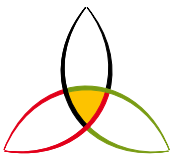




Australian Government
Department of Resources
Energy and Tourism

CYANIDE MANAGEMENT

LEADING PRACTICE SUSTAINABLE
DEVELOPMENT PROGRAM FOR
THE MINING INDUSTRY



SOCIAL
ECONOMIC
ENVIRONMENTAL

CYANIDE MANAGEMENT

LEADING PRACTICE SUSTAINABLE
DEVELOPMENT PROGRAM FOR
THE MINING INDUSTRY

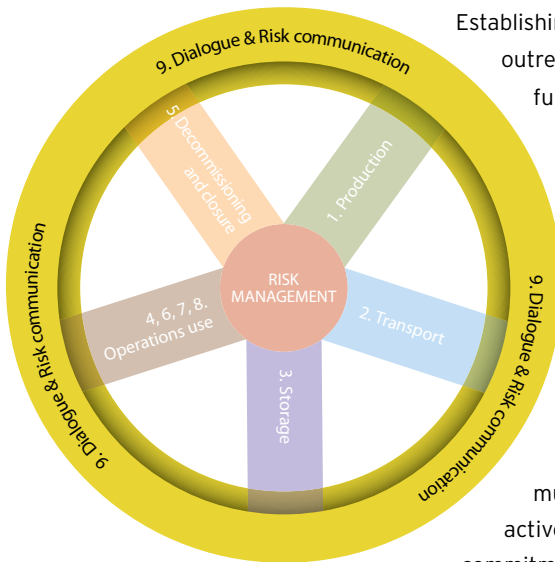


MAY 2008

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.

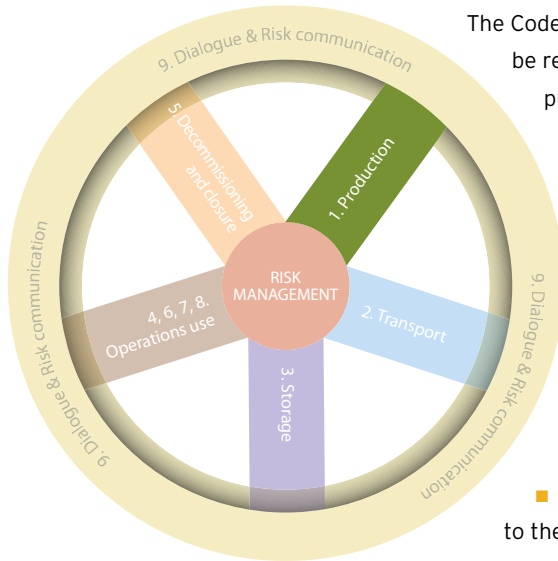
In addition, the company regularly meets local community, government and industry stakeholders at the bi-monthly Communities and Industries Forum (CIF). As an independently moderated forum, which is open to all, the relationships developed between all parties through the CIF provide companies such as 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



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

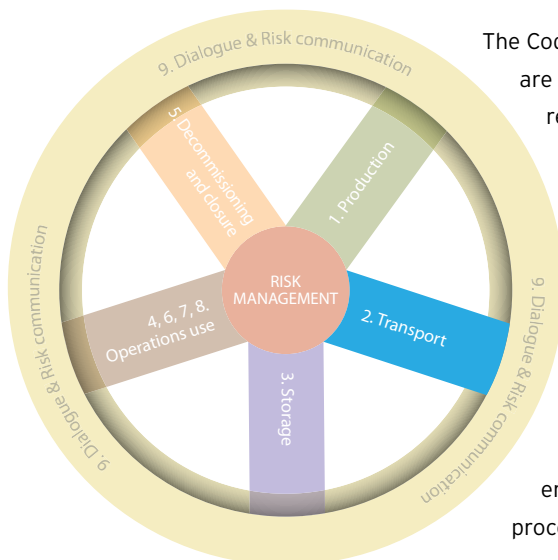
The Code refers to the application of standards of practice and that cyanide should be purchased from manufacturers who employ:

- 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



The Code requires that standards of practice are 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 processes.

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.

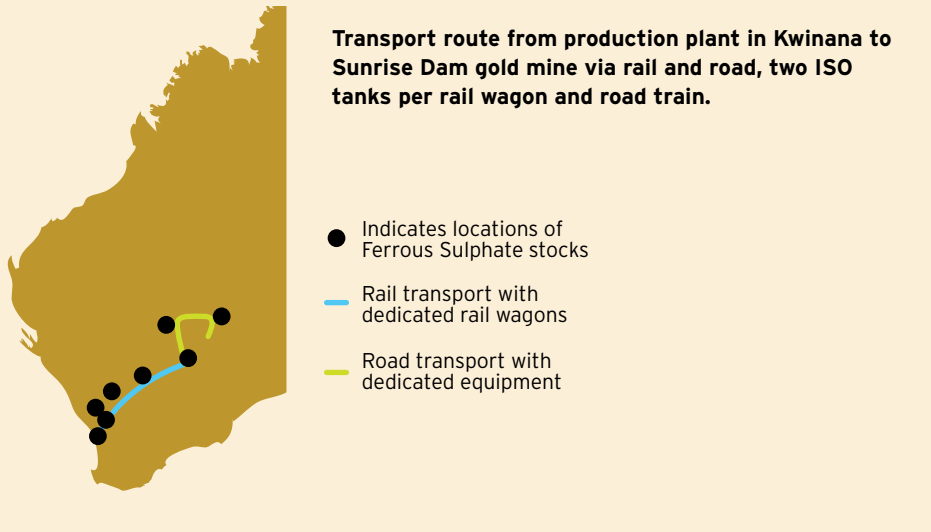
The sodium cyanide receipt and storage facility at SDGM has been designed by CSBP and approved by the WA Department of Consumer and Employment Protection.

