



**Australian Government**  
**Department of Resources**  
**Energy and Tourism**

# CYANIDE MANAGEMENT

LEADING PRACTICE SUSTAINABLE  
DEVELOPMENT PROGRAM FOR  
THE MINING INDUSTRY



**SOCIAL**  
**ECONOMIC**  
**ENVIRONMENTAL**

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DEVELOPMENT PROGRAM FOR  
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MAY 2008

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## FOREWORD

The Australian mining industry is well aligned to the global pursuit of sustainable development. A commitment to leading practice sustainable development is critical for a mining company to gain and maintain its “social licence to operate” in the community.

The handbooks in the *Leading Practice Sustainable Development in Mining* series integrate environmental, economic and social aspects through all phases of mineral production from exploration through construction, operation and mine-site closure. The concept of leading practice is simply the best way of doing things for a given site. As new challenges emerge and new solutions are developed, or better solutions are devised for existing issues, it is important that leading practice be flexible and innovative in developing solutions that match site-specific requirements. Although there are underpinning principles, leading practice is as much about approach and attitude as it is about a fixed set of practices or a particular technology.

The International Council on Mining and Metals (ICMM) definition of sustainable development for the mining and metals sector means that investments should be: technically appropriate; environmentally sound; financially profitable; and socially responsible. *Enduring Value*, the Australian Minerals Industry Framework for Sustainable Development, provides guidance for operational level implementation of the ICMM Principles and elements by the Australian mining industry.

A wide range of organisations have been represented on the Steering Committee and Working Groups, indicative of the diversity of interest in mining industry leading practice. These organisations include the Department of Resources, Energy and Tourism, the Department of the Environment, Water, Heritage and the Arts, the Department of Primary Industries (Victoria), the Department of Primary Industries (New South Wales), the Minerals Council of Australia, the Australian Centre for Minerals Extension and Research and representatives from mining companies, the technical research sector, mining, environmental and social consultants, and non-government organisations. These groups worked together to collect and present information on a variety of topics that illustrate and explain leading practice sustainable development in Australia’s mining industry. The resulting handbooks are designed to assist all sectors of the mining industry to reduce the negative impacts of minerals production on the community and the environment by following the principles of leading practice sustainable development.



**The Hon Martin Ferguson AM MP**  
Minister for Resources and Energy, Minister for Tourism



# 1.0 INTRODUCTION

Cyanide Management is one of 14 themes in the Leading Practice Sustainable Development Program for the Mining Industry. The program aims to identify the key issues affecting sustainable development in the mining industry and to provide information and practical case studies that identify sustainable approaches for the industry.

This handbook addresses cyanide management from a sustainable development perspective. The handbook updates the principles and procedures of cyanide use outlined in the Best Practice Environmental Management *Cyanide Management* booklet (Environment Australia 2003) and it also relates to sustainable development issues as discussed in the Minerals Council of Australia's *Enduring Value* (MCA 2004). This handbook also addresses the implementation of the International Cyanide Management Code (ICMI 2006) (the Code) together with recent regulatory changes in Australia. Leading practice cyanide management continues to develop through the Code process; however, the previous two best-management practice documents (Environment Australia 1998 2003) remain a source of fundamental technical details on cyanide management. This handbook outlines practices for cyanide management from a risk management perspective and presents a number of case studies highlighting strategies that are currently being implemented by the Australian mining industry.

Cyanide is any chemical compound that contains the cyano group ( $C\equiv N$ ), which consists of a carbon atom triple-bonded to a nitrogen atom. Hydrogen cyanide (HCN) is a colourless gas with a faint, bitter, almond-like odour. It should be noted however that not all people are able to smell this odour. Sodium cyanide and potassium cyanide are both white substances with a bitter, almond-like odour in damp air, due to the presence of hydrogen cyanide.

Managing cyanide to minimise risks to human and environmental health represents one of the key challenges that continues to face the mining industry. In order to assist the global mining industry to improve its management of cyanide, the Code was developed by a multi stakeholder steering committee and is today managed by the International Cyanide Management Institute (ICMI 2006) to provide a risk-based management process by which the mining industry is able to implement and demonstrate that it can meet leading practice for cyanide management. This handbook takes the currently accepted approach that adherence to the Code provides the mining industry with the means to produce, transport, store and handle cyanide in a safe way to ensure no adverse effects occur to workers, the environment and the community. The Code provides an audit protocol and guidance to address the production, transport, use and disposal of cyanide as well as procedures for the management and administration of a compliance verification and certification program.

Key aspects of the Code are transparency and third-party validation. Operations are evaluated for compliance with the Code through triennial on-site evaluations conducted by independent, certified auditors (who meet criteria on expertise, experience and conflict of interest established by the ICMI), and using the ICMI's Verification Protocol (ICMI 2006). Summaries of audit findings, the credentials of auditors conducting evaluations, corrective action plans to bring the operation from substantial to full compliance (if necessary), and company signatory status are available on the ICMI web site [www.cyanidecode.org](http://www.cyanidecode.org) for public review.

The key to leading practice cyanide management is to assess risks as early as possible, including environmental, human health, economic and reputational. Reputational risk can impact on both individual companies that use cyanide and the industry as a whole. The evidence of the adverse effect on industry reputation is demonstrated in the origins of the Code's development by the United Nations Environment Program (UNEP) and the former International Council on Metals and the Environment following the Baia Mare environmental incident in Romania in 2000 (Environment Australia 2003).

Mining companies that adopt the Code and adhere to associated leading practice principles recognise that these principles also make good business sense. Leading practice mining companies develop and implement management and operating practices for the use of cyanide in mining activities that assist achieving sustainable development. The following may be derived from this initiative:

- improved protection of wildlife
- improved relations with both the public and regulatory agencies
- improved economic and environmental performance
- reduced risks and liabilities
- improved access to capital and potentially lower insurance costs.

This handbook seeks to address all aspects of cyanide use in mining from production through to final disposal or destruction. It is a resource for mine planners and mine managers, but will also be relevant to environmental staff, consultants, government authorities and regulators, non-government organisations, interested community groups and students.



## 2.0 CYANIDE IN MINING

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### KEY MESSAGES

- The properties of cyanide need to be well understood to manage its use. The chemistry of cyanide is complex.
  - Most gold is extracted using cyanide because it remains the chemical of choice for this purpose. Other extraction techniques are only applicable in limited situations.
  - Currently cyanide use is focused on minimising on-site consumption and impacts and maximising cyanide recycling and gold recovery.
- 

### 2.1 Cyanide in context

Cyanide is a useful industrial chemical and its key role in the mining industry is to extract gold. Worldwide, mining uses about 13 percent of the total production of manufactured hydrogen cyanide while the remaining 87 percent is used in many other industrial processes, apart from mining (Environment Australia 2003). In Australia the mining industry uses about 80 percent of cyanide produced by the country's two cyanide producers. Cyanide is manufactured and distributed to the gold mining industry in a variety of forms. Sodium cyanide is supplied as either briquettes or liquid, while calcium cyanide is supplied in flake form and also in liquid form. Calcium cyanide, if used, may contain some carbide from its manufacture and present a risk of explosion from acetylene generation.

The hazard of cyanide derives from its property as a fast acting poison. Cyanide binds to key iron-containing enzymes required for cells to use oxygen and as a result tissues are unable to take up oxygen from the blood (Ballantyne 1987; Richardson 1992). In the absence of first aid, intake of toxic amounts of cyanide from gas inhalation, or ingestion or absorption through the skin, can kill within minutes. Low levels of cyanide from the consumption of foods are removed from the body by the liver. Cyanide is not carcinogenic and people who suffer non-fatal poisoning usually recover fully. However, chronic sub-lethal exposure above the toxic threshold, or repeated low doses, may cause significant irreversible adverse effects on the central nervous system and onset of Parkinson's syndrome. The effects detected in humans from repeated exposure at low doses may also apply to animals (ATSDR 1997).

Since its first use in mining in New Zealand in 1887, sodium cyanide has played a key role in extracting gold and other metals such as silver, copper and zinc from ores worldwide. Indeed about 80 percent of the world's gold production utilises cyanide in extraction, with about 2500 tonnes of gold being produced annually worldwide.

Despite its high human toxicity, there have been no documented accidental human deaths due to cyanide poisoning in the Australian and North American mining industries over the past 100 years which indicates that the hazard of cyanide to humans has been controlled by minimising the risk of its handling and of industrial exposure.

In spite of the increasing level of knowledge about cyanide and its proper management in mining, significant environmental incidents—some involving water bodies—have continued to occur globally (Donato et al. 2007; Mudder et al. 2001). These incidents attract concern from regulators and the public, and have led to calls for cyanide use in mining to be banned. A list of major cyanide incidents is provided in Box 1. In Australia, most spills of cyanide have occurred during transport to mine sites.

#### **Box 1: Major recent incidents involving cyanide**

1. In May 1998 loss of 1800 kilograms of sodium cyanide to the Barskaun River, Kyrgyzstan, followed a truck accident en route to the Kumtor mine (Hynes et al. 1999).
2. In 1995 thousands of migratory and non-migratory waterbirds were killed at the tailings dam of the Northparkes mine, NSW, Australia, due to a poor understanding of the significance cyanide chemistry and inappropriate analytical procedures (Environment Australia 2003).
3. In 2000 the tailings impoundment at Baia Mare, Romania, was breached, releasing a cyanide plume which travelled for 2000 kilometres downstream, killing very large numbers of fish in the Tisza and Danube rivers, and disrupting the water supply (UNEP/OCHA 2000) (Environment Australia 2003). Excessive treatment of cyanide with hypochlorite and chlorine exacerbated the problem.
4. A pallet of dry cyanide product, which fell from a helicopter en route to the Tolukuma gold mine in Papua New Guinea in 2000, was successfully cleaned up (Noller & Saulep 2004).
5. Cyanide solution from an incompletely discharged ISO-tainer was allegedly released on the roadside after a delivery truck left a mine in the Northern Territory in 2002.
6. Due to confusion over the number of valves in the cyanide plant at the San Andres mine, Honduras, 1200 litres of cyanide solution was discharged into the Lara River in January 2002.
7. Water contaminated with cyanide entered the Asuman River from the Tarkwa gold mine in the Wassu West District of Ghana in October 2001, killing fish and disrupting local water supplies. Another discharge into the river from a ventilation shaft in January 2003 rekindled community health and safety concerns, although this water was later shown to be potable.
8. In February 2007, a road train carrying three 20-tonne containers of solid sodium cyanide in the Northern Territory tipped over, spilling pellets onto the side of the road and into a non-flowing watercourse. Most spilled product was collected, and contaminated water and soil were cleaned up and disposed of at a nearby mine site.

In Australian state and territory jurisdictions, legislation relevant to cyanide use and waste disposal in mining has been reviewed and licensing revised to improve environmental protection. More stringent concentration limits now apply on tailings storage facilities and to releases of mine water to the environment, as a result of site-specific criteria determined by Environmental Protection Authorities at the environmental impact assessment/license application stage. The Australian Water Quality Guidelines (ANZECC/ARMCANZ 2000) provide a trigger value of 4 µg/L free cyanide for the protection of aquatic life in order to protect 99 percent of species. The mining industry has reduced the incidence of environmental impacts, regulatory non-compliance and community resistance by complying with the International Cyanide Management Code (ICMI 2006) and the Minerals Council of Australia's *Enduring Value* (MCA 2004).

## 2.2 Gold extraction

Most gold-containing ores comprise finely divided gold particles within other minerals, commonly sulfides. The gold extraction process separates and concentrates the gold. Depending on gold mineralogy and deportment, gold may be concentrated by gravity separation. However, at low gold concentrations and in the absence of sufficient difference in density, physical extraction processes alone are neither economical nor quantitative. When physical separation is not achievable, gold is usually separated from the other constituents of the ore by chemical dissolution in cyanide. This process is generically referred to as leaching, and as cyanidation with specific reference to cyanide. The process occurs in conjunction with physical processing (crushing, milling, gravity separation and flocculation). Alternative extractants to cyanide for leaching gold and silver from ore are less effective and cyanide remains the best industry option for safe and economic extraction of gold.

The role cyanide plays in a mining operation must be well defined and understood as part of the overall mine planning procedure (Mudder et al, 2001). There are a variety of cyanide complexes that exist making comparison of results difficult to compare. Personnel need to have a sound knowledge of the cyanide species and this should be taken into account during mine planning and environmental management.

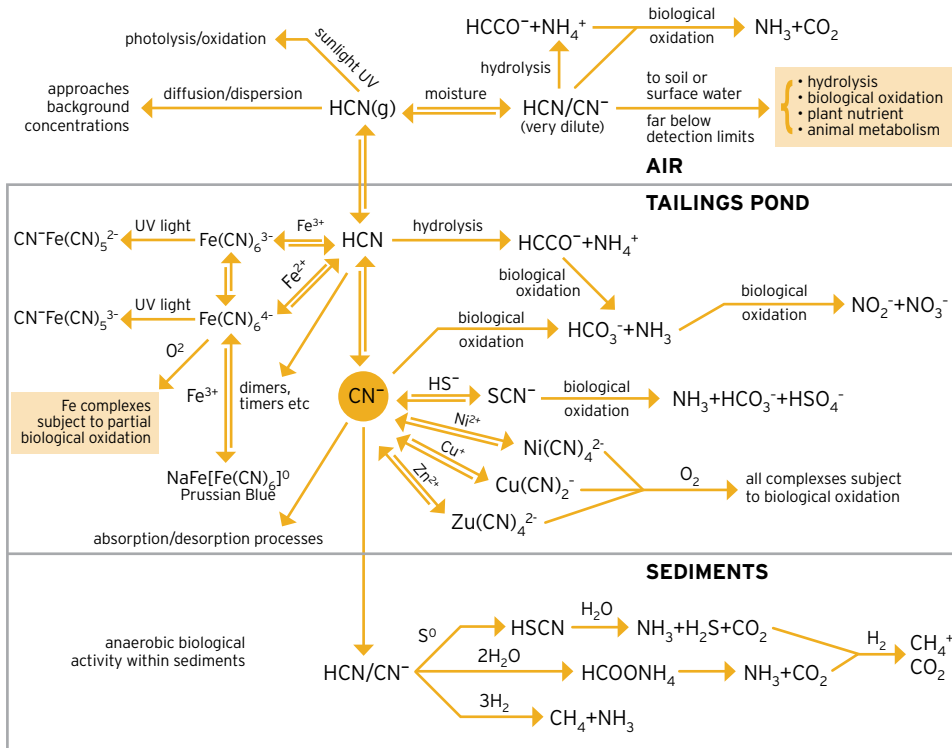
The process of dissolving gold with cyanide simply involves mixing wet slurry of finely ground ore with sodium cyanide. The slurry is made alkaline by addition of an alkali such as lime, and oxygen is added to complete the reaction (Adams 2001). The alkalinity ensures that free cyanide ions, which combine selectively with the gold, are not lost as free cyanide (HCN) gas. Gold in solution is further concentrated by adsorption onto activated carbon, although zinc precipitation is sometimes still utilised, particularly when silver concentrations are high. The concentrated gold solution is reduced to metallic gold electrolytically, whereafter it is typically smelted to produce gold bullion.



Leading practice mines use as little cyanide as possible and thereby minimise environmental effects, maximise safety for workers and reduce costs. Cyanide consumption is a major component of the total operating cost of a typical gold-producing plant. Only 0.3 grams to 0.4 grams of cyanide per tonne of typical ore should be required to dissolve and extract the gold. However in practice, consumption ranges from 300 grams per tonne to more than 2000 grams per tonne for efficient gold extraction.

The 'excess' cyanide consumption is partly accounted for by oxidation to cyanate and loss through volatilisation as HCN gas (Figure 1). Some cyanide can be consumed by complexation with copper, iron and zinc, or through reaction with sulfur species to form thiocyanate. Cyanide metal complexes in particular eventually find their way to tailings dams and then, potentially, into the wider environment. Cyanide will be lost in the tailings dams and the wider environment through natural degradation reactions so that, in the long term, only the less toxic and strongly complexed forms remain. Tailings storage facilities are designed to provide secure, long-term storage of materials containing such complexes and to avoid potential losses via seepage, overtopping, breaching, and pipe/channel failure. The more toxic forms of cyanide in tailings storage facilities are measured as weak acid dissociable (WAD) cyanide, free cyanide and complexed forms.

**Figure 1: Cyanide chemical loss pathways in the environment (Mudder et al. 1991)**





In addition to extracting gold, cyanide is used in very small quantities as a flotation agent in the separation of other minerals from mixed ores. For example, sodium cyanide is used as a depressant in the flotation of galena (lead sulfide). The unwanted pyrite (iron sulfide) is depressed by addition of cyanide, which acts to prevent the pyrite from becoming attracted to the mineral froth, thereby improving the purity of the galena concentrate.

### 2.3 Alternatives to cyanide

There is a wide range of techniques for separating gold and other precious metals from ore (McNulty 2001a), apart from gravity-based techniques. Other techniques that dissolve gold in ore use bromine/bromide/sulfuric acid, hypochlorite/chloride, ammonium thiosulfate/ammonia/copper, and thiourea/ferric sulfate/sulfuric acid. Alternatives to cyanide could be economically viable where operating costs are low and/or when gold prices are high. However, cyanide remains the method of choice unless there are circumstances preventing its use such as regulatory restrictions. In addition, alternatives can be equally or even more damaging to the environment than cyanide.

Currently many mines would be technologically and/or economically unable to operate without cyanide. The challenge for the mining industry is to ensure that use of cyanide and its management meets community expectations and maintains a level of responsible environmental and social stewardship consistent with leading practice environmental management and sustainability, and the Code.

### 2.4 Cyanide treatment, recovery and reuse

Cyanide consumption represents a significant cost to the mine operator. This emphasises the need to avoid over-consumption and consequent wastage. Because much more cyanide is required than is desirable from an economic or environmental viewpoint, leading practice is to recycle as much cyanide as possible. A large number of processes (at different stages of development) exist for the removal of cyanide from waste streams (Mudder et al. 2001). A comprehensive description of the chemistry and treatment of the wastes generated from cyanide use is provided in the earlier handbooks (Environment Australia 1998, 2003).

Cyanide levels in tailings ponds are reduced as follows:

- natural degradation
- enhanced natural degradation processes
- chemical, physical or biological methods
- recovery or recycling.

These processes have different economic and environmental impacts and therefore risk-benefit assessments must be undertaken before the processes are introduced.

## 2.5 Control of process losses

Eliminating spillage, including any accidental losses during transport to the mine site and systems failures within the mine site, is a key goal.

In open-circuit systems, which are in widespread use in the industry, precautions need to be undertaken to ensure that cyanide does not find its way into the natural environment. Appropriate responses to any possible cyanide loss depend on a variety of inter-related factors including:

- the physical form and the amount of cyanide lost
- the area and volume of material affected
- the response time, depending on how soon the incident is noticed
- the accessibility of the contaminant, for example, whether a surface spill or an underground plume
- the environment involved, such as land or water.

Further details are given in Section 5.3.4, Box 6 and Box 7.

The possibility of closed circuit systems for cyanide use and recovery in the future has been proposed (Moore and Noller 2000). The production of cyanide on site may be considered to overcome issues with the manufacture and transportation of cyanide to a mine site. However, consideration needs to be given to:

- availability/transportation of methane to site (or ammonia)
- the additional capital and operating costs
- the additional energy requirement.

Typically the issues and hazards of transporting methane (or ammonia) are similar to, or greater than those for cyanide itself. In addition, the nature of cyanide manufacture requires a chemical engineering skill-set that is not common for the gold mining industry. Therefore, on-site production of cyanide is only likely to be a viable alternative for a large mining operation where methane is locally available.



## 3.0 CYANIDE AND THE ENVIRONMENT

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### KEY MESSAGES

- Weak acid dissociable (WAD) cyanide is the recognised cyanide form to measure with respect to monitoring and potential adverse effects.
  - There is a wide difference in toxicity of cyanide to aquatic biota compared with terrestrial biota, with aquatic biota being much more susceptible.
  - There is a clear difference in susceptibility of cyanide to wildlife for freshwater tailings storage facilities (TSFs) compared with hyper saline. It is now recognised that wildlife at freshwater TSFs are protected by the accepted safe no discharge WAD cyanide level of 50 mg/L, whereas hyper-saline TSFs may show avoidance based on salinity alone.
  - Reliable monitoring of cyanide at TSFs requires specific attention to sampling and sample preservation techniques prior to analysis.
  - Wildlife monitoring is a necessary part of managing the impact of cyanide at TSFs and in the environment.
- 

### 3.1 Cyanide ecotoxicology

Cyanide is present in the environment but generally at low levels. More elevated levels may be found in certain plants (such as cassava) and animals (many plant and insect species contain cyanogenic glycosides) or near certain industrial sources. At high exposure levels, cyanide is a rapidly-acting, highly potent, poison to people, animals and plants. Animals are also affected by repeated low doses.

Cyanide poisoning may occur due to inhalation of cyanide gas (hydrogen cyanide), dusts or mists; absorption through skin following skin contact; or by consuming materials containing cyanide (such as drinking water, sediment, soil, plants). The poisonous action of cyanide to biota is similar regardless of the route of exposure. Cyanide bioavailability varies with the form of cyanide. The route of exposure and the conditions at the point of exposure (such as stomach pH, presence of other foods) are important considerations. Cyanide does not bioconcentrate as it undergoes rapid metabolism in exposed animals. Weak acid dissociable (WAD) cyanide is identified as the practical measurement of free and weakly complexed forms of cyanide that are toxic to both aquatic and terrestrial biota (Donato et al. 2007; Mudder 2001).

Exposure to cyanide in solution through consumption of surface water is the main exposure route for most animals affected by cyanide poisoning, but concurrent exposure through inhalation and skin absorption may also occur. In addition, animals may consume cyanide inadvertently in tailings slurry or sediments during foraging, when consuming carcasses or preening feathers. There are currently no published Australian criteria for cyanide in soils, sediments or air for the protection of aquatic or terrestrial plants or animals.

### 3.1.1 Aquatic ecosystems

Cyanide acts rapidly in aquatic environments. Fish are by far the most sensitive to cyanide and catastrophic impacts on downstream aquatic ecosystems have resulted where cyanide-contaminated waters have escaped as a result of dam failure or overtopping. Mine design must incorporate features to avoid the release of contaminated water into any ecologically significant aquatic systems in the vicinity.

In fish, cyanide targets organs where gaseous exchange or osmoregulatory processes occur; that is, principally the gills and the surface of egg capsules. Aquatic organisms show a range of sensitivities to cyanide, but fish are generally the most sensitive aquatic organisms, with 24-hour LC50 concentrations (that is concentrations at which 50 percent of the individuals die) as low as 40 µg/L free cyanide for some species. LC50 values for aquatic invertebrates range upwards from around 90 µg/L at ambient temperatures. Aquatic plants show effects at water concentrations from 30 µg/L to several milligrams per litre (USEPA 1989). In the aquatic environment, cyanide may degrade forming products of generally lower toxicity, but which may also be problematic in the environment, such as ammonia and nitrate.

