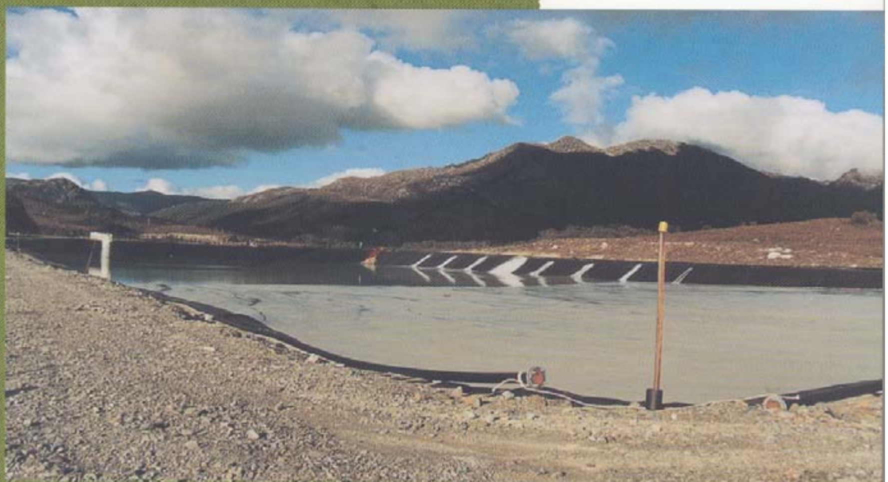
BEST PRACTICE ENVIRONMENTAL MANAGEMENT IN MINING

Cyanide Management



Environment Australia

Department of the Environment

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the principal authors Dr John Duffield and Professor Peter May, Division of Science, Murdoch University, Western Australia; case studies compiled by Keith Lindbeck formerly with BSD Consultants; contributions from Dr Terry Mudder, Times Limited, Bozeman, USA; the review team comprising Graham Terry, Ian Lambert, Stewart Needham, Dennis Brooks, Mark Horstman, Dr David Jones and Dr Terry Mudder, and the steering committee comprising representatives of the mining industry, government agencies and peak conservation organisations—the Minerals Council of Australia (MCA), the Australian Institute of Mining and Metallurgy (AusIMM), individual mining and energy companies, research institutions, the Australian Conservation Foundation (ACF) and the Australian Minerals and Energy Environment Foundation (AMEEF).
The review team and steering committee assists the authors without necessarily endorsing their views.

The series illustration of the Koalas by Christer Eriksson, commissioned by BHP Transport 1998. Reproduced courtesy of BHP Transport.

Cover photo: Henty Gold Mine, Queenstown, Tasmania. Detail of leach residue spiggot system in Pond A (lined).
Photo: Goldfields (Tasmania) Limited

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The review team and Steering Committee assisted the authors without necessarily endorsing their views.

Cover photo: A process water dam containing cyanide is lined and the water surface covered in floating "bird balls" to deny access to waterbirds, waders and other birds from the water surface and margins. *Cortez gold mine, Nevada USA.*

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Environment Australia incorporates the environment programs of the Federal Department of the Environment and Heritage.

FOREWORD

Protecting the environment is a priority for all members of our society. Representatives of the Australian minerals industry and Environment Australia, (the environment portfolio of the Federal Government), are working together through the Sustainable Minerals Program to benchmark best environmental practice and to present information to industry, regulators and the community on how it may be achieved.

This "Cyanide Management" booklet is one of the Sustainable Minerals series of publications, aimed at assisting the minerals industry apply the principles of best environmental practice to minimise the impacts of cyanide use. As much has changed in the field of cyanide management in recent years, this booklet updates the first edition (1998) of the booklet, covering recent technical developments, voluntary industry initiatives and regulatory change. It aims to introduce operations and environmental managers to the issues associated with cyanide use in minerals extraction and to provide the reader with an extensive and current bibliography. Like other booklets in the Sustainable Minerals series, it provides information that enables the community to gain a more clear and balanced appreciation of the challenges and environmental management practices of the minerals industry.

A key strategy in the series is the use of case studies to demonstrate practical and cost-effective operational options. These case studies often demonstrate technical and market leadership that exceed the requirements set by regulation. Case studies also demonstrate how best environmental practice can be adapted flexibly in diverse Australian landscapes and to meet the needs of large and small operations.

On behalf on the Sustainable Minerals partnership, we encourage mine managers and environmental officers to take up the challenge to continue to improve environmental performance and management of our global resources and to apply the principles outlined in these booklets.

Peter A. Roe Co-Chair,
Sustainable Minerals Steering Committee, and
Manager Environment
BHP Billiton Coal

Anthea Tinney
Deputy Secretary
Environment Australia

EXECUTIVE SUMMARY

Cyanide has been used safely and effectively in the mining industry for many years but it is a dangerous chemical that must always be used with caution. The aim of this booklet is to outline principles and procedures of cyanide management use so that it is used effectively, safely, economically and with no adverse effects on the environment.

This second edition updates the first edition published in 1998. It includes information on the International Cyanide Management Code, and discusses how the broad principles of sustainable development can be applied at the minesite. Greater emphasis is placed on the ecotoxicology of cyanide and how proactive approaches to risk reduction through cyanide reduction and setting of appropriate concentration limits for environmental protection are preferable to alternatives such as wildlife barriers.

Best practice cyanide management should be planned from the time of mine conception to closure and rehabilitation and should include:

- establishing a cyanide management strategy as part of the mine's environmental management;
- implementing initial and refresher cyanide management training for managers, workers and contractors;
- establishing well-defined responsibilities for individuals with clear chains of command and effective lines of communication within the workforce;
- instituting safe procedures for cyanide handling-governing transport, storage, containment, use and disposal;
- integrating the mine's cyanide and water management plans;
- identifying and implementing appropriate options for reusing, recycling and disposing of residual cyanide from plant operations;
- conducting regular cyanide audits and revising cyanide management procedures where appropriate;
- developing a cyanide occupational and natural environment monitoring program, and supporting this with a sound sampling, analysis and reporting protocol; and
- establishing carefully considered and regularly practiced emergency procedures.

Included in this booklet is an overview of cyanide chemistry. Cyanide exists in various forms and is able to undergo many different types of transformations. A familiarity with cyanide chemistry provides an invaluable background for understanding how cyanide chemicals can be used in a way that satisfies best practice principles. The section on chemistry describes the relationships between cyanide chemistry and extracting gold, recycling or disposing of cyanide, and minimising health and environmental risks.

Best practice environmental management means using cyanide responsibly to minimise the chance that workers or the environment will be harmed. This includes correctly managing transport, storage, handling and emergency procedures, and personal hygiene, and monitoring the working environment. It also requires well trained and properly equipped personnel who are aware of current treatment methods for cyanide poisoning and know the principles of how cyanide acts on humans and animals.

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

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

Systems should maximise recycling and effectively dispose of remaining cyanide. Mine managers need to stay abreast of the latest recycling techniques such as the AVA (acidification-volatilisation-absorption) methods, particularly CYANISORB®, and of effective detoxification methods like the Degussa peroxide process.

Case studies to support the material presented in this booklet have been chosen to demonstrate best management principles in action. Case studies for the first edition are updated, and new ones added to provide a more comprehensive coverage of cyanide best practice through its life cycle and in the context of chemical supplier, mining consumer and government regulator. Environmental and economic performance have become inextricably linked as society has moved towards the concepts of 'polluter pays', 'duty of care' and 'license to operate'. The environmental performance of the mining industry is increasingly being judged by the community and company shareholders. The minerals industry can only benefit from implementing best practice cyanide management.

Figure 1*: Henty Gold Mine, Queenstown, Tasmania - leach residue pipeline connecting the process plant with the leach residue ponds, some 4 km south of the processing plant. The pipeline is contained within a contingency bund to ensure that any unplanned discharges are contained. Flow meters attached to both ends of the pipeline ensure that pumping will automatically cut out in the event of a pipe failure. (photo: GOLDFIELDS (TASMANIA) LIMITED).*

CONTENTS

GLOSSARY/ABBREVIATIONS

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.
BW	Body weight.
CATC	Cyanide Amenable to Chlorination.
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.
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 resource. Eco-efficient businesses get more value out of their raw materials as well as producing less waste and less pollution.
Eh	Reduction potential (in units of volts or millivolts)-a measure of how oxidising or reducing a system is (more positive values tend to indicate oxidising environments, more negative values reducing).
EMS	Environmental Management System.
HACCP	Hazard Analysis at Critical Control Points-a formal procedure designed to identify the hazards associated with particular stages in a given process.
Heap leach	To dissolve minerals or metals out of an ore heap using chemicals. During heap leaching of gold, a cyanide solution percolates through crushed ore heaped on an impervious pad or base pads.
IBC	Intermediate bulk container.
LC50	Median Lethal Concentration - the concentration of material in water that is estimated to be lethal to 50% of organisms. The LC50 is normally expressed as a time-dependent value, eg 24-hour or 96-hour LC50, the concentration estimated to be lethal to 50% of the test organisms after 24 or 96 hours of exposure.
LD50	Median Lethal Dose - the does of material that is estimated to be lethal to 50% of the test organisms. Appropriate for use with test animals such as rats, mice and dogs, it is rarely applicable to aquatic organisms because it indicates the quantity of material introduced directly into the body by injection or ingestion rather than the concentration of material in water in which aquatic organisms are exposed during toxicity tests.
Lixiviants	Chemical leaching agents.
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
Slimes	The finest particles suspended in a tailings slurry.
Sparging	A procedure designed to minimise operator exposure to cyanide during transfer from transport container to storage facility at a minesite. Solid sodium cyanide (98%, in tablet form) is transported in 20 tonne containers. At the minesite, these are flushed with water through a system of valves and pipes directly into storage tanks.
Subsidiarity	The subsidiarity principle is intended to ensure that decisions are taken as closely as possible to the citizen and that constant checks are made as to whether action at Community level is justified in the light of the possibilities available at national, regional or local level.
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 case cyanide gas (HCN).
WAD cyanide	Weak acid dissociable cyanide that is readily released from cyanide-containing complexes when the pH is lowered. The detailed definition of WAD cyanide will differ depending on the analytical method used and so specific information should be sought from the laboratory operator (eg with Method OIA-1677, WAD cyanide may include CATC or 'Available CN').

1. INTRODUCTION

1.1 BACKGROUND

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

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

Although it is a common compound essential to nature, it is widely regarded as a highly dangerous substance. This view has been shaped by its use as a genocidal agent during World War II, in mass suicides, and its continued use in some parts of the world for judicial executions. Crime writers have also added to its notoriety:

Martha: 'Well dear, for a gallon of elderberry wine I take one teaspoonful of arsenic, and add half a teaspoonful of strychnine, and then just a pinch of cyanide.' From: *Arsenic and Old Lace,* by (Kesselring 1944)

Certainly it is a fast acting poison because it binds to key iron-containing enzymes required for cells to use oxygen and as a result tissues are unable to take up oxygen from the blood. In the absence of first aid, poisoning from gas inhalation, or ingestion or absorption through the skin, can kill within minutes. We are all in daily contact with low levels of cyanide through the foods we eat and the products we use. It is removed from our bodies by the liver and is not known to cause cancer. People who suffer non-fatal poisoning usually recover fully, although recent research indicates that significant irreversible health impacts may result from high-doses and repeat low-doses. However, sub-lethal exposure above these limits, and repeat low doses, may cause significant irreversible adverse effects such as degeneration of the central nervous system and Parkinson's syndrome. Cyanide has been used for more than 100 years for extracting gold. Although it is a highly toxic chemical that must be used with great care, it is rarely a cause of accidental deaths. There have been no documented accidental human deaths due to cyanide poisoning in the Australian and North American mining industries in the last 100 years. Further general information on cyanide is given in **Box 1**.

Unlike some synthetic chemicals, cyanide in its bioavailable (and hence toxic) forms is not persistent and will degrade through natural physical, chemical and biological processes into other, less toxic chemicals. It also oxidizes and degrades when exposed to air or other oxidants. While it is a deadly poison when ingested, inhaled or contacted in a sufficiently high dose, it does not accumulate in the food chain, and will generally not give rise to chronic health or environmental problems when present in low concentrations. However, the effects detected in humans from repeated exposure at low doses may also apply to animals (Hertting et al 1960).

There are alternatives to cyanide for extracting gold and silver from ore, but these are generally less efficient, more expensive, and less able to treat very low grade ores. Research is underway to find cost-efficient and more effective alternatives to cyanide. Based on the establishment and procedures employed under the current mining regime, gold would be much more costly to produce without cyanide and many Australian mines would be uneconomic. It is important, therefore, to know the facts about both the hazards and the benefits of using this highly effective chemical in mining. As summarised by Mudder and Smith (1994):

'Although cyanide has been used for about one hundred years worldwide for the recovery of metals and our knowledge of its chemistry, analysis, environmental fate, toxicity and treatment has grown dramatically in the last decade, various myths, misconceptions and fears still exist regarding this chemical. Cyanide, unlike some of the metals with which it combines in water, is not persistent in the environment. In nearly all instances the long term adverse effects (if any) associated with a mining site are related primarily to metals and not to the presence of cyanide.'

In spite of the increasing level of knowledge about cyanide and its proper management in mining, significant environmental impacts, particularly on rivers and streams, continue to occur as a result of poor management of cyanide at a number of mines around the world. These incidents attract concern from regulators and the public about the capacity of the mining industry to act responsibly, and have led in some quarters to calls for cyanide use in mining to be banned. In some jurisdictions, legislation relevant to cyanide use and waste disposal in mining has been reviewed and licensing tightened to improve levels of environmental protection. More stringent concentration limits are being applied on tailings storage facilities and to releases of mine water to the environment, commonly as a result of site-specific criteria determined by Environmental Protection Authorities at the environmental impact assessment /licence application stage. Revised guidelines have been developed in Australia for water quality (ANZECC/ARMCANZ 2000) which provide trigger values for the protection of aquatic life for a wide range of chemical toxicants and other parameters in ecologically relevant waters, based on the objective of providing high levels of ecosystem protection. The guidelines include trigger values for free cyanide of 4 μgl^{-1} in order to protect 99% of species (this is a theoretical estimation only). Clearly, the effectiveness of cyanide management in mining must improve to reduce the incidence of environmental impacts, regulatory non-compliance and community resistance to the industry, and to achieve the higher levels of ecosystem protection now expected.

The aim of the second edition of this booklet is to update the principles and procedures of cyanide use outlined in the first edition (1998), and to describe initiatives to improve the quality of cyanide management including the International Cyanide Management Code and recent regulatory changes. The booklet covers the principles involved and the practical actions which need to be taken in all areas of minesite operation from the initial planning stages through to post-closure rehabilitation. Interactions between cyanide, other metals, water and the environment are complex but because they have such a strong bearing on cyanide management they are discussed in some detail in this booklet. However, finer details are in appendices and boxes so that those readers who are familiar with cyanide chemistry or others who do not want such detail can concentrate on the main text. The text and references section include links to important information accessible electronically as well as citations to hard copy materials.

Mining companies that adopt best practice principles and take a pro-active approach to cyanide management are likely to derive many benefits, including:

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

Box 1: Some Facts About Cyanide

- The cyanide (CN^-) ion is the 'active agent' in terms of both the gold leaching process and toxicity to biological systems. Cyanide occurs in many different chemical species having different toxicities. Some are even used in foodstuffs, e.g. cyanide complexed to iron is an anti-caking agent in some table salt. Cyanide is also an integral part of a group of technologically and commercially important organic compounds, the nitriles, from which it may be released upon burning.
- Cyanide is ubiquitous in nature, with cyanide-containing chemicals being produced by a wide range of micro-organisms and approximately 2650 plant species as part of their normal metabolism (Ciba Foundation, 1988; Vennesland et al., 1981; US Fish & Wildlife Service, 1991). Cyanides thus occur naturally at low levels in many surface and ground waters. Humans and animals may be at risk from cyanide poisoning from eating plant materials that contain cyanide, including cassava, fruit pits (peaches, apricots), almonds and bamboo shoots (Hagelstein, 1997). Cyanide is also in vitamin B12.
- The human nose can be sensitive to the 'bitter almond' smell of hydrogen cyanide gas down to a concentration of about 1 ppm of cyanide in air, although about 4 in 10 people cannot smell it at all.
- Significant man-made sources include emissions from iron and steel production, coal combustion, petroleum refineries, solid waste incinerators, combustion of nitriles, vehicle exhausts and cigarette smoke. Levels of cyanide in inhaled cigarette smoke may reach concentrations that would be lethal if the smoke was not exhaled after short periods.
- A wide range of naturally occurring physical, chemical, and biochemical processes as illustrated in Figure 2 act upon cyanide and its compounds to break them down or form generally less toxic compounds. Hence, cyanide may degrade or attenuate by natural processes. However, some of these breakdown products are themselves toxic and able to pose unacceptable risks to human health and the environment (eg ammonia, cyanate, nitrate, nitrite, metal-cyanide complexes, thiocyanates, cyanogens, cyanogen chloride, chloroamines). Ammonia is about as toxic as cyanide, and can be more mobile (ANZECC/ARMCANZ 2000). Therefore the toxicity of breakdown products must be considered when assessing risk and designing response strategies.
- Cyanide is by no means as harmful as some naturally occurring toxins (Table 1). Many animals can metabolise small amounts of cyanide, rendering it non-toxic; the measured rate of cyanide detoxification by a human is 0.001 mg/kg-BW/min (Ballantyne, 1987). Plants are generally not susceptible to cyanide toxicity. On the other hand, cyanide (e.g. as HCN gas) is among the most toxic substances used industrially on a large scale (Table 2).

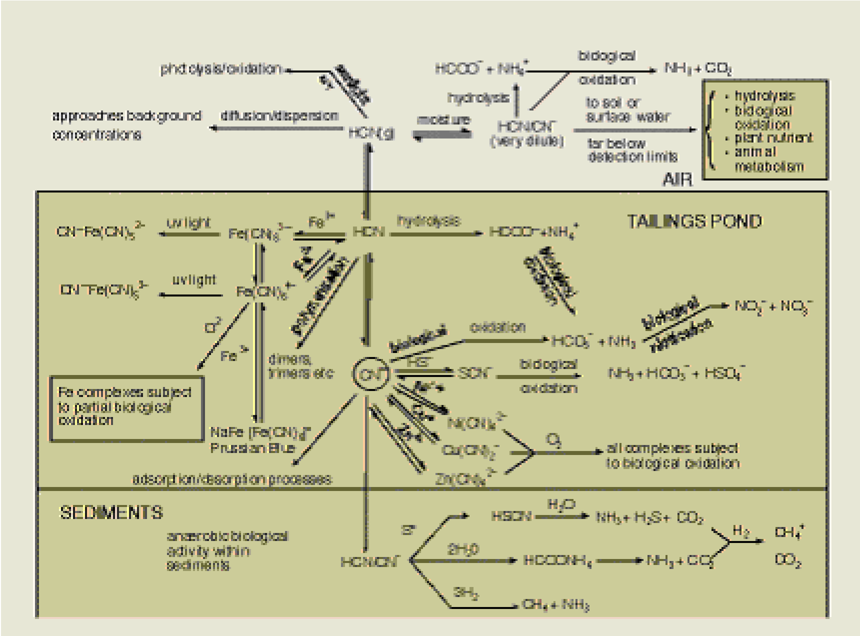


Figure 2: *Cyanide chemical loss pathways in the environment (after Smith and Mudder, 1991)*

Table 1: Toxicity of poisons derived from plants and animals compared with sodium cyanide (adapted from Mann 1992; Ballantyne 1987; USEPA 1989).