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.

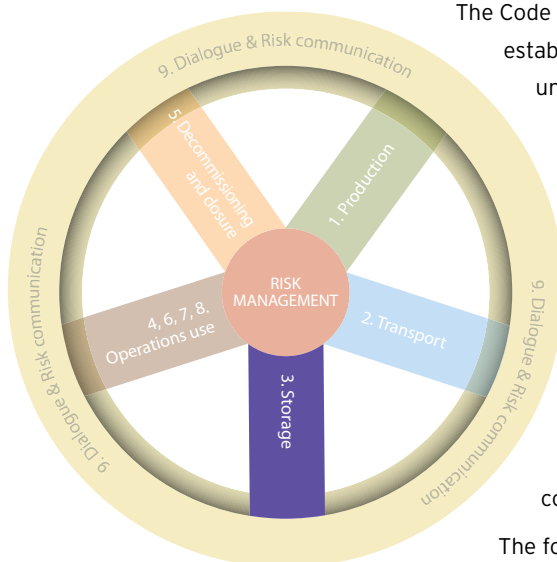
The stock management system ensures sufficient inventory required at SDGM for the ongoing supply of product to the gold recovery process is in place. The storage tanks have fitted manual level indicators as well as electronic level indicators, with the electronic level indicator being linked via telemetry 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.

The 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 NH³ 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:

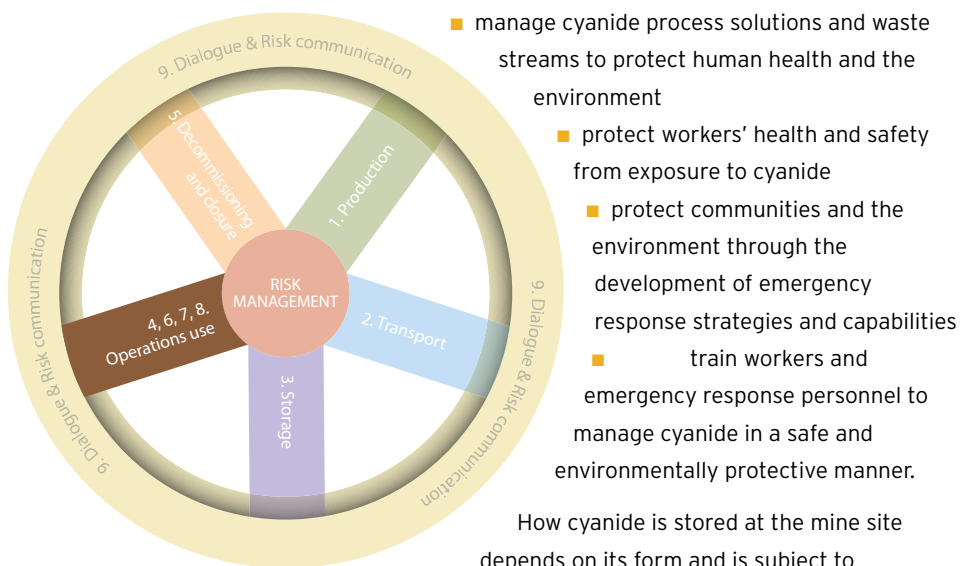
- installation of flow or pressure loss detection systems on pipelines to detect a failure
- installation of sleeves or covers over mechanical pipe joints to restrict leaks under pressure to a banded area
- alarm systems to alert personnel to pump or pipeline failure
- implementing regular inspection 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 streams 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/m³ 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.

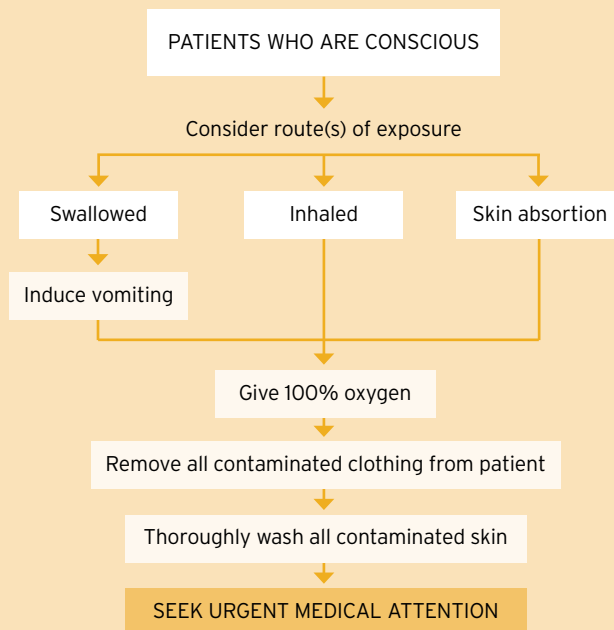
Contaminated protective gear and clothing should be securely discarded, or washed before being stored and reused.

