin contact, or by incidentally or consuming materials containing cyanide (eg. drinking water, sediment, soil, plants). The poisonous action of cyanide is similar regardless of the route of exposure (ICMI, 2002). Cyanide bioavailability varies with the form of cyanide. The route of exposure and the conditions at the point of exposure (eg. stomach pH, presence of other foods) are important considerations. Cyanide does not bioconcentrate as it will undergo rapid metabolism in exposed animals (Donato, 2002).

Implementing best practice in the workplace will inevitably have a positive effect on community perception, which will in turn influence views on the potential impact of cyanide use in mining on the environment (Farrell, 1997).

An understanding of the following principles of cyanide poisoning provides a valuable background for implementing health and safety principles (Duffield and May, 1998):

- Cyanide is toxic to humans and to animal species because it binds to key iron-containing enzymes required for cells to use oxygen. As a result, the tissues are unable to take up oxygen from the blood. The body then rapidly exhibits symptoms of oxygen starvation and suffocation, even if oxygen is available. Rapid damage to the central nervous system and to the heart thus results from breathing high levels of cyanide over a short time.
- Cyanide poisoning can result in death. Symptoms of acute exposure include breathing difficulty, irregular heartbeat, uncontrolled movement, convulsions and coma. It must be emphasized that effective treatment for cyanide poisoning depends largely on the speed and the professionalism of the medical response.
- At lower levels, individuals exhibit breathing difficulties, chest pains, vomiting and headaches but, on recovery, there is no residual disability.
- Health effects and symptoms of cyanide poisoning do not depend on the route of exposure, *i.e.* they are similar whether it is breathed, ingested or absorbed through the skin.
- Some typical dose *versus* response data for cyanide intoxication are given in Table 1, which shows that there is significant variability in the effects on different mammalian species (Hartung, 1982; Richardson, 1992).
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Most of the safety procedures that apply to the transport, storage and safe handling of cyanide aim to prevent the chemical from coming into contact with the human body and to prevent cyanide solids or liquids reacting to produce hydrogen cyanide gas. It is essential that these safety procedures are communicated to workers through practical training as well as being reviewed an updated as appropriate. It is important that mine managers be familiar with legislation governing the purchase, storage, transport and monitoring of cyanide.

Table 1
*Response of humans and various animal species to concentration of HCN in air*

| Species | Concentrations [ppm] | Response |
|---|---|---|
| Human | 270 | immediately fatal |
| | 181 | fatal after 10 minutes |
| | 135 | fatal after 30 minutes |
| | 110-135 | fatal after 30 to 60 minutes or longer |
| | 45-55 | tolerated for 30 to 60 minutes without immediate or subsequent effects |
| | 18-36 | slight symptoms after several hours |
| Mouse | 1300 | fatal after 1 to 2 minutes |
| | 110 | fatal after 45 minutes exposure |
| | 45 | fatal after 2.5 to 4 hours exposure |
| Cat | 315 | quickly fatal |
| | 180 | fatal |
| | 125 | markedly toxic in 6 to 7 minutes |
| Dog | 315 | quickly fatal |
| | 115 | fatal |
| | 90 | may be tolered for hour; death after exposure |
| | 35-65 | vomiting, recovery, convulsions; may be fatal |
| | 30 | may be tolerated |
| Rabbit | 315 | fatal |
| | 120 | no marked symptoms |

## Cyanide in gold extraction: best practice management principles

Cyanide management is not an individual or isolated issue; it is intimately linked with other important requirements for applying best practice environmental management in mining, in particular water management, storage and handing of hazardous materials, environmental monitoring, emergency response, workforce training and awareness, cleanup of contaminated sites, mine rehabilitation, and risk management (Chadwick and Sharpe, 1966; Devuyst *et al.*, 1982).

Therefore integration of cyanide management into management systems requires a broad and inclusive approach where all activities and associated risks related to cyanide are identified and addressed. This identification is normally conducted in the planning and environmental impact assessment stages in the pre-mining stage, but operational system changes and upgrades involving cyanide during the mine's life may require an environmental reassessment to ensure that all risks are known.