Poison	Lethal dose (µg/kg bodyweight for the mouse)
Botulinus toxin	0.03
Tetanus	0.07
Cobra neurotoxin	0.30
Ricin	1-5
Strychnine	500
Sodium cyanide	3400

Table 2: Toxicity to humans of industrial poisonous gases compared with hydrogen cyanide (adapted from Richardson 1992).

Poisonous gas	Threshold Limit Value (ppm)	Short-term Limit (ppm)
Carbon monoxide	25	300
Chlorine	0.5	1
Hydrogen cyanide	5	10
Hydrogen sulfide	10	10
Nitrogen dioxide	3	5
Sulfur dioxide	2	5

1.2 CYANIDE AND MINING

Since its first use in mining in New Zealand in 1887, sodium cyanide has played a key role in extracting gold and other metals such as silver, copper and zinc from ores in many countries of the world. Indeed it is estimated that about 90% of the world's gold production utilises cyanide in extraction, spread over about 460 of today's 875 operating gold mines.

Many gold-containing ores comprise finely divided gold particles locked up within other minerals, commonly sulfides. The gold extraction process must separate and concentrate the gold, but the low concentrations and particulate nature of the gold mean that purely physical extraction processes are neither economically viable nor quantitatively achievable. Therefore, gold is usually separated from the other constituents of the ore by chemically dissolving it, and then extracting it in conjunction with physical processing (crushing, milling, gravity separation, flocculation).

Although many chemical leaching agents (or lixiviants) have been investigated, only a few are suitable for commercial use. The alternatives are briefly described in section 1.4. Cyanide is still the preferred reagent for extracting gold when a leaching step is required, even after 100 years of research in this area. Indeed, as stated of the original inventors: 'There would have been no known method of working these low grade ores but for the discovery of the cyanide process ... in 1887 by John Stewart MacArthur and the brothers Forrest' (von Michaelis, 1984).

It should be the aim of all mines to use as little cyanide as possible and thus minimise environmental effects, maximise safety for workers and reduce costs. Cyanide consumption is one of the major components of the total operating cost of a typical gold-producing plant. Only 0.3 to 0.4 grams of cyanide per tonne of typical ore should be required to dissolve and extract the gold. However, in practice consumption ranges from 300 grams per tonne to more than 2000 grams per tonne. Much is thus wasted. The 'excess' cyanide consumption is partly accounted for by oxidation to cyanate and loss through volatilisation as HCN gas. Some is also often consumed by complexation with copper, iron and zinc or through reaction with sulfur species to form thiocyanate. Cyanide complexes in particular eventually find their way to tailings dams and then, potentially, into the wider environment. Cyanide will be lost in the tailings dams and the wider environment through natural degradation reactions (eg. volatilisation and loss to the atmosphere, or complexation, biodegradation, adsorption and degradation), so that in the long term only the less toxic and strongly complexed forms remain. Tailings dams are ideally designed to provide secure long-term storage of materials containing such complexes, as well as security against escape of more toxic forms (ie WAD and free cyanide) through seepage, overtopping, breaching, pipe/channel failure etc.

As well as being used to dissolve and extract gold from ore, cyanide is used as a flotation agent in the separation of other minerals from mixed ores. For example, sodium cyanide is used in the flotation of galena (lead sulfide) during which the galena is separated from pyrite (iron sulfide). The action of the cyanide is to reduce the tendency of the unwanted components of the ore to travel on froth and so inhibit separation.

1.3 RECENT INCIDENTS INVOLVING CYANIDE

The ongoing occurrence of significant environmental events involving cyanide indicates that knowledge and systems for cyanide management in mining must be further improved. In particular, engineering standards in the design, construction and maintenance of tailings dams, water management (including water balance), workforce training, tailings management, wildlife protection and emergency response resources and procedures are priority areas for attention.

The main reasons for environmental incidents at mines stem from poor water management and/or dam design or construction (ie dam failure, dam overtopping), inadequate design and maintenance (pipe failure), and transport accidents (Mudder and Botz 2001). Cyanide has been implicated in 9 of the 33 significant mining-related environmental incidents worldwide over the last 28 years. The presence of cyanide can often exacerbate the level of impact where contaminated water escapes into natural waterways. Recent incidents include:

- At Baia Mare in Romania in 2000 the tailings impoundment breached, releasing a cyanide plume which remained detectable for 2000km downstream, killed very large numbers of fish in the Tisza and Danube Rivers, and disrupted water supply. See Case Study *"Bai Mare, Romania: Findings of Investigations into the Cyanide Spill of 30 January 2000"*.
- Migratory and non-migratory waterbirds landing on the tailings dam at the Northparkes mine in Australia in 1995 were killed in their thousands from exposure to high cyanide levels resulting from a poor understanding of cyanide chemistry, and inappropriate analytical procedures and interpretation of monitoring data.
- A pallet of dry cyanide product fell from a helicopter en route to the Tolukuma gold mine in Papua New Guinea in 2000.
- Cyanide solution from an incompletely discharged ISO-tainer was allegedly released on the roadside after a delivery truck left a mine in the Northern Territory in 2002.
- Three hundred gallons of cyanide solution were accidentally discharged into the Lara River in Honduras in January 2002 owing to confusion over the numbering of valves in the cyanide plant at the San Andres mine.
- In May 1998, 1800 kg of sodium cyanide entered the Barskaun River in Kyrgyzstan after a truck accident en route to the Kumtor mine.
- Water contaminated with cyanide entered the Asuman River from the Tarkwa gold mine in the Wassa West District of Ghana in October 2001, killing fish and disrupting local water supplies; another discharge into the river from a ventilation shaft in January 2003 rekindled community health and safety concerns, although this water was later shown to be potable.

1.4 CYANIDE ECOTOXICOLOGY

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

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

Environmental incidents involving releases of cyanide are infrequent but continue to occur in Australia, particularly during transportation of cyanide, use at heap leach operations, and disposal of cyanide wastes to tailings storage facilities (TSFs). TSFs and other structures containing tailings and cyanide solutions are potentially susceptible to overflow or dam failure, potentially leading to environmental releases (eg. waterways). Unless controlled or excluded, animals - particularly birds - can gain access to cyanide solutions in tailings facilities, on heap leach pads and other structures, and poisonings have occurred as a result at some gold mines. Poisonings most frequently affect birds, but records indicate a wide range of important wild and domestic animal species been poisoned by cyanide. Mammals (including bats), frogs, reptiles (eg. snakes, lizards, tortoises) and insects are also susceptible to cyanide. In Australia, wildlife monitoring data from TSFs, heap leach operations and associated infrastructure are generally unavailable or are considered to represent minimum estimates (Donato 2002). Nevertheless, surveys indicate that mortality to birds, cattle, goats, pigs, frogs, lizards, mice, wallabies, kangaroos and small marsupials has been widespread.

Exposure to cyanide in solution through consumption of surface water is the main exposure route for most animals affected by cyanide poisoning, but concurrent exposure through inhalation and skin absorption may also occur. In addition, animals may consume cyanide inadvertently in tailings slurry or sediments (eg. during foraging, when consuming carcasses or preening feathers).

Cyanide acts rapidly in aquatic environments. In fish, cyanide targets organs where gaseous exchange or osmoregulatory processes occur, principally the gills and the surface of egg capsules. Signs of acute stress are increased ventilation, gulping for air, erratic swimming movements, muscular convulsions, tremors, sinking to the bottom, and extended gill covers. Aquatic organisms show a range of sensitivities to cyanide, but fish are generally the most sensitive aquatic organisms (of those tested thus far), with 24 hour LC50 concentrations (ie concentrations at which 50% of the individuals die) as low as 40 µg/L free cyanide for some species. LC50 values for aquatic invertebrates range upwards from around 90 µg/L at natural temperatures. Aquatic plants show effects at water concentrations from 30 µg/L to several milligrams per litre (USEPA 1989). In the environment, cyanide may degrade forming products of generally lower toxicity, but which may also be problematic in the environment (eg ammonia, nitrate).

Published environment protection guidelines pertain to cyanide in waters, and there are currently no published benchmarks for cyanide in soils, sediments or air for the protection of aquatic or terrestrial plants or animals. The current Australian water quality trigger values for free cyanide in freshwater and marine waters are 7 µg/L and 4 µg/L, respectively. These values, which are intended to protect the range of organisms in natural waterbodies, are considered of moderate reliability (ANZECC/ARMCANZ 2000). At 'no discharge' mine facilities, a water quality benchmark for the protection of wildlife of 50 mg WAD CN/L is recognised by the mining industry for cyanide solutions accessible to wildlife; however, this benchmark is considered an interim benchmark in Australia pending investigation of its validity. Using a precautionary approach, lower concentration benchmarks for the protection of wildlife have also been applied, and wildlife risk management through total exclusion of access to cyanide solutions is also practised. See also the Case Study: *Henty Gold Limited (Placer Dome Asia Pacific): Cyanide Management in a Highly Sensitive Environment.*

1.5 ALTERNATIVES TO CYANIDE FOR PROCESSING PRECIOUS METAL ORE

There is a wide range of techniques for separating gold and other precious metals from ore (McNulty 2001a), but cyanidation is the most studied and used method on the basis of reagent availability, effectiveness, cost, and environmental compatibility. In a comparison between reagents that are well understood, and have been implemented by the mining industry, cyanide was shown to be far superior to the other techniques in terms of "relative hazards" comprising an assessment of worker exposure, environmental, and overall hazard (the other techniques use bromine/bromide/sulfuric acid; hypochlorite/chloride; ammonium thiosulfate/ammonia/ copper; thiourea/ferric sulfate/sulfuric acid). Cyanide also required many less truck movements of lixiviants and associated compounds, and the cost of water treatment for the cyanide-based technique was calculated at an order of magnitude less than the alternatives assessed. For the situation assessed (heap-leaching of a low-grade gold-silver ore), cyanide was the only leaching system that yielded a positive cumulative cash flow (McNulty 2001b).

Clearly, cyanide remains the preferred lixiviant in terms of metallurgical efficiency, cost, and relative environmental hazard. Alternatives to cyanide could be economically viable where operating costs are low and/or when prices are high; however, cyanide would provide relatively greater return and would remain the method of choice unless there were circumstances preventing its use such as regulatory restrictions. The report, "Breaking new ground - mining minerals and sustainable development", of the Mining, Minerals and Sustainable Development Project (MMSD) summarises the situation thus:

'At the present time, there is no economically viable, environmentally sound alternative to using the reagent cyanide in the production of gold. Cyanide is also an hazardous chemical that requires careful management'. (MMSD 2002)

Without cyanide, many mines would be technologically and/or economically unable to operate. The challenge for the mining industry is to improve its record of cyanide management to meet community expectations and move towards a level of responsible environmental and social stewardship consistent with best practice environmental management and sustainability.

1.6 CONCEPTS AND TOOLS FOR SUSTAINABILITY IN MINING, AND THEIR RELATIONSHIP TO CYANIDE MANAGEMENT

Cyanide use poses higher risks to the environment, worker safety, and public health in jurisdictions where industry standards or the regulatory framework are weak. The level of environmental impact from some recent incidents, and the public's perception of cyanide as a poison, contribute strongly to the commonly negative opinions held of mining operations by local communities.

Because there are very few practical alternatives to cyanide in gold extraction, and these alternatives are generally significantly more costly (see section 1.5), it is true that the majority of gold mines around the world would become uneconomic without it. However, the ongoing hazards posed to environmental and human health by its use represent a very significant barrier to achieving sustainable development. The ability of the gold mining industry to achieve desirable economic, social and environmental performance is under challenge. Cyanide use can impinge upon the concept of natural, human, social and financial capital and their equitable distribution, which lies at the heart of the concept of sustainable development **(Box 2)**.

Box 2: Sustainable Development Principles
Economic Sphere • Maximise human well-being • Ensure efficient use of all resources, natural and otherwise, by maximising rents (ie user pay charges) • Seek to identify and internalise environmental and social costs • Maintain and enhance the conditions for viable enterprise **Social Sphere** • Ensure a fair distribution of the costs and benefits of development for all those alive today • Respect and reinforce the fundamental rights of human beings, including civil and political liberties, cultural autonomy, social and economic freedoms, and personal security • Seek to sustain improvements over time - through replacement with other forms of capital, ensure that depletion of natural resources will not deprive future generations **Environmental Sphere** • Promote responsible stewardship of natural resources and the environment, including remediation of past damage • Minimise waste and environmental damage along the whole of the supply chain • Exercise prudence where impacts are unknown or uncertain • Operate within ecological limits and protect critical natural capital **Governance Sphere** • Support representative democracy, including participatory decision-making • Encourage free-enterprise within a system of clear and fair rules and incentives • Avoid excessive concentration of power through appropriate checks and balances • Ensure transparency through providing all stakeholders with access to relevant and accurate information • Ensure accountability for decisions and actions, which are based on comprehensive and reliable analysis • Encourage cooperation in order to build trust and shared goals and values • Ensure that decisions are made at the appropriate level, adhering to the principle of subsidiarity where possible

It is clear that mining potentially impacts on sustainability in many ways. Indeed, of the issues identified as key drivers for action in order to achieve sustainable development, mining is or has the potential to be a contributor to every one:

Key drivers which identify the need for action on implementing sustainability

- The growing imbalance in development between different countries
- Poor progress in poverty alleviation in many countries
- High and increasing consumption of scarce resources related to continued population growth
- Increased pollution associated with increasing consumption
- Unintended and undesirable consequences of poor environmental and social impact management, such as climate change, ecosystem integrity and biodiversity
- Negative impacts on culture, with some cultures nearing extinction
- The apparent benefits to corporations and shareholders through globalisation, at the expense of smaller national and local institutions and communities
- Impacts on employment and competitive disadvantages in less developed countries as a consequence of continually improving technologies

The goal of achieving sustainability is a major issue confronting the minerals industry today. The global MMSD report concluded that *'One of the greatest challenges facing the world today is integrating economic activity with environmental integrity and social concerns. The goal of that integration can be seen as "sustainable development"* (MMSD 2002). Part of that challenge is for the operator to commit to achieving sustainable development, and providing adequate resources and support to do so. Another part if the challenge is to identify the specific actions necessary at the mine site - as the sustainable development applies to all types of human endeavour, its principles are necessarily expressed in high level and generic terms. There is little information to advise on how these general principles can be applied to specific industrial settings.

So how can a mine operator adopt practices which will achieve a sustainable development outcome? Over the last twenty years requirements and expectations from governments, customers and the general public have driven the development of a range of management tools to improve performance in safety and environmental protection, and to lessen societal impacts. All of these tools serve to raise the focus on social and environmental considerations in decision-making to a level similar to that given to other business considerations - in other words, to adopt a triple bottom line approach where success is measured through assessing performance against targets and indicators for social harmony, environmental protection and profitability.

Management tools consistent with actions to achieve sustainable development

- **Risk Management -** Encompassing systematic application of policies, procedures and practices to hazard identification; assessing the consequences of those hazards; estimating risk levels; assessing those levels of risk against relevant criteria and objectives; and making decisions to minimise identified risks (refer to the Environmental Risk Management booklet).
- **Bench-marking** - Adopting specific outcomes, levels or practices as a desired standard against which performance is measured. Bench-marking is being applied to complete integrated systems such as setting the Environmental Management System of one mine as the bench-mark for other operations to emulate.
- **Quality Assurance/TQM** - Applying measures to minimise the risk of poor performance through such principles as bench-marking and continuous improvement, doing it right the first time, routine monitoring of performance, and implementing corrective action as required.
- **Life Cycle Analysis/ Assessment** - A tool for assessing the environmental impacts associated with a product, process or service throughout its life cycle, from the extraction of the raw materials through to processing, transport, use, reuse, recycling or disposal.
- **Cleaner Production (or Ecoefficiency)** - Eco-efficiency and cleaner production are strategies that businesses can use to improve their bottom line and their environmental performance at the same time.

- **Product Stewardship** - An operator accepts responsibility for all aspects of the possible impacts directly or indirectly associated with the use or production of a product. A mining company would acknowledge and minimize risks associated with cyanide including its transport to and use and disposal on-site; the cyanide manufacturer would also acknowledge these risks and would work with the mining companies to ensure the potential risks from the use of its product are as low as possible. (Product stewardship features in the benchmark Australian Minerals Industry Code for Environmental Management).

Table 3: Translating general sustainable development principles into actions at the minesite

Moving from concept to action for Sustainable Development (MMSD 2002)	Application at the corporate or minesite level
A robust framework based on a agreed set of broad principles.	Mine Management Plan, which includes clear environmental and social protection objectives (refer to the Mine Planning booklet).
An understanding of the key challenges and constraints facing the sector at different levels and in different regions and the actions needed to meet or overcome them, along with the respective roles and responsibilities of actors in the sector.	Thorough understanding of cyanide technology, relevant codes, regulations applying to transport, storage, use and disposal of hazardous materials, regulatory environmental requirements. Determination of site-specific worker, environmental and social sensitivities. Nomination of responsible officers (with delegations and powers) for cyanide management & use (refer to the Environmental Impact Assessment and Hazardous Materials booklets).
A process for responding to these challenges that respects the rights and interests of all those involved, is able to set priorities, and ensures that action is taken at the appropriate level.	Site-specific Cyanide Management Plan including role and responsibilities for responsible persons, and environmental protection targets specific to cyanide (refer to the Environmental Management Systems and Environmental Risk Management booklets).
An integrated set of institutions and policy instruments to ensure minimum standards of compliance as well as responsible voluntary actions.	Cyanide Management Plan integrated with other relevant plans, including Water Management and Emergency Response Plans. Operational plans and schedules for workers, and workforce training resources and arrangements (refer to the Water Management, Cleaner Production, Workforce Awareness and Hazardous Materials booklets).
Verifiable measures to evaluate progress and foster consistent improvement.	Environmental Monitoring Program includes schedules, locations and techniques for cyanide sampling. Analysis at independent respected laboratories. Regular interpretation and reporting of results. Regular auditing and review of Cyanide Management Plan and Environmental Monitoring Program (refer to the Environmental Monitoring and Performance and Environmental Auditing booklets).