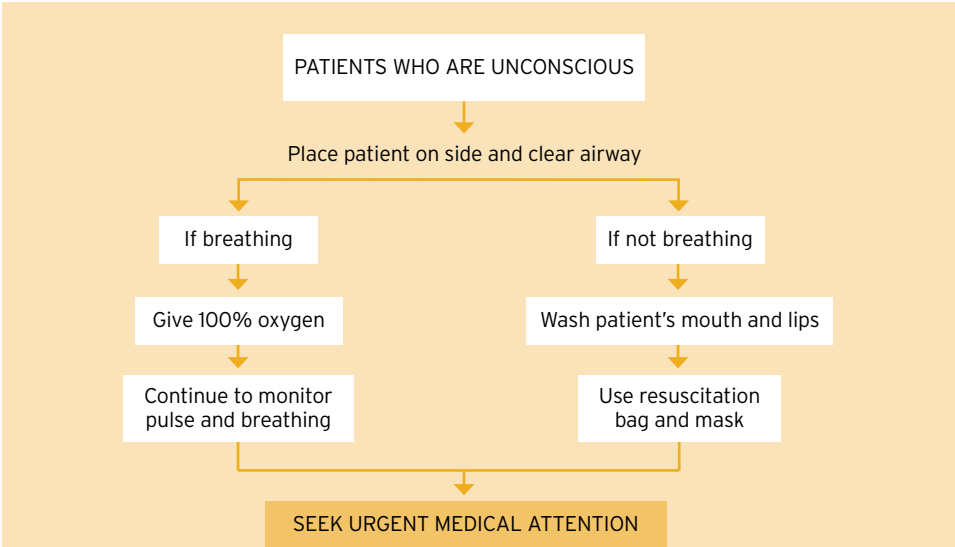
Box 6: Treatment of cyanide poisoning

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 (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 (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

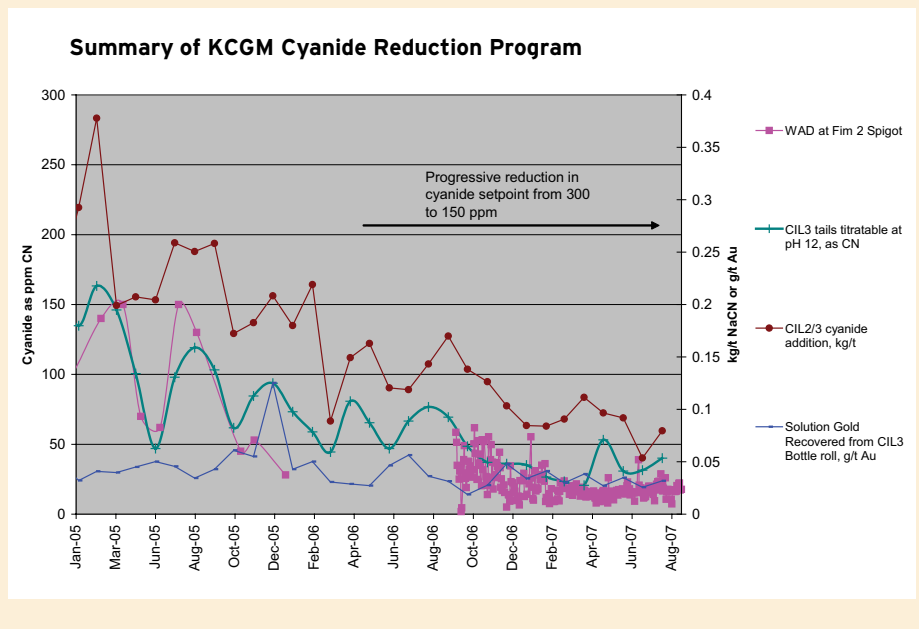
of control. The analysers are maintained by the laboratory staff on a daily basis, resulting in analyser availability in excess of 90 percent. Daily maintenance of all three units takes one person about two hours.



Analyser unit

Due to the equilibrium conversion of $CN^-_{(aq)} \rightarrow HCN_{(aq)}$ in the Fimiston operating range of pH 9.3, with conversion to $HCN_{(aq)}$ 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 pH 12 where $CN^-_{(aq)}$ is most stable, effectively reporting total cyanide. This stable titration pH avoids under reporting $CN^-_{(aq)}$ 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.