Published environment protection guidelines that are relevant to cyanide in Australian waters are the ANZECC/ARMCANZ guidelines (2000). The current Australian water quality trigger value for free cyanide in freshwater is 7 µg/L and marine waters is 4 µg/L. The Code applies a recommended guideline of 0.5mg/l free cyanide for discharge to surface water and an in stream limit of 0.022mg/l free cyanide for protection of aquatic life. A detailed description of the handling of treated cyanide-containing water in a sensitive river ecosystem at the Henty Gold mine, Tasmania is described as Case Study 4: *“Cyanide management in a highly sensitive environment”* in the earlier handbook (Environment Australia 2003).

### 3.1.2 Terrestrial wildlife

Poisonings most frequently affect birds, but records indicate a wide range of wild and domestic animal species have been poisoned by cyanide. Mammals (including bats), frogs, reptiles (such as snakes, lizards, tortoises) and insects are also susceptible to cyanide. In Australia, wildlife monitoring data from tailings storage facilities, heap leach operations and associated infrastructure has become available as an outcome of mining companies implementing the Code. However, surveys indicate that mortality to wildlife had been widespread (Donato 2002, 2007), particularly prior to the introduction of the Code.

At 'no discharge' mine facilities, 50 milligrams per litre WAD cyanide for cyanide solutions accessible to wildlife is widely recognised by the mining industry as a water quality benchmark for the protection of wildlife (Donato et al. 2007). This level is derived from observations in both the USA and Australia that bird mortalities tend to occur when the WAD cyanide concentration increases above 50 milligrams per litre (Donato et al. 2007). Using a precautionary approach, lower concentration benchmarks for the protection of wildlife have been applied and wildlife risk management, through total exclusion of access to cyanide solutions, is also practiced. The impact on wildlife is demonstrated to be low if tailings ponds contain WAD cyanide at levels less than 50 milligrams per litre, access to the ponded area is restricted and releases of water to the environment are avoided. Bird monitoring data supports the contention that WAD cyanide 50 milligrams per litre level is a safe level.

The most common approaches to positive control of environmental impacts of cyanide reporting to tailings storage facilities are cyanide destruction and netting. Minimising cyanide use, the effective application of process chemistry and risk assessment procedures, and further practical measures can minimise the effect of cyanide in tailings dams and ponds on wildlife and domestic animals. These measures to prevent access or to scare away birds and animals include:

- fencing
- floating balls
- remote-control airborne devices (Environment Australia 1998, 2003).

These measures typically supplement careful process chemistry design, operation and monitoring, and should never be seen as adequate wildlife protection measures in themselves. They are subject to cost effectiveness and practicality of use at each site. Providing water drinking troughs around the tailings facility and having decoy wetlands can also be effective in minimising the risk of poisoning wildlife. Proximity to human settlements may influence the choice of technique, for example, possible community impacts from noise and light need to be taken into consideration.

### **CASE STUDY: Sunrise Dam gold mine, tailings and compliance with the ICMC**

The AngloGold Ashanti Sunrise Dam gold mine (SDGM) operation is located 55 kilometres south of Laverton, Western Australia. The mine is situated immediately to the east of the hyper saline Lake Carey and is surrounded by numerous other smaller saline lakes. The operation is comprised of an open pit and underground mining operations as well as processing operations.

The tailings dam is currently a 320 hectare, single-cell CTD facility (central discharge system). Under normal operational conditions the thickened tailings are deposited at

approximately 65 percent solids and there is minimal or no supernatant liquor or associated ponding from tails discharge. The central discharge system essentially results in conical stacking of dry tails. A stock and wildlife-proof electric fence has been erected around the perimeter of the structure. Unique to this broader region the processing solutions and tailings are hyper saline, about 190 000 TDS or six times more saline than seawater.

The routine wildlife monitoring regime employed at SDGM has been designed as part of the industry-wide ACMER P58 project (Donato & Smith 2007) to collect data to assess the risk of cyanide-bearing water bodies to wildlife. It has been designed to fulfil the requirements for wildlife monitoring as outlined in Standard of Practice 4.9 of the Code. The monitoring program is ongoing.

Monitoring of waste stream solutions revealed that the concentrations of weak acid dissociable (WAD) cyanide in the tailings dam were in excess of 50 milligrams per litre WAD cyanide on 72 percent of sampled days. WAD cyanide concentrations of supernatant pooling at times exceeded 50 milligrams per litre.

On the primary cyanide-bearing mine waste impoundment, 1096 visitations and no wildlife cyanosis deaths were recorded on the CTD, and 748 visitations and no wildlife cyanosis deaths were recorded on the associated storm water pond/decant pond. Intensive wildlife observations by external consultants concurred with these findings over zero wildlife deaths.



### **Sunrise Dam Gold Mine CTD2**

Considering the recorded cyanide concentrations and the lack of recorded wildlife deaths (from the robust monitoring practice), this system departs from recognised literature and assumptions. The protective mechanisms of

reducing cyanide-bearing habitats (by management and tailings system design), lack of food provisions, minimal water and hypersalinity have resulted in no observed effect on wildlife. It was hypothesised that these mechanisms provide protective measures by eliminating and reducing the wildlife exposure pathways to those solutions.

In accordance with the Code these protective mechanisms were subject to an independent peer-review. This peer review finding did not contradict the currently described toxicity threshold of 50 milligrams per litre WAD cyanide concentration as it was derived from a fresh, peripheral-discharge tailings system. A toxicity threshold was not breached during two years of monitoring and therefore an alternative threshold specific to SDGM CTD cannot be provided (Donato & Smith 2007).

It should be noted that if these protective mechanisms cease or reduce in effectiveness then the risk of cyanosis may increase.

Birds are particularly susceptible to cyanide in tailings dams. Wading and swimming birds are more likely to receive a lethal dose by absorbing cyanide through their skin. Other birds at risk include raptors which are attracted to carrion on tailings dams. To identify birds at risk, operating and environmental personnel need to know which species are endemic to their area and the frequency and timing of visits by migratory species.

A sound understanding of the way different birds behave on and around the dams will also help in planning to minimise the risk of bird poisoning.

## 3.2 Environmental incidents

Although environmental incidents involving releases of cyanide have declined since the implementation of the Code, they continue to occur in Australia, particularly during cyanide transportation, use at heap leach operations, and disposal of cyanide wastes to tailings storage facilities (TSFs). The design of TSFs can also impact on wildlife.

The ongoing occurrence of significant environmental events involving cyanide around the world (Box 1 above) indicates that knowledge and systems for cyanide management in mining must be further improved. The main reasons for environmental incidents at mines stem from poor water management and/or dam design or construction (such as dam failure, dam overtopping), inadequate design and maintenance (pipe failure), and transport accidents (Mudder and Botz 2001).

## 3.3 Monitoring

Monitoring levels of cyanide in the environment is an essential part of leading practice cyanide management, but mine managers also need a high awareness of the significance of the levels being measured and the possible sources of cyanide. A summary of cyanide sampling, measurement and analysis is provided in Appendix 2. The importance of measuring WAD cyanide as the appropriate measure of potential toxicity is described in great detail in the earlier handbook (Environment Australia 2003). WAD cyanide is the most appropriate measure when determining toxicological and environmental impacts. Free and iron cyanides are not useful for these purposes.

A mine's environmental monitoring program, which should form part of the environmental management plan, should include:

- specification of sampling sites, frequency of sampling, sampling preservation and storage (see Appendix 1), method of analysis, parameters to measure, use of certified reference materials, and required action on detection of outliers or on non-compliance
- baseline information—existing water quality (surface and groundwater)
- monitoring during and after operations
  - water levels and quality of surface and groundwater, process ponds, drinking water, tailings dams
  - dust generation and deposition
  - fauna
  - rehabilitation.

Generation of acid tailings from waste rock dumps, for example, may cause HCN gas to be released. Warning of such potential problems can be gained from knowledge of environmental exposure pathways linked to monitoring of pH, WAD cyanide and free cyanide (see Box 2 below for detailed information on analysis of cyanide and cyanide complexes). The alkaline chlorination method, which is no longer used in Australia, should be used with caution. Different analytical methods (such as ligand or picric acid—see Appendix 2) are useful in particular situations but no one method is suitable for all requirements.

Only the analysis of total and WAD cyanide (by distillation) can be considered reliable measures of toxic cyanide. Furthermore, the detection of low levels of total or WAD cyanide may be the result of cyanide released from other natural or manufactured sources, or may be the result of error or interferences in the various cyanide analytical procedures (Mudder 1997). Measurement of total cyanide levels below 0.10 milligrams per litre and WAD cyanide below 0.05 milligrams per litre present in mining related discharges may be unreliable and should be reported as 'less than' and not used for compliance purposes (Mudder 1997). The possible reasons for reporting measured levels of cyanide in surface waters or treated effluents need to be taken into account when interpreting results of a monitoring program. The first is analytical error; the second is naturally produced cyanide excreted by plants, micro-organisms and insects; and the third is manufactured cyanide. Incorrect conclusions can easily be drawn, with potentially serious consequences, if valid measurements are not used.



## **Box 2: Analysing for cyanide**

To achieve acceptable results, each stage in the analytical procedure needs to consider:

- **Problem definition**—clearly define the purposes and limits of any monitoring activity. If information is required for toxicological purposes, measure the WAD cyanide. Environmental fate requires analysis of all forms of cyanide and its degradation products. The analytical costs are determined by the choice of analytical technique and cyanide form measured.
- **Sampling**—following problem definition, identify the spatial and temporal characteristics of the monitoring program. Take replicate samples for truly representative sampling.
- **Sample preservation**—requires that samples must be handled to prevent cyanide loss and any changes in its chemical form. Samples may be 'spiked' with a known amount of cyanide compound so that changes during transport and storage can be assessed. Samples should always be inspected visually for changes or signs of leakage before analysing.
- **Sample treatment**—will be required depending on the form(s) of cyanide to be measured (Appendix 1) and on the measurement technique used.
- **Standards**—whatever the measurement technique (classical or instrumental) calibration with suitable standards and reagent blanks is needed. Standards and blanks should fall within the working range of the analytical technique and should bracket the probable sample concentrations. For complex matrices, consider using standard addition techniques.
- **Measurement**—use a clearly-defined measurement protocol with samples being analysed in a pre-determined order and interspersed with blanks and standards. This allows possible cross-contamination and instrument drift to be monitored and corrected for. Replicate determinations should be made.
- **Compliance and reporting of results.**
- **Documentation**—all methods and procedures should be recorded and followed rigorously.
- **Reporting requirements (compliance and public interest).**

Standard statistical and reporting techniques should be used that include mean values and standard deviations. Reported values should be checked to ensure that they are within a realistic range and quoted with their level of precision. The lower limit of quantification (LLQ) for the analytical method used should be quoted, and unknowns falling between these values should be reported accordingly; that is, as being present but below the limit of quantification.



## 4.0 SUSTAINABLE DEVELOPMENT AND CYANIDE MANAGEMENT

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### KEY MESSAGES

- Achieving sustainable development requires the translation of its principles into management tools for use at the mine site.
  - Implementation of the Code requires a clear understanding of its complexity and needs to be comprehensive with regard to all its principles and standards of practice.
  - Continued operational certification under the Code requires strong support from all levels within the mining company.
- 

### 4.1 Mining and sustainable development

It is clear that mining potentially impacts on sustainability in many ways. The goal of achieving sustainability is a major issue confronting the mining industry today. The industry has developed a number of voluntary initiatives to regulate cyanide management including the high level principles contained in the International Council on Mining and Metals' *10 Principles for Sustainable Development*, the Minerals Council of Australia's *Enduring Value* (MCA 2004) as well as the cyanide management specific *International Cyanide Management Code* (Section 4.3). Cyanide use poses lower risks to the environment, worker safety, and public health in jurisdictions where industry standards or the regulatory framework are strong.

One challenge for gold mining companies when committing to achieving sustainable development is to take on board the requirements of the Code. Another challenge is that sustainable development applies to all types of human endeavour and that its principles are necessarily expressed in high level and generic terms. In contrast, the Code provides guidance on how general principles can be applied to specific industrial settings and allows mine operators to adopt practices which will achieve a sustainable development outcome.

Leading practice cyanide management requires developing, implementing and continually reviewing relevant organisational and operational procedures. The aim is to ensure that the risk of adverse health and environmental impacts is negligible and maintained at levels acceptable to the community and, therefore, to regulators. Leading practice is simply "the best way of doing things", and in this context it is essential that the regulatory requirements of the applicable jurisdiction are met, and that the principles and standards of practice of the Code are fully implemented.

Effective social engagement is increasingly acknowledged within the Australian mining industry as a requirement of sustainable development. Ensuring communities are informed of issues that may affect them is a cornerstone of responsible industry practice and recognised through key industry statements such as the International Council on Mining and Metals' Sustainable Development Principles and the Minerals Council of Australia's *Enduring Value* framework (MCA 2004) which promote signatory companies to "engage with and respond to stakeholders through open consultation processes".

The following sections are presented as a guide for consideration in respect to community engagement and cyanide management. In presenting these details, it is recognised that wide variants in operational contexts will be important in how each individual company or operation manages its consultation processes. Further, these sections are intended to supplement, and expand upon, other key industry good practice guides to community and stakeholder engagement such as the Leading Practice handbook on *Community Engagement and Development* (DITR 2006a).

Modern practice and legislation have moved inexorably towards the concepts of 'polluter pays' and 'stewardship'. As a result, environmental and economic performances have become inextricably linked and no longer represent opposite sides of the profit-loss equation. The mining industry is judged by the community, and increasingly by its own shareholders, on its environmental performance and its interactions with communities in which it operates. The key to operating successfully in such an environment is good planning. While pollution control and minimising environmental impact through strategic planning increases start-up costs, these are much lower than those costs associated with loss of public confidence and/or environmental remediation costs.

The productivity, profitability and efficiency of the gold mining industry, and its continued access for exploration and mine development, increasingly depend on its ability worldwide to demonstrate that the risks associated with cyanide use can be managed to the levels demanded by regulatory authorities and the general community. The success of the industry now depends heavily upon its willingness to commit to the lead provided by the Code framework, and to implement appropriate leading practice concepts and technologies.

## **4.2 Management tools to achieve sustainable development**

Risk management is the accepted approach through which sustainable outcomes can be achieved (AS 2004). The approach can be adapted to cyanide management in a framework which is comprehensive and forward-looking, which sets out long-term as well as short-term objectives, and which defines a set of risks through which the concepts of sustainable development can be achieved.

Actions which are consistent with the principles of sustainable development will only be fully effective in moving towards sustainability if they are implemented through applying the risk management tools as follows:

- risk management
- benchmarking
- quality assurance
- life cycle analysis/assessment
- cleaner production (or eco-efficiency)
- stewardship.

Further details can be found in the Leading Practice handbooks *Risk Assessment and Management* (DRET 2008a) and *Stewardship* (DITR 2006c).

**Table 1: Translating general sustainable development principles into actions at the mine site**

<b>MOVING FROM CONCEPT TO ACTION FOR SUSTAINABLE DEVELOPMENT (MMSD 2002)</b>	<b>APPLICATION AT THE CORPORATE OR MINE SITE LEVEL</b>
A robust framework based on an agreed set of broad principles.	Mine management plan, which includes clear environmental and social protection objectives.
An understanding of the key challenges and constraints facing the sector at different levels and in different regions and the actions needed to meet or overcome them, along with the respective roles and responsibilities of actors in the sector.	Thorough understanding of cyanide technology, relevant codes, regulations applying to transport, storage, use and disposal of hazardous materials, regulatory environmental requirements. Determination of site-specific worker, environmental and social sensitivities. Nomination of responsible officers (with delegations and powers) for cyanide management and use.
A process for responding to these challenges that respects the rights and interests of all those involved, is able to set priorities, and ensures that action is taken at the appropriate level.	Site-specific cyanide management plan including role and responsibilities for responsible persons, and environmental protection targets specific to cyanide.
An integrated set of institutions and policy instruments to ensure minimum standards of compliance as well as responsible voluntary actions.	Cyanide management plan integrated with other relevant plans, including water management and emergency response plans. Operational plans and schedules for workers, and workforce training resources and arrangements.

<b>MOVING FROM CONCEPT TO ACTION FOR SUSTAINABLE DEVELOPMENT (MMSD 2002)</b>	<b>APPLICATION AT THE CORPORATE OR MINE SITE LEVEL</b>
Verifiable measures to evaluate progress and foster consistent improvement.	Environmental monitoring program includes schedules, locations and techniques for cyanide sampling. Analysis at independent respected laboratories. Regular interpretation and reporting of results. Regular auditing and review of cyanide management plan and environmental monitoring program.

### 4.3 The International Cyanide Management Code

The development and implementation of the Code is the important and responsible action by gold producers, cyanide manufacturers and associated transportation companies to augment existing regulatory requirements or fill in gaps when such regulatory requirements are lacking. The Code provides comprehensive guidance for best practice in the use and management of cyanide at gold mines around the world and reaches beyond the requirements of most governments and regulatory agencies. A significant body of technical and administrative work in developing the Code has already been carried forward to its practical implementation and administration.

#### 4.3.1 Background to the Code

The world's attention became focused on the use of cyanide within the gold industry in January 2000, following the Baia Mare incident in Romania. The key outcome was the development and implementation of the Code for the use of cyanide in the gold mining industry as described above.

The participation and contribution of a diverse range of stakeholders was important to the development of the Code. Forty delegates were involved in an initial workshop, representing such organisations as the United Nations; the EU; the World Bank; the OECD; the ICME; various governments, environmental advocacy groups, gold mining companies and industry associations; the Gold Institute; and various expert technical consultants.

The Code was viewed as unique in two aspects: (i) it was the first voluntary industry Code of Practice requiring its signatories to demonstrate compliance through independent third-party professional audits; and (ii) it represented the first time that such a broad-ranging, international, multi-stakeholder group had worked cooperatively to produce a global voluntary program for specific industry improvement.

A key challenge that remains with the gold industry is to encourage take-up of the Code by small gold producers. While most of the larger gold producers are implementing the Code, ICMI and the Code signatories have recognised the importance of promoting the virtues of

the Code to small producers. A guide on management systems for small mine operators is under development.

### 4.3.2 Code content

The intent of the Code is articulated in its mission statement, which reads:

*“To assist the global gold mining industry in improving cyanide management, thereby minimizing risks to workers, communities and the environment from the use of cyanide in gold mining, and reducing community concerns about its use.”*

The objectives of the Code are to:

- protect workers, communities and the environment from adverse effects of cyanide
- improve cyanide management
- be used by large and small gold mining companies, cyanide manufacturers and transporters
- serve as a form of assurance for interested parties including regulators, financiers, communities and non-governmental organisations
- be applied internationally, in both developed and developing countries
- be credible and verifiable
- be dynamic over time.

The Code consists of nine principles; within each principle there are several standards of practice (Table 2). The principles broadly state commitments that signatories make to manage cyanide in a responsible manner. The standards of practice are essentially the “nuts and bolts” of the Code, and identify performance goals and objectives that must be met to comply with each principle (ICMI 2006). The full list of principles and standards of practice are available at [www.cyanidecode.org](http://www.cyanidecode.org).

**Table 2: Summary of Code principles**

PRINCIPLE NO.	DISCIPLINE	INTENT
1	Production	Encourage responsible manufacturing by only using cyanide produced in a safe and environmentally protective manner.
2	Transportation	Protect communities and the environment during cyanide transport.
3	Handling and Storage	Protect workers and the environment during cyanide handling and storage.
4	Operations	Manage cyanide process solutions and waste streams to protect human health and the environment.
5	Decommissioning	Protect communities and the environment from cyanide through development and implementation of decommissioning plans for cyanide facilities.

PRINCIPLE NO.	DISCIPLINE	INTENT
6	Worker safety	Protect worker health and safety from exposure to cyanide.
7	Emergency response	Protect communities and the environment through the development of emergency response strategies and capabilities.
8	Training	Train workers and emergency response personnel to manage cyanide in a safe and environmentally protective manner.
9	Dialogue	Engage in public consultation and disclosure.

#### 4.4 Adopting the International Cyanide Management Code

An expectation of Code signatories is to design, construct, operate and decommission their facilities consistent with the Code requirements. Their operations must be audited by an independent third party auditor and the results made public. The principles and standards of the Code must be implemented within three years of signing in order to receive certification. Independent auditing to demonstrate compliance with the Code is a prerequisite to certification. Comprehensive notes providing guidance on how the principles and standards of practice may be implemented are available at [www.cyanidecode.org](http://www.cyanidecode.org). Information on certified operators is posted on the web site of the International Cyanide Management Institute. In order to maintain certification, an operation must meet all the following conditions:

- full compliance or substantial compliance as indicated by the independent auditor
- operations in substantial compliance have submitted action plans to correct deficiencies and implement these within the agreed timeframe (maximum one year)
- there must be no evidence that the operation is not in compliance with Code conditions
- a verification audit is held within three years
- a verification audit is held within two years of change in ownership of the operation.

See case study on Code certification of Cowal gold mine below.

## **CASE STUDY: Experience of Cowal gold mine—first International Cyanide Management Institute (ICMI) Code certification in Australia**

The Cowal gold mine is located in Central New South Wales, Australia, 37 kilometres north of West Wyalong and 350 kilometres west of Sydney. The Cowal gold mine is an open cut mine with process facilities designed to treat approximately 6.4 million tonnes per annum of ore with conventional comminution, sulfide flotation, carbon-in-leach and cyanide destruct technologies. The mine began production in early 2006 and current ore reserves are 2.5 million ounces gold.

The mine is located adjacent to Lake Cowal, a recognised wetland habitat listed on the Register of the National Estate since 1992. In August 1995 the development application and an EIS submitted by North Limited were refused consent on environmental grounds. Since that time a range of studies and development scenarios were investigated by North and a new development application received consent in March 1999.

The Cowal gold mine is a heavily regulated operation. The development consent conditions for the project include 25 environmental management plans, independent environmental auditing and monitoring, the establishment of a Community Environmental Monitoring and Consultative Committee, as well as rigorous surface and groundwater monitoring requirements. As a result, Cowal is designed with features not commonly seen in the Australian gold industry, including:

- eight approved stormwater ponds to comply with a zero water discharge site, which includes all rainfall and runoff that falls within the mine lease
- fully fenced tailings storage facilities (TSF) with two metre-high wire mesh, buried 0.5 metres deep, including electric wires, stretching nine kilometres around the perimeter
- stringent cyanide management with discharge levels to the TSF never to exceed 30 ppm WAD and to remain below 20 ppm WAD more than 90 percent of the time.

Despite these conditions, the Cowal gold mine has attracted a minority of opponents to the development and continued operation of the site. It was identified in 2005 during the construction of the mine that compliance with Code was critical to core business and to maintaining broad community support.