These tools are mechanisms through which sustainable outcomes can be achieved. The tools should be adopted to cyanide management in a framework which is comprehensive and forward-looking; which sets out long-term as well as short-term objectives; and which defines a set of actions through which the concepts of sustainable development can be achieved.

Actions for cyanide management which are consistent with the principles of sustainable development are given in Table 3. These actions will only be fully effective in moving towards sustainability if they are implemented through applying the management tools listed above

1.7 DEVELOPMENT OF THE INTERNATIONAL CYANIDE MANAGEMENT CODE

In recognition of the toxicity of cyanide and its related risks, many countries have regulations applying to its manufacture, procurement, transport, storage, use, and disposal. Several also have severe civil and criminal penalties for accidental or intentional violation of these standards and regulations. Even so, accidents or intentional misuse in mining-related activities do happen periodically, and impacts are generally more frequent and significant in countries where the regulatory, monitoring and reporting systems are less developed.

During the 1990s a trend developed amongst some companies to prepare mission statements, guidelines, and codes of ethics in response to public concerns on environmental risks related to mining. Some gold operations prepared general or specific codes of practice and management plans for cyanide at their mines, but elsewhere information on cyanide management practice was included along with other issues relevant to worker safety, environmental protection and hazardous materials/emergency response, in general guidelines and operational procedures developed for cyanide around the world. Cyanide was regarded as being well-enough understood and managed to not require any specially coordinated attention internationally.

However, serious incidents involving cyanide continued, and in 2000 the major spill at Baia Mare in Romania indicated that a concerted effort was needed by industry to avert growing calls for cyanide to be banned in gold mining in several countries. In an unprecedented effort, the global mining industry, in conjunction with the United Nations Environmental Programme (UNEP), the International Council on Mining and Metals (ICMM), the Gold Institute, the World Wildlife Fund for Nature (WWF) and the International Finance Corporation (IFC), worked to develop the first international code for the management of cyanide - the International Cyanide Management Code. The Code is reproduced in Appendix 1.

The Code comprises two major elements: *Commitments* which signatories make to use cyanide in a responsible way at all times, and *"Standards of Practice"* which identify measurable performance goals to be met and maintained. The Code addresses production (ie gold extraction), transportation, handling and storage, processing plants with tailings ponds, decommissioning, worker safety, emergency response, training, dialogue and public relations.

The objective of the Code is to assist the global gold mining industry in improving cyanide management, thereby minimising the risks to workers, communities and the environment from the use of cyanide in gold mining and reducing community concerns about its use. The goal is for the Code to be used by large and small gold mining companies, cyanide manufacturers and transporters; to serve as a form of assurance for interested parties including regulators, financiers, communities and NGOs; to be applied internationally, in both developed and developing countries; to be credible and verifiable; and to be dynamic over time (Tayles 2002). See Case Study *"MPI Mines Ltd - Stawell Gold Mine, Victoria - Applying the International Cyanide Code at a Medium-scale Gold Mine"*

Key points for industry improvement in the Code include:

- increased tracking of cyanide from source to site;
- purchase of cyanide from reputable suppliers;
- improved monitoring and maintenance of on-site conveyance systems;
- enhanced protection of workers and the environment;
- recommendations for water management and treatment;
- identification of WAD cyanide compounds (which include free CN and weak dissociable cyano-metal complexes) as the toxicologically significant form), but not discounting the instability of strongly complexed forms under certain environmental situations (ie. sunlight);
- establishment of guidelines for storage of cyanide solution in ponds; and

- requirements for compliance auditing and certification.

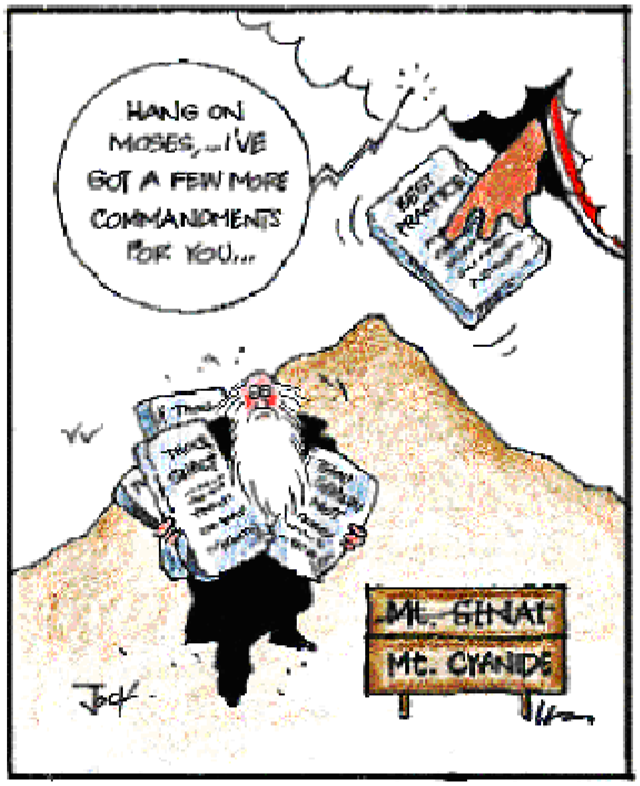
Administration of the Code is to be undertaken through the International Cyanide Management Institute, a non-profit corporation with a Board of Directors drawn from representatives of the gold mining industry and other stakeholder groups. Verification of compliance to the Code will be by independent third-party auditors. For compliance against the Code:

- the auditor must conclude that the operation is either in full compliance or substantial compliance;
- when found to be in substantial compliance, the company must submit an Action Plan to correct the deficiencies and fully implement this Action Plan within a year or by the agreed timeframe if sooner;
- there must be no verified evidence that the operation is not in compliance with the Code;
- a verification audit must be held at least every three years; and
- a verification audit must be undertaken within two years of a change in ownership (ie a change of the controlling interest of the operating company).

The Code website includes an "Implementation Guide" to assist operations in applying the Code's Principles and Standards, and a Small Mine Operators Management Systems Guide is under development.

1.8 BASIC PRINCIPLES OF BEST PRACTICE IN CYANIDE MANAGEMENT

Best practice cyanide management requires developing, implementing and continually reviewing relevant organisational and operational procedures. The aim is to ensure that the risk of adverse health and environmental impacts is negligible and maintained at levels acceptable to the community and, therefore, to regulators. All aspects of cyanide handling and use should be regarded as within the responsibility of the mine operator, from ensuring that the manufacturer maintains high environmental and health protection standards, through arrangements for transportation to the site, as well as its handling, storage, use, and treatment on the mine site, and its ultimate fate including possible short and long term impacts on the environment. In keeping with the concepts of eco-efficiency and cleaner production, the operator should also strive to reduce the quantities of cyanide brought onto and used on the site.



There is no one system applying to all operations which will deliver best practice, owing to each site differing in ore characteristics, climate, terrain, environmental and community sensitivity. Appropriate actions may depend on the stage in the mining life cycle of the operation. A site-specific and dynamic approach is therefore critical to achieving best practice. Best Practice is simply "the best way of doing things", and in this context it is essential that the regulatory requirements of the applicable jurisdiction are met, and that the principles and standards of practice of the International Cyanide Management Code are fully implemented.

A generic set of management principles that apply to all cyanide-using industries is listed under "Ten Commandments". It is critical that management provides resources to effectively implement them. See also Case Study: *"Newmont Pajingo, Queensland:: Paste Thickener Improves Ecoefficiency and Reduces Cyanide*

Consumption" and *"MPI Mines Ltd Stawell Gold Mine, Victoria: Managing Cyanide at a Medium-Scale Gold Mining Operation"*.

Ten Commandments

There are 'ten commandments' which must be followed to achieve best practice for cyanide.

1. Implement an **overall planning procedure**, from conception to closure and rehabilitation, for all mine operations that use cyanide, based on an assessment of risks that maximises the benefits and minimises liabilities and environmental impacts.
2. Establish, implement and regularly review a **cyanide management strategy** as part of the mine's environmental management plan for implementing best practice.
3. Implement initial and ongoing cyanide **safety and management training** for all personnel involved in cyanide including contractors, who have management, operational or maintenance responsibilities or who handle or are exposed to cyanide-this training should cover both the everyday roles of personnel and how they respond to cyanide-related emergencies.
4. Establish **well-defined responsibilities** for individuals with clear chains of command and effective lines of communication within the workforce.
5. Institute **safe procedures** for cyanide handling governing transport, storage, containment, use and disposal.
6. Integrate the mine's **cyanide and water management** plans
7. Identify and implement appropriate options for **minimising** demand for cyanide, and **reusing, recycling and disposing** of residual cyanide from plant operations.
8. Conduct regular **cyanide audits** and revise cyanide management procedures where appropriate.
9. Develop a cyanide occupational and natural **environment monitoring program**, supported through a sampling, sample preservation, analysis and reporting protocol.
10. Establish a carefully considered and regularly practiced **emergency response procedure**.

A major challenge is to ensure openness and transparency to the public of systems utilised by the mining industry, because without them community concern and resistance to cyanide use in mining will be very difficult to change. Commitment to good science and good management must extend to a commitment to communication - of risks and performance - so that real and perceived threats can be understood and for the community to develop more trusting attitudes towards the gold mining industry. Techniques for community engagement are described in the Community Consultation and Involvement booklet in this series.

Establishing effective public education and outreach programs with local communities is fundamental to a company's long-term success (Fox 2001a). 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 outreach program at any mine. If these objectives are met there should be no hesitation by the community in deciding whether a mining company would be welcomed back in the future (Fox 2001a).

2. CYANIDE IN GOLD EXTRACTION

As part of an overall planning procedure (see Commandment 1), the role cyanide will play in a mining operation must be well understood and defined. Personnel who have a sound knowledge of the types of cyanide and how their chemistry relates to extraction, recycling, workers' health and environmental risks should participate in planning the mine and its cyanide strategy (see Commandment 2).

2.1 TYPES AND NAMES OF CYANIDE COMPLEXES

Because there is such a variety of cyanide complexes, it is often difficult to compare results of toxicological and environmental investigations of cyanide. For this reason it is important that people responsible for managing cyanide understand and specify the type of cyanide being measured.

An essential chemical fact about cyanide is that it is not an element like, for example, gold, arsenic and mercury. The free cyanide ion comprises a nitrogen atom bonded to a carbon atom (CN^-). This ion combines with hydrogen to form hydrocyanic acid (HCN) and with metal ions to form salts. The term cyanide is imprecisely applied to all of these forms and more precise terms are defined as follows:

- free cyanide-the sum of the free cyanide (CN^-) ion and hydrocyanic acid, HCN(aq). It is the free cyanide ion that is generally measured after suitable sample treatment;
- titratable cyanide-the cyanide concentration determined in solution by titration with silver nitrate ($AgNO_3$); often taken to mean free CN- but may include cyanide from the dissociation of some cyano-metal complexes;
- simple cyano-metal complexes-these contain only one type of metal ion, commonly an alkaline or alkaline earth metal ion, and dissociate when dissolved in water to release free cyanide;
- complex cyanides-these contain more than one type of metal ion and dissociate in water to release a metal ion and a cyanide-metal ion complex via a reaction of the type, for example;

(1)*	$Ca_2Fe(CN)_6(s)$	$\rightleftharpoons$	$Fe(CN)_6^{4}$	+ $2Ca^{2+}$	*(s)=solid
	i.e. complex cyanide		metal-cyanide complex	+ counter ion	

- where the complex ion may then dissociate further to give free cyanide;
- total cyanide-the sum of all of the different forms of cyanide present in a system. 'Total cyanide' is a toxicologically meaningless term since its measurement requires harsh sample treatment to break down intractable complex cyanides before free cyanide can be measured;
- weak acid dissociable (WAD) cyanide-cyanide that is readily released from cyanide-containing complexes when the pH is lowered. Any free cyanide already present and cyanide released from nickel, zinc, copper and cadmium complexes (but not iron or cobalt complexes) is measured. WAD cyanide is measured by treating the sample with a weak acid buffer solution such as a sodium acetate/acetic acid mixture at pH 4.5 to 6. This is less harsh than the methods used for total cyanide. WAD cyanide is generally considered to be the best current measure for assessing human and animal toxicity;
- cyanide amenable to chlorination (CATC)-an analytical quantity that requires similar sample treatment to WAD but is much less reliable; and
- WAD CN, Available Cyanide and CATC generally measure the free and weakly dissociable cyano-metal complexes.

Different forms of cyanide can also be defined by reference to the various analytical techniques and the types of cyanide that each technique is able to measure. For example, free cyanide plus weak dissociable cyano-metal complexes may defined as 'WAD CN 4500-CN-I', 'CATC' or 'Available CN Method OIA-1677' depending on the method used (adapted from Schulz, 2002). This approach to cyanide nomenclature requires full disclosure of the method and the analytical protocol used to ensure that meaningful comparisons and check analyses can be undertaken.

2.2 KEY CHEMICAL REACTIONS

A knowledge of the chemistry of cyanide helps in understanding and predicting its behaviour not only as it is used to analyse and extract gold but also in the occupational and natural environments (Bard 1976; Chadwick and Sharpe 1966; Nichol et al 1987; Sharpe 1976; Sharpe 1987). Of particular importance is a knowledge of the way pH (i.e. acidity/alkalinity) and salinity (concentration of salts) affect the capacity of the various chemical forms of cyanide to remain stable and not release toxic hydrogen cyanide gas.

Extracting Gold

The total process of purifying gold by dissolving it, combining it with cyanide and then extracting it electrolytically is highly complex. However, in essence the technique is simply mixing ore with sodium cyanide in an alkaline solution to produce gold cyanide. The alkalinity ensures that free cyanide ions, which are essential for the reaction, are not lost as free cyanide (HCN) gas. The other two components necessary are oxygen and water.

Equations 2, 3 and the equilibrium constant (4) describe the pH dependency of the formation of hydrocyanic acid, which is depicted separately in Figure 2 as a function of salinity. It can be seen that, at a pH value of about 10, approximately 90% of the cyanide is present as the CN^- ion, with more and more becoming protonated (i.e. bound with hydrogen ions) as the solution pH falls. As CN- is the active ion in the gold complexation process (Equations 6 and 7), it is important that the cyanide is stabilised by the maintenance of a sufficiently high pH. In practice, this is achieved through the addition of lime, CaO(s), to the 'barren' process stream **(Box 3)**.

(2)*	$CN + H_2O^-$	$\rightleftharpoons$	HCN(aq)	+	OH^-	*(aq)=aqueous

(3)*	$CN^- + H^+$	$\rightleftharpoons$	HCN(aq)	*(g)=gas

(4)	K=[HCN(aq)]/[CN][H]

where K is the equilibrium constant describing formation of HCN(aq) and log K ~ 9.6 in 'pure' water at 25°C (Beck, 1987).

Equation 5 describes the loss of hydrocyanic acid from the aqueous phase to the vapour phase as hydrogen cyanide gas through the process of volatilisation. Being an equilibrium process, it may represent a pathway of significant loss if the pH of the solution is too low. This is a problem for operator safety, and for the efficient use of cyanide during extraction, but it may be highly desirable in the environment as a route for cyanide loss and degradation.

(5)*	HCN(aq)	$\rightleftharpoons$	HCN(g)	*(aq)=aqueous(g)=gas

Bodlander's equation

(6)	$2Au + 4CN + O_2 + 2H_2O$	$\rightleftharpoons$	$2Au(CN)_2 + H_2O_2 + 2OH^-$

Elsener's equation

(7)	$4Au + 8CN + O_2 + 2H_2O$	$\rightleftharpoons$	$4Au(CN)_2 + 4OH$

Both reactions (Equations 6 and 7) are electrochemical and describe how gold is dissolved through the combined presence of oxygen and cyanide. During the reaction the gold forms a gold (I)* cyanide complex in alkaline solution. Both equations emphasise the importance of the free cyanide ion and hence the need for a pH value greater than 10. However, they lead to the formation of hydroxide ions which means that less gold will dissolve if the alkalinity of the process stream is too high. A pH of 10.3 is a good compromise.

Recycling or Disposing of Cyanide

As discussed in Section 4.3, even with the best recycling efforts, there may be cyanide waste that needs to be treated to enhance its rate of degradation.

Natural degradation by volatilisation

Most cyanide is lost naturally by volatilisation to HCN gas. During gold extraction it is important to maintain a high pH of a cyanide solution to prevent dangerous levels of HCN gas being produced-and to retain cyanide for the reactions that allow gold to be extracted. However, this is reversed when the aim is to encourage the gradual release of waste cyanide into the air (ie from land-disposed waste materials or tailings storage facilities). The same equations (2, 3 and 4 above) are therefore relevant to disposal of cyanide.

Natural degradation by oxidation

Reactions that cause the oxidative loss of the cyanide ion from aqueous alkaline solutions are described by the following equations:

(8)	$CN^- + ½O_2 + 2H_2O$	$\rightleftharpoons$	$CNO^- + H_2O + 2e^-$	
(9)	$CN^- + 2OH^-$	$\rightleftharpoons$	$CNO^- + H_2O + 2e^-$	
(10)*	$2CN^-$	$\rightleftharpoons$	$(CN)_2(g) + 2e^-$	*e = electrons (g) = gas

Reactions 9 and 10 represent oxidative loss of cyanide ion giving rise to cyanate ion and cyanogen gas respectively. As can be seen from the pH versus the oxidation-reduction potential stability (Pourbaix) diagram presented in Figure 3, the cyanate ion is thermodynamically the most stable form of cyanide under the majority of operating and ambient environmental conditions. However, reaction 9 proceeds very slowly in the absence of a catalyst so that loss of cyanide by this route is limited during the ore extraction process.

Equation 8, in which cyanide is degraded by combining in aqueous solutions to produce ammonia and bicarbonate, is particularly relevant to cyanide analysis and is discussed further in Section 2.3 below.

Minimising Risks

Metal ion complexation

Equation 11 describes metal ion-cyanide-proton interactions in a generalised manner (ionic charges have been omitted for the sake of clarity).

(11)	pM + qCN + rH	$\rightleftharpoons$	$M_p(CN)_q$

With simple metal complexes this becomes:

pM + qCN	$\rightleftharpoons$	$M_p(CN)_q$

These reactions mean that the presence in the ore of metal ions other than gold will reduce the availability of cyanide to act as a lixiviant. In managing the efficient use of cyanide in the process, it is therefore important to take account of other metals. On the other hand, these equilibria may also be advantageous, since they can be responsible for holding cyanide in stable, non-labile, less toxic forms in the natural environment **(Table 4)**.