Best practice cyanide management should be planned from the time of mine conception to closure and rehabilitation and should include (Logsdon *et al.*, 1999):

- establishing a cyanide management strategy as part of the mine's environmental management;
- implementing initial and refresher cyanide management training for managers, workers and contractors;
- establishing well-defined responsibilities for individuals with clear chains of command and effective lines of communication within the workforce;
- instituting safe procedures for cyanide handling-governing transport, storage, containment, use and disposal;
- integrating the mine's cyanided and water management plans;
- identifying and implementing appropriate options for reusing, recycling and disposing of residual cyanide from plant operations;
- conducting regular cyanide audits and revising cyanide management procedures where appropriate;
- developing a cyanide occupational and natural environment monitoring program, and supporting this with a sound sampling, analysis and reporting protocol;
- establishing carefully considered and regularly practiced emergency procedures;
- hazardous waste should be handled by specialized providers (in accordance with regulatory permits) of hazardous waste management facilities specifically designed and operated for this purpose. When such services are unavailable within a feasible distance of the mine, the mine should establish and operate its own waste facility with the necessary permits.
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Best practice environmental management means using cyanide responsibly to minimize the chance that workers or the environment will be harmed. This includes correctly managing transport, storage, handling and emergency procedures, and personal hygiene, and monitoring the working environment. It also requires well trained and properly equipped personnel who are aware of current treatment methods for cyanide poisoning and know the principles of how cyanide act on humans and animals.

Important principles in managing cyanide effects on the environment are to:

- use the minimum effective amounts of cyanide required to recover metals;
- dispose of cyanide in a way that eliminates or minimizes environmental impacts;
- monitor all operations, discharges and the environment to detect and deal with any escape of cyanide and subsequent impacts of that release.

## General safety issues

Some processes of degradation and removal of cyanide in industrials effluents that are used, considered and developed exist. The choice of the most viable process depends on each specific case and some on factors related to the effluent are taken in account. Such factors are including the concentration of cyanide and the physical-chemical composition of the effluent, the maximum alloweable values imposed by the legislation, the location of handling and discarding the effluent into the environment.

Between the most common methods for the removal of cyanide from effluents, we can mention the following ones:

- natural degradation;
- oxidation processes;
- acidification -volatilization - regeneration (AVR);
- adsorption processes;
- electrolytic processes;
- conversion to less toxic species in solution;
- precipitation of insoluble metal cyanides;
- biological treatment;
- high-temperature hydrolysis.

No matter what technique is applied, there are several general safety requirements which should be consider to effectively manage the cyanide problem:

a. **Policy**: a safety program that lacks support from top management will fail. So, the most senior mine site manager should issue a policy statement emphasizing management's full commitment to, and involvement in, a general safety program which includes cyanide management.
b. **Accident investigation**: unforeseen events occur even in the most rigorously planned and well-managed systems. It is important to investigate and learn from such accidents.
c. **Communication**: effective lines of communication are essential to successfully manage a safety system. An organizational structure, of which all staff is aware, should be developed to ensure rapid, effective and unambiguous communication. It is important that these allow for a "bottom-up" as well as a "top-down" flow of information.
d. **Emergency readiness**: people responsible for emergency action should be fully instructed and trained. Mock emergencies and unscheduled drills should be

staged on a regular basis.

**e. Inspections**-both planned and surprise inspections should be carried out frequently to check on procedures and critical equipment.

**f. Training**: all supervisors should be formally trained in safety principles. Theoretical and practical training should be given to process-line personnel so they fully understand their safety roles and responsibilities which should be seen as integral, not additional, to their production or management roles.

Other important actions include:

- allocating clear responsibility for cyanide management;
- understanding the actual and potential hazards and environmental impacts in transporting, storing, using and disposing of cyanide;
- maximizing the recovery of cyanide where economically feasible or ensuring its destruction; constructing physical containment measures and implementing procedural measures to deal with spills or leaks of cyanide;
- conducting regular training in the above measures;
- to dispose of cyanide in a way that eliminates or minimizes environmental impacts;
- having emergency response plans in place to ensure immediate action to minimize environmental effects should an accidental or unplanned release occur;
- keeping adequate records with regular assessment so that future environmental problems can be anticipated.