### **Pre-operational certification**

In January 2005 work began towards Cowal obtaining full compliance with the ICMC. The first step was to obtain pre-operational compliance; with the initial task being a gap analysis between what Cowal had in place and the as yet draft ICMC pre-operational compliance documentation. At this time, interpretations of some aspects of the Code's



verification protocols were not yet clear. With strong support from the site General Manager, and department managers and a technical expert, a Cyanide Code Team was established with input from all areas including:

- environment and safety
- processing technical services, operations and maintenance
- community relations
- project construction.

The team was headed and directed by a single Cyanide Code Champion who organised task lists, regular review sessions and final compilation of information prior to the scheduled audit. While external parties were engaged to assist with decommissioning plans, structural engineering and water balances, the majority of the workload was borne internally. The pre-operational compliance audit was carried out in December 2005, and Cowal was officially confirmed as the first gold mine in the world to achieve full compliance with the ICMC Pre-Operational Certification on 17 April 2006.

#### **Operational certification**

The second stage of the journey was to achieve full compliance as an operating mine. During 2006 the ICMI released an auditor guidance document, within which was detailed information to assist in the interpretation of the ICMC verification protocols. This was crucial in being able to set up documentation, standard operating procedures and to make minor modifications to the processing plant with the goal of becoming fully compliant. Evaluation of interpretation is crucial in planning works to meet Code compliance, and has a significant bearing on the scope of works and budget for these works.

As Cowal worked its way to full operational compliance, it became clear that adapting existing site management systems to meet Code requirements was the most efficient course of action. It was deemed that developing stand-alone documentation and management systems for the ICMC risked not achieving integration within site systems and culture. Much of the workload during 2006 and early 2007 focused on improving the site training records, preventive maintenance plans and the emergency response on site.

The rigorous regulatory requirements imposed upon Cowal resulted in pre-existing compliance with most of the physical design and environmental monitoring requirements of the Code. Some additional civil works were required to ensure adequate containment of low-strength process solutions.

The audits for the pre-operational and operational certification were carried out in three and five days respectively, with a team of five auditors being used during the operational audit. This was in part due to the site's requirement to have a completed draft report and action plan in place and agreed to on the final day of the audit.

### Summary of key experiences

- Auditors received site orientation and inductions prior to beginning work on site.
- A dedicated area was created for the audit team to operate from and hold all hard documentation.
- A site schedule was developed prior to the audit, with time allowed daily for questions, answers and further clarification.
- All people likely to be interviewed or required for clarification were introduced to the audit team on day one and made available at a suitable time for the auditors.
- Construction photos proved extremely useful when trying to interpret PIDs and civil drawings, particularly on items that were no longer visible such as tank foundations.
- Be realistic when developing preventive maintenance plans, particularly inspection frequencies for pumps, tanks and pipe work inspections during 'commissioning' phases.
- Understand the resources required including time, people and money prior to committing to achieving pre-operational and operational certification.
- Continued compliance with the ICMC means that it must be a live system and live within existing procedures, policies, management plans, site records and training.

Continued certification with the ICMC now requires strong support from all levels within the company, as operational sites will need to provide historical data at subsequent compliance audits (three-year frequency) to remain compliant.



**Cowal Gold Mine.** Image Source: Barrick Gold of Australia



## 5.0 RISK MANAGEMENT OF CYANIDE USE

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### KEY MESSAGES

- Cyanide health and safety management are well understood and require management by professional staff with a high level of technical skills and training.
  - Leading practice in cyanide management equates with the best way of doing things in order to minimise the risks and impacts to people and the environment.
  - The risk assessment process provides the means to develop management and communication tools for safe cyanide use.
  - Implementation and continued operational certification under the Code requires a detailed understanding of its principles and their interrelation with gold mining operations.
  - Dialogue and risk communication is pivotal to successful Code implementation.
  - Handling of cyanide during the operational and decommissioning phases may need attention to selection of appropriate cyanide removal technologies. Mine closure may require specific attention to deal with cyanide clean-up including its degradation products.
- 

### 5.1 Cyanide health and safety

Safety for workers and responsible use of cyanide in mining are closely related matters that go hand-in-hand with implementing leading practice in the workplace. Acceptance by the community will inevitably have a positive effect on perception and views of the potential impact of cyanide use in mining on the environment.

An understanding of the following principles of cyanide poisoning (Box 3) provides a valuable background for implementing health and hygiene practices.

### Box 3: Cyanide toxicity

Principles of cyanide poisoning as background for implementing health and hygiene practices are:

- Cyanide is toxic to humans and to animal species because it binds to key iron-containing enzymes required for cells to use oxygen, preventing tissue uptake of oxygen from the blood. The body then experiences oxygen starvation and suffocation, even if oxygen is available. Rapid damage to the central nervous system and to the heart result from breathing high levels of cyanide over a short time.
- Cyanide poisoning can result in death. Symptoms of acute exposure include breathing difficulty, irregular heart beat, uncontrolled movement, convulsions and coma. Effective treatment for cyanide poisoning (Box 7) depends largely on the speed and the professionalism of the medical response.
- Individuals exposed to sub-lethal doses exhibit breathing difficulties, chest pains, vomiting and headaches may make a full recovery with no residual disability, depending on the dose. Near-lethal doses can cause irreversible effects.
- Health effects and symptoms of cyanide poisoning do not depend on the route of exposure; that is, they are similar whether cyanide is breathed, ingested or absorbed through the skin.
- There is significant variability in the effects of cyanide dose on different mammalian species (Environment Australia 2003, Hartung 1982; Richardson 1992).

It is essential that safety procedures are communicated to workers through practical training and are reviewed and updated when required. The toxicity to humans of hydrogen cyanide compared with other common toxic gases is given in Table 3.

**Table 3: Toxicity to humans of industrial poisonous gases compared with hydrogen cyanide (adapted from Richardson 1992).**

POISONOUS GAS	THRESHOLD LIMIT VALUE (PPM)	SHORT-TERM LIMIT (PPM)
Chlorine	0.5	1
Sulfur dioxide	2	5
Nitrogen dioxide	3	5
Hydrogen cyanide	5	10
Hydrogen sulfide	10	10
Carbon monoxide	25	300

The regulatory regime for cyanide use in mining in Australia is delivered at the state or territory government level. Different aspects of cyanide use are covered in different pieces of legislation, reflecting the types of risks and activities involved (such as legislation on poisons, dangerous goods, transport, mine safety and environmental protection). This situation is common in most jurisdictions around the world, where no single legislation specific to cyanide use is provided. Other regulations are applicable to reducing risks related to cyanide, particularly those dealing with water management and water and tailings storage facility design, construction and operation. It is important that mine managers be familiar with legislation governing the purchase, storage, transport, and monitoring of cyanide in their state or territory.

Cyanide is included in the publicly accessible Internet databases, such as the National Pollutant Inventory (Australia), National Pollutant Release Inventory (Canada), and the Toxics Release Inventory (United States). These databases provide nation-wide information on the type and amount of pollution emitted to the air, land and water across the country.

### 5.1.1 General safety issues (pace-it for safety)

- Policy—a safety program that lacks support from top management will fail. Therefore, the most senior mine site manager should issue a policy statement emphasising management’s full commitment to, and involvement in, a general safety program which includes cyanide management.
- 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.
- Communication—effective lines of communication are essential to successfully manage a safety system. An organisational structure, that all staff members are aware of, 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. Communication should extend to regular liaison with the chemical manufacturer, emergency services, police, fire brigade, local council/community, and the regulatory authorities.
- Emergency readiness—people responsible for emergency action should be fully instructed and trained. Simulated emergencies and unscheduled drills should be staged on a regular basis. Material Safety Data Sheets (MSDS) and emergency procedures sheets should be posted in appropriate areas.
- Inspections—both planned and surprise inspections should be carried out frequently to check on procedures and critical equipment.
- 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.

## CASE STUDY: Development of mini-sparge cyanide mixing process at Beaconsfield gold mine

Orica's Yarwun facility, which is located about eight kilometres by road from Gladstone, Queensland, commenced operations in 1989 and is engaged in the manufacture of both solid and liquid cyanide. Cyanide produced at Orica's Yarwun facility can be packaged and delivered in three ways with each product having its own particular application (that is, sparge-solid cyanide briquettes, IBC-solid cyanide briquettes and ISO tank containers for liquid cyanide).

When commissioned in 1999, the Beaconsfield gold mine in Tasmania received cyanide in 21-tonne IBC containers that were transported in sea containers. Upon arrival at site the individual IBC containers were then unloaded into a locked storage compound within the processing facility. When cyanide solution was required for the process, a one-tonne box was retrieved from the compound where two operators with full personal protective equipment (PPE) equipment, including gas masks, mixed the cyanide in a barricaded area. The cyanide bags were removed from the wooden box and lifted by overhead crane to a mixing vessel where the base of the bag was spiked allowing the cyanide to discharge from the bag into an agitated vessel partly filled with water to allow dissolution.

The underlying consideration in using cyanide at the Beaconsfield gold mine was how it could be effectively managed so that it did not pose a risk or cause harm to the environment or human life. A job safety analysis was conducted to identify the health and safety hazards on the cyanide mixing procedure. Some of the issues identified were the production of cyanide dust, spillages, disposal of empty boxes and bags, and safety issues when handling boxes. This process highlighted various areas for improvement, with the only way to improve the system being to change the way the cyanide was delivered to site. Through consultation between ORICA and Beaconsfield technical representatives, the concept of the Minisparge™ system was developed.

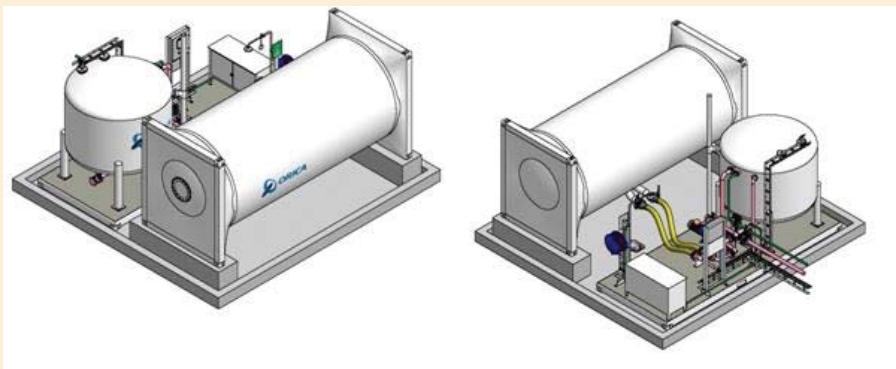


Image Source: Orica Limited

A typical installation of the Orica Minisparge™ system on previous page has the purpose-built, 22 tonne-capacity iso-containers unloaded onto plinths adjacent to a 5000 litre sparging tank. Hoses are then used to connect the sparge container to the sparging tank where the water is circulated through the bulk sparge container in a batch process to dissolve the cyanide and, after a predetermined time, the cyanide liquor is transferred to the mine's storage tank for further use.

The innovative process and commissioning of the cyanide Minisparge™ system has resulted in the following benefits to the Beaconsfield operation:

- reduced risk rating for the onsite mixing of cyanide through engineering the solution out rather than reliance on administrative and PPE controls
- reduced security and environmental risk for transportation, storage and use.

The mini-sparge system is now being embraced by operations within Australia that have low cyanide consumption (<1000 tonnes per annum) including base metal treatment plants that use cyanide as a depressant during the flotation stage.

### 5.1.2 Prevention of cyanide incidents

The transport, storage, use and disposal of cyanide at a mine site can be hazardous both to human health and the environment. Leading practice cyanide management requires that the risk of damage is minimised by understanding the properties of cyanide. The main goals should be to:

- use the minimum amounts of cyanide required to recover metals
- dispose of cyanide in a way that eliminates or minimises environmental impacts
- monitor all operations, discharges and the environment to detect any excess of cyanide.

According to a review of cyanide-related spills over the past quarter century (Mudder et al. 2001), the causes include an absence of:

- a dynamic site water balance and comprehensive water management plan
- implementation of improper water treatment capabilities
- integrity and secondary containment within the solution conveyance system (storage tanks, mixing systems, pipelines or drains along which cyanide-contaminated waters may flow).

The environmental impacts of spills have been primarily related to the toxic effects on aquatic life resulting from either cyanide entering surface water or the neutralisation chemicals themselves, such as excess use of chlorine or sodium or calcium hypochlorite.

Cyanide management is intimately linked with other important requirements for applying leading practice sustainable development in mining, in particular, water management, storage and handling of hazardous materials, environmental monitoring, emergency response, workforce training and awareness, clean-up of contaminated sites, mine rehabilitation, and risk management. Leading practice approaches to these issues are discussed in the *Water Management* (DRET 2008b) and *Tailings Management* (DITR 2007a) handbooks. See also Case study 4.

Periodic environmental auditing is a tool now commonly used by operators and regulators to assess the quality and outcomes of environmental management systems in mining. The audits examine the adequacy of high-level and operational level goals, objectives, systems and plans, and in particular determine how well these arrangements are interlinked. Of particular relevance for cyanide is operational integration of worker safety and environmental monitoring standards, operational arrangements for the water management system, worker awareness and training, and emergency response procedures.

Generically, health, safety, environmental and community (HSEC) audits should involve five distinct yet interrelated steps (Greeno et al 1988; Fox 2001b):

- Understanding the facility's (responsible party's) existing management systems and procedures
- Assessing the soundness of the facility's internal controls
- Gathering evidence through site visits and interviews consistent with the audit objectives
- Evaluating audit findings and exceptions to management systems and procedures
- Reporting audit findings and exceptions.

Even though the probability of a major cyanide incident occurring could be considered by some to be unlikely, it is incumbent upon all mining operations using cyanide to ensure that adequate HSEC cyanide management systems and procedures are in place to protect employees, the public and the environment from the adverse consequences of an accident. To do this, all mining companies using cyanide should conduct strategic risk reviews of site-specific cyanide management practices using HSEC auditing procedures suitable for evaluating whether existing training, transportation and handling procedures; operating practices and engineering designs are adequately maintained and regularly reviewed to minimise the likelihood of an accident.

Every emergency response plan should be regularly updated and tested for improvement. Due to the public's perception of the hazards and risks associated with using cyanide, trained experts should be readily available to communicate to media and interested parties, regardless of the facility's location or the magnitude of the accident (Fox 2001b).



### 5.1.3 Setting and maintaining appropriate guidelines to ensure leading practice

Leading practice in cyanide management simply states the best way of doing things to minimise the risk of impacts to people and the environment. The Code is designed to be relevant to every mine site regardless of climate; geography; mineralogy; metallurgy; operational systems; and political, regulatory and community environments.

A key element of leading practice is the need to recognise that appropriate leading practice behaviours and systems will change over time. Operators should be aware of the necessity to periodically re-examine systems to ensure they are modified as appropriate in response to:

- changes in operational systems and parameters during the mining life cycle—from the design, development, operational and decommissioning stages of a mine
- changes in ore characteristics or product specifications
- indications of the effectiveness of cyanide management systems in the level of protection being provided to humans and the environment, based on interpretation of monitoring data
- technological improvements which impinge upon all aspects of cyanide supply, delivery, storage, use, recycling, treatment, and disposal
- any changes in regulatory requirements or guidelines developed by authorities; for example, relating to cyanide concentrations in different types of water bodies; discharge limits; sampling and analytical methods; and monitoring locations, frequency and interpretation
- feedback and concerns from regulatory authorities, stakeholder groups and the local community.

One system of providing assurance that leading practice is being maintained during the life of a long-term mining operation is 'benchmarking'. Benchmarking is a performance measurement tool used in conjunction with improvement initiatives to measure comparative operating performance and identify best practices, or to identify the 'best-in-class' operators for a given activity. Appropriate benchmarking techniques involve identification of lead operators, research into operator performance, data collection, and site visits to meet with the lead operators. Benchmarking shares many elements in common with Total Quality Measurement (TQM) and re-engineering. Benchmarking requires performance to be measured, and for those measurements to be used as guides to improving cyanide management.

## 5.2 Risk assessment

Management and communication tools can be developed by utilising a risk assessment process that is applied to control adverse effects from chemical applications such as the use of cyanide (Ricci 2006). Risk assessments comprise the discrete steps of identifying source and hazard, dose response and exposure, and calculating risk (AS 2004). Through risk characterisation, adverse effects can be identified and, if required, risk management responses developed. Risk is managed on the basis of the assessments given below. There are risk management concepts arising from exposure to cyanide from gold mining that apply to public health and the environment that are acceptable to regulators, stakeholders and comply with the Code.

The risks associated with cyanide must be incorporated into mine environmental risk management plans to ensure that the potential hazards to workers, community and the environment are minimised from the planning stage through to mine development, operations and closure. Systems for risk management are described in the *Risk Assessment and Management handbook* (DRET 2008a).

There are several major risk scenarios for cyanide use in mining described in the Code (ICMI 2006) that need to be addressed through site-specific plans:

- exposure of workforce to cyanide in relation to manufacturing, transportation, handling and storage, and all operational and decommissioning activities
- protecting worker health by identifying cyanide exposure pathways to workers; operating and monitoring facilities safely by eliminating or reducing sources; and having emergency response plans in place
- exposure of humans (other than workforce) and other biota to releases of cyanide from manufacturing, transportation, handling and storage, and all operational and decommissioning activities
- exposure of humans, livestock and other biota through releases of cyanide in solution to surface or groundwater and subsequently which may be ingested.

In the risk assessment process, exposure studies of biota may need to take into account the cyanide species and their bioavailabilities. The risks to the environment from cyanide need to take into account effects on terrestrial and aquatic species. Assessment of drinking water quality is undertaken by following the procedures outlined by the Australian Drinking Water Guidelines (NHMRC 2004), which were based on AS/NZS 4360:2004 (AS 2004).

The currently accepted procedures in Australia of the Department of Health and Aged Care for human health (eNHealth 2004) and the USEPA of ecological health (USEPA 1998) enable the formalised approach of risk assessment to be applied when required (Ricci 2006). There are two sequential steps: assessment is first undertaken then the management tool is developed based on identified risks. When complete risk assessments are not undertaken due to practical reasons decision making tools are developed to provide a risk-based framework.

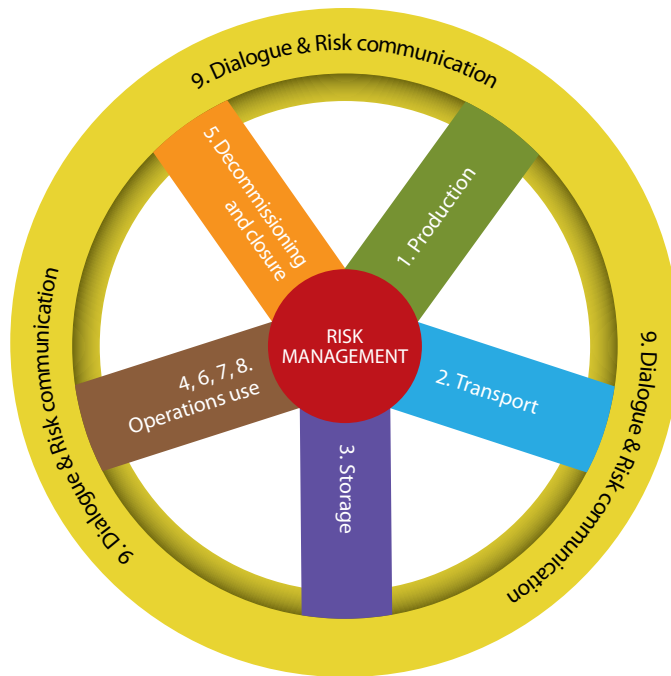
Risk assessment forms one part of the structured procedures within risk management necessary to analyse risk, assess risk, and treat risk. The first step of risk assessment is hazard identification.

Several comprehensive frameworks for ecological risk assessment and human health risk assessment related to chemicals and contamination are available, such as the Australian National Environmental Protection Measures (NEPMs; NEPC 1999) and USEPA (1998). Risk assessment procedures appropriate to cyanide in the mining industry are described by Logsdon et al (1999).

### 5.3 How to implement the Code

This section outlines the depth and spread of detail required to implement and maintain Code certification for mine sites. Figure 2 provides a schematic of the steps according in which dialogue and risk communication is pivotal to the Code's principles.

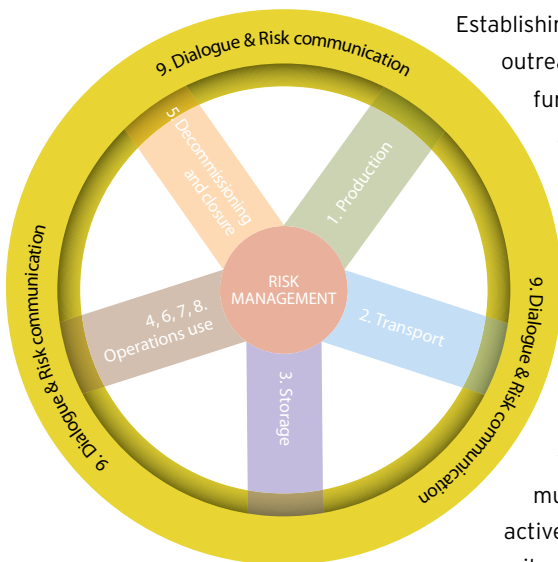
**Figure 2: The Code Implementation Wheel**



### 5.3.1 Dialogue and risk communications

The Code requires that standards of practice are established for public consultation and disclosure. These standards aim to:

- provide stakeholders with the opportunity to communicate issues of concern and address these issues
- communicate crisis management and cyanide management procedures
- seek feedback through proactive dialogue.



Establishing effective public education and outreach programs with local communities is fundamental to a company's long-term success (*Community Engagement and Development Handbook*, DITR 2006a). Regardless of any prevailing rights granted by law or regulation, any mining operation should regard itself as an invited guest in the country and community where it is being developed. The operation's actions and interactive relationships with local communities should be mutually beneficial. Mutual respect, active partnerships and long-term commitments with the local community throughout mine life and beyond are key objectives for

the community and stakeholder engagement program at any mine.

Continuing negative public perceptions of cyanide, coupled with the operational and environmental risk management issues associated with its transportation and use, mean that stakeholder communications may pose particular challenges for cyanide manufacturers and users. The ICMC recognises the importance of these challenges in Principle 9: Dialogue. Risk communication and community engagement are implicit in other ICMC principles, therefore communication is represented as an encompassing principle in the Code Wheel.

Building on Principle 9 of the ICMC, Box 4 identifies a series of steps that should be undertaken as part of site-specific risk communication assessments. Mining operations and companies with Indigenous stakeholders are referred to the handbook *Working with Indigenous Communities* (DITR 2007b); and techniques for community engagement are described in the *Community Engagement and Development* handbook (DITR 2006a).