Precipitation reaction

$$\text{(12)} \quad Cu(CN)_3^{2-} + 2H^+ \rightleftharpoons CuCN(s) + 2HCN$$

$$\text{(13)*} \quad 2M^{2+} + Fe(CN)_6^{4-} \rightleftharpoons M_2Fe(CN)_6(s) \qquad \text{*(s) = solid}$$

The formation of solid metallocyanides may, or may not, be desirable from an environmental perspective. Equation 12 illustrates the potential for release of hydrogen cyanide after a soluble cyanide complex has been acidified. Such a reaction is possible in uncontrolled conditions under which carbon dioxide dissolves and acidifies surface waters contaminated with certain complexes [e.g. $Cu(CN)3^{2-}$]. Equation 13 on the other hand represents a way for cyanide to be removed from solution and its potential toxicity reduced.

Reactions with sulfur-containing compounds

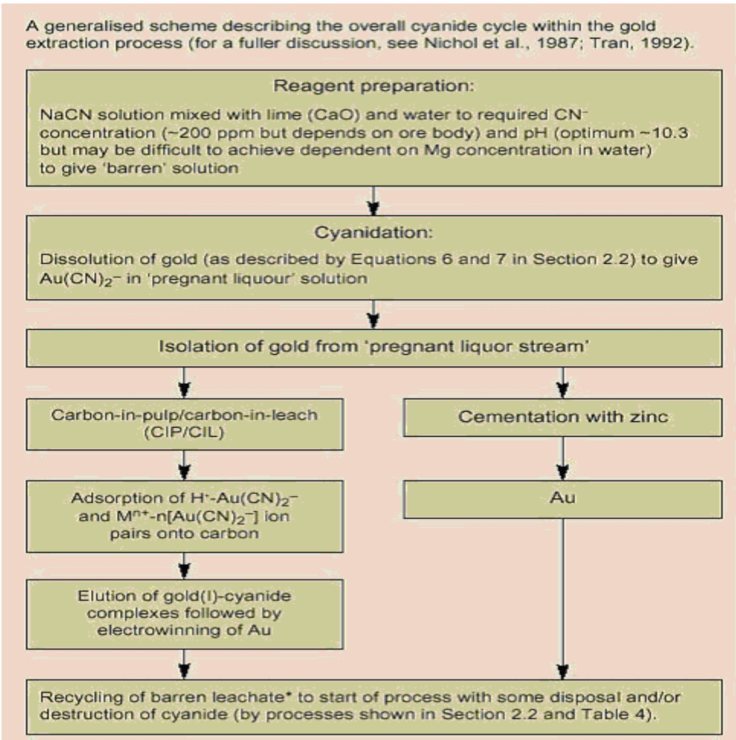
If sulfur-containing minerals are present cyanides may combine with the sulfur and be lost.

$$\text{(14)} \quad 2S^{2-} + 2CN^- + O_2 + 2H_2O \rightleftharpoons 2SCN^- + 4OH^-$$

$$\text{(15)} \quad S_2O_3^{2-} + CN^- \rightleftharpoons SCN^- + SO_3^{2-}$$

However, Equations 14 and 15 are generally beneficial environmentally as the thiocyanate ion is much less toxic than the cyanide ion **(Table 4)**. In addition, thiosulfate has been used as an antidote to cyanide poisoning **(Box 5)**.

Box 3: Cyanide Process Chemistry



* The barren (gold-free) solution contains CN^- ion and cyanide complexes of metals such as copper, iron, nickel and zinc that dissolve simultaneously with the gold from the ore body. Much of the barren solution is recycled, but a portion must be discharged from the mill to avoid deleterious build-up of complexes that would interfere with subsequent gold dissolution cycles. Consequently, two principle cyanide waste streams are discharged from a conventional gold mill: waste barren solution and leached tailings slurry.

TABLE 4: Nomenclature, stability and toxicity of some important cyanide species in gold mining tailings

Term	Analytical type [a]	Species or compound	log equilibrium constant [b] and solubility data	Toxicity to fish [c] (LC_{50} in mg/L)
1. Free cyanide	free cyanide	CN^-	not applicable	~ 0.1
		HCN	9.2	0.05 to 0.18
2. Simple compounds				
a) readily soluble	free cyanide	KCN(s)*	sol = 71.6g/100g H_2O (25°C)	0.02 to 0.08
		$NaCN.2H_2O(s)$	sol = 34.2g/100g H_2O (15°C)	0.4 to 0.7
		$Ca(CN)_2(s)$		–
b) relatively insoluble	WAD/CATC/total	CuCN(s)	–19.5	–
		$Zn(CN)_2(s)$	–15.9	–
		$Ni(CN)_2(s)$	sol = 9.1 x 10^{-4}g/100g H_2O (25°C)	–
3. Weak complexes	WAD/CATC/total	$Cd(CN)_4^{2-}$	17.9	–
		$Zn(CN)_4^{2-}$	19.6	0.18
4. Moderately strong complexes	WAD/CATC/total	$Ni(CN)_4^{2-}$	30.2	0.42
		$Cu(CN)_2^-$	16.3	–
		$Cu(CN)_3^{2-}$	21.6	0.71 (24 hours)
		$Cu(CN)_4^{3-}$	23.1	–
		$Ag(CN)_2^-$	20.5	–
5. Strong complexes	total	$Fe(CN)_6^{4-}$	35.4	35.0 (light); 860 to 940 (dark)
		$Fe(CN)_6^{3-}$	43.6	35.2 (light); 860 to 1210 (dark)
		$Au(CN)_2^-$	38.3	–
Thiocyanate		SCN^-	not relevant	50–200
Cyanate		CNO^-	not relevant	34–54

(a) WAD = weak acid dissociable; CATC = cyanide amenable to chloride; total = total cyanide following acid distillation (see Section 2.1).
(b) Measure of stability, given only for comparative purposes; values quoted in the literature are quite variable.
(c) Toxicity data is given only for guidance and should be used for comparative purposes only, a dash indicates 'no relevant data found'.
(Beck, 1987; Hagelstein, 1997; Minerals Council of Australia,1996; Richardson, 1992)
* (s) = solid

Photodecomposition reactions of hexacyanoferrate (II) and (III) ions

Cyanide reacts with both Fe^{2+} and Fe^{3+} ions in aqueous solutions to form, respectively, stable $Fe(CN)_6^{4-}$ and $Fe(CN)_6^{3-}$ complexes (Table 4). Also, complexes of these types may be stabilised and attenuated by precipitation with other metal ions (see Equation 13). However, in the presence of sunlight, even these stable complexes may be photolysed, breaking down to give free cyanide which is then photo-oxidised to the cyanate ion (Equations 16 and 17).

$$[Fe(CN)_6]^{3-} + H_2O \underset{}{\overset{UV}{\rightleftharpoons}} [Fe(CN)_5H_2O]^{2-} + CN^- \quad (16)$$

$$2[Fe(CN)_6]^{3-} + CN^- + H_2O \overset{UV}{\rightleftharpoons} 2[Fe(CN)_6]^{4-} + OCN^- + 2H^+ \quad (17)$$

This is not only a potential degradation pathway for cyanide in the environment but also represents a possible source of error in the analytical determination of free and total cyanide should the presence of these species go unrecognised in the sample preservation step of the analytical process (Box 4).

Cyanide solubility increases with rising pH in the presence of excess iron, which may be caused by coprecipitation of iron hydroxide and iron cyanide to form a solid solution during the aging process (Ghosh et al 1999). Consequently cyanide solubility increases with pH in iron-rich soils and is higher than in iron-poor soils. Mixing or equilibrium may also exist with other phases such as manganese iron cyanide, in that case leading to lower solubilities. Besides uncertainties regarding the solution chemistry of iron cyanide compounds, there are also questions and discrepancies regarding the influence of daylight, UV and particularly the UV component of daylight on the decay of iron cyanide complexes. These uncertainties also sometimes raise questions about analytical results. Excluding microbial activity, iron-complexed cyanide degrades extremely slowly in soils in the dark, with half-lives from decades to 1000 years (Kjeldsen 1999; Souren 2000).

Adsorption reactions

The adsorption of free cyanide ion and complexed cyanides from the aqueous phase onto solids present in the process stream, tailings dam or the wider environment represents a final route by which cyanide may be temporarily removed from solution. A generalised reaction describing this phenomenon is given as Equation 18.

(18)	$Me\text{-}OH + CN^-$	$\rightleftharpoons$	$Me\text{-}CN + OH^-$

where Me-OH represents a mineral surface. Once again such reactions may be detrimental to the gold-winning process but beneficial in the environment.

2.3 ANALYSING AND REPORTING OF CYANIDE

Chemical reactions relevant to analysis include those that are used to break down complex cyanides to give free, measurable cyanide ions (see Section 2.1). Also important is the natural decomposition reaction (Equation 19). This reaction is favoured by high pH and temperatures and analysts must be aware it can reduce levels of cyanide in standards and samples.

For this reason, standards should be made up as alkaline solutions and either stored at 4oC or made up and discarded relatively frequently. Samples should also be held at 4°C and tested as soon as possible.

(19)	$CN^- + ½O_2 + 2H_2O$	$\rightleftharpoons$	$NH_3 + HCO_3^-$

It is important also to consider the effects of adsorption of free cyanide ion and complexed cyanides from the aqueous phase on to surfaces of solids during sampling (see equation 18 above).

The analysis of cyanide is discussed in greater detail in Box 4.

Monitoring Cyanide Complexes/States

Analysis of cyanide presents special problems to the analytical chemist. On the one hand, free cyanide is particularly reactive so analyte loss is always a possibility; on the other hand some cyanide compounds are intractable and require severe treatment to release measurable cyanide. In between these extremes, there is a range of species with differing levels of stability and distinct toxicological and analytical properties. At this stage, only the analysis of total and WAD cyanide (by distillation) can be considered reasonably reliable. While both analyses have been and are being conducted in an automated manner, the most accurate approach is still manual distillation (see Box 4 for detailed information on analysis of cyanide and cyanide complexes).

Associated with any analytical procedure are interferences, both positive and negative, which affect the precision and accuracy of that method. All of the analytical methods for cyanide are affected by interferences to varying degrees (Mudder et al 2001). The WAD cyanide procedure, which measures the weakly complexed forms of cyanide, is least affected by interferences, while the total cyanide, ion-selective electrode and titrimetric free cyanide methods are susceptible to many interferences. The interferences are caused principally by oxidizing agents; sulfides; thiocyanate; nitrite and nitrate; carbonates; thiosulfates; sulfates and other related sulfur compounds; and metals.

The various interferences and some useful techniques to counter them are listed by Ingersoll et al (1981). The following general conclusions can be made (Mudder et al 2001).

- Ascorbic acid treatments to reduce oxidizing agents should not exceed 30 mg/L excess ascorbic acid.
- Thiosulfate acts as a negative interference to cyanide analysis (total) at concentrations as low as 25 mg/L.
- Sulfide which gains access to the absorption solution may cause positive or negative interference with colourimetric procedures at very low concentrations.
- Thiocyanate is a major interference to the total cyanide distillation method, usually resulting in high cyanide values; however, decomposition is not predictable and the mechanism is uncertain.
- Bisulfite appears to be a primary negative interference with the potential for some degree of cyanide destruction. Residual bisulfite is an interference.
- Sulfur species interference may be minimized by the following treatments:
  - Sulfide precipitation from the sample
  - Distillation of smallest possible sample
  - Sulfide precipitation from the absorption solution
  - Increased levels of chloramine-T in the colourimetric procedure.

A summary of cyanide sampling, measurement and analysis is provided in Appendix 4.

Box 4: Analysing for Cyanide

To achieve acceptable results, each stage in the overall analytical procedure needs to be considered carefully:

- **Problem definition**-it is very important at the outset to clearly define the purposes and limits of any monitoring activity. For example, if information is required for toxicological purposes, determination of WAD cyanide may be most appropriate. On the other hand, if the study is concerned with environmental fate, analyses for all forms of cyanide and its degradation products may be required. Such decisions determine the cost of the study and the nature of the best analytical process. It is surprising, how often analytical measurements are made with no clear purpose in mind!
- Sampling - once the problem has been defined, the spatial and temporal characteristics of the monitoring program can be selected. It is essential to take replicate samples and for the samples to be truly representative.
- Sample preservation-samples must be handled to maintain their integrity, in particular to minimise cyanide loss and any changes in its chemical form. Samples may be 'spiked' with a known amount of cyanide in a defined form so that changes during transport and storage can be assessed. In any case, samples should always be inspected visually for changes before proceeding with the analysis.
- Sample treatment-some chemical treatment will be required depending on the form(s) of cyanide to be measured (Section 2.1) and on the measurement technique used.
- Standards-whatever the measurement technique (classical or instrumental) calibration with suitable standards and reagent blanks is needed. Standards and blanks should fall within the applicable range of the analytical technique and should bracket the probable sample concentrations. For some applications, and particularly for complicated samples, consider using standard addition techniques.
- Measurement-a clearly-defined measurement protocol should be followed with samples being analysed in a pre-determined order and interspersed with blanks and standards. This makes it possible to monitor cross-contamination and instrument

drift and to make appropriate adjustments. Replicate determinations should be made.
- Compliance and reporting of results (see section 2.3).
- Documentation-all methods and procedures should be recorded and followed rigorously.

The current best practice (see Appendix 3) follows that suggested by the American Public Health Association (APHA 1995) with some modifications (Noller and Schulz 1997).

Reporting Requirements (Compliance and Public Interest)

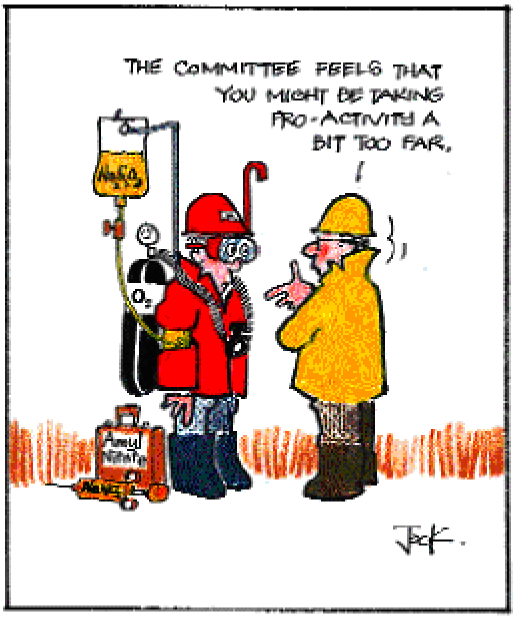
Standard statistical and reporting techniques should be used so that mean values and standard deviations can be calculated and quoted. In assessing changes to an environmental system, significance testing is generally appropriate. Reported values should be checked to ensure that they are within a realistic range and should be quoted with their level of precision. The limit of detection and lower limit of quantification for the analytical method in question should be established, and unknowns falling between these values should be reported accordingly, i.e. as being present but below the limit of quantification. As the analytical data may be needed at some later date to demonstrate compliance, the statistical analysis and reporting of data should be transparent and realistic.

Once the analytical results are received, interpreted and reported, a periodic data quality evaluation (DQE) should be undertaken (Kennedy 1997; NEPC1999; NSW EPA 1995,1998). This is a specific process undertaken jointly by the laboratory and by the sampling organisation to ensure the sampling, preservation, handling, analysis and reporting of data are acceptable within Standard limits and therefore reliable. In order to satisfy DQE requirements, the analytical laboratory needs to be NATA registered for the analyses performed. When reporting data, mining companies should ensure that the laboratory reports and DQE are reported in full, including sampling methodology (samplers, containers, etc), full laboratory reports, sample chain of custody forms, and details of the sampling plan.

3. CYANIDE: HEALTH & HYGIENE IN THE WORKPLACE

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, which will in turn influence views on the potential impact of cyanide use in mining on the environment (see Hazardous Materials booklet in this series).

3.1 CYANIDE POISONING



An understanding of the following principles of cyanide poisoning provides a valuable background for implementing health and hygiene practices:

- Cyanide is toxic to humans and to animal species because it binds to key iron-containing enzymes required for cells to use oxygen. As a result, the tissues are unable to take up oxygen from the blood. The body then rapidly exhibits symptoms of oxygen starvation and suffocation, even if oxygen is available. Rapid damage to the central nervous system and to the heart thus results from breathing high levels of cyanide over a short time.
- Cyanide poisoning can result in death. Symptoms of acute exposure include breathing difficulty, irregular heart beat, uncontrolled movement, convulsions and coma. It must be emphasised that effective

treatment for cyanide poisoning (Box 5) depends largely on the speed and the professionalism of the medical response.

- Individuals exposed to sublethal doses exhibit breathing difficulties, chest pains, vomiting and headaches but dependent on the dose may make a full recovery with no residual disability. Near-lethal doses can cause irreversible effects.
- Health effects and symptoms of cyanide poisoning do not depend on the route of exposure, *i.e.* they are similar whether it is breathed, ingested or absorbed through the skin.
- Some typical dose *versus* response data for cyanide intoxication are given in Table 5, which shows that there is significant variability in the effects on different mammalian species (Hartung 1982; Richardson 1992). *Note: the data in the table are derived from a range of inhalational tests undertaken at different times/places/methods and durations, and are probably not directly comparable.*

Most of the safety procedures that apply to the transport, storage and safe handling of cyanide aim to prevent the chemical from coming into contact with the human body and to prevent cyanide solids or liquids reacting to produce hydrogen cyanide gas. It is essential that these safety procedures are communicated to workers through practical training as well as being reviewed and updated as appropriate (see Commandments 3 and 4).

Table 5: Response of humans and various animal species to concentrations of HCN in air

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

It is important that mine managers be familiar with legislation governing the purchase, storage, transport and monitoring of cyanide in their State or Territory. In Western Australia, for example, the principal relevant statutes are: *The Poisons Act 1964; Explosives and Dangerous Goods Act 1961* and *Dangerous Goods (Storage Regulations) 1992*; *The Environmental Protection Act 1986*; and *Mines Regulation Act 1946, and Regulations* (see Appendix 2). See also the Case Study: *Reporting Cyanide to the National Pollutant Inventory.*

3.2 GENERAL SAFETY ISSUES (PACE-IT FOR SAFETY)

- **Policy** - a safety program that lacks support from top management will fail. So, the most senior minesite manager should issue a policy statement emphasising management's full commitment to, and involvement in, a general safety program which includes cyanide management (see Commandment 2).
- **Accident investigation** - unforeseen events occur even in the most rigorously planned and well-managed systems. It is important to investigate and learn from such accidents.
- **Communication** - effective lines of communication are essential to successfully manage a safety system. An organisational structure, of which all staff are aware, should be developed to ensure rapid, effective and unambiguous communication. It is important that these allow for a 'bottom-up' as well as a 'top-down' flow of information. Communication should extend to regular liaison with the chemical manufacturer, emergency services, police, fire brigade, local council/community, and the regulatory authorities.
- **Emergency readiness** - people responsible for emergency action should be fully instructed and trained. Mock emergencies and unscheduled drills should be staged on a regular basis. MSDS (Material Data Safety Sheets) and emergency procedures sheets should be posted in appropriate areas.
- **Inspections** - both planned and surprise inspections should be carried out frequently to check on procedures and critical equipment.
- **Training** - all supervisors should be formally trained in safety principles. Theoretical and practical training should be given to process-line personnel so they fully understand their safety roles and responsibilities which should be seen as integral, not additional, to their production or management roles (Commandments 3 and 4).