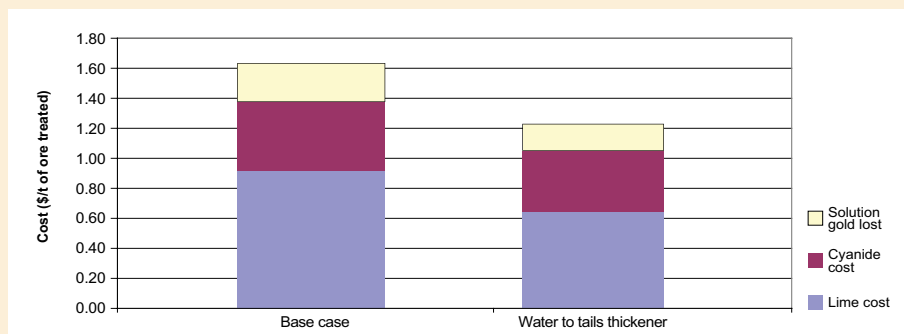
Traditionally, new circuit water is added to the grind. One way of reducing the WAD cyanide at the discharge spigot is to add new water to the tails and increase the level of recycle. The WAD cyanide concentration at the discharge spigot is thereby reduced through dilution with the use of a tailings 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
A. OXIDATIVE			
Alkaline chlorination (C)	Oxidation to CNO^- and then N_2 and CO_3^{2-} with Cl_2 or ClO^- at $\text{pH} > 11$	Cl_2/ClO^- , NaOH	CNO^- , CO_3^{2-} , N_2
SO_2/air (C)	Oxidation to CNO^- with SO_2/air and soluble Cu catalyst; INCO process	SO_2 , air, Cu catalyst	CNO^-
Hydrogen peroxide (C)	Oxidation to CNO^- with H_2O_2 and Cu^{2+} catalyst; Degussa process	H_2O_2	CNO^- , CO_3^{2-} , NH_4^+
Caro's acid (C)	Oxidation via CNO^- with H_2SO_5	H_2SO_5	CO_3^{2-} , NH_4^+
Activated carbon (C & P)	Oxidation to CNO^- and then partially to CO_3^{2-} and NH_4^+ with activated carbon and Cu catalyst	Activated carbon, air/ O_2 , Cu catalyst	CNO^- , CO_3^{2-} , NH_4^+
Biodegradation (B)	Oxidation to CO_3^{2-} and NH_4^+ and then NO_3^- using indigenous microorganisms	Na_2CO_3 , H_3PO_4	CO_3^{2-} , NH_4^+ , NO_3^- , SO_4^{2-}
UOP catalytic oxidation (C)	Oxidation to CO_2 , N_2 and NH_4^+ with air at mild temperatures ($< 130^\circ\text{C}$) and pressures (550 kPa) with a catalyst	Catalyst	CO_2 , N_2 and NH_4^+
Ozonation (C)	Oxidation to CO_3^{2-} and N_2 with O_3	O_3	CO_3^{2-} , N_2
Wet air oxidation (C)	Oxidation to CO_2 and N_2 at high temperatures ($175\text{-}320^\circ\text{C}$) and high pressures (2,100-20,700 kPa)	none	CO_2 , N_2
Photocatalytic oxidation (C & P)	Oxidation to CNO^- and then NO_3^- and CO_3^{2-} using uv/visible light and semiconductor-type substrate, e.g. TiO_2 , ZnO or CdS	none	CO_2 , N_2

TECHNOLOGY (AND TYPE*)	SHORT DESCRIPTION	BASIC REAGENTS	BASIC PRODUCTS
B. NON-OXIDATIVE			
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 ₂ SO ₄ , NaOH	HCN, SCN ⁻ ?
CYANISORB® (C & P)	Similar to AVR but HCN(g) stripped at higher pH values (5.5-7.5)	H ₂ SO ₄ , NaOH	HCN, SCN ⁻ ?
CRP (C & P)	Cyanide regeneration process; similar to AVR but with better HCN(g) stripping and metal precipitation	H ₂ SO ₄ , NaOH	HCN, SCN ⁻ ?
SART	Sulfidisation, acidification, recycling and thickening	Na ₂ S, H ₂ SO ₄	Cu ₂ S
Thermal hydrolysis (C)	Hydrolysis to NH ₄ ⁺ and formate at high temperatures	none	NH ₄ ⁺ , HCOO ⁻
Alkaline hydrolysis (C)	Hydrolysis to NH ₄ ⁺ and formate at high temperatures (100-250°C) and high pH	NaOH	NH ₄ ⁺ , HCOO ⁻
IX - GM (C and P)	Gas membrane-Ion exchange; ion exchange concentrates CN. After regeneration the gas membrane recovers pure CN.	Resin	CN ⁻
IX - AVR (C and P)	Ion exchange concentrates CN. After regeneration CN recovered by AVR	Resin	CN ⁻
Prussian blue precipitation (C)	Precipitation of Fe ₄ [Fe(CN ₆) ₃] on addition of FeSO ₄	FeSO ₄	Fe ₄ [Fe(CN ₆) ₃]
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 ₂ SO ₄ ?	CN ⁻
Flotation (P)	Adsorption of precipitated CN particles onto fine air bubbles	FeSO ₄ , Surfactant	Fe ₄ [Fe(CN ₆) ₃]
High rate thickeners (P)	Fast thickening and recycling of CIP tailings	none	CN ⁻

* 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 (SO₂)/air process is a simple method that requires little supervision and does not interrupt gold recovery. SO₂ 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 (Na₂S), sulfuric acid (H₂SO₄) 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:

	UNIT	RANGE
SART feed flow	m ³ /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 ₂ /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 1×10^{-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, Fe²⁺, Fe³⁺, Ni and derivatives NH₃, 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-/m³. 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

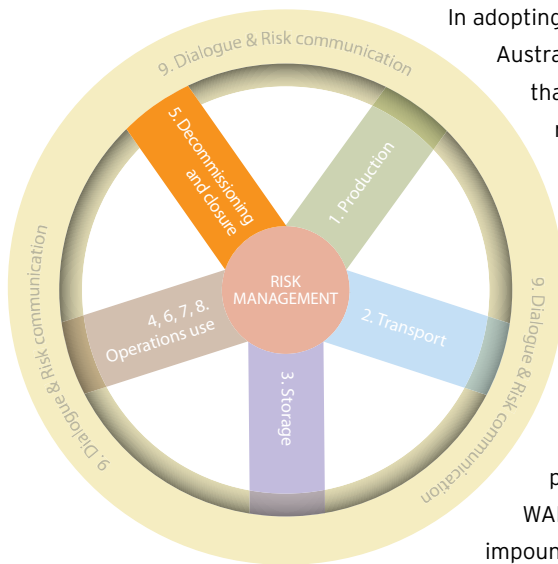
The results from the TCLP extracts indicated that moderate amounts of iron and manganese will be leached from the TSF residue if the leaching solution is weakly acidic (pH of around five). None of the potential environmentally toxic metals, including arsenic, were leached to any significant amount. The 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.



In adopting *Enduring Value* (MCA 2004), the Australian 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 WAD 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.

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.

REFERENCES AND FURTHER READING

Adams, MD 2001, 'A methodology for determining the department of cyanide losses in gold plants', *Minerals Engineering*, vol. 14 (4), pp. 383-390.

AMIRA 1997, *Cyanide Waste Management: Minimising Environmental and Economic Impacts*, AMIRA Project P497, Phase 1 completed September 1997, Phase 2 deals with the experimental research results and is available from MERIWA Project M309 Report No 214.

ANZECC/ARMCANZ 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, vo. 1, The Guidelines, Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), October 2000.

ATSDR 1997, *Toxicological Profile for Cyanide*, Agency for Toxic Substances and Disease Registry, US Department of Health and Human Services, Atlanta, Georgia, USA, p. 46.

AS 2004, *Risk Management AS/NZS 4360:2004*, Standards Association of Australia: Strathfield NSW.

Ballantyne, B 1987, 'Toxicology of cyanides' in B Ballantyne, TC Marrs (eds.), *Clinical and Experimental Toxicology of Cyanides*, Wright Publishers, Bristol, UK 1987.

Botz, MM 2001, 'Cyanide treatment methods' in *The Cyanide Guide, Mining Environmental Management Journal*, May 2001, pp. 28-30.

Botz, MM, Devuyst, E, Mudder, TI, Norcross, R, Ou, B, Richins, R, Robbins, G, Smith, A, Steiner, N, Stevenson, JA, Waterland, RA, Wilder, A, and Zaidi, A 1995, *Cyanide: An Overview of Cyanide Treatment and Recovery Methods in Mining Environmental Management*, The Mining Journal Limited, London vol. 3 (2) pp. 4-16.

Botz, MM & Mudder, TI 2001, 'Chemical and physical treatment', Chapter 5 in TI Mudder and MM Botz, 2001, *The Cyanide Monograph*, Mining Journal Books, London.

Den Dryver, J 2002, 'Relevance of International Code on Cyanide Management within Newmont Australia. *Sustainable Development Conference*, 10-15 November 2002, Minerals Council of Australia, Canberra.

Department of Consumer and Employment Protection 2007, 'Cyanide poisoning-first aid and medical treatment', *WA Medical Bulletin*, No. 5, revised August 2007.

Department of Industry Tourism and Resources 2006a, Leading Practice Sustainable Development handbook on *Community Engagement and Development*, Department of Industry Tourism and Resources, Canberra.

Department of Industry Tourism and Resources 2006b, Leading Practice Sustainable Development handbook on *Mine Closure and Completion*, Department of Industry Tourism and Resources, Canberra.

Department of Industry Tourism and Resources 2006c, Leading Practice Sustainable Development handbook on *Stewardship*, Department of Industry Tourism and Resources, Canberra.

Department of Industry Tourism and Resources 2007a, Leading Practice Sustainable Development handbook on *Tailings Management*, Department of Industry Tourism and Resources, Canberra.

Department of Industry Tourism and Resources 2007b, Leading Practice Sustainable Development handbook on *Working with Indigenous Communities*, Department of Industry Tourism and Resources, Canberra.

Department of Minerals and Energy (Western Australia) 1992, *Cyanide Management Guideline* Department of Minerals and Energy, Perth.

Department of Resources, Energy and Tourism 2008a, Leading Practice Sustainable Development handbook on *Risk Assessment and Management*, Department of Resources, Energy and Tourism, Canberra.

Department of Resources, Energy and Tourism 2008b, Leading Practice Sustainable Development handbook on *Water Management*, Department of Resources, Energy and Tourism, Canberra.