## Transport, storage, handling and emergency procedures

Although cyanide delivery to the mine site is primarily the responsibility of the manufacturer or the transport company, mines should develop a contingency plan for cyanide spillage. This applies particularly to mines in remote mountainous regions that experience severe winters (White, 1997). The mine operator should discuss transport with the manufacturer or transport company because:

- an accident causing cyanide spillage close to or at the mine site may involve mine personnel. Accordingly, mine site personnel, the manufacturer and the transport company should liaise on emergency planning;
- the manufacturer can advise on the most appropriate form and packaging for the volume requirements of the mining operation in question. Use of sparge containers is best as it reduces the requirement for manual handling of the solid as well as minimizing possibilities of spillage during transfer and handling at the mine site storage facility;
- Intermediate Bulk Containers or steel drums should be returned to the supplier.

How cyanide is stored at the mine site depends on the form of cyanide and is subject to regulation. The following summarizes regulatory and best practice issues.

Holding facilities and compounds should be designed and maintained with the following in mind (Smith and Mudder, 1991):

- provide adequate ventilation to disperse any build up of hydrogen cyanide gas;
- minimize the possibility of contact with water (appropriate measures for storage of solid sodium cyanide include provision of roofing, ensuring adequate drainage and storage above ground level or on an impervious surface);
- avoid potential contamination of water bodies by locating storage in bunded areas well away from natural drainage channels;
- store cyanide separately from corrosive, acidic and explosive materials;
- fence and lock the storage area to prevent accidental entry or access by unauthorized individuals (post clear warning signs) - any theft of cyanide should be reported immediately to the mine manager and police;
- as fire is a potentially serious problem, locate and build facilities with this in mind. It may also be desirable to periodically remove vegetation from around storage facilities;
- adequate containment facilities and bunding of liquid and solid cyanide containers are necessary to minimize the effects of accidental spillage (consider local weather conditions in providing such containments).

Best practice means not only adopting measures that minimize the likelihood of cyanide losses during operations but also ones that limit the effects of any loss. Capacity to do this will depend on emergency response procedures being established and practiced regularly (Fox, 2001).

Cyanide handling must take into account the occupational exposure standard or Threshold Limit Value (TLV).

Operators undertaking hazardous procedures involving cyanide should wear appropriate protective clothing and work in pairs with one acting as a "sentry". The role of a sentry needs to be carefully defined and followed. As a passive observer of the handling process, the sentry should participate in the process only in an emergency.

Hazardous operations include:

- opening storage containers;
- dissolving sodium cyanide pellets;
- cleaning-up cyanide spillages.
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Should an operator be exposed to cyanide, effective and timely medical care is essential. Personnel should be familiar with the general principles above and treatment procedures for personnel affected by cyanide exposure.

Protective gear needed depends on the procedure. For respirable forms of cyanide, a full-face respirator should be worn. Cyanide can be absorbed throught skin and for liquid cyanide workers should wear disposable coverall, PVC gloves and waterproof boots. Working with cyanide demands a culture of cleanliness. Workers should wash their hands before eating, drinking or smoking and before applying topical lotions. Contaminated protective gear and clothing should be securely discarded, or washed before being stored and re-used.

## Risk assessment and working environment monitoring

In all aspects of cyanide management, it is important that workers and emergency services are able to react efficiently and effectively. Best practice required identifying, planning and training for contingencies. An appropriate approach is to adopt Hazard Analysis at Critical Control (HACCP). Once a risk has been identified it can often be designed out of the mine site operation. However, when this is not feasible, steps must be taken to minimize the problem.

In respect of cyanide use in mining, there are four major risk scenarios that need to be addressed through site-specific plans:

- exposure of humans or ecological receptors to cyanide spilled during transportation;
- exposure of workers, particularly to HCN gas in enclosed areas;
- exposure of humans through releases of cyanide in solution to surface or ground water and which may subsequently be ingested;
- exposure of other biotic ecological receptors, such as birds or fish, to cyanides.

It is important that workers are protected through a monitoring and sampling program for airborne contaminants (Noller, 1997).

Such procedures are often covered by regulation and local rules should be followed when available. Some principles are that samples:

- be representative of worker exposure;
- be collected by an approved method;
- not be tampered with.