ORICA Australia provides a set Technical Guide to Sodium Cyanide which describes procedures for first aid, safety, packaging, handling, transport, spills, detoxification and equipment. See Case Study *"Orica Australia: Cyanide Mixing and Handling Procedures"*.

3.3 TRANSPORT AND PACKAGING

Incidents involving cyanide off-site from the mine result in negative community perceptions of the mining industry and can often give rise to higher levels of concern than on-site incidents because of proximity to habitation, water supply for human consumption and aquatic wild-life habitat. The Australian Minerals Industry Code for Environmental Management recognises that best practice should apply to the relevant activities of contractors and suppliers. This applies particularly to mines in remote mountainous regions that experience high rainfall and/or severe winters. The mine operator should discuss transport with the manufacturer or transport company because:

- An accident causing cyanide spillage close to or at the minesite may involve mine personnel. Accordingly, minesite personnel, the manufacturer and the transport company should liaise on emergency planning.
- The manufacturer can advise on the most appropriate form and packaging for the volume requirements of the mining operation in question. In Australia, cyanide is commonly available as a solid tablet of approximately 98% NaCN or in a liquid form of approximately 30% NaCN. Given that the liquid form is 70% water, it is generally only transported over short distances by road. Solid sodium cyanide is packaged either in 100 kg drums, in Intermediate Bulk Containers, or IBCs, (containing 'bulkabags') of 800 to 1000 kg or in bulk solid sparge containers of 20 tonnes. Use of sparge containers is best as it reduces the requirement for manual handling of the solid as well as minimising possibilities of spillage during transfer and handling at the minesite storage facility (White 1997).
- 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 handing 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; and
- 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, 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. See also Case Study: Cyplus Corporate: Best Practice in Packaging and Transport of Sodium Cyanide.

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 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.

3.4 STORAGE

How cyanide is stored at the minesite depends on the form of cyanide and is subject to regulation (Appendix 2). 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 preventative maintenance on storage facilities;
- carry out regular auditing and report all incidents;
- develop and document emergency response procedures and undertake regular emergency response exercises; and
- 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; and
- 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.

3.5 HANDLING AND EMERGENCY PROCEDURES

Best practice means not only adopting measures that minimise the likelihood of cyanide losses during operations (Box 8) but also ones that limit the effects of any loss. Capacity to do this will depend on emergency response procedures being established and practiced regularly (Commandment 10).

Cyanide handling must take into account the occupational exposure standard or Threshold Limit Value (TLV). This is 5 mg/m^3 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 (PPE). Operators should work in pairs with one acting as a 'sentry' (Pesce, 1993, p. 764 onwards). 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; and
- 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 outlined in 3.1 above and treatment procedures for personnel affected by cyanide exposure **(Box 5).**

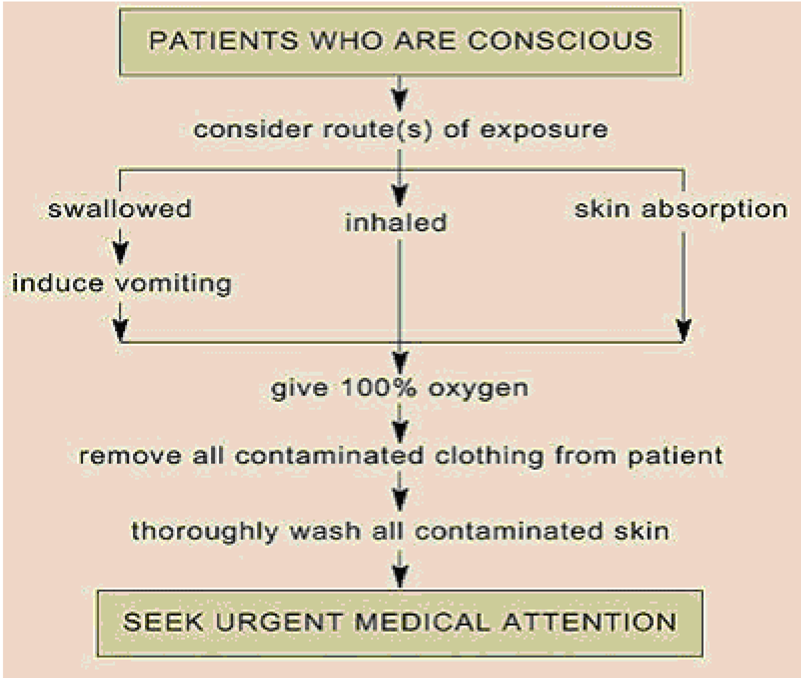
Best Practice requires that as far as possible, the probability of accidents is reduced through proactive measures. UNEP's APELL program sets out a framework for building awareness of and preparedness for emergencies, and includes a ten-step model for developing effective and integrated community emergency response plans **(see Box 6)**.

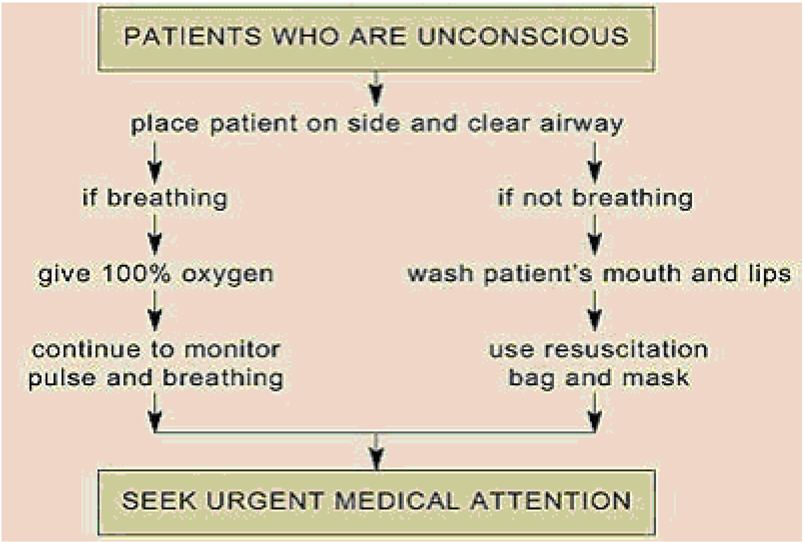
Box 5: Treatment of Cyanide Poisoning

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).

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

a) First aid treatment immediately following an exposure incident





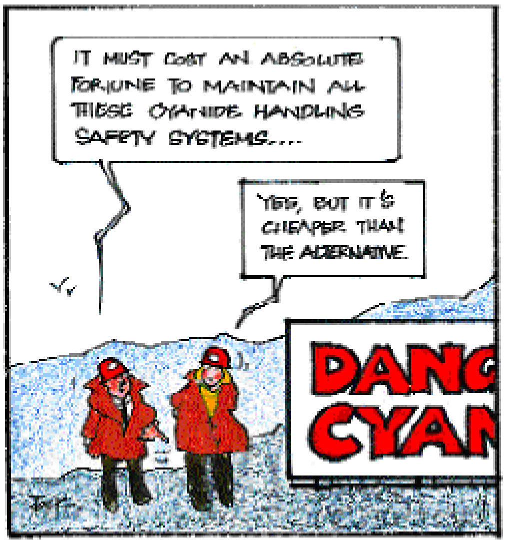
b) Professional medical treatment

Two types of medical treatment have been recommended in the literature. It is important to note that these treatments should not both be applied to the same patient; they are mutually exclusive.

- Use of KELOCY transferase enzyme in the body, to form the less toxic thi ANOR®, [cobalt(II)-edetate]: Administered intravenously and only given by a medical practitioner when absolutely certain that cyanide poisoning has occurred and only if the patient is lapsing into unconsciousness. During the course of Kelocyanor treatment, 100% oxygen should continue to be given and should be maintained afterwards if necessary. The rationale for this treatment is that Kelocyanor dissociates in the bloodstream releasing cobalt which complexes with the cyanide and causes its excretion via the urine.
- The second form of treatment is more complicated than the use of Kelocyanor but it has a long history of use. Amyl nitrite is first inhaled and then sodium nitrite ($NaNO_2$) is injected intravenously; this 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 ($Na_2S_2O_3$). This reacts with cyanide, in the presence of a sulfur ocyanate ion (SCN^-) which is then excreted in the urine.

N.B. The effectiveness 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.'* It appears that administration of oxygen is accepted as best practice for cyanide poisoning treatment.

3.6 PROTECTIVE GEAR AND HYGIENE



The protective gear needed depends on the procedure. 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. Requirements change over time, and so the current MSDS and PPE recommendations should be used to determine appropriate gear 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, *e.g.* sunscreen. (Do none of these in areas where cyanide is stored or used).

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

Box 6: The Ten-Step Approach to the Apell Process for Emergency Preparedness (UNEP 1988; UNEP APELL)
1. Identify the emergency response participants and establish their roles, resources and concerns. 2. Evaluate the risks and hazards that may result in emergency situations in the community. 3. Have participants review their own emergency plan for adequacy relative to a co-ordinated response. 4. Identify the required response tasks not covered by existing plans. 5. Match these tasks to the resources available from the identified participants. 6. Make the changes necessary to improve existing plans, integrate them into an overall community plan and gain agreement. 7. Commit the integrated community plan to writing and obtain approvals from local governments. 8. Educate participating groups about the integrated plan and ensure that all emergency responders are trained. 9. Establish procedures for periodic testing, review and updating of the plan. 10. Educate the general community about the integrated plan. UNEP has also published information on applying APELL to mining emergencies, particularly relating to tailings dams, waste dumps, transport to site and loading, pipeline failure, subsidence, fire and explosion, chemical spill, and risks at closed mines (APELL for Mining). Cyanide can be implicated in most of these settings and thus add significantly to the level of hazard.

3.7 MONITORING THE WORKING ENVIRONMENT

It is important that workers are protected through a monitoring and sampling program for airborne contaminants. Such procedures are often covered by regulation and local rules should be followed when available. Some principles are that samples:

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

Where practical, samples should be collected using equipment that is calibrated in accordance with manufacturer requirements, and 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 action in emergency situations.

3.8 RISK ASSESSMENT

In all aspects of cyanide management, it is important that workers and emergency services are able to react efficiently and effectively. Best practice required identifying, planning and training for contingencies. An appropriate approach is to adopt Hazard Analysis at Critical Control Points (HACCP - see Glossary). Areas where such an approach may be helpful are described in **Boxes 7** and **8.** Once a risk has been identified it can often be designed out of the minesite operation. However, when this is not feasible, steps must be taken to minimise the problem.

Risk assessment forms one part of the structured procedures within Risk Management necessary to analyse risk, assess risk, and treat risk. The risks associated with cyanide must be incorporated into Environmental Risk Management for a minesite to ensure that the potential hazards to workers, community and the environment are minimised from the planning stage through to mine development, operations and closure. Systems for risk management are described in the Environmental Risk Management booklet. The majority of cyanide incidents are associated with failures in water management systems, and intentional or accidental actions by workers. The Sustainable Minerals booklets on Water Management and Workforce Awareness provide useful resources to reduce the level of risk in these areas critical to best practice cyanide management. See Case Study: *"Using a Risk Management Approach to Establish Regulatory Levels for Cyanide in Mining"*.

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

1. **Hazard identification** [part of "Problem Formulation" in USEPA framework] determines the adverse effects that chemical, physical and biological agents may potentially cause to humans and the environment. Physical hazards include combustion, explosivity, flammability and corrosivity. Health hazards are categorized as acute (e.g. skin and eye irritation, mortality, asphyxiation) or chronic (e.g. carcinogenicity, sensitization, effects on reproductive system, effects on nervous system, effects on organs). Ecological hazards include mortality (acute) and reduced growth and reproduction (chronic) in species. *(Note that the acute hazards can also be chronic hazards and vise versa, ie. a repeat dose may be irritating).*

   Hazard identification is only the first step in risk assessment. It is not an appropriate basis upon which to make a risk management decision. However, hazard identification is a critical step commonly carried out before chemicals and products are introduced to the market. In the case of human health and the environment, results of toxicity/ecotoxicity testing and epidemiology data are used to determine hazard.

2. **Dose-response evaluation** [also commonly referred to as "Toxicity Assessment"] is the determination of the relationship between the magnitude of an administered, applied or internal dose and a specific biological response. The dose is the total amount of a substance administered to or ingested, inhaled or absorbed by an organism under standardized laboratory conditions used for toxicology testing. The end points of toxicity (or dose response) can be expressed as the measured or observed incidence, the percent response in groups of subjects (or population), or the probability of occurrence of a response in a population. Toxicity Assessment may simply involve obtaining an environmental media quality assessment guideline (eg. water quality guideline (ANZECC/ARMCANZ 2000), or wildlife toxicity reference value (TRV) from a publication), but in the absence of relevant information it may involve literature reviews of effects, and direct toxicity assessments.

3. **Exposure assessment** is the evaluation of the pathways by which the hazard may contact a sensitive receiver. The receiver may be a single person, a real or hypothetical population, or a set of ecological recipients such as fish or birds. The exposure assessment determines how and under what circumstances the receiver may be exposed to the hazard. It may also determine the quantities of the hazardous substance and the length of exposure.

4. **Risk characterization** summarizes the information from hazard identification, dose-response evaluation and exposure assessment into an overall conclusion on risk in a form that is useful to decision makers, legislators, the media and members of the public. Risk characterization provides a quantitative or qualitative description of the potential hazards of a particular exposure. Quantitative risk characterization conveys a numerical estimate of the magnitude of the risk that a substance poses to human health or to the environment. This risk may be expressed as individual risk or population risk. Qualitative risk characterization describes in narrative form the

adverse effect or effects associated with exposure to an agent and provides some measure of the evidence for the association.

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

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

Transportation regulations and diligent safety programs limit the risks associated with the first scenario. As to the second, while adverse impacts from releases of process solutions have occurred in the past, scientific and engineering procedures exist to allow the safe and reliable operation of cyanidation processes. Generally, when operations and site-specific standards meet the water quality regulatory framework and design and operation of the water management and hazardous materials systems feature best practice, protection of human health and the environment relating to the third and fourth scenarios can be effectively realized.

4. MINIMISING ENVIRONMENTAL IMPACTS

4.1 PREVENTION OF CYANIDE INCIDENTS

The transport, storage, use and disposal of cyanide at a minesite can be hazardous both to human health and the environment. Best practice environmental management requires minimising the risk of environmental damage from accidental cyanide release (see Box 8). The main goals should be to:

- use the minimum effective amounts of cyanide required to recover metals;
- dispose of cyanide in a way that eliminates or minimises environmental impacts; and
- monitor all operations, discharges and the environment to detect any escape of cyanide and subsequent impacts of that release - and conduct regular cyanide audits (Commandments 8 & 9).

Other important actions include:

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

A review of cyanide related spills over the last quarter century (Mudder 2003) has shown the causes to include:

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

The environmental impacts of these spills have nearly all been related to the toxic effects on aquatic life resulting from cyanide entering surface water, such as a river. In some instances, the impacts were more severe than anticipated due to the type of response taken by the gold mining operation. The most severe cyanide spills have resulted from the breaching or overtopping of tailings dams during high precipitation or runoff events, or the rupture of pipelines without adequate secondary containment and collections systems. In conjunction with the spills, improper emergency treatment exacerbated the impacts on aquatic life and the environment due to toxicity of the cyanide antidote chemicals employed, such as chlorine or sodium or calcium hypochlorite. In order to minimize the number and severity of these spills, there is a need for development and implementation of both spill prevention and plans and procedures.

The three critical components for developing and implementing a cyanide spill prevention plan are therefore water management, water treatment and water quality, both generally throughout the minesite, and specifically in relation to the tailings storage facility. Best practice approaches to these issues are discussed in the Water Management and Tailings Containment booklets. The strategic framework for tailings management being developed jointly by the Ministerial Council on Mineral and Petroleum Resources (MCMPR) and the Minerals Council of Australia (MCA) will provide a sound background for design and management of TSFs including those used to contain cyanide-contaminated mine water. A Draft Strategic Framework for Tailings Management was circulated for public comment in early 2003. Also see Case study: Newmont Waihi Martha Mine, New Zealand: Stakeholders and Setting of Discharge Standards.

4.2 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. A range of site specific data must be collated and integrated during the initial planning stages of the operation, with suitable adjustments when changes in operating parameters and ambient conditions occur. Even though the cyanide balance measurement cannot be exact, given the uncertainties of environmental systems, it will help identify problems at an early stage and find appropriate solutions.

Key factors in developing a cyanide balance include:

- knowledge of ore body composition and how this may change during the life of the mine - linked with the chemical considerations described in Section 2.2, this determines cyanide consumption; and
- local meteorology - this affects cyanide consumption directly through evaporation and photolytic degradation (Equations 5, 16 and 17 in Section 2.2) and indirectly by dilution and concentration effects caused by changes in water balance.

Cyanide management needs to be well integrated with the overall water management plan for the minesite (Commandment 6; information on planning and operation of water management systems is provided in the Water Management booklet). 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.

4.3 CYANIDE TREATMENT, RECOVERY AND REUSE

Cyanide consumption represents a major cost to the mine operator. This emphasises the need to avoid over-consumption and consequent wastage. However, much more cyanide may sometimes be required than is desirable from an economic or environmental viewpoint. In such circumstances, it is obviously both good practice and cost efficient to recycle as much cyanide as possible (Commandment 7). A large number of processes (at different stages of development) exist for the removal of cyanide from waste streams (Table 6). Many require or produce chemicals that have an ecotoxicological impact in their own right. Therefore, the potential use of these processes will require the issues raised in the Hazardous Materials Management, Storage and Disposal booklet to be considered and addressed. A comprehensive description of the chemistry and treatment of the wastes generated from cyanide use is provided by Mudder et al (2001).