Donato, D, 1999, Bird Usage Patterns on Northern Territory Mining Water Tailings and their Management to Reduce Mortalities, Department of Mines and Energy, Darwin NT, pp. 1-36.

Donato, D 2002, 'Cyanide use and wildlife protection: International Cyanide Management Code and the Australian experience', workshop notes on *Technical Issues in the Use and Management of Cyanide in the Gold Industry*, Perth, WA, July 2002, Australian Centre for Mining Environmental Research, Kenmore, Queensland.

Donato, DB, Nichols, O, Possingham, H, Moore, M, Ricci, PF & Noller, BN 2007, 'A critical review of the effects of gold cyanide-bearing tailings solutions on wildlife', *Environ. Int.*, vol. 33, pp. 974-984.

Donato, DB & Smith, GB 2007, *Summary of Findings : ACMER Project 58*, Sunrise Dam gold mine sponsor's report, AngloGold Ashanti Australia, Donato Environmental Services SA, pp. 27.

Elliot, R 1996, 'Cyanide poisoning (new recommendations on first aid treatment', *Toxic Substances Bulletin*, January 1996, pp. 8-9.

eNHealth 2004, *Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards*, Department of Health and Aged Care and eNHealth Council, Canberra, 2004, p. 227.

Environment Australia 1998, *Cyanide Management*, Best Practice Environmental Management booklet, Environment Australia, Canberra.

- Environment Australia 2003, *Cyanide Management*, practice environmental management booklet, Environment Australia, Canberra.
- Fox, FD 2001(a), 'Public education and community outreach' in *The Cyanide Guide, Mining Environmental Management Journal*, May 2001, pp. 33-34.
- Fox, FD 2001(b), 'Environmental auditing and emergency response' in *The Cyanide Guide, Mining Environmental Management Journal*, May 2001, pp. 31-32.
- Greenway, M 2004, 'Constructed wetlands for water pollution control—processes, parameters and performance', *Dev. Chem. Eng. Mineral Process*, Vol. 12(5/6), pp. 1-14.
- Greeno, J, Hedstrom, G & Diberto, M 1988, *The Environmental, Health, and Safety Auditor's Handbook*, Centre for Environmental Assurance, Arthur D Little Inc, New York.
- Hartung, R 1982, 'Cyanides and nitrites' in *Patty's Industrial Hygiene and Toxicology*, 3rd rev. edn, vol. 2C, Toxicology, GD Clayton and FE Clayton (eds), John Wiley and Sons, New York, pp. 4845-4900.
- Hertting, GO, Kraupp, E & Schentz, E 1960, *Investigation About the Consequences of a Chronic Administration of Acutely Toxic Doses of Sodium Cyanide to Dogs*, *Acta Pharmacol. Toxicol*, vol. 17, pp. 27-43.
- Hurse, JT & Connor, AM 1999, 'Nitrogen removal from wastewater treatment lagoons', *Wat. Sci. Tech.*, vol. 39, pp. 191-198.
- Hynes, TPJ, Harrison, E, Bonitenko, TM, Doronina, Baikowitz, H, James, M & Zinck, JM 1999, 'The International Scientific Commission's assessment of the impact of the cyanide spill at Barkasaun, Kyrgyz Republic', May 20, 1998, in *Mining and Mineral Sciences Laboratories report MMSL 98-039(CR)*, August 1999.
- International Cyanide Management Institute 2006, *International Cyanide Management Code*.
- International Cyanide Management Institute 2005, *Implementation Guidance for the International Cyanide Management Code*.
- Logsdon, MJ, Hagelstein, K & Mudder, TI 1999, *The Management of Cyanide in Gold Extraction*, International Council on Metals and the Environment, Ottawa, Canada.
- Matsumoto, MR 2004, 'Abiotic nitrogen removal mechanisms in rapid infiltration wastewater treatment systems', *Technical Completion Report W-952*, University of California Water Resource Center, Riverside, CA USA, pp. 1-43, <<http://repositories.cdlib.org/wrc/trc/matsumoto>>.
- McNulty, T 2001a, 'Alternatives to cyanide for processing precious metal ores', *Mining Environmental Management Journal*, May 2001.
- McNulty, T 2001b, 'Comparison of alternative extraction lixiviants', *Mining Environmental Management Journal*, May 2001.