Examples of the inclusive community engagement approach are provided in the Waihi and CSBP case studies.

## **CASE STUDY: Waihi risk communication and stakeholder consultation of cyanide management**

### **Introduction**

Newmont Waihi Gold (NWG) manages the Waihi mine, which is adjacent to the town of Waihi, located 150 kilometres south-east of Auckland, New Zealand, with a population of around 4700. The mine facilities comprise the Martha open pit, Favona underground mine, a processing plant and two tailing storage facilities (TSF). The operation employs about 300 employees and contract workers.

The commitment to the Cyanide Code was made by the Newmont Mining Corporation in 2005. Newmont was one of the 14 initial signatories to the Code. The Cyanide Code audit was carried out by Golders between 18 and 22 June 2007.

This case study presents a range of communication processes initiated by NWG to maintain positive relationships with key stakeholders and to discuss issues of mutual concern, one of which is the safe management of the transport, storage and use of cyanide.

### **Consultation**

A company liaison officer was appointed in 1998 as a requirement of a consent condition. The purpose of this role is to:

- liaise between the community (including Maori), management and staff and the regulatory authorities
- respond to and investigate complaints and concerns as they arise
- inform the public of activities taking place at the mine by way of written information, the regular update newsletter, and personal visits.

The company consults with the local community and community groups, tangata whenua and the appropriate Iwi authorities, local and regional councils, and government departments and agencies.

### **Waihi Information Centre**

Newmont was instrumental in setting up the Waihi Information Centre which was built by the company in 1990. It is now located in new premises in upper Seddon Street. It caters for visitors, providing information and brochures relating to tourist attractions throughout New Zealand but focusing on Waihi and the surrounding district.

### **Golden Legacy Centre and Newmont Mine Interpretation Centre**

A mine information centre called the Golden Legacy Centre in Moresby Avenue was built in 2003. The centre provides photographic and historical displays, videos and models describing the mining process, from geological sampling and assaying to excavation, processing, and the extraction of the precious metals. Further displays outline the

environmental monitoring, progressive rehabilitation and closure plans. Information about the Favona underground project and ongoing exploration programs in and around Waihi is available at the centre and staff members are available to answer questions. In 2007, the facility was merged with the Waihi Information Centre and a new Mine Information Centre (MIC) was formed. The MIC has been redesigned to provide a number of live interactive and static displays for visitors.

### **Education**

Links between the company and education institutions have grown considerably. The Martha mine is a popular destination for a variety of educational groups. The study of gold mining is part of the secondary school syllabus for geography, history, science, economics and technology. Preschool, primary and intermediate schools study aspects of gold mining as centre-of-interest topics and as part of the technology curriculum. Students from universities and polytechnics visit the mine as part of their geology, environmental science, environmental law, and tourism courses. Educational resource material is provided by the company.

## **CYANIDE SPECIFIC COMMUNICATION INITIATIVES**

### **Cyanide emergency response exercises at Martha mine**

The Martha Mines Rescue Team is made up of 18 members drawn from all areas of the site. All members are volunteers and carry out their allotted mine rescue role in addition to their regular duties. The team has participated in a variety of training exercises with local Emergency Services including Fire Service, Ambulance, Civil Defence, Police, Coastguard and Surf Life Saving.

About 75 litres of cyanide, comprising 30 percent spent electrolyte solution, is stored on site. A further 60 boxes in Solids to Liquids form is kept as an emergency backup. It is delivered by bulk liquid tanker holding 28 000 litres. The process plant uses between 0.8 kilograms and one kilogram per tonne cyanide per week. About 300 milligrams per litre cyanide is in the system at any one time.

Liaison meetings and response exercises are periodically run to ensure that mine staff and contractors, the management team, mine rescue team and local emergency response and medical providers have a current and practical understanding of effective incident management involving cyanide, understand each other's capabilities, and can work together efficiently.

### **Emergency services liaison 31 July 2004**

The mine rescue team liaises annually with emergency service providers and emergency medical providers to ensure that they:

- are familiar with all site access and alternative site access routes, and know how to use these

- have a working knowledge of site layout, entry/egress, and the location, concentration and use of all hazardous substances, including all utilities, fuel supplies and isolation points
- have a working knowledge of emergency water standpipe locations, medical supplies and any other infrastructure, equipment or resources they may require to access
- know the location of the windsock to check for hazardous substance drift
- understand NWG emergency procedures and evacuation procedures
- are familiar with NWG site communication protocols (for example, the rescue team's emergency channel)
- are familiar with NWG staff and emergency responsibilities and functions
- understand the role and capability of the mine rescue team
- are familiar with mine rescue equipment and compatibility with their own resources
- understand and are prepared for possible cyanide emergency scenarios
- know the location of medical supplies.

Staff members from the local medical centres also review their skills, capabilities, equipment and procedures for the benefit of mines rescue team members.

#### **Cyanide Kit Doctor Pack and SOP 31 January 2007**

An information pack is provided to doctors and medical centres located at Waihi and adjoining communities. The information packs contain a copy of the NWG procedure for emergency first aid and medical treatment for cyanide poisoning.

The procedure is also available at the site's Baxter Road security gate and in the first aid room. The kit also contains information on the location of three cyanide poisoning treatment kits and guidelines for professional medical treatment and care.

#### **Box 4: Community and stakeholder engagement guidelines for the management of cyanide**

- **Identify** communities and stakeholders potentially impacted by the handling and transportation of cyanide including those along transport corridors.
  - Communities and stakeholders could include communities located in the vicinity of the operation as well as those located along transport corridors, government agencies and service providers, NGOs, and employees.
- **Assess** the risk to communities and stakeholders and evaluate appropriately targeted engagement processes.
  - Map communities and stakeholders, identify the context of operational relationships, and assess risk (potential or perceived) profiles.
- **Engage** with communities and stakeholders to provide key information in a clear and accessible way. Provide appropriate, two-way mechanisms for community feedback and promote transparent, open dialogue.
  - Aim to educate, inform and reassure, highlighting regulatory and emergency response frameworks.
- **Listen** to concerns, address concerns, and build trust through dialogue.
  - Take stakeholder concerns seriously.
  - Be timely and responsive.
- **Regularly monitor** and review engagement strategies and evaluate effectiveness against community feedback.

#### **CASE STUDY: CSBP community engagement**

This case study outlines the benefits of an ongoing, inclusive community engagement approach, as opposed to project by project liaison. Since 1988, CSBP Limited has been manufacturing and distributing solution sodium cyanide in a joint venture with Coogee Chemicals Pty Ltd. This joint venture, in which CSBP Limited has a 75 percent interest, is known as Australian Gold Reagents Pty Ltd (AGR).

Community consultation is an important part of the success of AGR's business as its licence to operate is underpinned by community support. Consultation allows both community and business to proceed with more informed decision-making, ultimately avoiding misconception and reducing delays. This was demonstrated in 2005 when CSBP proposed to expand the solid sodium cyanide plant on its site at Kwinana. Given the nature and scale of the proposed plant expansion, AGR was cognisant of the need to ensure that the local community was adequately consulted. The proposed expansion was communicated to local stakeholders using a variety of well-established mechanisms which were important components of the plant expansion approvals process.



For example, information is regularly provided to the local community about the company's operations through community newsletters and the local media. Annually, the company publishes a detailed sustainability report which is distributed to community stakeholders, schools and libraries. Sharing this detailed information about the business builds trust on both sides of company-community relationship which is critical for our ongoing success and participation in the region.

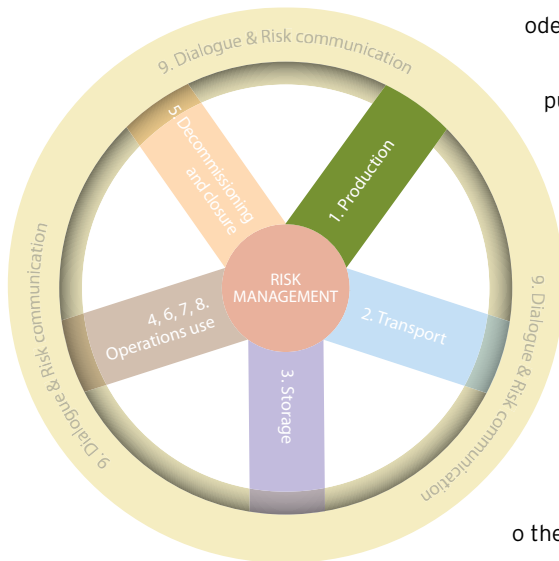
In addition, the company regularly meets local community, government and industry stakeholders at the bi-monthly Communities and Industries Forum (CIF). As an independently moderated forum, which is open to all, the relationships developed between all parties through the CIF provide companies such as AGR with opportunities to keep stakeholders up-to-date with business operations, and also to listen and respond to community concerns. Information about the proposed expansion was presented to this forum, which provided feedback and indicated the most pressing community concerns about the project. In this case, the comments raised were all related to site security concerns and did not refer directly to the proposed upgrade.

AGR, through its operating agent CSBP, is also represented at industry level in the Kwinana Industries Council (KIC). The KIC is also actively involved in community consultation and promotes a number of initiatives to improve and strengthen dialogue between community and industry. One of these initiatives includes a dedicated telephone-based community information service. Community members can listen to the latest information on public safety, environmental and other issues. Through this service, AGR advises the local community of standard operational procedures (such as plant start-up or shut down) and business updates.

Using the above mechanisms over a period of time, the local community has developed a greater understanding of AGR's business which, in turn, assisted the community engagement and approvals process for the proposed solid sodium cyanide plant upgrade. Because AGR understood the concerns of the community very early in the process and was able to address them through established communication channels, ultimately the approvals process proceeded on schedule and without costly delays.

The audits should be conducted by credible experts in the areas of cyanide/hazardous materials packaging and transport, storage, mixing and plant delivery systems, training, operating and emergency procedures, solution containment and design, and health, safety and environmental management and protection.

### 5.3.2 Production



Code requires that cyanide manufacturers be responsible and that cyanide is purchased from manufacturers who operate safely and are environmentally protective.

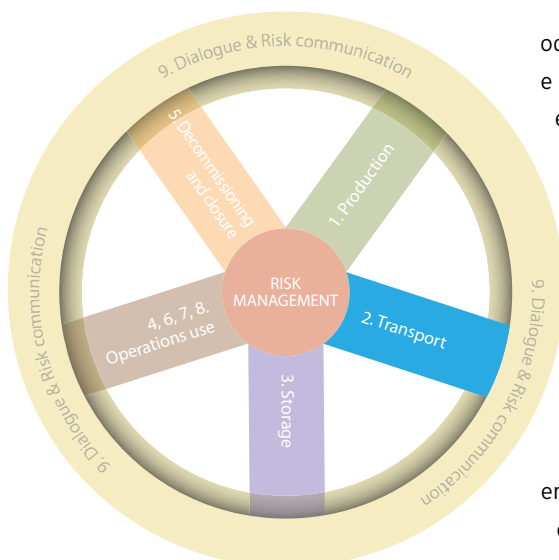
The Code refers to the application of standards of practice and that cyanide should be purchased from manufacturers who employ:

- appropriate practices and procedures to limit exposure of the workforce to cyanide
- prevent the release of cyanide to the environment.

Safety for workers and responsible use of cyanide in mining are closely related. Implementing best practice in the workplace will inevitably have a positive effect on community perception and this will, in turn, influence views on the potential impact of cyanide use in mining on the environment.

It is important that mine managers be familiar with legislation governing the purchase, storage, transport and monitoring of cyanide in their state or territory.

### 5.3.3 Transport



Code requires that standards of practice be established that have clear lines of responsibility for safety, security, release prevention, training and emergency response, and that these are included in written agreements with producers, distributors and transporters. The Code also requires transporters to implement emergency response plans, specify management procedures to be applied in the event of an incident and employ adequate cyanide measurement devices.

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 the environment, and to prevent cyanide solids or liquids reacting to produce hydrogen cyanide gas (see Box 5). It is essential that these safety procedures are communicated to workers through practical training and that they are reviewed and updated when required. Case Study 5 describes the Code-compliant transport and delivery of sodium cyanide solution from Australian Gold Reagents (AGR) Pty Ltd at Kwinana to Sunrise Dam Gold Mine (SDGM) 220 kilometres north-east of Kalgoorlie in Western Australia.

#### **Box 5: Transport and packaging**

Incidents involving cyanide off the mine site result in negative community perceptions of the mining industry and can often give rise to higher levels of concern than on-site incidents, primarily due to their proximity to habitation, human water supply and aquatic wildlife habitat. *Enduring Value* (MCA 2004) recognises that best practice should apply to relevant contractor and asupplier activities. This applies particularly when mines are located in remote mountainous regions that experience high rainfall and/or severe winters. Effective communication should occur between the mine operator and the manufacturer or transport company, and under the Code the parties are required to liaise on emergency planning. In addition, the manufacturer can advise on the most appropriate form and packaging for the volume requirements of mining operations. In Australia, cyanide is commonly available as a solid tablet of around 98 percent NaCN or in a liquid form of about 30 percent NaCN. Given that the liquid form is 70 percent water, it is generally only transported by road over short distances. Solid sodium cyanide is packaged either in 100 kilogram drums, in intermediate bulk containers (IBCs) containing 'bulkabags' of 800 kilograms to 1000 kilograms, or in bulk solid sparge containers of 20 tonnes. Sparge containers are the better option because they reduce the need for manual handling and minimise possibilities of spillage during transfer and handling at the mine storage facility (see also Case Study 5). IBCs or steel drums should be returned to the supplier.

Key actions in reducing risks relating to cyanide transport are:

- acquire and read relevant legislation
- comply with all regulatory requirements
- ensure all vehicles and drivers used in cyanide transport are appropriately licensed and trained in dangerous goods transport
- identify the risks and select the right equipment to alleviate the risks
- obtain MSDS and post at all relevant locations including in vehicles transporting cyanide

- adopt safe handling practices and procedures
- comply with all regulatory requirements
- ensure your staff or contractors are properly trained in cyanide handling and are competency tested
- carry out audits of operations and report all incidents
- have an emergency response plan and conduct emergency response exercises
- have emergency medical equipment available.

Selection of the transport route should be undertaken in consultation with regulatory and local authorities and involve community consultation. The consultation should advise on identified risks, and describe arrangements for driver fatigue management, auditing, incident reporting, emergency response, and emergency exercises. Neutralising agent should be carried or be available at strategic points along the route.

General guidance for the transport of dangerous goods and the development of emergency plans is available from UNEP's TRANSAPELL Program. Guidance on marine transport is provided by the International Maritime Dangerous Goods Code. A code for rail and road transport of dangerous goods is available from the Australian National Occupational Health and Safety Commission.

Packaging and labelling should be tested and approved to ensure they meet legislative requirements for Class 6 Toxic Substances and conform to national codes for transport of dangerous goods and the International Maritime Dangerous Goods Code for marine transport. Staff should be trained in safe handling practices and procedures and be subject to competency testing. Audits and incident reporting should be undertaken, and security measures put in place to reduce the risk of misuse and theft.

## **CASE STUDY: The transport and delivery of sodium cyanide solution from Kwinana to Sunrise Dam gold mine (SDGM) in Western Australia**

Sunrise Dam gold mine (SDGM) is situated on the edge of Lake Carey in Western Australia's Northern Goldfields, about 220 kilometres north-east of Kalgoorlie. The operation purchases its sodium cyanide from Australian Gold Reagents (AGR) Pty Ltd, located at Kwinana, Western Australia.

The cyanide supply contract between AngloGold Ashanti Australia (AGAA) and Australian Gold Reagents (AGR) requires that the cyanide meets the Australian Dangerous Goods Act and Dangerous Goods (Transportation; Road, Rail) Regulations and all requirements of the Code. The sodium cyanide solution is transported in 18 000 litre, dedicated ISO tanks (6058 millimetres long, 2438 millimetres wide and 2591 millimetres high) specially designed for the transport of cyanide via rail to the West Kalgoorlie Transit Yard and then by road train to SDGM. All freight contractors are accredited and audited regularly.

As part of its emergency response management plan, AGR has stocks of neutralising agent (ferrous sulfate) along the specified transport routes (rail and road). CSBP Ltd, as the operating and sales agent for AGR, has a highly trained and skilled emergency response team that is available 24 hours-a-day, seven days-a-week to handle any emergency. For response to an incident at a remote site, CSBP has a contract with a flight service provider for immediate transfer of technical or emergency personnel to the incident site.

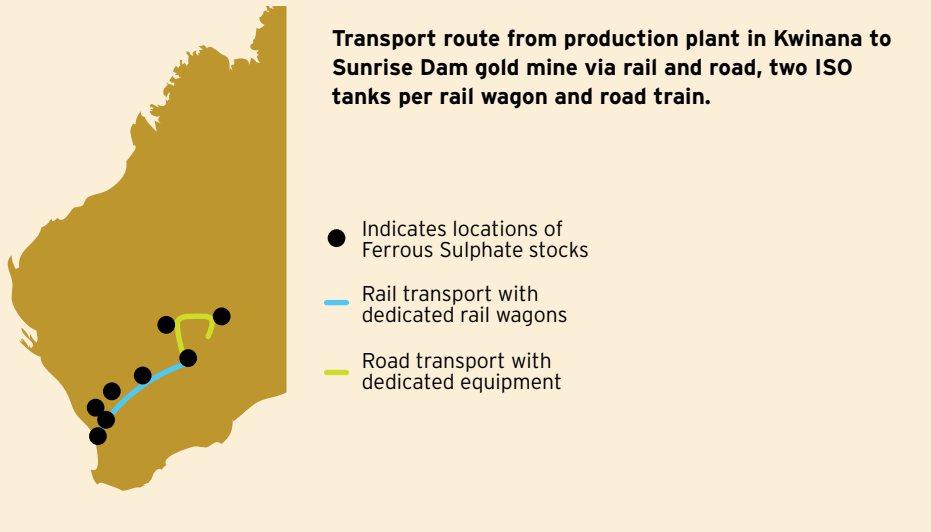
The sodium cyanide receipt and storage facility at SDGM has been designed by CSBP and approved by the WA Department of Consumer and Employment Protection.

The vehicle operator conducts the unloading process on arrival at SDGM under the supervision of a site representative. CSBP has trained SDGM personnel in the procedures they need as the site representative. The site procedure to unload the cyanide requires the site representative to observe the unloading to ensure site safety, that the unloading takes place in a controlled environment and that actions are taken in an emergency, such as shutting down the unloading process and raising the alarm.

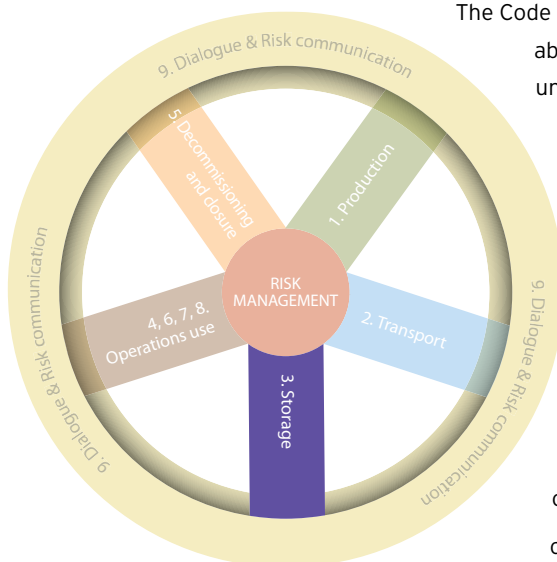
The stock management system ensures sufficient inventory required at SDGM for the ongoing supply of product to the gold recovery process is in place. The storage tanks have fitted manual level indicators as well as electronic level indicators, with the electronic level indicator being linked via telemetry to CSBP as part of the stock management system. Deliveries to site and product unloading are only instigated if there is sufficient capacity in the tanks to safely accept a road delivery of two ISO tanks.

The SDGM Processing Department maintains equipment for dealing with in-plant spills of a minor nature. SDGM also has an emergency response team that is trained in handling chemical hazards and incidents.

CSBP conducts an annual audit of this facility to ensure its continuing compliance to the regulatory standards. A formal report on the findings is provided to AGAA management on completion of the audit. CSBP has a facility inspection/checklist for ongoing house keeping and preventative maintenance inspections.



### 5.3.4 Handling and storage



The Code requires that standards of practice be

established to design and construct unloading, storage and mixing facilities

that are consistent with sound,

accepted engineering practices,

quality control, quality assurance

procedures, spill prevention and

have spill containment measures.

The unloading, storage and mixing

facilities should be operated with

inspections, preventive maintenance

and contingency plans that prevent

or contain releases of cyanide and

control and respond to worker exposure.

Following scenarios should be considered

and adapted to suit the spills and other releases

of cyanide (White 1997).

- Spills of solid sodium cyanide onto land can be cleaned up quantitatively by collecting the solid form from the contaminated area. In wet weather, sodium cyanide pellets should be covered with a tarpaulin and, if necessary, surrounded by a trench to prevent contamination of rainwater.
- Liquid spills, and spills of solid sodium cyanide into surface waters, with pipelines and drains should be addressed as follows:
  - surface spills onto land may be treated by trained personnel with hydrogen peroxide or sodium hypochlorite (Staunton et al 1989). If a significant time has elapsed since the spillage occurred, cyanide levels should be monitored and a decision made on whether clean-up is appropriate
  - treatment with solid ferrous sulfate to form less-toxic ferricyanide is a preferred option due to the high health risk of peroxide reaction releasing HCN and NH<sup>3</sup> gases
  - spills into surface waters are particularly difficult to remediate without further damaging the aquatic environment unless the surface water body can be sealed off from the surrounding environment.
- Preservation of sensitive fauna may be possible by collection and relocation, while netting and fencing may be used to prevent entry to contaminated ponds.

Cyanide may be lost during all stages of normal mining operations from preparing reagents through to waste disposal. Potential losses include:

- spillage during transfer to or from waste storage facilities
- process spillage as a result of human error, burst pipes or leaky valves
- seepage from barren ponds, heap leach pads, pregnant liquor ponds, or tailings dams which lead to contamination of surface and groundwater
- from electro-winning circuit mainly as ammonia
- catastrophic escape due to some natural or other event.

Leading practice recognises the potential spillage pathways and works towards minimising their potential impact. Regulatory requirements include the following:

- bunding liquid sodium cyanide storage areas
- bunding critical pipe work, pumps and valves and inspecting them more rigorously and more frequently than non-critical equipment
- lining ponds and heap leach pads with impervious material
- drilling boreholes to monitor seepage of cyanide from ponds and tailings dams.