The ways in which cyanide levels in tailings ponds are reduced can be broadly categorised into four groups:

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

All of these processes come at both an economic and environmental cost, so impact and risk-benefit assessments must be undertaken before they are introduced. Also see Case Studies: *Porgera Joint Venture, Papua New Guinea: Waste Cyanide Treatment Circuit* and *SGS Lakefield Oretest: Process Flowsheet Selection Methodology for Cyanide Detoxification and Recovery*.

Natural processes

Many mechanisms, including hydrolysis, photodegradation, chemical and bacteriological oxidation, and precipitation as metal complexes, contribute to the natural degradation of cyanide, but the main processes are the dissociation of metal cyanide complexes and volatilisation of cyanide as hydrogen cyanide. The principal factors affecting degradation are considered to be pH, temperature, ultraviolet irradiation and aeration (Botz et al 1995).

Enhancing natural losses

Some relatively simple procedures can effectively increase the speed of natural degradation. This has been practiced in Canada for many years. For example, a shallow pond with a large surface area provides greater contact with atmospheric CO_2 which lowers the pH thus increasing the rate of conversion to HCN and volatilisation. Aeration and mixing have a similar effect.

Chemical, physical and biological intervention

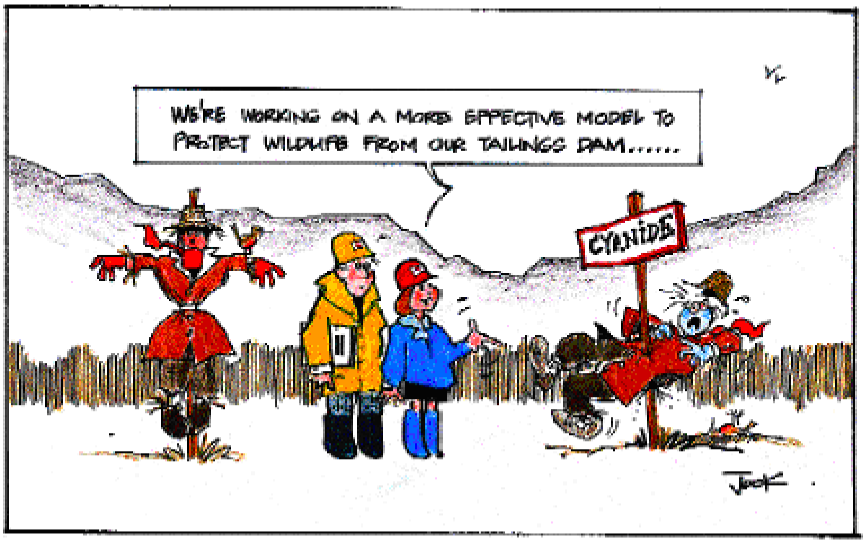
An increasingly popular method for detoxifying residual cyanide is the Degussa peroxide process. Put simply, hydrogen peroxide oxidises free and WAD cyanides to cyanate, which is further hydrolysed to biodegradable ammonia and carbonate. Metals such as copper, zinc and cadmium complexed with cyanide 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 partially 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. Active and passive biological treatments are discussed by Mudder (1987), and chemical and physical treatments by Botz and Mudder (2001).

Table 6: 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 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 to CNO^- with H_2SO_5	H_2SO_5	CNO^-
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°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 (175-320 °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		
B. NON-OXIDATIVE			
Natural Degradation (B, C & P)	Mainly volatilisation of HCN from tailings dams	none	Mainly HCN
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_2SO_4, NaOH	HCN, SCN^-?
CYANISORB® (C & P)	Similar to AVR but HCN(g) stripped at higher pH values (5.5-7.5)	H_2SO_4, NaOH	HCN, SCN^-?
CRP (C & P)	Cyanide Regeneration Process; similar to AVR but with better HCN(g) stripping and metal precipitation	H_2SO_4, NaOH	HCN, SCN^-?
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^+, $HCOO^-$
GM-IX (C & P)	Gas Membrane-Ion Exchange; Ion Exchange concentrates CN. After regeneration the Gas Membrane recovers pure CN.	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_2SO_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 Devuyst et al 1982; Dubey and Holmes 1995; Gonen et al 1996; Grosse 1990; Hoecker and Muir 1987; Nugent, 1997; Ritcey, 1989; Robbins,1996; and Stevenson et al, 1995).			

The Inco sulfur dioxide (SO_2)/air process is a simple method that requires little supervision and does not interrupt gold recovery. SO_2 in liquid or gaseous form acts with air to oxidise WAD cyanide to cyanate and sulfuric acid while releasing metals into solution. Inco detoxification was used at the Red Dome Gold Mine in north Queensland through to closure in 1997. The Beaconsfield and Henty Gold Mines in Tasmania also use the Inco/SO_2 process.

Oxidative chlorination using chlorine gas, hypochlorite or in situ electrolytic generation can also be used to detoxify cyanide residues.



At present, considerable effort is being expended both in Australia and internationally to identify and isolate bacteria that can be used to facilitate degradation of cyanide in waste streams, tailings storage facilities and contaminated environments (CSIRO, 1997). A bio-degradation process has been used successfully since 1984 at the Homestake Mining Company in South Dakota, USA (Mudder and Whitlock 1984; Whitlock 1989) and at Homestake's Nickel Plate Mine in Canada. Overall, biotechnological approaches potentially have a significant role to play in detoxifying cyanide-containing waste waters but are not a universal panacea. Each minesite waste stream is unique; some possess the correct nutrient balance and availability for bacterial growth, others may require significant input of, say, phosphate.

Recovery or Recycling

When residual cyanide occurs as free and WAD cyanide, it may be recovered using various non-oxidative processes (Table 6). 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% 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 article on cyanide treatment and recovery methods is provided by Botz et al (1995). . See Case Study *"Golden Cross Mine, New Zealand: Cyanide Recovery and Recycling Using the Cyanisorb® Process"*.

Table 7 summarises the suitability of treatment processes for removal of cyanide and its related compounds cyanate, thiocyanate, ammonia and nitrate. This simplified summary can be used as a conceptual screening tool when tabular evaluating cyanide treatment processes.

The application of various treatment processes to slurries, tailings and CCD circuits is discussed in Chapter 3 of the Cyanide Monograph (Mudder and Botz 2001).

Table 7: Preliminary selection guide for cyanide treatment processes (from Botz 2001; www.cyantists.com/cyanide_treatment.pdf				
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 attentuation	✓	✓	✓	✓

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; and
- 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

While it is desirable that as much cyanide as possible is recycled, it is virtually unavoidable that some cyanide will find its way to waste streams and, particularly, to tailings storage facilities and ponds. This waste cyanide must be managed to reduce its environmental impact to acceptable levels. This requires integrating and applying knowledge from a variety of disciplines so containment can be effective and sustained (Ritcey 1989). Environmental contamination problems, particularly those contaminating groundwater, can be very costly to remedy. They also tend to have very limited prospects of success. In other words, prevention is better than cure.

In many significant ways, best practice in cyanide waste management is a subset of best practice in tailings management and readers are referred to the relevant booklets in this series (Water Management, Tailings Containment). 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;
- 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 (*e.g.* catchment run-off, 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, *i.e.* 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 unadulterated 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; and
- monitoring of the waste facility, physical loss pathways and the environment for cyanide forms.

4.4 PROTECTING WILDLIFE AND LIVESTOCK

Birds are most at risk from tailings dams containing cyanide. Other species are also at risk (eg bats, lizards and small mammals), although the impacts on these species are rarely monitored. If tailings ponds contain WAD cyanide at levels less than 50 mg/L^{-1} and access to the ponded area and releases of water to the environment are avoided, the impact on wildlife is low. Fish are by far the most sensitive group to cyanide, and catastrophic impacts on downstream aquatic ecosystems have resulted where cyanide-contaminated waters have escaped as a result of dam failure or overtopping. The

ANZECC Water Quality Guidelines provide trigger values for cyanide of 4, 7, 11 and 18 μgL^{-1} in order to ensure confidence of species protection at the 99, 95, 90 and 80 % levels respectively in ecologically significant waters. Mine design must incorporate features to avoid the release of water containing cyanide that may approach these trigger values for any ecologically significant aquatic systems in the vicinity.

In addition to minimising cyanide use and impact through the effective application of process chemistry and risk assessment procedures, further practical measures can minimise the effect of cyanide in tailings dams and ponds on wildlife and domestic animals as a second line of protection. These should supplement actions taken to reduce risks to wildlife through careful process chemistry design, operation and monitoring, and should never be seen as an adequate wildlife protection measure in themselves. These measures are generally either to prevent access, or to scare away, and include:

- fencing,
- floating balls,
- netting (though this is not effective for large impoundments and is now being replaced by floating balls), and
- a variety of hazing (fireworks, lights, music, sound guns).

Surrounding the tailings facility with water drinking troughs and having decoy wetlands can also be effective in minimising the risk of poisoning wildlife. Proximity to human settlements may influence the choice of technique, eg possible community impacts from noise and light need to be taken into consideration. See Case Study *KCGM Fimiston Mine, Western Australia: Tailings Storage Facility Water Management at the "Superpit"* and Case Study *Newmont Waihi Martha Mine, New Zealand: Water Management to Reduce Cyanide Related Risks*.

Birds are particularly susceptible to cyanide in tailings dams. Wading and swimming birds are more likely to receive a lethal dose by absorbing cyanide through their skin. Other birds at risk include raptors which are attracted to carrion on tailings dams. To identify birds at risk, mine managers and personnel need to know which species are endemic to their area and the frequency and timing of visits by migratory species (information on bird species distribution and migration routes and times in Australia is available from Birds Australia and the Australian Bird Atlas (in preparation - view online data). A sound understanding of the way different birds behave on and around the dams will also help in planning to minimise the risk of bird poisoning.

While netting and hazing can help prevent bird losses, it is important that tailings dams be designed correctly. If dams have extensive surface areas they will attract more birds, particularly waders and swimmers. To reduce the need for methods such as hazing, management should first ensure that:

- the cyanide levels in the tailings are as low as practicable; and
- ponds have a small surface area preferably covered with netting and fenced.

Guidance on measures to reduce the risk to birds from cyanide in tailings dams is provided in a guideline on protecting birdlife prepared by the Northern Territory government. See Case Study *Northparkes, NSW: The 1995 Bird Kill on the Northparkes Tailings Dam*.

Figure 3: Martha Mine, Waihi Gold, New Zealand. Birdlife on the tailings storage facility. (photo: Waihi Gold Mining Company

4.5 SPILLAGE AND UNINTENDED PROCESS LOSSES

Limited).

Spillage includes any accidental losses during transport to the minesite, as well as systems failures within the minesite whether they are contained within the site or flow offsite into the environment.

The possibility of completely closed circuit systems for cyanide use and recovery in the future has been proposed. These would provide very high levels of insurance against cyanide spillage and loss (Moore and Noller 2000) however such systems may be prohibitively costly for very low grade ores and mines with low profit margins.

In open circuit systems in widespread use today, cyanide will eventually find its way into the natural environment even with the most careful precautions (Box 8). Low levels of free cyanide may be degraded and attenuated rapidly, in which case monitoring and reporting on environmental levels may be sufficient. For higher levels, a more interventionist approach is necessary to protect human and animal life. The appropriate response depends on a variety of inter-related factors including:

- the physical form and the amount of cyanide lost, *e.g.* liquid or solid spill, seepage from tailings pond or heap leach pad, presence of HCN gas;
- the size and area of incident;
- the response time - depending on how soon the incident is noticed;
- the accessibility of the contaminant, *e.g.* whether a land surface spill or an underground plume is involved; and
- the environment involved, *e.g.* land or water.

The following scenarios should be considered and adapted to suit the circumstances (White 1997).

- Spills of solid sodium cyanide onto land are likely to be localised and may 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 entry and contamination of rainwater. Natural drainage channels should be protected.
- Liquid spills, and spills of solid sodium cyanide into surface waters, are likely to be a bigger problem, with pipeline and drain security the key risk points:
    - surface spills onto land, if notified promptly, may be treated with an appropriate oxidising agent. For example, hydrogen peroxide or sodium hypochlorite (Staunton et al 1989) can be used but this should be by trained personnel who understand that reactions between sodium cyanide and the oxidising agents may be vigorous. After being treated, contaminated topsoil can be removed if necessary. 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; and
    - spills into surface waters are particularly difficult to remediate without further damaging the water body by, for example, adding oxidising agents. For such spills, the only appropriate action may be to allow natural degradation, coupled with dilution and dispersal, to take its course.
- Preservation of sensitive fauna may be possible by collection and relocation, while netting and fencing may be used to prevent entry to contaminated ponds.

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 cleanup method used should aim to immobilise and contain the cyanide, and convert into a less toxic compound. Research is being conducted into different bacteria which may be used to treat contaminated soils; examples of trials and limited field applications are given by Souren (2000).

After any spill, protective clothing and other equipment used should be decontaminated at the site of the incident.

Box 8: Physical Loss of Cyanide During Mining Operations and its Consequences
Cyanide may be lost during all stages of normal mining operations from preparing reagents through to waste disposal. The reasons for a potential loss of cyanide are numerous. It is obviously important to identify such pathways to avoid serious deleterious effects on both operational efficiency and the surrounding environment. 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, leading to contamination of surface- and groundwater; and • catastrophic escape due to some natural or other event such as flooding, earthquake, plane crash or sabotage. Best practice involves recognising the potential spillage pathways and working towards minimising their potential impact. This is best done during the minesite planning phase with appropriate strategies then being built into plant inspection, maintenance and monitoring schedules. For example, consider the following: • bunding liquid sodium cyanide storage areas; • bunding critical pipework, pumps and valves and inspecting them more rigorously and more frequently than non-critical equipment; • lining ponds and heap leach pads with impervious material; and • drilling boreholes to monitor seepage of cyanide from ponds and tailings dams. Where possible, the potential effects of cyanide loss on minesite personnel, the general population and the environment should be analysed through a formal risk assessment procedure (see the Hazardous Materials booklet in this series). The size and seriousness of the potential impact, and hence of the required response, depends on the magnitude, location and chemical form of the cyanide loss. All such factors must be considered when performing the risk assessment and potential response to an unplanned loss. In addition, account must be taken of possible routes of exposure to individuals (Section 3) and to domestic animals and wildlife (Section 4).

4.6 MINE CLOSURE AND REHABILITATION

When a site is no longer being mined, it needs to be rehabilitated according to some clearly defined future landuse for the area. Australian Accounting Standards require mine closure to be planned and provided for over the life of the operation and this point is listed as Commandment 1 in this booklet. Cyanide management needs to be included in these provisions. The long-term objectives of rehabilitation will vary from minesite to minesite depending on local conditions and needs (refer to the Rehabilitation and Revegetation booklet and see case studies Golden Cross Mine, New Zealand: Closure and Rehabilitation, Kidston Gold Mine, Queensland: Safety Aspects of Decommissioning of a Cyanide Processing Plant at a Large Mine and Telfer Gold Mine, Western Australia: Dealing with Cyanide Issues at Telfer).

From a best practice point of view it is highly desirable that the closure strategy is documented in the initial mine planning stage. Particular mention of heap leach pad and mine tailings rehabilitation is needed. Weak acid dissociable cyanide is the potential reservoir of most concern in this context. This is because, on the one hand, natural degradation and attenuation pathways will account for much of the free cyanide and, on the other, strongly complexed cyanides, such as the ferricyanides, are extremely unlikely to release free cyanide at a rate fast enough to be significant. The corollary of this is that strongly bonded cyanide complexes will persist for the long term. The implications of future land use and disturbance should be considered in terms of their potential to exacerbate the rate of transformation into other possibly toxic compounds and related risks. Measures such as soil removal and clay encapsulation have been used to deal with cyanide pollution at disused manufactured gas plants in Holland (Souren 2000).

It should be noted that:

- WAD cyanides will generally dissociate as heap leach pads and tailings age and, in general, become more acidic through equilibration with atmospheric carbon dioxide (thus releasing cyanide at a faster rate); and
- Precipitation reactions (*e.g.* Equation 12, Section 2.2) may also release HCN gas.

Issues to consider when developing a decommissioning strategy for cyanide facilities (modified after Wardell-Johnson 2002) include:

For Plant Areas:
Revise safety procedures
Preclosure drawdown of cyanide stock
Preclosure cyanide tank cleanout
Detailed task development
Post closure plant cleanup
Specialised tank cleaning contractors
Soil contamination

For Tailings storage facilities:
Risk assessment, including water balance
Preclosure decant pond drawdown
Water spreading
Water release and cyanide destruction
Water quality monitoring
Long term structural integrity
Erosion prevention
Capping design including barriers to capillary action or physical disturbance as appropriate.

For Cyanide disposal:
Design liquid facility for back-loading
Transport restrictions
Dilution and discharge
Electrolysis
Cyanide destruction if a significant volume of contaminated water remains.

For Closure management and planning:
Cost estimation (including labour which is a major cost component)
Scheduling (seasonal weather can influence optimum timing)
Plan early
Comply with regulatory requirements and the International Cyanide Management Code
Poor planning may incur significant liabilities related to contaminated land and relinquishment of title.

4.7 MONITORING CYANIDE IN THE ENVIRONMENT

Figure 4: Red Dome Gold Mine, far North Queensland. Fertilising a recontoured waste rock dump prior to planting. (photo: Niugini Mining (Australasia) Pty Limited)

Monitoring levels of cyanide in the environment is an essential part of best practice management, but mine managers also need a high awareness of the significance of the levels being measured and the possible sources of cyanide. As noted under section 2.3, only the analysis of total and WAD cyanide (by distillation) can be considered reasonably reliable. Furthermore, as concluded by Mudder (1997) 'the detection of low levels of total or WAD cyanide may be the result of actual cyanide released from natural or man-made sources, or may be the result of error or interferences in the various cyanide analytical procedures.' Mudder also points out that total cyanide levels below 0.10 mg/L and WAD cyanide below 0.05 mg/L present in mining related discharges are unreliable, should be reported as 'less than' and not used for compliance purposes.

In interpreting results of a monitoring program, the possible sources of cyanide reported in surface waters of treated effluents need to be taken into account. The first is analytical error, the second naturally produced cyanide excreted by plants, micro-organisms and insects, and the third manufactured cyanide.