Sampling of hydrogen cyanide gas can be either continuous, using electronic detection equipment, or semi-batch, using air pumps and sampling tubes. The former gives a faster response and allows more time for action in emergency situations.

## Discussion and conclusions

Innovation in mineral processing technology can enable mining companies to combine gains in productivity with improvements in environmental management. Although the mining industry has a reputation for technological conservatism it is obvious that the development, acquisition and assimilation of new technologies may be an increasingly important determinant of a company's competitive position in the context of growing market and regulatory pressures.

Specific examples of innovative process and remediation technologies are reviewed, and their ability to improve competitiveness and sustain best-practice environmental management is linked to the capacity of the company to manage technological and organizational change.

In many aspects mining activities are considered harmful to the environment. In some cases, this is strictly reality, but more and more one can feel a better level of conscientiousness towards the protection of the working environment, with its preservation for future generations, and a better control of environmental harm.

A great deal of scientific literature and information is available on cyanide, particularly on its chemistry and environmental fate. However, more work is needed to provide the necessary rigorous quantitative understanding to plan, implement and operate cyanide management practices with greater confidence. This includes establishing sound, systematic environmental systems for:

- **cyanide analyses:**
  - although analytical methods can reach the lower limits of quantification needed by current legislation, in practice, variable results are often obtained because of inconsistent sample preparation and preservation methods;
  - determining cyanide forms needs systematizing so that such analyses better reflect environmental and toxicological needs;
  - annual proficiency testing (round robin) exercises, and their costs, should be incorporated into the services provided by analytical service laboratories.
- **environmental chemistry and fate:**
  - although cyanide degradation and attenuation pathways have been reasonably well identified and are understood qualitatively, much more work is required to quantify cyanide levels associated with the different chemical degradation;
  - better computer modeling with improved input data and a wider array of software will help in problem solving at existing mine site and in the planning and (toxicological) risk assessment of proposed mining operations.
- **removal processes:** an array of removal processes exist and it is apparent that some cyanide degradation products and other components of cyanide containing waste streams are environmental threats. Choice of process needs systematizing on the basis of site-specific criteria; this may be achieved, at least partially, through biomonitoring and whole effluent toxicity testing.
- **regulation/legislation/public perception:** armed with a better knowledge of the above, it is likely that communal understanding of important issues between mine operators, regulators and the general public can be improved; educational and communication programs thus need to be enhanced.

While these are well understood, the point is to employ a systematic approach to each of them on a site-by-site basis.

No industrial (or, indeed, any human activity) can take place without impacting, to a greater or lesser extent, on the environment. In the past, economic performance could sometimes be enhanced by pushing the effects and costs of pollution onto the wider community. However, this is no longer acceptable to society; modern practice and legislation are moving inexorably towards the concepts of "polluter pays" and "duty of care". As result, environmental and economic performance has become inextricably linked and no longer represent opposite sides of the profit-loss equation.

In line with this change, the mining industry is being judged by the community, and increasingly by its own shareholders, on its environmental performance. The key to operating successfully in such a modern "environmental marketplace" is good planning. While pollution control and minimizing environmental impact through strategic planning increases start-up costs, these are much lower than those costs associated with both loss of public confidence and/or environmental remediation costs. Implementing best practice is very much to the advantage of the mining industry and of industrial operators.

Best practice in cyanide management can be said to be simply the best way of doing things to minimize the risk of impacts to people and the environment.

Given the situational difference between mine sites, the best practice solution will not be the same at every site. However, the same principles and general standards apply. Those provided by the International Code for Cyanide Management are designed to be relevant to every mine site regardless of climate, geography, mineralogy, metallurgy, operational systems, and political, regulatory and community environments.

The productivity, profitability and efficiency of the gold mining industry, and its continued access for exploration and mine development, increasingly depends on its ability world-wide to demonstrate that the risks associated with cyanide use can be managed to the levels demanded by regulatory authorities its willingness to commit to the lead provided by the International Cyanide Management Code framework, and to implement appropriate best practice concepts and technologies.

Clearly, implementing best practice is very much to the advantage of the mining industry and of industrial operators.

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