Common management measures used to minimise the potential for loss of cyanide include:

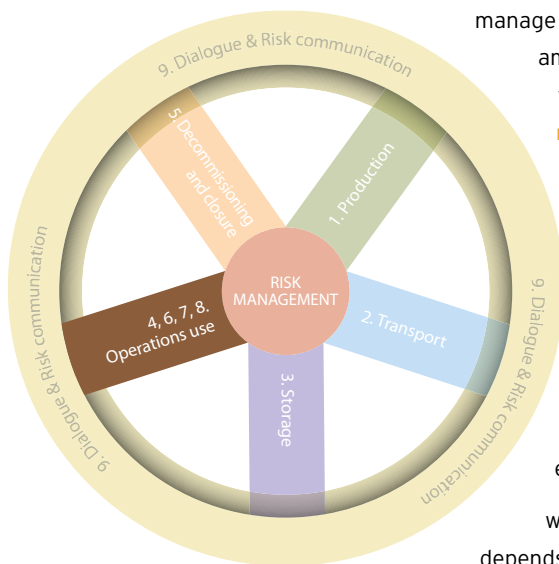
- installation of flow or pressure loss detection systems on pipelines to detect a failure
- installation of sleeves or covers over mechanical pipe joints to restrict leaks under pressure to a banded area
- alarm systems to alert personnel to pump or pipeline failure
- implementing regular inspection and maintenance procedures.

The potential effects of cyanide loss on mine site personnel, the general population and the environment should be analysed through a formal risk assessment procedure (see the *Risk Assessment and Management* handbook in this series (DRET 2008a)).

Care should be taken to ensure that the appropriate form of treatment is used: cyanogen chloride may form after treatment with sodium hypochlorite whereas hydrogen peroxide oxidises cyanide into cyanate, which is much less toxic. The clean up method used should aim to immobilise and contain the cyanide, and convert it into a less toxic compound. After any spill, protective clothing and other equipment used should be decontaminated at the site of the incident.

### 5.3.5 Operations use

The Code requires that Standards of Practice be established in order to:



manage cyanide process solutions and waste  
aims to protect human health and the  
environment

- protect workers' health and safety from exposure to cyanide
- protect communities and the environment through the development of emergency response strategies and capabilities
- train workers and emergency response personnel to manage cyanide in a safe and environmentally protective manner.

How cyanide is stored at the mine site depends on its form and is subject to regulation. Similar to measures applying to transport

and packaging, arrangements should be in place to:

- identify risks and design facilities to minimise the identified risks
- develop and document safe practices and procedures
- post MSDS, storage and handling protocols, and requirements for personal protective equipment;
- train staff and conduct competency testing
- instigate a program of preventive maintenance on storage facilities
- carry out regular auditing and report all incidents
- develop and document emergency response procedures and undertake regular emergency response exercises
- maintain an adequate supply of neutralising agent on site.



Holding facilities and compounds should be designed and maintained in accordance with regulatory and best practice issues, in particular:

- provide adequate ventilation to disperse any build up of hydrogen cyanide gas
- minimise 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 unauthorised 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. 'HAZCHEM' code 4X warning signs are needed for identification by fire-fighters
- adequate containment facilities and bunding of liquid and solid cyanide containers are necessary to minimise the effects of accidental spillage (consider local weather conditions in providing such containments).

UNEP's APELL program provides a technical guide to *Warehousing of hazardous materials*.

The Code requirements for compliance with emergency preparedness are significant and cannot be addressed with generic procedures. This means there is a need to have a close relationship between the supplier and end user. An outline of the treatment of cyanide poisoning is given in Box 6.

## Handling and emergency procedures

Leading practice means not only adopting measures that minimise the likelihood of cyanide losses during operations but measures that limit the effects of any loss. Capacity to do this will depend on those emergency response procedures being established and practiced regularly.

Cyanide handling must take into account the occupational exposure standard or Threshold Limit Value (TLV). This is 5 mg/m<sup>3</sup> for sodium cyanide powder and 10 ppm for hydrogen cyanide gas.

Operators undertaking hazardous procedures involving cyanide should wear appropriate protective clothing as described in the MSDS and the manufacturer's recommendations for personal protective equipment. Operators should work in pairs with one acting as a *Signs and becons in potentially dangerous area* 'sentry' (Pesce 1993). 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.

Should an operator be exposed to cyanide, effective and timely medical care is essential. Personnel should be familiar with the general principles and treatment procedures for personnel affected by cyanide exposure.

Leading practice requires that, as far as possible, the probability of accidents is reduced through proactive measures. UNEP's APELL program sets out a framework for building awareness of and preparedness for emergencies, and includes a 10-step model for developing effective and integrated community emergency response plans.

## Protective equipment and hygiene

A range of protective equipment is available for each cyanide handling requirement. For respirable forms of cyanide, a full-face respirator should be worn. Cyanide can be absorbed through skin and, for liquid cyanides, workers should wear disposable coveralls, PVC gloves

and waterproof boots. Because cyanide handling requirements change over time, the current MSDS and PPE recommendations should be used to confirm appropriate equipment and procedures.

Working with cyanide demands a culture of cleanliness. Workers should wash their hands before eating, drinking or smoking, and before applying topical lotions, such as sunscreen. None of these activities should be undertaken in areas where cyanide is stored or used.

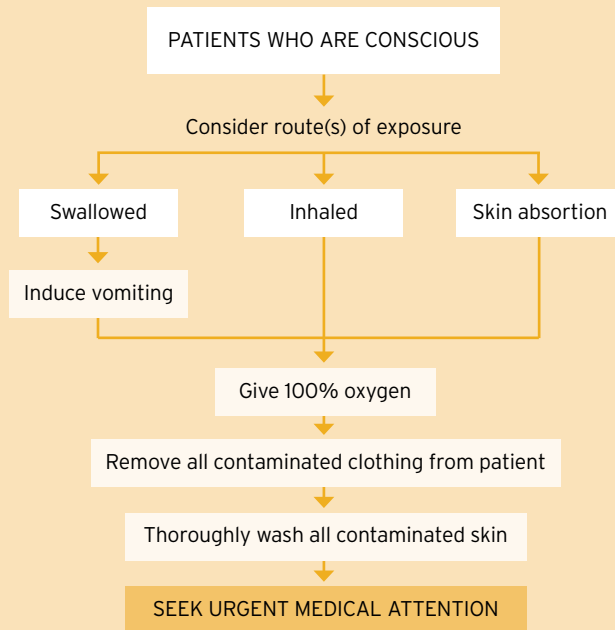
Contaminated protective gear and clothing should be securely discarded, or washed before being stored and reused.

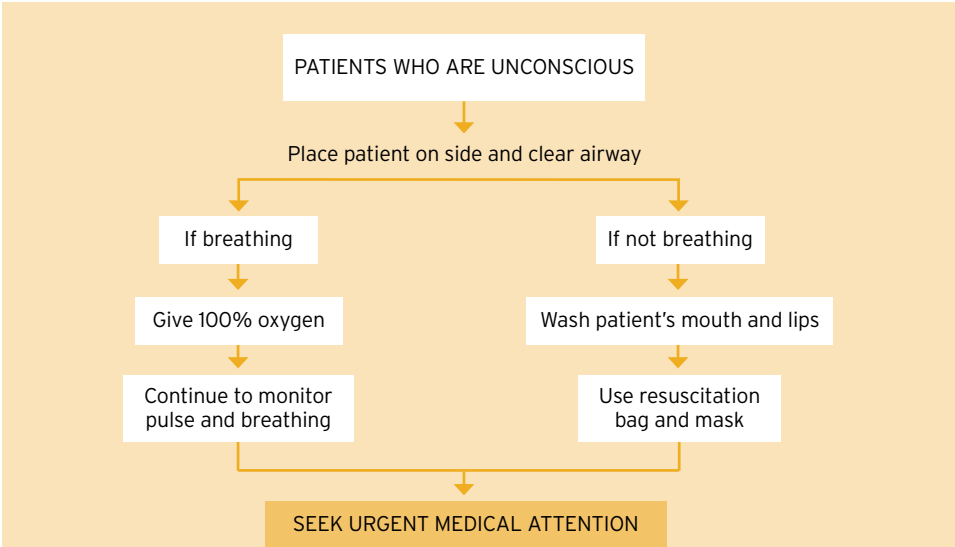
### Box 6: Treatment of cyanide poisoning

Current treatment of cyanide poisoning falls into two consecutive categories, both of which need to be undertaken swiftly and efficiently by well-trained and properly equipped personnel (Department of Minerals and Energy, WA, 1992; National Occupational Health and Safety Commission 1993; Pesce 1993, p. 763 and Department of Consumer and Employment Protection WA Medical Bulletin No5. Revised August 2007 Cyanide poisoning - first aid and medical treatment).

The procedures below are general in nature and best practice indicates that local advice should be sought regarding the most appropriate response and treatment. Advice may change with advances in medical knowledge.

#### a) First aid treatment immediately following an exposure incident





**b) Professional medical treatment**

Although various types of medical treatment for cyanide poisoning have been recommended in literature, treatment options should be reviewed with the medical practitioner responsible for patient treatment. Mines with cyanide antidote kits on site should seek professional medical advice regarding antidotes suitable for use by site medical staff. Cyanide poisoning treatments are mutually exclusive and not all treatments can be applied to the same patient.

Hydroxycobalamin is approved by the US Food and Drug Administration for treatment of cyanide poisoning, and is available through the Therapeutic Goods Administration Special Access Scheme. It reacts with the cyanide to form cyanocobalamin, which is excreted by the kidneys. Five to 15 grams of hydroxycobalamin should be administered intravenously (Cyanokit® contains two 2.5 gram bottles) over 30 minutes or faster if the patient's condition is deteriorating.

Sodium thiosulphate is a sloweracting agent but may be useful as an adjunct to hydroxycobalamin. It reacts with cyanide to form thiocyanate. Administer 12.5 grams of sodium thiosulphate (50 millilitres of 25 percent solution) over 10 to 20 minutes through a separate intravenous line. This may be repeated at half the initial dose 30 minutes later.

The use of oxygen (100 percent) as an initial treatment and, if required due to the patients condition, followed up with the hydroxycobalamin and sodium thiosulphate, is now considered best practice for the treatment of cyanide poisoning.

Use of KELOCYANOR®, (cobalt(II)-edetate) is no longer a preferred antidote.

Amyl nitrite is another form of treatment that has a long history of use. It is first inhaled and then sodium nitrite ( $\text{NaNO}_2$ ) is injected intravenously which causes the body to generate methaemoglobin which sequesters cyanide ion from the cytochrome oxidase pathway. The cyanide is then detoxified by intravenous administration of sodium thiosulfate ( $\text{Na}_2\text{S}_2\text{O}_3$ ). This reacts with cyanide, in the presence of a sulfur cyanate ion ( $\text{SCN}^-$ ), which is then excreted in the urine. Amyl nitrite can also be used as an immediate treatment prior to administration of the hydroxycobalamin and sodium thiosulphate. The application and/or use of amyl nitrite will depend on the emergency guidelines and protocols stipulated by the managing medical practitioner.

N.B. The effectiveness of some of these treatments has been disputed. The United Kingdom Health and Safety Executive (*Advisory leaflet on cyanide poisoning*; Elliot 1996) indicates that this regulatory authority will 'no longer recommend the use of any antidote in the first aid treatment of cyanide poisoning and will not require employers to keep supplies' and 'will in future advise that administration of oxygen is the most useful initial treatment for cyanide poisoning. This implies that in premises where cyanides are used at least one person should be trained to administer oxygen. If breathing has stopped, artificial respiration is essential.'



**Cyanide Emergency Box**

## **Monitoring the working environment**

The protection of workers from airborne contaminants through monitoring and sampling programs are often covered by regulations, and local rules should be followed when available. Some principles are that samples:

- be representative of worker exposure
- be collected, preserved and analysed by an approved method (accuracy and precision will be assured if analyses are conducted by a NATA-approved laboratory)
- not be tampered with.

Where practical, samples should be collected using equipment that is calibrated in accordance with manufacturer requirements, calibrated before use, and checked after use against calibration standards.

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 managing emergency situations.

## **Cyanide balance**

The balance between uptake and loss of cyanide from the environment can be determined in much the same way that water balance is established. Key factors in developing a cyanide balance include:

- knowledge of ore body composition and its change during the life of the mine; linked with the chemical considerations described in Section 2.2, this determines cyanide consumption
- local meteorology–this affects cyanide consumption directly through evaporation and photolytic degradation, and indirectly by changes in water balance.

Cyanide management needs to be well integrated with the overall water management plan for the mine site. It is essential that cyanide treatment and recovery is emphasised from the outset. Metallurgical and environmental personnel must collaborate in evaluating the cyanide monitoring data.

The following case studies describe process improvements to reduce WAD cyanide at tailings discharge.

## CASE STUDY: Process improvements at Kalgoorlie Consolidated Gold Mines Pty Ltd (KCGM) to reduce WAD cyanide concentrations at tailings discharge

The KCGM Fimiston plant on the Kalgoorlie Golden Mile, Western Australia, operates three cyanide leach circuits—one being high cyanide concentrate leach, the others being a low cyanide floatation tails leach. The roaster calcine leach circuit is operated at the Gidji plant 20 kilometres to the north.

The Fimiston cyanide leach circuits are arranged so that the concentrate leach tails of CIL1 (head ~3500 milligrams per litre, tail ~2000 milligrams per litre) are directed to the head of one of the two floatation tails circuits (CIL2). This not only provides additional leach time for the concentrates but utilises residual cyanide and lime. Cyanide concentration in CIL2 had historically been kept at +200 milligrams per litre. The second parallel floatation tails leach circuit (CIL3) had also typically been kept at a similar cyanide concentration. The tails of both floatation tails leach circuits are then pumped to the Fimiston tailings storage facility (TSF).

In December 2006, the decision was made to decrease the cyanide concentrations in both CIL2 and CIL3 in an effort to reduce HCN levels on tanks, save cyanide and therefore also lower the WAD cyanide readings at the TSF. Dropping these targets to ~140/160 milligrams per litre total CN (from +200 milligrams per litre) has resulted in WAD CN at the TSF spigots consistently around 25 milligrams per litre—much less than the 50 milligrams per litre Cyanide Code guideline. Laboratory work has indicated no subsequent increase in gold lost to final tails from the leach circuits and plant recoveries for 2007 support these findings.

Additional improvement in cyanidation efficiency and discharge concentrations was achieved via process control and cyanide analyser maintenance. Each leach circuit at Fimiston is fitted with an online cyanide analyser to control the addition of cyanide in the circuits to the set-point. These are backed up with manual titrations to add another level

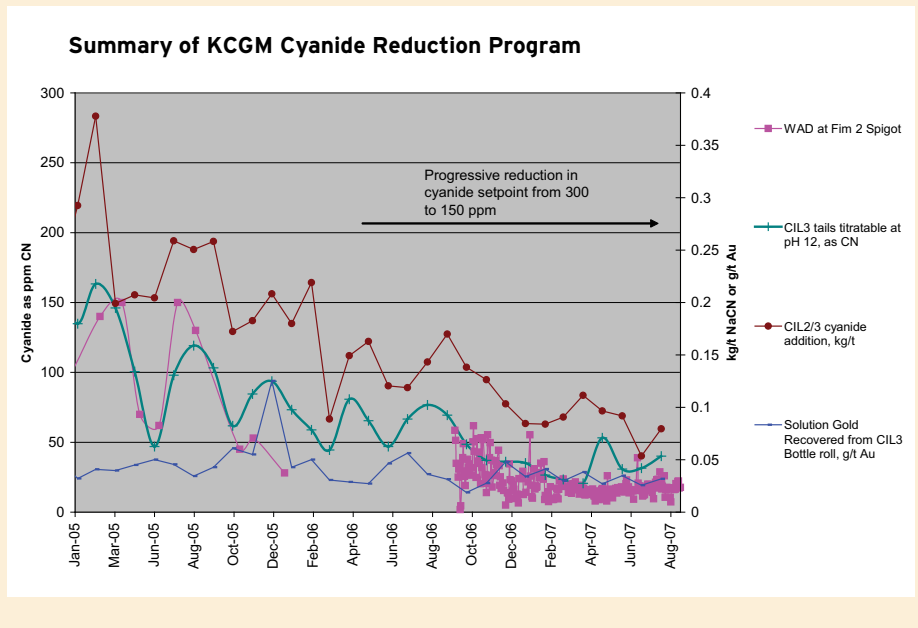
of control. The analysers are maintained by the laboratory staff on a daily basis, resulting in analyser availability in excess of 90 percent. Daily maintenance of all three units takes one person about two hours.



**Analyser unit**

Due to the equilibrium conversion of  $\text{CN}^-_{(\text{aq})} \rightarrow \text{HCN}_{(\text{aq})}$  in the Fimiston operating range of pH 9.3, with conversion to  $\text{HCN}_{(\text{aq})}$  increasing as pH falls, the flotation tails leach analysers (CIL2/3) are fitted with caustic addition to the titration cell. This ensures that cyanide titrations are consistently reported at a known pH of  $\sim\text{pH } 12$  where  $\text{CN}^-_{(\text{aq})}$  is most stable, effectively reporting total cyanide. This stable titration pH avoids under reporting  $\text{CN}^-_{(\text{aq})}$  when pH is below set-point, therefore avoiding an overdose of cyanide to the leach circuit and the subsequent cyclic instability caused by variations in circuit pH. Ultimately, tighter cyanide reagent control is obtained.

Other controls include limiting the maximum flow of cyanide solution to the circuits via the plant control system, and installing a second analyser stream to further monitor cyanide concentration in the second tank of each leach circuit. Further controls are being adapted for mill shutdown and start-up periods, to avoid increased cyanide concentrations when plant flows are reduced.





## CASE STUDY: Reducing WAD cyanide at the discharge spigot by the addition of new circuit water to a tails thickener

Using a gold circuit water chemistry model (SysCAD interfaced with the Outokumpu thermodynamic database HSC Chemistry 5.11) it can be demonstrated that in some circumstances it is possible to meet environmental obligations while reducing operating costs at the same time.

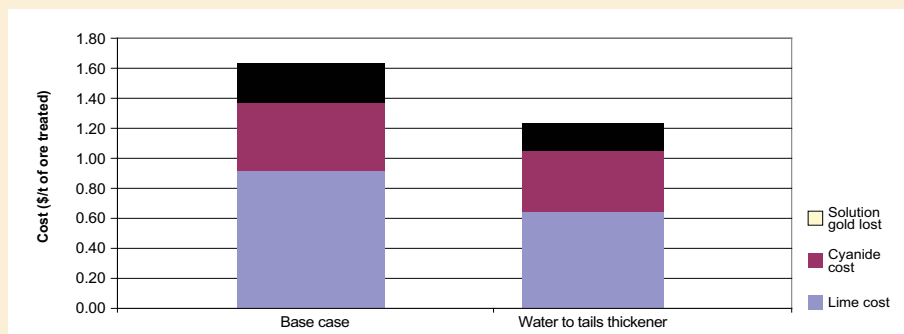
Traditionally, new circuit water is added to the grind. One way of reducing the WAD cyanide at the discharge spigot is to add new water to the tails and increase the level of recycle. The WAD cyanide concentration at the discharge spigot is thereby reduced through dilution with the use of a tailings thickener. Obviously the flow of streams, their chemistry and the impact of recycles becomes very complex and is the reason why models have been used to develop a quantifiable understanding of the processes occurring.

Quantifying the consequences of the dilution strategy demonstrates that the benefits can be significant. Under the conditions modelled, the combined effect of dilution plus recycle reduces the WAD cyanide at the discharge spigot from 124 to 61 milligrams per litre and the amount of cyanide discharged from 45 kilograms per hour to 18 kilograms per hour.

WAD cyanide concentration and flow to the TSF discharge spigot.

Additional advantages are that the water recycled to the front of the circuit contains residual solution gold, cyanide and is low in magnesium. This results in lower lime and cyanide requirements. Not only are there environmental benefits, it is also calculated that adding new water to the tails thickener may reduce operating costs from \$1.63 to \$1.23 per tonne of ore treated. Solution gold lost to tails has been counted as an operating 'cost' which makes the benefits of recycling solution gold to the head of the leach circuit and providing a second opportunity to capture this gold become clearly apparent.

### Lime and cyanide operating costs combine with cost of gold lost in solution to give the overall cost



Information on further scenarios and complexities investigated with this model can be found in Rumball, Munro & Habner (2007).

## Chemical, physical and biological removal techniques

A common method for detoxifying residual cyanide is the Degussa peroxide process; that is, hydrogen peroxide oxidises free and WAD cyanides to cyanate, which is further hydrolysed to biodegradable ammonia and carbonate. Metals such as copper, zinc and cadmium complexed with cyanide are precipitated as hydroxides and iron cyanide complexes. These are then removed by a further treatment step which precipitates the iron cyanide complex by combining it with copper ions.

The most cost-effective way to detoxify tailings slurries is to use peroxymonosulfuric acid (Caro's acid) which can be generated safely on site from hydrogen peroxide and sulfuric acid. Because it is a stronger oxidising agent than peroxide, it is a more cost-effective use of these chemicals and also oxidises cyanate and thiocyanate. Active and passive biological treatments are discussed by Mudder (1987), and chemical and physical treatments by Botz and Mudder (2001), noting that they should not be used in excess.