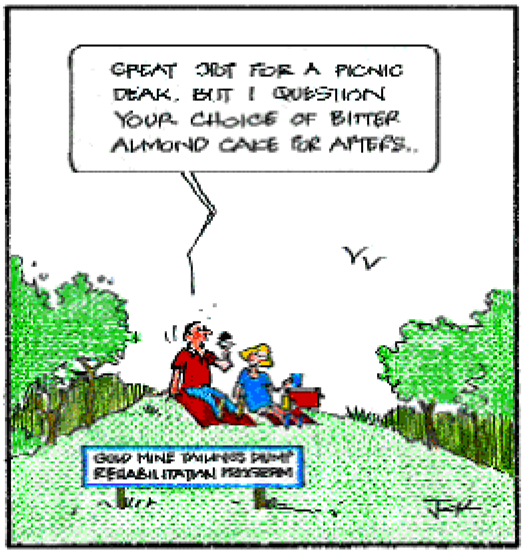
The environmental monitoring program, which should form part of the environmental management plan, should include:

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

The cyanide monitoring program must consider all these factors. Generation of acid tailings from waste rock dumps, for example, may change the chemical form of the cyanide and cause HCN gas to be released. Warning of such potential problems can be gained from a knowledge of environmental exposure pathways linked to monitoring of pH, WAD cyanide and free cyanide.

Some specific comments on environmental sampling and analysis of cyanide are given in Box 4. It is a truism, but nonetheless important, that unless such measurements are valid, wrong conclusions can easily be drawn, with potentially serious environmental and economic consequences. See also Case Studies Case Study: SGS Lakefield Oretest: Emissions Estimation and Reporting Methodology for Cyanide Reporting and Newmont Australia Limited:: Cyanide Management Standard and Audit Process.

5. INTEGRATING BEST PRACTICE FOR CYANIDE USE INTO MANAGEMENT SYSTEMS



Cyanide management is not an individual or isolated issue; it is intimately linked with other important requirements for applying best practice environmental management in mining, in particular water management, storage and handing of hazardous materials, environmental monitoring, emergency response, workforce training and awareness, cleanup of contaminated sites, mine rehabilitation, and risk management. Therefore integration of cyanide management into management systems requires a broad and inclusive approach where all activities and associated risks related to cyanide are identified and addressed. This identification is normally conducted in the planning and environmental impact assessment stages in the pre-mining stage, but operational system changes and upgrades involving cyanide during the mine's life may require an environmental reassessment to ensure that all risks are known.

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

Environmental audits can be designed to examine particular elements of an operation as described in the Environmental Auditing booklet, and an audit focussing on all aspects of an operation relating to cyanide is an effective way of determining how well the various operational components work together and to identify areas for improvement to reduce potential health and environmental risks associated with cyanide.

Generically, HSE (health safety and environmental) audits should involve five distinct yet inter-related steps (Greeno et al 1988; Fox 2001b):

- understanding the facility's (ie responsible party's) existing management systems and procedures;
- assessing the soundness of the facility's internal controls;
- gathering evidence through site visits and interviews consistent with the audit objectives;
- evaluating audit findings and exceptions to management systems and procedures; and
- Reporting audit findings and exceptions.

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 HSE management and protection.

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

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

5.1 ADOPTING THE INTERNATIONAL CYANIDE MANAGEMENT CODE

The application form for intending signatories to the code, and related information including criteria for signatories and application fees are under development and will be available at http://www.cyanidecode.org.

Code signatories are expected to design, construct, operate and decommission their facilities consistent with the code requirements (see Appendix 1), and must have their operations audited by an independent third party auditor and make the audit results public. The principles and standards of the code must be implemented within three years of signing in order to receive certification. Independent auditing to demonstrate compliance with the code is a prerequisite to certification.

The principles and standards are stated briefly in the code. Comprehensive notes providing guidance on how these may be implemented can be downloaded from http://www.cyanidecode.org. A guide on management systems for small mine operators in under development.

Implementation requirements will differ from mine to mine, dependent upon the quality of current cyanide facilities, systems, knowledge, and behaviours, and the character and level of risks related to protecting human and environmental health. More specific information which will assist in determining how best to implement the principles and standards of the code to suit the particular circumstances on a minesite is available in this and other booklets in the Sustainable Minerals series (in particular Water Management, Environmental Monitoring, Mine Planning, Risk Management, Environmental Auditing, Hazardous Materials, and Workforce Awareness).

Other practical information sources include the guidelines produced by a number of regulatory authorities. Examples include:

- Department of Industry and Resources, Western Australia, 1992 - Cyanide Management Guideline;
- Government of Western Australia - Cyanide Information on Handling, Storage and First Aid;
- Department of Environment and Heritage, Queensland 1990 - Guidelines on Prevention of Water Pollution from Cyanide Use in Gold Ore Processing;
- National Occupational Health and Safety Commission, Australia - Cyanide Poisoning Guide; and
- British Columbia Technical and Research Committee on Reclamation, 1995 - Technical Guide for the Environmental Management of Cyanide in Mining.

The code requires signatories to comply with principles and standards to protect the environment, workers and community and all stages of cyanide use, ie during:

- cyanide production,
- transport to the minesite,
- handling and storage on site,
- all aspects of mine operations, and
- mine decommissioning.

In implementing these measures, particular actions are expected in relation to:

- worker safety,
- emergency response
- workforce training, and
- community consultation and disclosure.

A key objective of the code is to certify compliance of code principles and standards, and to post information on certified operators on the website of the International Cyanide Management Institute. In order to maintain certification, an operation must meet all of the following conditions:

- full compliance or substantial compliance in indicated by the independent auditor;
- operations in substantial compliance have submitted Action Plans to correct deficiencies and implement these within the agreed timeframe (maximum 1 year);
- there must be no evidence that the operation is not in compliance with code conditions;
- a verification audit is held within three years; and
- a verification audit is held within two years of change in ownership of the operation.

The main impediments to industry's adoption of the code are currently the burden of compliance, the complexity of implementation guidelines, and adequacy and independence of ownership and administration of the code scheme via the International Cyanide Management Institute (Den Dryver 2002). However, these problems are outweighed by the benefits of improved standards in cyanide management by signatories; resultant reduction in risks; and improved legitimacy amongst stakeholders to environmental reporting by signatories. The potential for improved acceptance by jurisdictions and communities of code signatories represents a strong business incentive for companies to implement the code (Den Dryver 2002). See Case Study: "MPI Mines Ltd Stawell Gold Mine, Victoria: Applying the International Cyanide Code at a Medium-Scale Gold Mine".

5.2 SETTING AND MAINTAINING APPROPRIATE STANDARDS TO ENSURE BEST PRACTICE

Best practice in cyanide management can be said to be simply the best way of doing things to minimise the risk of impacts to people and the environment. Given the situational differences between minesites, the best practice solution will not be the same at every site. However, the same principles and general standards apply. Those provided by the International Code for Cyanide Management are designed to be relevant to every minesite regardless of climate, geography, mineralogy, metallurgy, operational systems, and political, regulatory and community environments.

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

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

One system of providing assurance that best practice is being maintained during the life of a long-term mining operation is "benchmarking". Benchmarking, as defined by The BenchMarking Network™, is a performance measurement tool used in conjunction with improvement initiatives to measure comparative operating performance and identify best practices, or to identify the "Best in Class" operators for a given activity. Appropriate techniques involve research into appropriate operators, identification of lead operators, data collection, and site visits to the lead operators. Benchmarking shares many elements in common with TQM (Total Quality Measurement) and Re-Engineering, some aspects of which are discussed in the Cleaner Production booklet. Benchmarking requires performance to be measured, and for those measurements to be used as guides to improving cyanide management (ie "Managing by Measuring"; Czarecki 1998).

6. CONCLUSION

A great deal of scientific literature and information is available on cyanide, particularly on its chemistry and environmental fate. Indeed, Mudder (1997) has stated that: *'The chemistry, toxicology and environmental fate of the various cyanide complexes and related compounds are well understood'*. However, more work is needed to provide the necessary rigorous quantitative understanding to plan, implement and operate cyanide management practices with greater confidence. This includes establishing sound, systematic environmental management systems for:

- Cyanide analyses:
  - Although analytical methods can reach the lower limits of quantification needed by current legislation, in practice, variable results are often obtained because of inconsistent sample preparation and preservation methods.
  - Determining cyanide forms (see Section 2.1) needs systematising so that such analyses better reflect environmental and toxicological needs.
  - Annual proficiency testing (round robin) exercises, and their costs, should be incorporated into the services provided by analytical service laboratories.
- Environmental chemistry and fate:
  - Although cyanide degradation and attenuation pathways have been reasonably well identified and are understood qualitatively (see Section 2.2), much more work is required to quantify cyanide levels associated with the different chemical degradation pathways.
  - Better computer modelling with improved input data and a wider array of software will help in problem solving at existing mine-sites and in the planning and (toxicological) risk assessment of proposed mining operations.
- Removal processes:
  - A bewildering array of removal processes exists (Table 6) and it is apparent that some cyanide degradation products and other components of cyanide containing waste streams are environmental threats. Choice of process needs systematising on the basis of site-specific criteria; this may be achieved, at least partially, through biomonitoring and whole effluent toxicity testing.
- Regulation/legislation/public perception:
  - Armed with a better knowledge of the above, it is likely that communal understanding of important issues between mine operators, regulators and the general public can be improved; educational and communication programs thus need to be enhanced.

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

6.1 BENEFITS OF IMPLEMENTING BEST PRACTICE

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

In line with this change, the mining industry is being judged by the community, and increasingly by its own shareholders, on its environmental performance. The key to operating successfully in such a modern 'environmental marketplace' is good planning. While pollution control and minimising environmental impact through strategic planning increases start-up costs, these are much lower than those costs associated with both loss of public confidence and/or environmental remediation costs. A fuller discussion of the costs associated with best practice is given on pages 13 and 14 in the Overview booklet to this series.

Cyanide is clearly the lixiviant of choice for the gold mining industry, and without it many gold operations around the world would have no option but to close down. Owing to continued concern about the dangers related to cyanide use in mining, heightened in particular by the Baia Mare incident in Romania, cyanide use in mining has been banned in the Czech Republic and calls for a ban have been made in several US states, Argentina, Costa Rica and elsewhere.

The productivity, profitability and efficiency of the gold mining industry, and its continued access for exploration and mine development, increasingly depends on its ability world-wide to demonstrate that the risks associated with cyanide use can be managed to the levels demanded by regulatory authorities and the general community. The success of the industry rising to this challenge depends heavily upon its willingness to commit to the lead provided by the International Cyanide Management Code framework, and to implement appropriate best practice concepts and technologies. Clearly, implementing best practice is very much to the advantage of the mining industry and of industrial operators.

7. REFERENCES AND FURTHER READING

7.1 MAJOR COMPILATIONS AND RECORDS OF RECENT MEETINGS WITH MUCH USEFUL INFORMATION ON CYANIDE USE IN MINING

The Cyanide Compendium. CD-ROM based resource published by Mining Journal Books Ltd, London, containing:

- Chemistry and Treatment of Cyanidation Wastes (2nd Edition), Mudder et al 2001, Mining Journal Books Ltd, London (391 pp)
- The Cyanide Monograph (2nd Edition), Mudder and Botz 2001, Mining Journal Books Ltd, London (647 pp) *English and Spanish versions*
- Cyanide Management (1st Edition), Environment Australia 1998 (97 pp)
- Making Sense of Cyanide, Mudder 1999, The Gold Institute (12pp)
- The Management of Cyanide in Gold Extraction, Logsdon et al, 1999, International Centre for Metals and the Environment, Ottawa (44 pp)
- The Cyanide Guide - Special Edition of the Mining Environmental Management Journal May 2001. The Mining Journal, London (18 articles, 42 pp)

A brochure describing the Cyanide Compendium, and a hard copy order form are at www.cyantists.com/compendium_brochure.PDF. Alternatively it may be ordered on-line at www.mining-journal.com/shop/bindex.htm

Selected Papers on the Management of Cyanide. Collection of papers (247pp) presented at Short Courses on the Management of Cyanide in Mining, conducted by the Australian Centre for Mining Environmental Research in Perth, Western Australia, 14-16 April 1997 and in Townsville, 8 October 1999. Copies can be ordered from the following address or at www.acmer.com.au/publications/attachments/Publications%20Order%20Form.pdf

Australian Centre for Mining Environmental Research
PO Box 883
KENMORE Qld 4069 Australia
fax: +61 7 3327 4574 tel: +61 7 3327 4555 email: acmer.admin@mailbox.uq.edu.au

Technical Issues in the Use and Management of Cyanide in the Gold Industry. Collection of papers (220pp) presented at a Workshop conducted by the Australian Centre for Mining Environmental Research in Perth, Western Australia, 19 July 2002. Copies can be ordered from the ACMER address or website shown above.

Implementation of the International Cyanide Management Code. Collection of papers (176pp) presented at a Workshop conducted by the Australian Centre for Mining Environmental Research in Perth, Western Australia, 18 July 2002. Copies can be ordered from the ACMER address or website shown above.

7.2 WEBSITES RELEVANT TO CYANIDE MANAGEMENT IN MINING

www.cyantists.com - "The Cyantists" website

www.acmer.com.au - Australian Centre for Mining Environmental Research

http://www.cyanidecode.org/library/References1.pdf - International Cyanide Management Institute, Additional Information on Cyanide

www.deh.gov.au/industry/industry-performance/minerals/ - Sustainable Minerals booklets on-line, produced by Environment Australia

http://natindex.nohsc.gov.au/metacatalogue.asp?search=cyanide - NOHSC (Australian National Occupational Health & Safety Commission) items on cyanide use

www.bt.cdc.gov/agent/cyanide/index.asp - USA Centres for Disease Control & Prevention (CDCP) Fact sheet and Emergency Response Cards for cyanide

www.atsdr.cdc.gov/toxprofiles/tp8.html - Agency for Toxic Substances & Disease Registry, toxicological profile for cyanide

www.naturalresources.org/minerals/generalforum/csr/docs/guidelines/Cyanide%20Management%20Code%20-%20Draft%208.pdf - Draft UNEP/ICME International Cyanide Management Code for the Management, Transport and Use of Cyanide in the Production of Gold (draft #8 September 2001

www.natural-resources.org/minerals/csr/practices.htm#Cyanide - UNCTAD site for Corporate Social Responsibility in Mining, list of best practice guidelines and standards

7.3 CITATIONS AND USEFUL REFERENCES

In addition to the following listing, the reader's attention is drawn to the reference listings in the case studies accompanying this second edition of the Cyanide Management booklet.

ANZECC/ARMCANZ, 2000 *Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 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

APHA, 1995 *Standard Methods for the Examination of Water and Wastewater, 4500-Cyanide, 19th Edition*, Greenberg, AE Clesceri LS and Eaton AD (eds), American Public Health Association, American Water Works Association, Water Pollution Control Federation, Washington DC

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

Bard AJ, 1976 *Encyclopaedia of Electrochemistry of the Elements*, Vol. VII Marcel Dekker, New York

Beck MT, 1987 *Critical Survey of Stability Constants of Cyano Complexes in Solution*. Pure Appl. Chem., 59, 1703-1720

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

Black SB and Schulz RS, 1999 *Ion Chromatography as an Analytical Tool for Monitoring Cyanide in the Gold Mining Industry*. 15th Royal Australian Chemical Institute Annual Conference, Melbourne, Victoria, July 1999

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, 3 (2) 4-16. The Mining Journal Limited, London

Botz MM, and Mudder TI, 2001 *Chemical and Physical Treatment*. Chapter 5 in Mudder TI and Botz MM 2001, The Cyanide Monograph. Mining Journal Books, London

Chadwick BM, and Sharpe AG, 1966 *Transition metal cyanides and their complexes*. Adv. Inorg. Chem. Radiochem., 8, 83-176

Ciba Foundation, 1988 *Cyanide Compounds in Biology* (Ciba Foundation Symposium 140), John Wiley, Chichester, England

Clark DR, 1991 Bats, Cyanide and Gold Mining. *BATS*, 9(3): 17-21. Bat Conservation International, Inc.

CSIRO, 1997 *Research Finds Cyanide-Eating Bacteria*, The Minerex Report, June, p 14

Czarecki MT, 1998 *Managing by Measuring; how to improve your organisation's performance through effective benchmarking.* American Management Association, New York USA

Deacons Graham and James (Consultants), 1997 *Guide to Environmental Legislation in Australia and New Zealand*. Report No. 31 (5th ed.), Australian and New Zealand Environment and Conservation Council

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

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

Devuyst EA, Conard BR, and Ettel VA, 1982 *Pilot Plant Operation of the Inco Sulfur Dioxide/Air Cyanide Removal Process*. Can. Min. J., 103, 27-30

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

Dowel AM, Tucker DH, Merritt RF, and Teich CI, 1993 *Hydrogen Cyanide in* Inorganic Chemicals Handbook, Volume 2, McKetta, J.J. (ed), Marcel Dekker, New York, pp. 1025-1038

Dubey SK, and Holmes DS, 1995 *Biological Cyanide Destruction Mediated by Microorganisms*. World J. Microbiol. Biotechnol., 11, 257- 265

Eisler R, Clark DR Jnr, Wiemeyer SN and Henry CJ, 1999 *Sodium Cyanide Hazards to Fish and other Wildlife from Gold Mining Operations*. Chapter 5. pp 55-67 Azcue JM (ed) Environmental Impact of Mining Activities: Emphasis on Mitigation and Remedial Measures. Springer-Verlag.

Elliot R, 1996 *Cyanide Poisoning (New Recommendations on First Aid Treatment)*, Toxic Substances Bulletin 29, January 1996, 8-9

Environment Australia, 2002 *Overview of Best Practice Environmental Management in Mining*, 2nd edition. Environment Australia, Canberra

Environment Australia, 1997 *Hazardous Materials Management, Storage and Disposal* (A Booklet in the Series on Best Practice Environmental Management in Mining). Environment Australia, Canberra

Environment Protection Agency, 1995a *Rehabilitation and Revegetation* (A Booklet in the Series on Best Practice Environmental Management in Mining). Environment Protection Agency (now Environment Australia), Canberra

Environment Protection Agency, 1995b *Tailings Containment* (A Booklet in the Series on Best Practice Environmental Management in Mining). Environment Protection Agency (now 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

Ghosh RS, Dzombak DA, and Luthy RG, 1999 *Equilibrium precipitation and dissolution of iron cyanide solids in water.* Environmental Engineering Science 16 (4), 293-313

Gonen N, Demir E, Kose HM, and Ozdil G, 1996 *Natural Degradation, Chemical Destruction and Regeneration Process of Cyanide* in Changing Scopes, Miner. Process., Proc. 6th Int. Symp., ed. M. Kemal, Balkema, Rotterdam, Neth., 603-606

Greeno J, Hedstrom G, and Diberto M, 1988 *The Environmental, Health, and Safety Auditor's Handbook.* Centre for Environmental Assurance, Arthur D Little Inc, New York

Grosse DW, 1990 *Waste Treatment Processes, Cyanide Destruction and Waste Minimization* Encyclopedia of Environmental Control Technology, 4, 580-597

Hagelstein K, 1997 *The Ecotoxicological Properties of Cyanide* in Short Course Notes on Management of Cyanide in Mining, Perth, WA, April 1997. Australian Centre for Mining Environmental Research, Kenmore, Queensland

Hartung R, 1982 *Cyanides and Nitriles* in Patty's Industrial Hygiene and Toxicology (3rd Revised Edition). Volume 2C. Toxicology, G.D. Clayton and F.E. Clayton (eds), John Wiley and Sons, New York, pp. 4845-4900

Hertting GO, Kraupp E, and Schentz E, 1960 *Investigation about the consequences of a chronic administration of acutely toxic doses of sodium cyanide to dogs.* Acta Pharmacol. Toxicol. 17: 27-43.