- Minerals Council of Australia 2004, *Enduring Value: The Australia Minerals Industry Framework for Sustainable Development*, Canberra, Australia.
- MMSD 2002, *Breaking New Ground—Mining Minerals and Sustainable Development*, report of the Mining, Minerals and Sustainable Development Project, International Institute for Environment and Development, London.
- Moore, MR & Noller, BN 2000, 'Future challenges facing the mining industry - an environmental health perspective', UNEP Industry and Environment 23, *Special Issues 2000*, pp. 41-43.
- Mudder, TI 1997, 'The Sources and Environmental Significance of Low Levels of Cyanide', in short course notes on *Management of Cyanide in Mining*, Perth, WA, April 1997, Australian Centre for Mining Environmental Research, Kenmore, Queensland.
- Mudder, TI 1987, 'Active and passive biological treatment', Chapter 4 in TI Mudder & MM Botz, 2001, *The Cyanide Monograph*, Mining Journal Books, London.
- Mudder, TI & Botz, MM 2001, 'Recovery and reuse', Chapter 3 in TI Mudder & MM Botz, 2001, *The Cyanide Monograph*, Mining Journal Books, London.
- Mudder, TI, Botz, MM & Smith, A 2001, *The Chemistry and Treatment of Cyanidation Wastes, 2nd edn*, Mining Journal Books Ltd, London.
- Mudder, TI & Whitlock, JL 1984, 'Biological treatment of cyanidation wastewaters', *Miner. Metall. Process*, vol, 1, pp. 161-165.
- National Occupational Health and Safety Commission 1993, *Cyanide Poisoning*, Australian Government Publishing Service, Canberra.
- NEPC 1999, *National Environmental Protection (Assessment of Site Contamination) Measures*, National Environment Protection Council, Adelaide.
- NHMRC 2004, *Australian Drinking Water Quality Guidelines*, NH&MRC, Canberra.
- Noller, BN & Saulep, G 2004, 'Loss of cyanide during transport to Tolukuma gold mine, Papua New Guinea', *European Journal of Mineral Processing & Environmental Protection*, vol. 4(1) pp. 49-61.
- Pesce, LD 1993, 'Cyanides', in *Kirk-Othmer Encyclopedia of Chemical Technology*, 4th edn, vol. 7, Composite Materials to Detergency, John Wiley and Sons, New York, pp. 753-782.
- Richardson, ML (ed.) 1992, *The Dictionary of Substances and their Effects*, Royal Society of Chemistry, UK, pp. 716-718.
- Ricci, PF 2006, *Environmental and health risk assessment and management: principles and practices*, Springer, Dordrecht, NL.
- Ritcey, GM 1989, *Tailings Management: Problems and Solutions in the Mining Industry*, Elsevier, Amsterdam.

Rumball, JA, Munro, SD & Habner, ML 2007, 'Reducing WAD cyanide at the discharge spigot', *Ninth Mill Operators' Conference*, AusIMM, Carlton, Victoria, Australia, pp. 229-233.

Staunton, WP, Formby, S, Schulz, RS & Avraamides, J 1989, 'Transportation of liquid sodium cyanide-response strategies for spills', in *World Gold '89*, RB Bhappu and RJ. Harden (eds), Society of Mining, Metallurgy and Exploration, Littleton, Colorado, USA, pp. 357-362.

Stevenson, J, Botz, M, Mudder, T, Wilder, A & Richins, R 1995, 'Cyanisorb recovers cyanide', *Mining Environmental Management*, June 9-10.

Trapp, SAJ & Christiansen, H 2003, 'Phytoremediation of cyanide-polluted soils', Chapter 28 in *Phytoremediation: Transformation and Control of Contaminants*, SC McCuthcheon & JL Schoor eds, Wiley-Interscience, New Jersey, pp. 829-862.

UNEP/OCHA 2000, *Spill of Liquid And Suspended Waste at the Aurul SA Retreatment Plant in Baia Mare, Romania*, United Nations Environment Programme/Office for the Coordination of Humanitarian Affairs, Assessment Mission on the Cyanide Spill At Baia Mare, Romania, 23 February to 6 March 2000, UNEP, Geneva, March 2000.

USEPA 1998, *Guidelines for Ecological Risk Assessment*, US Environmental Protection Agency, Washington, DC, pp. 188.

White, RK 1997, 'Sodium cyanide transport, handling and safety issues, in short course notes on *Management of Cyanide in Mining*, Perth, WA, April 1997, Australian Centre for Mining Environmental Research, Kenmore, Queensland.

Whitlock, JL. 1989, 'The advantages of biodegradation of cyanides', *J Metals*, vol. 41, pp. 46-47.

FURTHER WEB SITES

- Department of Resources, Energy and Tourism www.ret.gov.au.
 - *Leading Practice Sustainable Development Program* www.ret.gov.au/sdmining.
 - MCMPR www.ret.gov.au/resources/mcmp.
- Minerals Council of Australia www.minerals.org.au.
 - *Enduring Value* www.minerals.org.au/enduringvalue.
- International Council on Mining & Metals www.icmm.com.
 - *ICMM Sustainable Development Principles* www.icmm.com/icmm_principles.php.
- International Cyanide Management Institute www.cyanidecode.org.
 - Additional information on cyanide www.cyanidecode.org/library/References1.pdf.
- The Parker Cooperative Research Centre for Hydrometallurgy Solutions www.parkercentre.com.au.
- Australian Centre for Minerals Extension and Research, The University of Queensland www.acmer.uq.edu.au.
- AMIRA International www.amira.com.au.
- "The Cyantists" website www.cyantists.com.

GLOSSARY

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 ⁻ .
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 ⁻ 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 ⁻ , 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.