**Table 4: Cyanide removal technologies**

TECHNOLOGY (AND TYPE*)	SHORT DESCRIPTION	BASIC REAGENTS	BASIC PRODUCTS
<b>A. OXIDATIVE</b>			
Alkaline chlorination (C)	Oxidation to $\text{CNO}^-$ and then $\text{N}_2$ and $\text{CO}_3^{2-}$ with $\text{Cl}_2$ or $\text{ClO}^-$ at $\text{pH} > 11$	$\text{Cl}_2/\text{ClO}^-$ , $\text{NaOH}$	$\text{CNO}^-$ , $\text{CO}_3^{2-}$ , $\text{N}_2$
$\text{SO}_2/\text{air}$ (C)	Oxidation to $\text{CNO}^-$ with $\text{SO}_2/\text{air}$ and soluble Cu catalyst; INCO process	$\text{SO}_2$ , air, Cu catalyst	$\text{CNO}^-$
Hydrogen peroxide (C)	Oxidation to $\text{CNO}^-$ with $\text{H}_2\text{O}_2$ and $\text{Cu}^{2+}$ catalyst; Degussa process	$\text{H}_2\text{O}_2$	$\text{CNO}^-$ , $\text{CO}_3^{2-}$ , $\text{NH}_4^+$
Caro's acid (C)	Oxidation via $\text{CNO}^-$ with $\text{H}_2\text{SO}_5$	$\text{H}_2\text{SO}_5$	$\text{CO}_3^{2-}$ , $\text{NH}_4^+$
Activated carbon (C & P)	Oxidation to $\text{CNO}^-$ and then partially to $\text{CO}_3^{2-}$ and $\text{NH}_4^+$ with activated carbon and Cu catalyst	Activated carbon, air/ $\text{O}_2$ , Cu catalyst	$\text{CNO}^-$ , $\text{CO}_3^{2-}$ , $\text{NH}_4^+$
Biodegradation (B)	Oxidation to $\text{CO}_3^{2-}$ and $\text{NH}_4^+$ and then $\text{NO}_3^-$ using indigenous microorganisms	$\text{Na}_2\text{CO}_3$ , $\text{H}_3\text{PO}_4$	$\text{CO}_3^{2-}$ , $\text{NH}_4^+$ , $\text{NO}_3^-$ , $\text{SO}_4^{2-}$
UOP catalytic oxidation (C)	Oxidation to $\text{CO}_2$ , $\text{N}_2$ and $\text{NH}_4^+$ with air at mild temperatures ( $< 130^\circ\text{C}$ ) and pressures (550 kPa) >with a catalyst	Catalyst	$\text{CO}_2$ , $\text{N}_2$ and $\text{NH}_4^+$
Ozonation (C)	Oxidation to $\text{CO}_3^{2-}$ and $\text{N}_2$ with $\text{O}_3$	$\text{O}_3$	$\text{CO}_3^{2-}$ , $\text{N}_2$
Wet air oxidation (C)	Oxidation to $\text{CO}_2$ and $\text{N}_2$ at high temperatures ( $175\text{-}320^\circ\text{C}$ ) and high pressures (2,100-20,700 kPa)	none	$\text{CO}_2$ , $\text{N}_2$
Photocatalytic oxidation (C & P)	Oxidation to $\text{CNO}^-$ and then $\text{NO}_3^-$ and $\text{CO}_3^{2-}$ using uv/visible light and semiconductor-type substrate, e.g. $\text{TiO}_2$ , $\text{ZnO}$ or $\text{CdS}$	none	$\text{CO}_2$ , $\text{N}_2$

TECHNOLOGY (AND TYPE*)	SHORT DESCRIPTION	BASIC REAGENTS	BASIC PRODUCTS
<b>B. NON-OXIDATIVE</b>			
AVR (C & P)	Acidification-volatilisation-reneutralisation. After acidification to pH <3, HCN(g) is volatilised and absorbed in NaOH and recycled. Metals are precipitated after reneutralisation.	H <sub>2</sub> SO <sub>4</sub> , NaOH	HCN, SCN <sup>-</sup> ?
CYANISORB® (C & P)	Similar to AVR but HCN(g) stripped at higher pH values (5.5-7.5)	H <sub>2</sub> SO <sub>4</sub> , NaOH	HCN, SCN <sup>-</sup> ?
CRP (C & P)	Cyanide regeneration process; similar to AVR but with better HCN(g) stripping and metal precipitation	H <sub>2</sub> SO <sub>4</sub> , NaOH	HCN, SCN <sup>-</sup> ?
SART	Sulfidisation, acidification, recycling and thickening	Na <sub>2</sub> S, H <sub>2</sub> SO <sub>4</sub>	Cu <sub>2</sub> S
Thermal hydrolysis (C)	Hydrolysis to NH <sub>4</sub> <sup>+</sup> and formate at high temperatures	none	NH <sub>4</sub> <sup>+</sup> , HCOO <sup>-</sup>
Alkaline hydrolysis (C)	Hydrolysis to NH <sub>4</sub> <sup>+</sup> and formate at high temperatures (100-250°C) and high pH	NaOH	NH <sub>4</sub> <sup>+</sup> , HCOO <sup>-</sup>
IX - GM (C and P)	Gas membrane-Ion exchange; ion exchange concentrates CN. After regeneration the gas membrane recovers pure CN.	Resin	CN <sup>-</sup>
IX - AVR (C and P)	Ion exchange concentrates CN. After regeneration CN recovered by AVR	Resin	CN <sup>-</sup>
Prussian blue precipitation (C)	Precipitation of Fe <sub>4</sub> [Fe(CN <sub>6</sub> ) <sub>3</sub> ] on addition of FeSO <sub>4</sub>	FeSO <sub>4</sub>	Fe <sub>4</sub> [Fe(CN <sub>6</sub> ) <sub>3</sub> ]
Pregnant pulp air stripping (P)	Air stripping from pregnant pulps	Air	HCN
Reverse osmosis	Physical removal of cyanide and its complexes by a semipermeable membrane process under pressure	H <sub>2</sub> SO <sub>4</sub> ?	CN <sup>-</sup>
Flotation (P)	Adsorption of precipitated CN particles onto fine air bubbles	FeSO <sub>4</sub> , Surfactant	Fe <sub>4</sub> [Fe(CN <sub>6</sub> ) <sub>3</sub> ]
High rate thickeners (P)	Fast thickening and recycling of CIP tailings	none	CN <sup>-</sup>

\* Process type: B = biological; C = chemical; P = physical

? indicates there is some uncertainty about the data

(Sourced from Environment Australia (2003) and references therein: Devuyst et al. 1982; Dubey & Holmes 1995; Gonen et al. 1996; Grosse 1990; Hoecker & Muir 1987; Nugent 1997; Ritcey 1989; Robbins, 1996; and Stevenson et al. 1995). Also in AMIRA P497 in more detail.

The Inco sulfur dioxide (SO<sub>2</sub>)/air process is a simple method that requires little supervision and does not interrupt gold recovery. SO<sub>2</sub> in liquid or gaseous form acts with air to oxidise WAD cyanide to cyanate and sulfuric acid while releasing metals into solution. Inco detoxification has been used at various mines including the Beaconsfield and Henty gold mines in Tasmania (Environment Australia 2003).

Oxidative chlorination using chlorine gas, hypochlorite or in situ electrolytic generation can also be used to detoxify cyanide residues. Alkaline chlorination remains in use as a method of cyanide destruction in Russia.

An advanced procedure to remove copper and recycle cyanide is described in the case study below on the implementation of SART at Telfer.

### **CASE STUDY: Implementation of SART at Telfer to reduce the impact of cyanide soluble copper**

In order to avoid environmental problems in treating high cyanide soluble copper gold ores at Telfer, an evaluation was initially made of possible process routes. These included established, piloted and opportunity (bench scale) technologies for destruction, recovery and recycle of cyanide. In addition, consideration was given to the use of existing equipment and occupational health and safety issues relating to cyanide regeneration.

The choice of sulfidisation, acidification, recycling and thickening (SART) at Telfer was advantageous as the operation had four CCD thickeners (former Merrill-Crowe plant) that could be used for washing the copper and cyanide from the CIL tailings. It also has a heap leach operation to cope with a positive water balance which would have otherwise required alternative techniques and a higher capital cost. Copper and cyanide are both recovered with the copper sulfide produced able to be sold with the copper sulfide concentrate produced from the flotation plant. Pilot plant test work indicated copper and cyanide recoveries of >90 percent could be achieved with NaSH addition at 95 percent of stoichiometry.

The SART process at Telfer recovers copper sulfide from clarified copper cyanide solution by mixing with sodium sulfide (Na<sub>2</sub>S), sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) and a recirculated precipitate of copper sulfide (seed) which nucleates copper sulfide precipitation at pH 4.5. Small amounts of hydrogen cyanide and hydrogen sulfide gas are also formed, which are extracted to a scrubber and removed from the air using a recirculating caustic solution. Copper sulfide is recovered in a thickener and a bleed neutralised prior to reporting to the flotation concentrate. The thickener overflow solution is neutralised with lime and recycled gypsum (seed) to a pH of around 10 or 11. The gypsum is recovered using a thickener with a bleed off to the CCD circuit. The gypsum thickener overflow solution is mixed with the scrubber solution and is the final cyanide return solution. This solution is

utilised in the pyrite leach circuit, the ILR circuit and for dump leach irrigation.

The Telfer SART circuit was commissioned in early 2006. The performance data ranges shown below are primarily based on daily spot samples:

	<b>UNIT</b>	<b>RANGE</b>
SART feed flow	m <sup>3</sup> /hr	28-42
SART feed copper	mg/L	1500-3000
SART feed WAD CN	mg/L	3500-10000
Cyanide return copper	mg/L	50-500
Cyanide return WAD CN	mg/L	3000-6400
Copper recovery	%	70-90
WAD CN recovery	%	50-90
WAD CN conversion to free CN	%	65-98

Further work is planned to optimise this circuit, particularly in relation to pH control and reagent addition. This is also expected to lower the operating costs.

### **Removal and recycling**

When residual cyanide occurs as free and WAD cyanide, it may be recovered using various non-oxidative processes (Table 5). Two such processes rely on reducing pH to release HCN. One is AVR (acidification-volatilisation-absorption) which uses shallow aeration basins and high pressure air blowers to recover free cyanide and some metal-cyanide complexes. The other method which is more efficient and cost-effective is CYANISORB®, which was developed in New Zealand in 1989 and recovers about 90 percent of cyanide from tailings (Stevenson et al. 1995). HCN is removed when the tailings contact high volumes of turbulent air in stripping towers and is captured by hydrated lime slurries in absorption towers. Recovered cyanide is recycled to leaching operations as calcium cyanide. A review of cyanide treatment and recovery methods is provided by Botz et al (2001).

**Table 5. Summary of suitability of treatment processes for removal of cyanide and related compounds (Mudder and Botz 2001).**

TREATMENT PROCESS	IRON CYANIDE REMOVAL	WAD CYANIDE REMOVAL	SLURRY APPLICATION	SOLUTION APPLICATION
SO <sub>2</sub> /air	✓	✓	✓	✓
Hydrogen peroxide	✓	✓		✓
Caro's acid		✓	✓	
Alkaline chlorination	✓	✓		✓
Iron precipitation	✓	✓	✓	✓
Activated carbon	✓	✓		✓
Biological	✓	✓		✓
Cyanide recovery		✓	✓	✓
Natural attenuation	✓	✓	✓	✓

An example of cyanide destruction and seepage recovery is given in the case study below.

### **CASE STUDY: Cyanide destruct and seepage recovery at the Granites-Bunkers inpit TSF**

The Granites lease is about 550 kilometres north-west of Alice Springs and is owned and operated by Newmont Tanami Operations (NTO). It has been operating since the mid 1980s. The mine initially placed tailings in conventional paddock tailings storage facilities (TSF) and later expanded this practice to inpit tailings disposal.

For inpit tailings deposition, tailings slurry is pumped and discharged into one of a number of mined out pit voids. Process water is recovered from pits and reused through the process circuit. The tailings slurry is pumped at 60 percent solids and contains 130 milligrams per litre WAD cyanide at the process plant. Without adequate controls, the WAD cyanide levels may pose risks to wildlife and groundwater quality. The Tanami region sits within the east Asian-Australasian flyway for migratory shorebirds. Daily bird checks conducted on the Granites lease since early 2005 have detected 12 of the 43 species listed in the 1993 National Plan for Shorebird Conservation in Australia. A further three species are likely to be found in the area during migration but have not been sighted on the lease. The Newmont Standard for Tailings Management states that tailings activities will not impact on groundwater.

This case study discusses how these risks are addressed in the operation of the latest inpit tailings facility on the Granites lease, Bunkers Hill pit.

### ***Bunkers Hill pit***

The Bunkers Hill pit is a relatively small pit located in the western end of the Granites lease. It is about 1.3 kilometres from a freshwater bore which provides potable water for the nearby outstation which receives infrequent visits from the local senior Traditional Owner and his family. The main concern associated with tailings deposition in Bunkers Hill pit was the potential for contamination of this freshwater bore.

Although hydrogeological investigations indicated that there was no connectivity between the aquifers around Bunkers pit and the aquifer used by the outstation, additional control measures were implemented to further reduce the risk and to satisfy the Newmont standards for tailings management as well as the Cyanide Code.

### ***Cyanide destruction***

A cyanide destruction system was installed at the process plant to reduce WAD cyanide levels to below 50 milligrams per litre, prior to discharge to Bunkers pit. The system uses Caro's acid generated on site in a small reactor supplied by Solvay Interlox. The Caro's acid is produced by mixing sulphuric acid and hydrogen peroxide. Cyanide is oxidised by the Caro's acid to form a cyanate ion, which is relatively inactive. The principle purpose of the Caro's acid plant is to maintain safe WAD cyanide levels in the pit, so that any birds that visit the pit will not be affected. The installation and use of this system is a key part of NTO's program for ensuring compliance with the Cyanide Code.

The occupational health and safety risk aspects of operating a cyanide destruct plant need to be carefully considered and weighed up against the environmental benefits of such a system. Risks include transporting additional hazardous chemicals to site and ensuring that exposure of plant operators to these chemicals is managed carefully. The addition of these chemicals to the plant infrastructure has also involved a considerable amount of training in the handling of the chemicals and the maintenance of the facilities holding these chemicals.



**Granites processing facility**

### ***Seepage recovery***

NTO commissioned Robertson GeoConsultants Inc to investigate options for mitigating potential impacts to the surrounding groundwater systems during tailings discharge into Bunkers Hill pit. The preferred option to limit groundwater contamination was to install seepage recovery bores.

The bulk permeability of the bedrock (schist and granite) surrounding Bunkers Hill pit is estimated to be in the order of  $1 \times 10^{-6}$  metres per second. The pumping yield and radius of influence of each bore is limited due to the nature of the fractured bedrock. The installation includes six bores at 400 metres spacing to a depth of around 70 metres in order to achieve acceptable tailings seepage recovery. Five bores were found to be viable for use as seepage interception bores. Commissioning problems with the seepage recovery system are being experienced and are being addressed.

### ***Stakeholder acceptance***

NTO has consulted extensively with the Department of Primary Industries, Fisheries and Mines (DPIFM) and the Central Land Council (CLC), on behalf of the Traditional Owners. The Traditional Owners have expressed a desire that Bunkers Hill pit be filled and rehabilitated in the same manner as the Bullakitchie pit, also located on the Granites lease.

### ***Conclusion***

There are potential environmental impacts associated with in-pit tailings deposition in the Tanami including fauna mortalities associated with cyanosis and groundwater contamination. The water surrounding Bunkers Hill pit has been found to range from brackish to saline. The deposition of tailings into Bunkers Hill pit will probably result in a saline plume infiltrating the surrounding bedrock and being detectable for up to 250 metres from the pit. Tailings into Bunkers pit commenced in June 2007 and to date, groundwater contamination has only been detected in one seepage interception bore. As yet there is no evidence of connectivity between the surrounding groundwater and the pit in the other seepage interception or monitoring bores. This may change as the tailings rises in the pit, therefore, the bores are routinely monitored.

It is believed that the potential impacts can be managed by implementing cyanide destruction technology, installing a seepage interception system, and with diligent operational management and monitoring.



The key to successful implementation of cyanide treatment processes is to consider the following (Botz 2001):

- Site water and cyanide balances under both average and extreme climatic conditions
- The range of cyanide treatment processes available and their ability to be used individually or in combination to achieve treatment objectives
- Proper testing, design, construction, maintenance and monitoring of both water management and cyanide management facilities.

By carefully considering these aspects of water and cyanide management before, during and after mine operation, operators can reduce the potential for environmental impacts associated with the use of cyanide.

Another aspect of cyanide treatment to be considered is the potential environmental impact of the cyanide-related compounds cyanate, thiocyanate, ammonia and nitrate. These compounds may be present in mining solutions to varying extents and may require treatment if water is to be discharged. Each of these cyanide-related compounds is affected differently in the treatment processes discussed and this should be considered when evaluating cyanide treatment alternatives for a given site.

#### **Box 7: Cyanide waste management**

Effectively managing waste cyanide by integrating and applying knowledge from a variety of disciplines will contain cyanide and reduce its impact on the environment (Ritcey 1989). Leading practice in cyanide waste management is a subset of leading practice in tailings management and the *Tailings Management* handbook in this series (DITR 2007a) provides further information. Some of the main considerations in planning, operating and closing a (tailings) disposal facility critical to cyanide management are:

- high engineering standards in the design, construction, maintenance and decommissioning of TSFs, including consideration of design aspects to deter wildlife access
- reliable barriers—sufficient geotechnical, hydraulic and engineering design data should be gathered at the planning stage to show that safe containment, aimed at essentially zero-discharge, can be achieved
- volume of effluent generated—this will affect the optimum size of the facility and can be assessed using hydrological models within the overall water management plan
  - inflows—water with tailings, precipitation, other inflows (such as catchment runoff, sewage, concentrated effluents, groundwater)
  - outflows—return water, evaporation, interstitial water (water retained in the pores of tailings), seepage loss (no dam or pond structure is completely watertight)
- effluent characteristics (components, concentrations, physico-chemical properties) –in the case of cyanide, other components of the waste matrix may enhance retention, degradation or attenuation of toxicity, that is, they act as chemical barriers

- expected quality of seepage water and the types of cyanide that may contaminate it (see Section 2.1)
- expected seepage rates
- presence of natural drainage channels
- the natural capacity of underlying strata to attenuate seepage contaminants
- assessment of groundwater quality and condition - amount and quality of water, depth to water table, ability of aquifer to transmit water, type and degree of current use
- monitoring of the waste facility, physical loss pathways and the environment for cyanide forms.

See also the case study below on the chemical characterisation of a tailings storage facility at Wiluna.

### **CASE STUDY: Chemical characterisation of a tailings storage facility at Wiluna gold operations**

When the closure of the tailings storage facility (TSF) at Wiluna gold operations was being considered in late 2000, it was decided to assess the potential environmental risk that the closure option might pose.

New TSF characterisation techniques and analytical methodology developed by the WA Chemistry Centre were applied. At five locations evenly spaced from the edge of the TSF to the centre of the structure, holes were drilled from the surface to the base of the TSF and cores were collected at one metre-intervals. These samples were complemented with regular groundwater monitoring from bores around the TSF. In addition, HCN emissions were measured on the dry TSF, no discharge had been directed to this TSF for some months to provide the best conditions for the assessment.

Since the Wiluna operations processed a sulfidic-high, arsenic-containing ore, there was concern regarding the risk posed to the environment from residual arsenic and non-oxidized sulfides to acidify the tailings residue and release cyanide and metals, including arsenic, into the environment. As a result the characterisation assessment included the analytical determination of cyanide species (total cyanide, WAD cyanide, metal cyanide complexes of Au, Co, Cr, Cu, Fe<sup>2+</sup>, Fe<sup>3+</sup>, Ni and derivatives NH<sub>3</sub>, SCN and OCN), heavy metals, complete acid base accounting (ABA) and leachability using distilled water and TCLP tests. A complete mineralogical determination was made of each test sample.

#### ***Assessment of HCN emissions from the TSF***

HCN emissions were measured at a height of 100 millimetres at five locations on the TSF using the NIOSH procedure (wind velocity between three and 12 knots, ambient temperature about 40°C). All HCN concentrations in the air above this dry TSF cell were <0.002 mg CN-/m<sup>3</sup>. At these levels any HCN emissions are unlikely to cause any environmental or human health problems.



## **Chemical Characterisation of Tailing Storage Facility**

### ***Assessment of potential cyanide impact***

The impact on the environment from cyanide parameters was determined after careful assessment of each of all the above-mentioned cyanide forms throughout the depth of each hole drilled in the TSF. In addition the correlation with the detailed mineralogy profile was determined.

Virtually all the cyanide in the TSF was locked up as iron cyanide complexes with minor contribution from the cobalt cyanide complex and traces of copper cyanide complexes. The iron cyanide complexes reduced in all holes from the surface to the base and from the edge of the TSF towards the centre. The attenuation of the iron and cobalt cyanide complexes appeared to be strongly correlated with the presence of mica/illite mineralogy. Any mobility would be very slow through the TSF.

Leachable cyanides were very low and, based on computer modelling, would have a negligible small discharge to the groundwater. Groundwater monitoring results confirmed this.

### ***Assessment of leachability and acid base accounting***

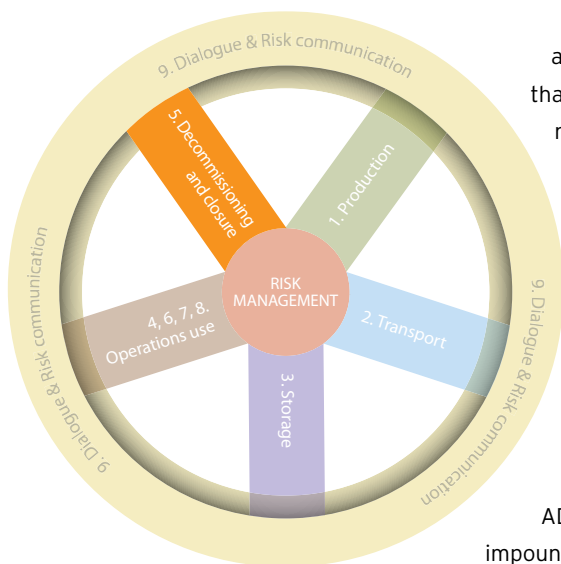
The results from the TCLP extracts indicated that moderate amounts of iron and manganese will be leached from the TSF residue if the leaching solution is weakly acidic (pH of around five). None of the potential environmentally toxic metals, including arsenic, were leached to any significant amount. The ABA results indicated that a significant neutralising capacity existed throughout the profile. Distilled water extracts were alkaline with considerable bicarbonate and some carbonate salts content. All sulfur present in the TSF was in the oxidised sulfate form and not available for acid production.

### ***Conclusion***

Some minor seepage may occur, particularly following heavy rainfall events. These seepages and the potential eluants are expected to be well below regulatory requirements. The TSF was unlikely to become acidic since it is acid consuming.

### 5.3.6 Decommissioning and closure

The Code requires that standards of practice be established to protect communities and the environment from cyanide. The standards of practice require the development and implementation of decommissioning plans for cyanide facilities that protect human health, wildlife and livestock and provide assurance mechanisms that are capable of providing fully funded, cyanide-related, decommissioning activities.



*Enduring Value* (MCA 2004), the global mining industry has recognised that a mine closure and completion plan need to be in place. The overall key principles and elements of mine closure are described in detail in the Leading Practice Handbook on *Mine Closure and Completion* (DITR 2006b) and provides a pathway for mining industry to meet the requirements of the Code.

Particular attention also needs to be paid to ensuring that excessive levels of AD cyanide do not remain in tailings

impoundments and that degradation products from cyanide such as thiocyanate, cyanate and

nitrate do not cause further impacts in the future.

### Options for removal of cyanide degradation products

#### *Constructed wetland systems*

Constructed wetland systems are recognised as an ecologically sustainable option for water pollution control, particularly the removal of nitrate and cyanate which degrades to ammonia and carbon dioxide. Thiocyanate will dissociate under mildly acidic conditions and will chemically and biologically oxidise into carbonate, sulfate and ammonia. Thiocyanate is about seven times less toxic than cyanide. There are basically two types of constructed wetlands (Greenway 2004).

- Free water surface (FWS) systems that consist of channels, or free-form, shallow basins, with a natural or constructed base of clay or impervious geotechnical material to prevent seepage, and a layer of suitable substrate to support rooted emergent macrophytes. Water depth can vary to suit the plant species used and lagoon configurations can also support emergent macrophytes.

- Sub-surface flow (SSF) systems comprising SSF trenches with impermeable lines and substrate of gravel and/or soil supporting emergent macrophytes such as *Typha* sp., which is commonly found on mine sites. The systems can be designed to allow the wastewater to flow horizontally through the root zone maximising filtration and sorption in the substrate, nutrient uptake by plants and micro-organisms, and the microbial degradation. Vertical flow systems and layered gravel-sand reed beds are typically dosed intermittently from the top with wastewater. The wastewater drains vertically down. The bed is then allowed to aerate before the next dosing. The absence of standing water precludes the use of many truly aquatic plant species.

### ***Land treatment of wastewater***

There are distinct types of land-based systems for wastewater treatment, each defined by their own characteristic loading rates, types of soil and operation (Matsumoto 2004). These are slow rate, overland rate and rapid infiltration systems. When considering a land-based system it is important to look at the soil conditions.

Generally slow rate systems are able to achieve the highest level of overall nitrogen removal. Although most water does not percolate into groundwater, when designed for nitrogen removal, the slow rate system hydraulic loading rate is limited by the amount of nitrate that is expected to enter the groundwater.

Overland flow systems are used in areas where soil has low permeability, such as clayey soils. In overland systems wastewater is applied at the top of a slope covered by grass or vegetation and allowed to flow down to a collection ditch. This process allows for higher loadings than for slow rate systems. Very little of the applied wastewater percolates into groundwater and very little is lost via evapotranspiration.

### ***Microbial treatment***

The treatment of wastewater in microalgal-bacterial treatment ponds exploits the physical and biochemical interactions that occur naturally in aquatic systems to remove nitrogen (Hurse and Connor 1999). The system of microalgal-bacterial treatment ponds has been viewed as effective and a low-cost method of removing nitrogen from wastewater. In theory, nitrogen in cyanide degradation products is converted to nitrogen gas and will be lost to the atmosphere by going through the three major biological transformations during removal of nitrogen in microalgal-bacterial treatment ponds. Microbe-based treatment techniques are efficient in achieving denitrification but have ongoing maintenance issues. They may be stand-alone facilities or ponds, or may be added to other specific processes to create bioreactors.

Wastewater containing nitrogen can be treated on a large scale using a bioreactor, with packed gel envelopes. The envelopes are constructed from non-woven fabrics which are attached with polymeric gel containing bacteria that remove either nitrate or ammonia. These specialist techniques need to be carried out by skilled personnel.

### ***Reverse osmosis***

Reverse osmosis facilities are efficient at removing dissolved salts including nitrate/nitrite but are expensive to maintain. This approach may be suitable for treatment of smaller volumes of water but not on a large scale.

### ***Phytoremediation of cyanide-contaminated soils***

Phytoremediation may be applicable to take up free and complexed metal cyanide compounds. However, not much is known about uptake of cyanides into plants, the phytotoxicity or degradation kinetics. Total cyanide concentrations up to 1000 milligrams per kilogram as mainly iron complexes can be tolerated by certain tree species (Trapp & Christiansen 2003). Transpiration of trees will reduce infiltration of water and thereby minimise the leaching of cyanide to groundwater. A risk assessment needs to be undertaken at any site utilising phytoremediation to ensure that plants and trees do not accumulate cyanide.



## 6.0 RESEARCH AND DEVELOPMENT ACTIVITIES IN AUSTRALIA

The use of cyanide in the mining industry in Australia has been supported by a number of significant cross industry/organisation activities and programs of ACMER, AMIRA, MERRIWA, MCA and the Northern Territory Bird Usage of Tailings Storage Facilities Coordinating Group.

The AMIRA Project P497 'Cyanide Waste Management: Minimising Environmental and Economic Impacts', completed September 1997 was a significant project. Its 10-year time limit before the project is made publicly available has almost expired. AMIRA may soon allow the use of the 'Comprehensive Literature Compilation and Critical Review of Cyanide Behaviour and Control'. Phase 2 of the AMIRA P497A project deals with the experimental research results and is available from MERRIWA Project M309 Report No 214.

The Northern Territory Mining Water Tailings Bird Usage and Mortality Study, conducted from 1996 to 1997 (Donato 1999) identified susceptible bird species and showed that reducing WAD cyanide levels to below 50 milligrams per litre reduced bird mortalities.

The ACMER Project R58 assessed risk of the effects of cyanide-bearing tailings solutions on wildlife, and involved case studies at several Australian mine sites. The outcomes of the project will be placed on the ACMER web site at [www.acmer.uq.edu.au](http://www.acmer.uq.edu.au).

A follow-up study under MERRIWA, Project M398, builds upon R58, but with specific reference to hyper saline tailings. Both AMIRA P420A-C Gold Processing Technology and the Parker Centre-Gold Market have research into optimisation/improvements of the cyanidation process and alternatives to cyanide.



## 7.0 CONCLUSION

Cyanide handling and management are clearly linked to the profitability and sustainability of gold mining. As one of 14 themes in the Leading Practice Sustainable Development Program for the Mining Industry, this cyanide management handbook has identified the key issues relating to cyanide use that may affect sustainable mining. The handbook provides information and several practical case studies that identify a more sustainable approach for the industry and updates the principles and procedures of cyanide use outlined in the Best Practice Environmental Management *Cyanide Management* booklets (Environment Australia 1998, 2003).

This handbook is released at a pivotal period for the gold mining industry, particularly in light of the sustainable development issues discussed in the context of the Minerals Council of Australia's *Enduring Value* (2004), and industry take-up and implementation of the International Cyanide Management Code (ICMI 2006) (the Code) together with recent regulatory changes. Through compliance with the Code—a guide to risk-based management—the Australian gold mining industry is developing leading practice cyanide management. The chemical properties and management of cyanide as a hazard are now generally well understood.

Complying with the Code provides the mining industry with the means to control the potential exposure of workers and communities to harmful concentrations of cyanide, limit releases of cyanide to the environment, and to enhance response actions in the event of an exposure or release. It also makes good business sense. In keeping with the goal of achieving sustainable development, leading practice mining companies take a proactive approach to cyanide management and achieve stakeholder acceptance of the continued use of cyanide in mining activities.

This handbook covers relevant aspects of cyanide use in mining from production through to final disposal or destruction. It is a resource for mine planners and mine managers, but will also be relevant to environmental staff, consultants, government authorities and regulators, non-government organisations, interested community groups, and students.



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- AMIRA International [www.amira.com.au](http://www.amira.com.au).
- "The Cyantists" website [www.cyantists.com](http://www.cyantists.com).

## GLOSSARY

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Aq	Aqueous medium.
Barren pond	Storage pond for solution from which gold has been extracted.
Bund	A low embankment often constructed around potential spillage areas to reduce the risk of environmental contamination. It is important these structures can retain the volume of any potential spillage.
CIL	Carbon-in-leach. A process used to recover gold into activated carbon during the agitation leach process.
CIP	Carbon-in-pulp.
Cleaner production	Cleaner production is a strategy to continuously improve products, services and processes to reduce pollution and waste at the source, which can also result in financial benefits.
Cyanide	A singularly charged anion consisting of one carbon atom and one nitrogen atom joined with a triple bond, CN <sup>-</sup> .
Cyanide forms	These are complexes of cyanide with gold, mercury, cobalt, and iron that are very stable even under mildly acidic conditions. Both ferrocyanides and ferricyanides decompose to release free cyanide when exposed to direct ultraviolet light in aqueous solutions. This decomposition process is reversed in the dark. The stability of cyanide salts and complexes is pH dependent and, therefore, their toxicities can vary.
Eco-efficiency	Eco-efficiency is a combination of economic and ecological efficiency, and is basically about 'doing more with less'. Eco-efficiency means producing more goods and services with less energy and fewer natural resources. Eco-efficient businesses get more value out of their raw materials as well as producing less waste and less pollution.
EMS	Environmental management system.
Free cyanide	The most toxic form of cyanide which includes the cyanide anion itself and hydrogen cyanide, HCN, either in a gaseous or aqueous state. At pH 9.3 to 9.5, CN <sup>-</sup> and HCN are in equilibrium with equal amounts of each present. At a pH of 11, more than 99 percent of the cyanide remains in solution as CN <sup>-</sup> , while at pH 7, more than 99 percent of the cyanide will exist as HCN.
Heap leach	Using chemicals to dissolve minerals or metals out of an ore heap. During heap leaching of gold, a cyanide solution percolates through crushed ore heaped on an impervious pad or base pads.

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Hydrogen cyanide	Hydrogen cyanide, HCN, is highly soluble in water but its solubility decreases with increased temperature and under highly saline conditions. Both HCN gas and liquid are colourless and have the odour of bitter almonds, although not all individuals can detect the odour.
IBC	Intermediate bulk container.
LC50	Median lethal concentration—the concentration of material in water that is estimated to be lethal to 50 percent of organisms. The LC50 is normally expressed as a time-dependent value, such as, 24-hour or 96-hour LC50—the concentration estimated to be lethal to 50 percent of the test organisms after 24 or 96 hours of exposure.
Lixiviant	Chemical leaching agents to extract gold.
Metal cyanide complexes	Metal cyanide complexes form salt-type compounds with alkali or heavy metal cations, such as potassium ferrocyanide ( $K_4Fe(CN)_6$ ) or copper ferrocyanide ( $Cu_2[Fe(CN)_6]$ )’ the solubility of which varies with the metal cyanide and the cation. Almost all alkali salts of iron cyanides are very soluble. Upon dissociation these double salts dissociate and the liberated metal cyanide complex can produce free cyanide. Heavy metal salts of iron cyanides form insoluble precipitates at certain pHs.
MSDS	Materials safety data sheets.
pH	The measure of acidity (or alkalinity) defined as being the negative log (to base 10) of the free hydrogen ion concentration. The pH scale ranges from 0 to 14; a pH of 7 is neutral, less than 7 acidic and more than 7 alkaline.
PPE	Personal protective equipment
Sparging	A procedure designed to minimise operator exposure to cyanide during transfer from transport container to storage facility at a mine site. Solid sodium cyanide (98 percent, in tablet form) is transported in 20-tonne containers. At the mine site, these are flushed with water through a system of valves and pipes directly into storage tanks.
Tailings	Material rejected from a mill normally as a slurry after the recoverable valuable minerals have been extracted. Tailings resulting from ore processing involving cyanide will contain cyanide in various chemical forms and concentrations as well as crushed ore, various metals and minerals, and other chemical additives. Tailings are typically discharged to a TSF.



TLV	Occupational exposure standard for handling cyanide—this is 5 mg/m <sup>3</sup> for sodium cyanide powder and 10 ppm for hydrogen cyanide gas.
TSF	Tailings storage facility.
Volatilisation	Release of gaseous phase of a chemical, in this handbook cyanide gas (HCN).
WAD cyanide	Weak acid dissociable (WAD) cyanide comprises both the free cyanide and the weak or moderately stable complexes such as those of cadmium, copper and zinc, that is readily released from the cyanide-containing complexes (cyanide forms) when the pH is lowered using a weak acid such as acetic acid. The detailed definition of WAD cyanide may differ depending on the analytical method used (refer to Appendix 1).

# APPENDIX 1: PROTOCOLS FOR FIELD SAMPLING, MONITORING AND ANALYSIS

Amended from APHA 4500-CN, 2005 and the International Cyanide Management Code.

The correct sampling and sample handling of cyanide, prior to delivery to the laboratory, is of utmost importance:

**The result of analysis can be no better than the sample on which it is performed.**

While the taking of aqueous or solid samples may appear easy, the collection of correct samples, both in terms of location and with respect to the analytes to be monitored, is fraught with difficulties. Any sampling must focus on collecting a representative portion of the substance to be analysed. When the portion is presented for analysis, the parameters to be determined must be present in the same concentration and chemical or biological form as found in the original environment from which the portion was removed.

Once samples are removed from their natural environment, chemical or biological reactions can occur to change the composition of the sample. Preservation of the sample will keep the parameter of interest in the same form as it was prior to the removal from its surrounding. No single preservation technique will preserve all parameters, so each parameter of interest must be considered and preserved specifically.

## Representativeness of sampling

### *Process water ponds and tailings ponds*

Because the environment being sampled dictates where the samples should be taken, they must be representative of the liquor present. For process water ponds, they must be taken at inlet and outlet points and at a standard, measured site from the pond edge. If conditions are dynamic, transect and depth profile sampling will be needed.

For tailings ponds, samples must be taken at the inlet and from decant ponds. These samples are likely to be non-homogeneous due to changing inlet locations for tailings. It may be necessary to make specific studies of surface transects and depth profiles to understand homogeneity characteristics. To gain access to all areas, flat bottom boats or a hovercraft may be needed. Water, tailings and biota may all need to be sampled.

### *Heap leach, groundwater and surface waters*

Samples from a heap leach should be taken at the main drainage collection point and at any seepage point.

Sampling of groundwater could be from shallow water or deep bores. It is preferable to take samples by pumping rather than bailing. Water quality should be checked for consistency of flow and samples taken and prepared on site.

When sampling surface waters the following must be taken into account: flow characteristics of streams or rivers; the extent of the mixing zone; downstream impacts; and designated monitoring sites using a geographic positioning system (GPS) to identify coordinates or locate on aerial photographs.

### ***Sample composition***

It is important to make use of composite sampling and to take at least five samples. Grab samples may be representative of flow during a short period and any other sample shown to be representative of waters being sampled may be applicable.

### **Field collection and sample preservation**

The collection of samples for cyanide determination will require treatment to preserve the constituents. Procedures such as those described by APHA and ASTM are complicated and not easily undertaken in the field. This problem can be overcome by using a field laboratory facility or truck (Noller et al. 1993).

### ***General conditions applying to sample preservation (Mudder et al. 2001)***

- Cyanide species exist as cyanide ion, molecular cyanide and/or metal cyanide complexes
- Thiocyanate, ammonia and cyanate may be present
- Iron cyanide complexes are subject to photolytic degradation
- Metal cyanide complexes vary in stability and solubility
- Thiocyanate acts as an interference
- Sulfides and reduced sulfur compounds interfere through formation of thiocyanate
- Oxidants such as residual chlorine or hydrogen peroxide are known to interfere.

### ***Factors affecting cyanide stability prior to analysis (Mudder et al. 2001)***

- Cyanide standards in de-ionised water, preserved by the addition of sodium hydroxide to pH > 12 and kept at 4°C in the dark, are generally stable.
- Complex solutions from gold processing waters are unlikely to be stable or represented if preserved only as above.
- Exposure to light will cause degradation of iron cyanide complexes. Elevated temperatures and agitation will cause loss of cyanide from solution.
- Sulfide or reduced sulfur compounds must be removed prior to pH elevation to prevent thiocyanate formation.
- Oxidising compounds must be removed.
- Solids in the sample will adsorb cyanide and give lower values.
- Filtration alone may reduce the cyanide value.
- Volatilisation at pH < 10.5 is a major source of free cyanide loss.
- Sodium hydroxide will become contaminated if exposed to a cyanide atmosphere.
- Pre-scrubbing of air entering the distillation flask may be required to avoid contaminating a sample.

### **Recommended preservation procedure**

Due to the high reactivity of cyanide sample solutions, they must be tested for the main interferants, oxidising substances and sulfides on site and, if present, the interferant must be removed prior to preservation.

Oxidants interfere by oxidising cyanides to cyanates which are not detected in the normal total cyanide, WAD cyanide and free cyanide procedures, therefore, the results will be negatively affected.

The presence of oxidants is detected by potassium iodide/starch test papers. Moisten the test strip with a sodium acetate buffer solution and place a drop of sample solution on it. A blue discoloration of the test paper indicates the presence of sufficient oxidant to potentially react with the cyanide present during transport to the laboratory. The oxidant must be reduced prior to preserving the sample.

#### ***Procedure for removal of oxidising matter***

1. Remove and retain any solids by decantation or pressure filtration.
2. Add sodium arsenite\* (very toxic, refer to MSDS) and mix. About 0.1 g/L is usually sufficient.
3. Retest, if test strip discolours again, retreat as per step 2.
4. Return solids (from 1.) to sample solution and raise pH to 12 by adding 1-2 pellets of solid sodium hydroxide. \*\*

The presence of sulfides is indicated by lead acetate test paper turning black. Place a drop of the sample solution on previously moistened (with acetic acid buffer solution) lead acetate test paper and if the test paper darkens, sulfides are indicated. Sulfides are removed by reaction with lead carbonate.

#### ***Procedure for removal of sulfides***

1. Remove and retain any solids by decantation or pressure filtration.
2. Add lead carbonate (about 0.1 g/L) and mix.
3. Remove the formed black lead sulfide precipitate by pressure filtration and discard the precipitate.
4. Retest the sample solution. If test strip is discoloured, retreat as for steps 2 and 3.
5. Return solids (from 1.) to sample solution and raise pH to 12 by adding 1-2 pellets of solid sodium hydroxide. \*\*

Samples should be stored in a dark place at about 4°C, such as an esky (cool box) during transport to the laboratory.

Soil samples for cyanide analysis (as cores or in jars) must be wrapped in dark plastic and kept cool at 4°C without further treatment.

Note: \* Sodium arsenite is the preferred reagent but needs to be handled with care. Ascorbic acid is no longer recommended as it forms cyanide in the presence of nitrite or nitrate during the distillation process. Sodium thiosulfate is not recommended as any excess remaining after

reducing the oxidant will react with cyanide to form thiocyanate.

\*\*Sample solutions that are saline or hypersaline should be treated cautiously as up to 30 sodium hydroxide pellets may be required to raise the pH to 12. This is excessive as the pH cannot be raised until all magnesium present in the sample solution has been precipitated. Only then can the pH be raised. This magnesium precipitate will remove other analytes (metals and metal complexes) from solution and may lead to lower results. The addition of extra sodium hydroxide pellets to improve the stability of the changed sample matrix should be carefully weighed up against the potential erroneous results. Special arrangements, such as faster delivery to the laboratory and priority treatment for key analytical parameters, may be preferable and should be negotiated with the service laboratory.

### Apparatus and chemicals

1. Field filtration unit, preferably hand-operated syringe (not vacuum filtration)
2. 500 mL black plastic (HDPE) screw-top bottles
3. Sodium arsenite (poisonous)
4. Lead carbonate powder
5. Sodium hydroxide pellets (corrosive)
6. Potassium iodide starch test paper
7. Lead acetate test paper
8. Plastic teaspoons
9. Esky with ice or cold bricks
10. Acetate buffer pH 4
11. Gloves and protective clothing
12. Extendable sampling pole.

#### NOTE:

1. If, after several weeks of sampling, no sulfides and/or oxidising agents (such as hydrogen peroxide, chlorine) have been detected—and if metallurgical advice is that sulfides and/or oxidising agents are unlikely to be encountered in the future, steps 3 and/or 5 can be omitted. However, it is worth checking every few weeks for sulfides and oxidising agents.
2. For cyanide at levels of less than 100-200 ppb CN (0.1-0.2 milligrams per litre), the test strips may not be able to detect correspondingly low levels of oxidants and sulfides. It is therefore advisable to treat such samples for oxidants and sulfides using the procedures described above. If test strips are not available, then apply the treatment for oxidants and sulfides.

**\*CAUTION:** Sodium hydroxide is corrosive. Do not handle with bare hands!

### References

Mudder, TI, Botz, MM & Smith, A 2001, *The Chemistry and Treatment of Cyanidation Wastes*, 2nd edn, Mining Journal Books Ltd, London.

## APPENDIX 2: CYANIDE SAMPLING, MEASUREMENT AND ANALYSIS

This summary is based on Noller (1997), Mudder et al. (2001), and the International Cyanide Management Code (ICMI 2002).

Cyanide has a complex chemistry (see Section 2), and its monitoring is correspondingly complex. Cyanide can exist in soluble and insoluble forms as both simple and complex metal cyanide species as well as derivatives such as thiocyanate and cyanate. The presence and stability of these cyanide species is influenced by the sample matrix and its exposure to external influences—both chemical and physical—such as mining and milling processes. Hence degradation products containing nitrogen or sulfur may need to be monitored to understand the proportion of chemical forms present.

The chemical forms of cyanide to be quantified and their degradation products in tailings solution or seepage will determine which preservation techniques are appropriate. These are described in detail in Appendix 1.

### Requirements and design

Many sampling regimes may be developed and the main basic approaches are depicted in the following table:

APPROACH	NO OF SAMPLES	POTENTIAL RELATIVE BIAS	BASIS OF SITE SELECTION	COST
Judgmental	Small	Very large	Prior history, visual assessment, and/or technical judgement	Low
Systematic	Large	Large	Consistent grid or pattern	High
Random	Very large	Small	Simple random selection	Very high

A sampling scheme such as that of Maher et al. (1994) is suggested, taking into account all aspects of the mine project, and any phenomena that may change with time. The design must be such that the expected routine analytical results can provide assurance with respect to the quality of the plant operations as well as any potential effects on the environment such as surface and groundwater resources and the health of local and migratory wildlife. Some of the monitoring requirements should include:

- problems or questions being addressed and their relationship to the sampling procedures
- monitoring during mining/milling phase
- monitoring after rehabilitation

- forms of cyanide being monitored
- process control of gold extraction
- environmental fate, for example, cyanide in tailings dam and heap leach groundwater
- environmental effect on biota—birds accessing ponds or beached areas, heap leach
- environmental impact of any discharge to surface waters and toxicity testing.

### Where to sample

Samples are taken to determine the efficient operation of the gold leaching process and suitable sites within the plant are selected by the metallurgical staff. Sites for environmental considerations include process water ponds, tailings dams, seepage trenches, recovery drains (heap leach), and groundwater. Actual sampling locations to meet objectives of the site environmental management plan are best determined in consultation with environmental protection experts.

If there is discharge of cyanide-containing wastewater to external waterways, samples should be taken from surface water upstream of discharge and surface water within and downstream of the mixing zone. The extent of the mixing zone should be established to allow the determination of any downstream effects to be established. Note that in tropical waters cyanide degradation may be very rapid.

### Sampling frequency

Depending on the aim of the monitoring, including compliance monitoring for regulators and/or the International Cyanide Code, the frequency may vary significantly from every few minutes to hourly, daily, weekly, or at some special interval. Automatic samplers and analysers should be considered for fixed short-time interval sampling such as as currently used in leach circuits. Replicate samples should be included every five to 10 samples and a blank included in each batch sent to the laboratory.

Some suggestions for sampling locations and for representativeness are provided above.

### Selecting an analytical method for cyanide determination

A quality, NATA-accredited laboratory for the required cyanide assays—that has the necessary technical experience including basic knowledge of cyanide chemistry, and an understanding of the strengths and weaknesses of the various methods—will provide the best results. Accepted methods are provided in the table below.