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 ³ 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 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 ₃ titration	Preferred method For process solutions primarily above 1 mg/L LQL ¹ : 1 mg/L HCN(aq), CN ⁻ , Zn(CN) _x , parts of Cu(CN) ₄
	AgNO ₃ 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 ⁻ , Zn(CN) _x , parts of Cu(CN) ₄ + ?
	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 ⁻ , 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 ¹ : 0.10 mg/L HCN(aq), CN ⁻ , Zn/Cd/Cu/Ni/Ag/Fe(CN) _x , parts of Au/Co/Pt/Pd(CN) _x
	SFIA, in-line UV irradiation, micro-distillation + colorimetric finish [ASTM D4374]	Alternate method Measures same species as primary method also Cr(CN) _x and better recovery of Au/Co/Pt ?/ Pd ?(CN) _x

¹: 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 ₃	0.49	7.9
N-NO ₃	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 S²⁻ being equivalent to 0.025 mg CN⁻. 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 S²⁻ 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 μg 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 μg 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 μg 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

Bianting, Sun & Noller 1998,, 'Simultaneous determination of trace amounts of free cyanide and thiocyanate by a stopped-flow spectrophotometric method', *Water Research*, vol. 32, pp. 3698-3704.

Iamarino, PF 1989, 'The direct spectrophotometric determination of cyanide with picric acid reagent', *JRGL*, June 1 1989, INCO Ltd. (based on VJZatka method (*JRGL*, November 1980, which was a modification of the method of DJ Barkley and JC. Ingles, Report 221), CANMET, (February 1970).

International Cyanide Code (ICMI) 2002, 'Additional information on cyanide', May 2002, www.cyanidecode.org.

Maher, WA, Cullen, PW & Norris, RH 1994, Framework for designing sampling programs. *Environmental Monitoring and Assessment*, vol. 30, pp, 139-162.

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

Noller, BN 1997, 'Cyanide, sampling, measurement and analysis', in short course notes on *Management of Cyanide in Mining*, Australian Centre for Mine site Rehabilitation Research, 14-16 April 1997, Perth Western Australia.

Noller, BN & Schulz 1995,, 'The effect of cyanide preservation procedures on analytical results', proceedings of the 4th *Environmental Chemistry Conference*, D Dundas and B Salter-Duke (eds), Darwin, NT, 9-14 July 1995. Pp. E025-1-E025-3.

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 _{WAD} CN _{Total} CN _{Free} 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 _{WAD} CN _{Total} CN _{Free} 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 _{WAD} CN _{Total} CN _{Free} 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 _{WAD} CN _{Total} CN _{Free} 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 _{Free}	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 ≥ 50 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"> ■ observer's name ■ location ■ weather conditions ■ start and finish times ■ species ID ■ number present ■ habitat usage ■ record zero bird presence on the data sheet if applicable ■ area of water available 	<p>Record habitats as:</p> <ul style="list-style-type: none"> S-supernatant (open water) B/DT-beach/dry tailings B/WT-beaches/wet tailings B/W-beach/walls WT-wet tailings SP-spigot pooling DT-dry tailings BG-bare ground W-dam walls Is-islands A-aerial V-vegetation I-infrastructure. <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

FREQUENCY - TYPE	WATER BODY	TIME	OBSERVATIONS	DESCRIPTION
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"> ■ 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 number of irrigated pads. 	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"> ■ Number of carcasses. ■ Record observer's name. ■ Identify alive species (or guild), number, habitat usage. ■ Record zero bird presence on the data sheet if applicable. 	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.

References

Donato, D 1999, *Bird Usage Patterns on Northern Territory Mining Water Tailings and their Management to Reduce Mortalities*, Public Report, 1999, Darwin, Northern Territory, Department of Mines and Energy. p. 179.

Donato, D, Noller, B, Moore, M, Possingham, H, Ricci, P, Bell, C & Nicholls, O, 'Cyanide use, wildlife protection and the International Cyanide Management Code: An industry brokered approach', in *Inaugural Global Sustainable Development Conference*, Melbourne, Minerals Council of Australia.

Donato, D Griffiths, SR 2005, 'Wildlife cyanosis: managing the risks, in workshop on *Good Practice of Cyanide Management in the Gold Industry*, Perth, ACMER.

Smith, GB & Donato, DB, 2007, 'Wildlife cyanide toxicosis: monitoring of cyanide-bearing tailing and heap leach facilities compliance with the International Cyanide Management Code, in *World Gold Conference*, Cairns, AusIMM.

Handbooks in the Leading Practice Sustainable Development Program for the Mining Industry Series

Completed

- Biodiversity Management - *February 2007*
- Community Engagement and Development - *October 2006*
- Cyanide Management - *May 2008*
- Managing Acid and Metalliferous Drainage - *February 2007*
- Mine Closure and Completion - *October 2006*
- Mine Rehabilitation - *October 2006*
- Risk Assessment and Management - *May 2008*
- Stewardship - *October 2006*
- Tailings Management - *February 2007*
- Water Management - *May 2008*
- Working with Indigenous Communities - *October 2007*

Future Titles

- Hazardous Materials Management
- Monitoring, Auditing and Performance
- Particulate, Noise and Blast Management

These themes do not limit the scope of the program, which will evolve to address leading practice management issues as they arise.

Electronic versions of completed titles are available at www.ret.gov.au/sdmining

For further information on the program or to request hard copies of these Handbooks please email sdmining@ret.gov.au.