Table of primary and alternate analytical methods

ANALYTE	METHOD	COMMENTS
Free cyanide	AgNO <sub>3</sub> titration	Preferred method For process solutions primarily above 1 mg/L LQL <sup>1</sup> : 1 mg/L HCN(aq), CN <sup>-</sup> , Zn(CN) <sub>x</sub> , parts of Cu(CN) <sub>4</sub>
	AgNO <sub>3</sub> titration with potentiometric endpoint detection	Alternate method Precise method of endpoint determination, measures same species as primary method
	Micro diffusion of HCN from static sample into NaOH [ASTM D4282]	Alternate method close to 'free cyanide'
	Ion selective electrode	Alternate method close to 'free cyanide'
	Direct colorimetry	Alternate method HCN (aq), CN <sup>-</sup> , Zn(CN) <sub>x</sub> , parts of Cu(CN) <sub>4</sub> + ?
	Amperometric determination	Alternate method Measures same species as primary method
WAD cyanide	Manual distillation pH4.5+ potentiometric or colorimetric finish [ISO/DIS 6703/2, DIN 38405 Part 13.2:1981-02]	Preferred method LQL1: 0.05 mg/L HCN(aq), CN <sup>-</sup> , Zn/Cd/Cu/Ni/Ag(CN) Better results than ASTM method in presence of high copper concentrations
	SFIA in line micro-distillation pH 4.5 + colorimetric finish [ASTM D4374]	Alternate method Measures same species as primary method
	FIA In-line ligand exchange + amperometric finish [US-EPA OIA-1677]	Alternate method Measures same species as primary method
	Picric acid, colorimetric determination	Alternate method Measures same species as primary method
Total cyanide	Manual distillation + titration/potentiometric or colorimetric finish [ISO/DIS 6703/1,DIN 38405 Part 13.1:1981-02]	Preferred method LQL <sup>1</sup> : 0.10 mg/L HCN(aq), CN <sup>-</sup> , Zn/Cd/Cu/Ni/Ag/Fe(CN) <sub>x</sub> , parts of Au/Co/Pt/Pd(CN) <sub>x</sub>
	SFIA, in-line UV irradiation, micro-distillation + colorimetric finish [ASTM D4374]	Alternate method Measures same species as primary method also Cr(CN) <sub>x</sub> and better recovery of Au/Co/Pt ?/ Pd ?(CN) <sub>x</sub>

<sup>1</sup>: Lower quantitation level (LQL), is defined as about three times detection level or 10 times the standard deviation at near blank level.



## Processing and preservation of mine samples

Detailed information is provided in the “Protocol for field sample collection and preservation for cyanide determination” above.

## Evaluation of treatment for oxidants

Noller & Schulz (1995) compared various treatments for removing oxidants prior to cyanide analysis (see following tables).

### Table Comparison of treatments for sample preparation

#### Example A

	WAD CYANIDE PPB		TOTAL CYANIDE PPB	
	APHA*	ASTM#	APHA	ASTM
Untreated	130	10	200	225
pH adjusted and lead carbonate	80	30	<10	125
Plus:				
1. No treatment for oxidants	100	30	150	110
2. Ascorbic acid	160	20	110	(-ve)
3. Sodium thiosulfate	100	20	140	(-ve)
4. Sodium arsenite (poisonous)	130	40	<10	125
5. Oxalic acid	130	20	200	140
Blanks	<10	<10	<10	<10

(Thiocyanate measured as <500 ppb)

\*American Public Health Association

#American Society for Testing and Materials

### Table Comparison of treatments for sample preparation

#### Example B

	WAD CYANIDE PPB	TOTAL CYANIDE PPB	THIOCYANATE PPB
Untreated	12	93	400
pH adjusted and lead carbonate			
Plus:			
1. No treatment for oxidants	31	380	700
2. Ascorbic acid	28	180	900
3. Sodium thiosulfate	41	33	400
4. Sodium arsenite (poisonous)	48	84	900
Blanks (all treatments)	<2	<2	<100

## Summary example of measurements

An integrated analytical scheme includes some or all of the following (see Table below as an example):

- total and WAD cyanide
- free Cyanide, if applicable (the differences between WAD and the sum of cyanide species gives an indication of free cyanide concentration)
- cyanide species including thiocyanate
- metal concentrations (Cu, Co, Fe, Cr, Au by ICP-MS)
- Nitrogen species (Total-N, nitrite, nitrate, ammonium).

The use of thiocyanate to standardise colorimetric determination of cyanide has been established (Bianting, Sun & Noller 1998).

**Table Examples of comprehensive cyanide analysis**

	TAILINGS DAM 1 (MG/L)	TAILINGS DAM 2 (MG/L)
Total cyanide	120	9.6
WAD cyanide	95	8.6
Cu-CN	6.3	2.0
Co-CN	< 0.1	< 0.1
Cr-CN	< 0.5	< 0.5
FeII-CN	4.4	0.41
FeIII-CN	< 0.1	< 0.1
Ni-CN	< 0.2	< 0.2
Au-CN	< 0.5	< 0.5
N-NH <sub>3</sub>	0.49	7.9
N-NO <sub>3</sub>	9.4	26
N-Total	100	47
SCN	37	0.6

## Direct spectrophotometric method using picric acid reagent (iamarino 1989)

### Outline

Free cyanide and weak-dissociable cyanide reacts with picric acid in solution to produce a bright orange colour which can be measured using a spectrophotometer at 520 nm. The dissolved alkali metal picrate is converted by cyanide into the coloured salt of isopurpuric acid and its concentration is measured. The presence of a small amount of nickel in analysed solutions has a positive effect on the overall performance of the method. The detection limit of this procedure is 0.26 milligrams per litre. The method is suitable for the determination of weak acid dissociable cyanide. The reduction of picric acid is effected by free cyanide only.

Cyanide that is complexed with copper, nickel, zinc or cadmium complexes can be liberated by metathesis with diethylenetriaminepentaacetic acid (DTPA) or ethylenediaminetetraacetic acid (EDTA). Iron-cyanide complexes, cobalt-cyanide complexes, gold-cyanide complexes, and silver-cyanide complexes do not react leaving their complexed cyanide in tact.

The direct spectrophotometric method allows for the measurement of 20-300 µg cyanide in a sample aliquot of up to 75 millilitres. Samples containing greater than 600 µg cyanide need to be diluted. The method should not be used to measure free cyanide and weak-dissociable cyanide below five milligrams per litre.

### **Interferences**

Thiocyanate, cyanate and thiosulfate ions have no adverse effects and can be tolerated at levels normally occurring in gold mill effluents. Sulfide is a source of interference, 0.1 mg S<sup>2-</sup> being equivalent to 0.025 mg CN<sup>-</sup>. If present, sulfide ions can be readily removed by the addition of lead salts. However, it is unlikely that mill effluents would contain sulfide at levels large enough to significantly interfere in the cyanide determination. Sulfide particles which contact the picric acid reagent due to improper filtering of a gold-bearing slurry will also cause the S<sup>2-</sup> interference.

The method requires close control of pH since it affects the colour intensity produced by the cyanide-picric acid reaction. The most intense coloration results at pH 9.0 to 9.5. For maximum sensitivity and good reproducibility of analytical results, the picric acid reagent solution should therefore be buffered. In the present procedure a mixture of sodium tetraborate and carbonate as well as DTPA itself serve this purpose. DTPA is preferred to EDTA due to more favourable values of acid ionisation constants and stability constants of some metal chelates.

### **Safety precautions**

Picric acid (trinitrophenol) in the dry form has explosive properties and is no longer sold in Australia as a laboratory reagent. Picric acid is sold as a one percent solution (maximum one litre) which is safe to use. However care is needed to ensure that crystals do not form under the lid of the bottle. Solutions of picric acid are safe in ordinary laboratory use. The local regulatory and institutional requirements need to be confirmed by undertaking a risk assessment before use. It may be necessary to collect solutions and have them treated before disposal. Spills must be carefully wiped up. Picric acid has the tendency to stain the skin and therefore, wearing protective hand gloves, is recommended. Glass stained by picric acid is best washed with methanol or acetone.

## Reagents

### *Buffered picric acid reagent*

Dissolve 40g of diethylenetriaminepentaacetic acid and 16 g of NaOH in 300-350 mL of water. Next add, in the order given, 600 mL of one percent picric acid solution, and dissolve 14 g of anhydrous sodium tetraborate or 27 g  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$  and 8 g of anhydrous sodium carbonate. The pH of this solution is 8.7, and would increase to 9.0 on a four-fold dilution. After reacting with cyanide the solution's final pH should be 9.2-9.3.

### *Nickel solution, about 100 mg/L Ni.*

Dissolve 0.22 g of  $\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$  and 1 g of NaCl in 500 mL of water.

### *Standard cyanide solution, 1000 mg/L cyanide*

Dissolve 2.503 g of KCN and 1 g of KOH or NaOH in water and dilute to one litre. Make further dilutions as necessary for the preparation of the calibrating working standard.

## Procedure

Transfer into a 150 mL beaker a suitable volume of samples solution which contains 1-300  $\mu\text{g}$  of cyanide. Add 1 mL of nickel solution, swirl, and dilute with water to about 70 mL. Measure about 70 mL of water in another beaker, add 1 mL of nickel solution and carry through the procedure as the reagent blank. Add 25.0 mL of buffered picric acid reagent to each beaker and heat for 35 minutes on a hotplate with surface temperature adjusted to 160 °C, without allowing to boil. If a white precipitate of calcium carbonate forms add 0.1-0.2 g of EDTA disodium salt. Cool the solutions to room temperature, transfer to 100 mL volumetric flasks and dilute to volume.

Measure the absorbance of the solutions more deeply coloured than the reagent blank at 520 nm using the reagent blank as the reference. The absorbance of the reagent blank usually varies between 0.006 - 0.009 (520 nm, slit width 0.03 mm, 1 cm path cell). Dispose of solutions according to MSDS and regulatory requirements.

## Calibration

Into 150 mL beakers pipette aliquots of the standard cyanide solution containing 25, 50, 100, 200 and 300  $\mu\text{g}$  cyanide. Add 1 mL nickel solution to each of them, mix, and dilute to about 70 mL with water. Add 25.0 mL of buffered picric acid reagent and proceed as described under 'procedure'. Always measure absorbance against the respective reagent blank. Plot the absorbance readings versus  $\mu\text{g}$  cyanide added in the aliquots of the standard cyanide solution, and construct the calibration graph.

## Calculation

Convert the absorbance reading of the aqueous solution or the extract into micrograms of cyanide using the calibration graph. Calculate the cyanide concentration in the original samples solution as follows:

$\text{mg/L CN}^- = A/B$  where : A =  $\mu\text{g CN}^-$  found from the graph and B = volume, in mL, of the sample solution used for the analysis.

## References

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## APPENDIX 3: PROTOCOLS FOR WILDLIFE MONITORING

Wildlife Cyanide Toxicosis: Monitoring of Cyanide-bearing Tailing and Heap Leach Facilities

Compliance with the International Cyanide Management Code (the Code) requires design and implementation of robust monitoring programs for compliance under the following standards of practice: 4.1, 4.4 and 4.9. Industry monitoring of this issue has been inconsistent, with wildlife deaths likely to have been underestimated, and the composition of at-risk species (including threatened and protected species) not well documented (Donato 1999). This may have given the perception that no risk exists or that the impact fluctuates. There are now recognised requirements under the Code for deliberate wildlife observations on cyanide-bearing mine tailings and there is a need to have established protocols for associated analysis of monitoring data. A greater understanding by mining companies of these issues will enable a proactive approach to significantly reduce, or preferably eliminate, these environmental risks. A significant knowledge gap exists in understanding, monitoring and managing the risks of wildlife exposure to cyanide-bearing tailings and, while this remains, full certification under the Code will be challenging for some operations (Donato et al. 2004; Donato & Griffiths 2005).

A robust monitoring regime can be complicated as each processing and tailings system is different. The following metallurgical processing systems are commonly used in Australia: carbon-in-leach (CIL), carbon-in-pulp (CIP), and heap leach process ponds. Tailings disposal systems include peripheral discharge, central discharge and in-pit disposal.

Some terrestrial wildlife can be denied access by fencing or other physical barriers to tailings storage facilities (TSFs), thereby limiting wildlife interaction with cyanide-bearing tailings and solutions to mainly birds and bats.

While wildlife monitoring programs for process plants and TSFs contain similar core attributes, it is necessary to adapt monitoring to take into account the site-specific features of each system. These core attributes are only to be considered appropriate for tailings systems that discharge at less than 50 milligrams per litre weak-acid-dissociable (WAD) cyanide. The issue is considerably complicated if tailings solutions are deemed or discovered to be greater than 50 milligrams per litre WAD cyanide.

Essentially cyanides are required to be measured to gain an understanding of the concentrations to which wildlife may be exposed. This usually equates to measuring the cyanide concentration of solutions entering and leaving a tailings system. To assess the risk to wildlife presented by tailings and heap leach systems it is necessary to monitor both the hazard (cyanide concentrations) and the exposure (live wildlife species, presence and interaction). These tasks need not be arduous and a system of simple frequent monitoring has been developed and implemented for Code compliance. The wildlife monitoring developed by Donato Environmental Services (Smith & Donato 2007) and used at mining operations departs from the industry norm. It documents observer effort, live wildlife presence, habitat and behaviour in a tailings system, as well as deaths and carcasses.

A greater understanding of wildlife cyanide toxicosis associated with this monitoring approach will enable mining companies to adopt a proactive approach to significantly reduce, or preferably eliminate, the impact on wildlife and gain Code compliance more easily.

***Establish a monitoring regime for tailings storage facilities***

Determining the habitat features, identifying the cyanide sampling points, and understanding the at-risk species behaviour in the associated habitats allows operations to develop appropriate monitoring regimes, and comply with the Code.

The table below presents a typical TSF cyanide monitoring regime that measures cyanide concentrations going in and out of a system and the variability.

**Typical routine cyanide monitoring of tailings waste solutions**

TYPE	FREQUENCY	ANALYTES	COMMENTS
Tailings discharge spigot cyanide concentration	At a frequency that takes into account the measured variability. Daily (if >50 mg/L)	CN <sub>WAD</sub> CN <sub>Total</sub> CN <sub>Free</sub> pH	Samples should be taken as early in the morning as possible. Note: duplicate samples should be taken from time to time to examine for analytical error.
Supernatant cyanide concentration (peripheral discharge systems)	At a frequency that takes into account the measured variability. Daily (if >50 mg/L)	CN <sub>WAD</sub> CN <sub>Total</sub> CN <sub>Free</sub> pH TDS	Samples should be taken as early in the morning as possible. Samples should be taken at the decant tower (or return water point).
Spigot-derived pooling (central discharge systems)	At a frequency that takes into account the measured variability. Whenever spigot-derived pooling is present. Daily (if >50 mg/L)	CN <sub>WAD</sub> CN <sub>Total</sub> CN <sub>Free</sub> pH TDS	Samples should be taken as early in the morning as possible. Samples should be taken where spigot-derived pooling is present.
Nocturnal cyanide concentrations	At a frequency that takes into account the measured variability.	CN <sub>WAD</sub> CN <sub>Total</sub> CN <sub>Free</sub> pH TDS	Samples should be taken as early in the morning as possible. Samples should be taken where safe to do so.
Cyanide dosage at mill	As frequent as possible.	CN <sub>Free</sub>	Correlate daily free cyanide dosage to expected WAD cyanide at discharge (spigot) and in spigot-derived supernatant.

Note: Every effort must be made to standardise the exact sampling point for routine process water chemistry sampling (within safety and logistical constraints), as this will greatly increase the consistency of data obtained.

The table below presents a typical TSF wildlife monitoring regime to identify whether deaths are occurring, identify risk-contributing factors and determine at-risk species.

**Typical routine wildlife monitoring of tailings waste solutions**

FREQUENCY - TYPE	WATER BODY	TIME	OBSERVATIONS	DESCRIPTION
<p>Daily wildlife monitoring.</p> <p>Note: Daily wildlife surveys are required as long as discharge concentrations are <math>\geq 50</math> mg/L WAD cyanide.</p> <p>If cyanide detoxification is implemented to discharge concentration at below 50 mg/L WAD cyanide then the frequency of wildlife monitoring can be reduced (for example to weekly).</p>	Cyanide-bearing water bodies.	<p>Sunrise.</p> <p>Suggested minimum observation period of 30 minutes at each TSF.</p>	<ul style="list-style-type: none"> <li>■ observer's name</li> <li>■ location</li> <li>■ weather conditions</li> <li>■ start and finish times</li> <li>■ species ID</li> <li>■ number present</li> <li>■ habitat usage</li> <li>■ record zero bird presence on the data sheet if applicable</li> <li>■ area of water available</li> </ul>	<p>Record habitats as:</p> <ul style="list-style-type: none"> <li>S-supernatant (open water)</li> <li>B/DT-beach/dry tailings</li> <li>B/WT-beaches/wet tailings</li> <li>B/W-beach/walls</li> <li>WT-wet tailings</li> <li>SP-spigot pooling</li> <li>DT-dry tailings</li> <li>BG-bare ground</li> <li>W-dam walls</li> <li>Is-islands</li> <li>A-aerial</li> <li>V-vegetation</li> <li>I-infrastructure.</li> </ul> <p>Record condition of wildlife as alive or dead.</p> <p>Document obvious signs of stress.</p>
			<p>Carcass presence</p>	<p>Concurrent with wildlife surveys.</p> <p>Record any carcasses (location and species).</p> <p>If any at-risk species are present (alive), attempts should be made to actively haze them from the TSF.</p>
<p>Monthly passive monitoring of insectivorous bat activity at cyanide-bearing water bodies –suggested minimum of four nights per month.</p>	Cyanide-bearing water bodies.	<p>Sunset: devices are programmed to turn on and off at the same time every night automatically.</p>	<p>Bat identification to the level of species or genera</p> <p>Measure of activity patterns, that is, calls per species per hour.</p> <p>Preliminary measure of behaviour, that is, number of feeding and drinking passes.</p>	<p>Echolocation recording devices can be sent to site and set up by onsite Environment Department staff (minimal training is required).</p> <p>The devices need only be activated once on the first sampling night and then collected four days later. The devices are then sent off site and the data analysed.</p>



## Nocturnal wildlife observations

Nocturnal wildlife recordings are crucial as most wildlife that interacts with tailings systems are nocturnal or crepuscular. Monitoring by spotlight is very limiting and does not provide any new data in addition to diurnal wildlife monitoring. If insectivorous bats are common to the environment, monitoring of these needs to be considered. Nocturnal observations make it difficult to observe the presence of wildlife and carcasses, and therefore early morning observations are more appropriate. Consideration can be given to monitoring water bodies to document the presence of any at risk species in the region.

## Establish a wildlife monitoring regime for the heap leach cyanide circuit

To move toward industry best practice in cyanide management, wildlife interaction observations are required where a risk to wildlife exists, that is:

- cyanide-bearing irrigated heap leach pads
- ponding at the foot of a heap leach facility
- cyanide-bearing open drains
- process ponds.

Current best practice requires daily observations at all water bodies where wildlife is exposed to cyanide at concentrations exceeding 50 mg/L.

Observations on the active irrigation pad are likely to illustrate minimal wildlife interaction as identified elsewhere. Nevertheless this needs to be demonstrated with observations and data recording. The whole irrigation pad need not be observed. A survey area of 200 metres x 100 metres is recommended, which is within the skill level likely available on site. The survey area needs to include the irrigation system and the edge of the irrigation system including ponding on the perimeter of the irrigated pad. During periods immediately after irrigation ceases, when the pad is still wet, it is important that monitoring continues on a daily basis until the ponding dries out.

Drains, pooling areas and solution ponds should also be monitored according to the regime set out below, however if exposure to wildlife is physically denied, then they need not be monitored.

The table below illustrates a typical wildlife monitoring regime of a heap leach facility.

**Typical wildlife monitoring regime of a heap leach facility**

<b>FREQUENCY - TYPE</b>	<b>WATER BODY</b>	<b>TIME</b>	<b>OBSERVATIONS</b>	<b>DESCRIPTION</b>
Active irrigation pad. Survey subset of the area, 100 m x 200 m.	Daily	Record the start and finish time. Conduct observations for a set time (20 minutes).	<ul style="list-style-type: none"> <li>■ Identify alive species (or guild), number, habitat usage. Count carcasses.</li> <li>■ Record observer's name.</li> <li>■ Record zero bird presence on the data sheet if applicable.</li> <li>■ Record number of irrigated pads.</li> </ul>	Record habitats as aerial (A), edge ponding (P), under sprinkler (US), bare ground (BG) or infrastructure (I) for each species.
Pooling at the foot of the heap leach pad.	Daily (if present)	Time, start and finish. Date.	Number of carcasses, number of ponds per observation day. Estimate size of each pond. Document number and location of ponds.	
Drains	Daily (if open drains)	Time, start and finish. Date.	<ul style="list-style-type: none"> <li>■ Number of carcasses.</li> <li>■ Record observer's name.</li> <li>■ Identify alive species (or guild), number, habitat usage.</li> <li>■ Record zero bird presence on the data sheet if applicable.</li> </ul>	Record habitats as solution/open water (S), wall (W) and aerial (A).

FREQUENCY - TYPE	WATER BODY	TIME	OBSERVATIONS	DESCRIPTION
Solution ponds	Daily (if netting not present and >50 mg/L CN)	Record the start and finish time. Conduct observations for a set time (5 minutes).	Identify alive species (or guild), number, habitat usage. Count carcasses. Record observer's name. Record zero bird presence on the data sheet if applicable. If drains covered record condition.	Record habitats as aerial (A), solution/open water (S), plastic lining (L), walls (W), beach (B) or infrastructure (I).
Any other cyanide-bearing water bodies containing cyanide levels of below 50 ppm.	Monthly	Record the start and finish time. Conduct observations for a set time (five minutes).	Identify alive species (or guild), number, habitat usage. Count carcasses. Record observer's name. Record zero bird presence on the data sheet if applicable. Record condition of netting if applicable.	Record habitats as aerial (A), solution/open water (S), walls (W), beach (B) or infrastructure (I).

***Measuring impact: wildlife deaths***

The generic methodologies described in this handbook do not have the ability to document the number of deaths and, to a lesser extent document the impact to the species level. Field observation has found that documenting carcass presence and carcass residence time is difficult, time-consuming and requires a high level of skill and experience that is not expected on a mining operation.

To accurately document the extent and species level, impact of wildlife cyanide toxicosis requires specialist input beyond the methodology prescribed here.

## Conclusion

Developing wildlife cyanosis monitoring regimes can be complicated by a variety of case-specific operational systems and environments. The essence is to measure cyanide concentrations, the habitats that contain bioavailable cyanide, wildlife visitation (alive), wildlife deaths and habitat use. Such data can competently be collected, with training, by mine site staff. The monitoring regime also provides data and an understanding of those factors that can contribute to risks, allowing for preventive management to be implemented. In essence the monitoring methodologies remove the need to locate carcasses prior to determining if risks exist.

Reliance on lack of carcasses has repeatedly proven inappropriate to predict, identify and document wildlife cyanosis risk.

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