Hiskey JB, and DeVaries FW, 1992 *Environmental Considerations for Alternatives to Cyanide Processing,* in Symposium on Emerging Process Technology for a Cleaner Environment, Phoenix, Arizona, USA, February 1992 Chapter 11, 73-79

Hoecker W, and Muir DM, 1987 *Degradation of Cyanide*. Symp. Ser.-Australas. Inst. Min. Metall., 51, 29-36

Ingersoll D, Harris W, Bomberger D, and Coulson D, 1981 *Development and evaluation of procedures for the analysis of simple cyanides, total cyanide and thiocyanate in water and wastewater.* US EPA, EPA-600/u_83-054. October 1981

Jones H, and Kamarudin S, 1997 *Cyanide Use in Australia-Consumption and Regulation* in Short Course Notes on Management of Cyanide in Mining, Perth, WA, April 1997. Australian Centre for Mining Environmental Research, Kenmore, Queensland

Kennedy S, 1997 *Options for Data Validation Principles for Checking Analytical Data Quality*. In WTQA '97 - 13th Annual Waste Testing & Quality Assurance Symposium. pp 169-172

Kesselring J, 1944 *Arsenic and Old Lace.* Warner Bros.

Kjeldsen P, 1999 *Behaviour of cyanides in soil and groundwater: a review.* Water, Air and Soil Pollution 115, 279-307

Logsdon MJ, Hagelstein K, and Mudder TI, 1999 *The Management of Cyanide in Gold Extraction.* International Council on Metals and the Environment, Ottawa, Canada

Maher WA, Cullen PW, and Norris RH, 1994 *Framework for Designing Sampling Programs.* Environmental Monitoring and Assessment, 30 139-162

Mann J, 1992 *Murder, Magic and Medicine,* Oxford University Press

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, 1996 *Tailings Storage Facilities at Australian Gold Mines:* Submission to the Senate Environment, Recreation, Communications and the Arts References Committee

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, and Noller BN, 2000 *Future challenges facing the mining industry - an environmental health perspective.* UNEP Industry and Environment 23, Special Issues 2000, 41-43

Mudder TI, 2003 *Cyanide spills - Prevention and Response*. www.cyantists.com

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 Mudder TI and Botz MM 2001 The Cyanide Monograph. Mining Journal Books, London

Mudder TI, and Botz MM, 2001 *Recovery and Re-use*. Chapter 3 in Mudder TI and Botz MM 2001 The Cyanide Monograph. Mining Journal Books, London

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

Mudder TI, and Smith A, 1994 *An Environmental Perspective on Cyanide, Mining* World News, 6 (9)

Mudder TI, and Whitlock JL, 1984 *Biological Treatment of Cyanidation Wastewaters,* Miner. Metall. Process. 1, 161-165

National Occupational Health and Safety Commission, 1993 *Cyanide Poisoning*, Australian Government Publishing Service, Canberra

NEPC (National Environment Protection Council), 1999 *National Environment Protection (Assessment of Site Contamination) Measure.* 10 December 1999. 20 pp.

Nichol MJ, Fleming CA, and Paul RL, 1987 *The Chemistry of the Extraction of Gold in South Africa*. Inst. Min. Metall. Monograph Series M7, Stanley, G.G, (ed) South Afr. Inst. Mining Metallurgy, Johannesburg, RSA, 831-905

Noller BN, 1997 *Cyanide: Sampling, Measurement and Analysis* in Short Course Notes on Management of Cyanide in Mining, Perth, WA, April 1997. Australian Centre for Mining Environmental Research, Kenmore, Queensland

Noller BN, and Schulz RS, 1997 *Effect of Cyanide Preservation Procedures on Analytical Results*, in Short Course Notes on Management of Cyanide in Mining, Perth, WA April 1997. Australian Centre for Mining Environmental Research, Kenmore, Queensland

Noller BN, and Schulz RS, 1995 *The Effect of Cyanide Preservation Procedures on Analytical Results* in Proceedings of the 4th Environmental Chemistry Conference, Compiled by D. Dundas and B. Salter-Duke, Darwin NT, July 1995. EO25-1-EO25-3

Noller BN, Woods PH, and Milne FJ, 1993 *Sampling and Preservation of Surface and Ground Waters at Northern Territory Sites for General and Trace Analysis*, NT Department of Mines and Energy, Environmental Internal Report 93/1

NSW EPA, 1998 *Guidelines for Consultants Reporting on Contaminated Sites*

NSW EPA (New South Wales Environment Protection Authority), 1995 *Contaminated Sites: Sampling Design Guidelines*

Nugent AJ, 1997 *Hydrogen Peroxide and Efflox™ Processes for Cyanide Destruction,* in Short Course Notes on Management of Cyanide in Mining, Perth, WA, April 1997. Australian Centre for Mining Environmental Research, Kenmore, Queensland

Pesce LD, 1993 *Cyanides*, in Kirk-Othmer Encyclopaedia of Chemical Technology (4th Edition). Volume 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, 716-718

Ritcey GM, 1989 *Tailings Management: Problems and Solutions in the Mining Industry*. Elsevier, Amsterdam.

Robbins GH, 1996 *Historical Development of the INCO SO2/AIR Cyanide Destruction Process.* CIM Bulletin 89, 63-69

Schulz RS, 2002 *Cyanide monitoring and analysis*. In ACMER (2002) Technical Issues for the Use and Management of Cyanide in the Gold Industry. Workshop Notes. Australian Centre for Mining Environmental Research, 19 July 2002, Perth, Western Australia.

Schulz RS, Black SB, and Dixon L, 1999a *Determining the Status of Gold Mine Tailing Facilities by Application of Mineralogical, Chemical and Metal Cyanide Complex Fingerprinting Techniques.* Environment and Mining II, Sudbury 99, Sudbury, Canada, September 1999

Schulz RS, Black SB, Dixon L, Clark G and Staunton W, 1999b *Cyanide Tailings Status Technology applied to upfront Site Investigation for Proposed Residue Storage Facility of a New Gold Mine.* Environment and Mining II, Sudbury 99, Sudbury, Canada, September 1999

Schulz RS, Black SB, Lotz P, and Wright P, 1999c *Best Practice - Analytical Methods for the Gold Mining Industry*. Tailings Management for Practitioners Seminar, Darwin, Northern Territory, October 1999

Schulz RS, Black SB, Lotz P, Lye P, Hefner G, May P, and Murray K, 2000 *Advances in Cyanide Management and Gold Mine Decommissioning.* 4th International and 25th Annual Minerals Industry Environmental Workshop, Perth, Western Australia, October 2000

SharpeA.G, 1987 *Cyanides and Fulminates in Comprehensive Coordination Chemistry*, Wilkinson G, Gillard RD, and McCleverty JA (eds), Pergamon Press, 7-14

Sharpe AG, 1976 *The Chemistry of Cyano Complexes of the Transition Metals,* Academic Press, London

Smith A, and Mudder TI, 1995 *Cyanide-Dispelling the Myths*. Min. Environ. Management, June, 4-5

Smith A, and Mudder TI, 1991 *TheChemistry and Treatment of Cyanidation Wastes.* Mining Journal Books Ltd, London

Souren AWMG, 2000 *Living with Cyanide.* The Geochemical News 105, October 2000. pp16-26

Staunton WP, Formby S, Schulz RS, and Avraamides, J, 1989 *Transportation of Liquid Sodium Cyanide-Response Strategies for Spills* in World Gold '89, R.B. Bhappu and R.J. Harden (eds), Society of Mining, Metallurgy and Exploration, Littleton, Colorado, USA, 357-362

Stevenson J, Botz M, Mudder TI, Wilder A, and Richins R, 1995 *Cyanisorb Recovers Cyanide* . Min. Environ. Management, June, 9-10

Tayles K, 2002 *Background to the International Cyanide Management Code.* Workshop on implementation of the International Cyanide Management Code, Perth, Western Australia, July 2002. Australian Centre for Mining Environmental Research, Kenmore, Queensland

Tran T, 1992 *The Hydrometallurgy of Gold Processing,* Interdisc. Sci. Rev., 17, 356-365

UNEP, 1988 *APELL - a process for responding to technological accidents.* UNEP Industry and Environment Office, Paris

US EPA, 1998 *Guidelines for Ecological Risk Assessment*. Federal Register, May 14 1998. pp 26846-26924US EPA, 1989 *Cyanide.* Review Environ. Contam. Toxicol.107: pp 53-64.

U.S. Fish and Wildlife Service, 1991 *Cyanide hazards to fish, wildlife and invertebrates: a synoptic review.* Biological Report 85 (1.23), Contaminant Hazard Review Report 23, U.S Department of the Interior, December 1991

Vennesland B, Conn E., Knowles CJ, Westley J, and Wissing F (eds), 1981 *Cyanide in Biology*, Academic Press, London

von Michaelis H, 1987 *The Prospects for Alternative Leach Reagents; Can Precious Metals Producers get Along Without Cyanide?* Engineering and Mining Journal, 188, June 1987, 42-44,47

von Michaelis H, 1984 *Role of Cyanide in Gold and Silver Recovery in Cyanide and the Environment*, Proc. Conf. Tuscon, Arizona, D. Van Zyl (ed), 51-64

Wardell-Johnson G, 2002 *Cyanide issues in decommissioning and closure*. Workshop 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

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, J.L. 1989, *The Advantages of Biodegradation of Cyanides*. J. Metals, 41, 46-47.

APPENDIX 1: INTERNATIONAL CYANIDE MANAGEMENT CODE

BACKGROUND

For over a century, cyanide has been the primary reagent used by the mining industry for the production of gold. It is a hazardous chemical that requires careful management. Since no other commercially viable and environmentally sound alternatives currently exist, gold mines will continue to use cyanide.

In January 2000, the accidental release of large amounts of cyanide solutions and tailings from the Aurul mine in Romania resulted in significant pollution of the receiving river system. This incident dramatically increased the consciousness of governments, international organizations, industry and the public of the environmental hazards associated with the use of cyanide in the gold mining industry.

To address concerns about cyanide use and management, a two-day multi-stakeholder workshop was held in May 2000 to consider development of a voluntary industry code of practice for the use of cyanide in mining. Workshop participants determined that a voluntary code, implemented industry-wide, could improve the management of cyanide. The International Cyanide Management Code For The Manufacture, Transport and Use of

Cyanide in the Production of Gold ("the Code") was developed as this voluntary industry code. The Code was prepared under the direction of a multi-stakeholder Steering Committee, whose members were chosen by the United Nations Environment Programme and the International Council on Metals and the Environment. The Committee, consisting of participants from the gold mining industry, governments, non-governmental organizations, labor, cyanide producers and financial institutions, worked cooperatively toward the common goal articulated in the Code's Mission Statement:

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

The objectives of the Code as identified by the Committee are:

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

The Code encourages improvement on an industry-wide basis by aggressively promoting participation in the Code, and by requiring signatories to the Code to take appropriate action to manage cyanide responsibly. The public, workers, industry and the environment will derive their greatest benefits if operations using cyanide to extract gold adopt the Code and upgrade their practices as required to meet the Code.

SCOPE

The Code is a gold mining industry voluntary code, intended to complement an operation's existing regulatory requirements. Compliance with the rules, regulations and laws of theapplicable political jurisdiction is necessary; this Code is not intended to contravene such laws. The Code focuses exclusively on the safe management of cyanide and cyanidation mill tailings and leach solutions. It addresses production, transport, storage, and use of cyanide and the decommissioning of cyanide facilities. It includes requirements related to financial assurance, accident prevention, emergency response, training, public reporting, stakeholder involvement and verification procedures. It does not address all safety or environmental activities that may be present at gold mining operations such as the design and construction of tailings impoundments or long-term closure and rehabilitation of mining operations.

The term "cyanide" used throughout the Code generically refers to the cyanide ion, hydrogen cyanide, as well as salts and complexes of cyanide with a variety of metals in solids and solutions. It must be noted that the risks posed by the various forms of cyanide are dependent on the specific species and concentration. Information regarding the different chemical forms of cyanide is found at *http://www.cyanidecode.org/library/cn_facts_chemistry.html*.

CODE IMPLEMENTATION

The Code is comprised of two major elements. The Principles broadly state commitments that signatories make to manage cyanide in a responsible manner. Standards of Practice follow each Principle, identifying the performance goals and objectives that must be met to comply with the Principle. Operations are certified as being in compliance with the Code upon an independent third-party audit verifying that they meet the Standards of Practice.

For implementation guidance, visit *http://www.cyanidecode.org/library/impl_resources.html*

The programs and procedures identified by the Code's Principles and Standards of Practice for the management of cyanide can be developed separately from other programs, or they can be integrated into a site's overall safety, health and environmental management programs. Since operations typically do not have direct control over all phases of cyanide production, transport or handling, gold mines will need to require that other entities involved in these activities commit to and demonstrate that they adhere to the Code's Principles and meet its Standards of Practice for these activities.

This Code, the implementation guidance, mine operators guide, and other documents or information sources referenced at *www.cyanidecode.org* are believed to be reliable and were prepared in good faith from information reasonably available to the drafters. However, no guarantee is made as to the accuracy or completeness of any of these other documents or information sources. The implementation guidance, mine operators guide, and the additional documents and references are not intended to be part of the Code.

No guarantee is made in connection with the application of the Code, the additional documents available or the referenced materials to prevent hazards, accidents, incidents, or injury to employees and/or members of the public at any specific site where gold is extracted from ore by the cyanidation process.

Compliance with this Code is not intended to and does not replace, contravene or otherwise alter the requirements of any specific national, state or local governmental statutes, laws, regulations, ordinances, or other requirements regarding the matters included herein.

Compliance with this Code is entirely voluntary and is neither intended nor does it create, establish, or recognize any legally enforceable obligations or rights on the part of its signatories, supporters or any other parties.

PRINCIPLES AND STANDARDS OF PRACTICE

1. Production **- Encourage responsible cyanide manufacturing by purchasing from manufacturers who operate in a safe and environmentally protective manner.**

Standard of Practice

1.1 Purchase cyanide from manufacturers employing appropriate practices and procedures to limit exposure of their workforce to cyanide and to prevent releases of cyanide to the environment.

2. Transportation **- Protect communities and the environment during cyanide transport.**

Standards of Practice

2.1 Establish clear lines of responsibility for safety, security, release prevention, training and emergency response in written agreements with producers, distributors and transporters.

2.2 Require that cyanide transporters implement appropriate emergency response plans and capabilities, and employ adequate measures for cyanide management.

***3. Handling and Storage* - Protect workers and the environment during cyanide handling and storage.**

Standards of Practice

3.1 Design and construct unloading, storage and mixing facilities consistent with sound, accepted engineering practices and quality control and quality assurance procedures, spill prevention and spill containment measures.

3.2 Operate unloading, storage and mixing facilities using inspections, preventive maintenance and contingency plans to prevent or contain releases and control and respond to worker exposures.

***4. Operations* - Manage cyanide process solutions and waste streams to protect human health and the environment.**

Standards of Practice

4.1 Implement management and operating systems designed to protect human health and the environment including contingency planning and inspection and preventive maintenance procedures.

4.2 Introduce management and operating systems to minimize cyanide use, thereby limiting concentrations of cyanide in mill tailings.

4.3 Implement a comprehensive water management program to protect against unintentional releases.

4.4 Implement measures to protect birds, other wildlife and livestock from adverse effects of cyanide process solutions.

4.5 Implement measures to protect fish and wildlife from direct and indirect discharges of cyanide process solutions to surface water.

4.6 Implement measures designed to manage seepage from cyanide facilities to protect the beneficial uses of ground water.

4.7 Provide spill prevention or containment measures for process tanks and pipelines.

4.8 Implement quality control/quality assurance procedures to confirm that cyanide facilities are constructed according to accepted engineering standards and specifications.

4.9 Implement monitoring programs to evaluate the effects of cyanide use on wildlife, surface and ground water quality.

***5. Decommissioning* - Protect communities and the environment from cyanide through development and implementation of decommissioning plans for cyanide facilities.**

Standards of Practice

5.1 Plan and implement procedures for effective decommissioning of cyanide facilities to protect human health, wildlife and livestock.

5.2 Establish an assurance mechanism capable of fully funding cyanide-related decommissioning activities.

***6. Worker Safety* - Protect workers' health and safety from exposure to cyanide.**

Standards of Practice

6.1 Identify potential cyanide exposure scenarios and take measures as necessary to eliminate, reduce and control them.

6.2 Operate and monitor cyanide facilities to protect worker health and safety and periodically evaluate the effectiveness of health and safety measures.

6.3 Develop and implement emergency response plans and procedures to respond to worker exposure to cyanide.

7. Emergency Response - Protect communities and the environment through the development of emergency response strategies and capabilities.

Standards of Practice

7.1 Prepare detailed emergency response plans for potential cyanide releases.

7.2 Involve site personnel and stakeholders in the planning process.

7.3 Designate appropriate personnel and commit necessary equipment and resources for emergency response.

7.4 Develop procedures for internal and external emergency notification and reporting.

7.5 Incorporate into response plans monitoring elements and remediation measures that account for the additional hazards of using cyanide treatment chemicals.

7.6 Periodically evaluate response procedures and capabilities and revise them as needed.

***8. Training* - Train workers and emergency response personnel to manage cyanide in a safe and environmentally protective manner.**

Standards of Practice

8.1 Train workers to understand the hazards associated with cyanide use.

8.2 Train appropriate personnel to operate the facility according to systems and procedures that protect human health, the community and the environment.

8.3 Train appropriate workers and personnel to respond to worker exposures and environmental releases of cyanide.

***9. Dialogue* - Engage in public consultation and disclosure.**

Standards of Practice

9.1 Provide stakeholders the opportunity to communicate issues of concern.

9.2 Initiate dialogue describing cyanide management procedures and responsively address identified concerns.

9.3 Make appropriate operational and environmental information regarding cyanide available to stakeholders.

CODE MANAGEMENT

Administration

The International Cyanide Management Institute ("The Institute") is a non-profit corporation established to administer the Code through a multi- stakeholder Board of Directors consisting of representatives of the gold mining industry and participants from other stakeholder groups.

The Institute's primary responsibilities are to:

- Promote adoption of and compliance with the Code, and to monitor its effectiveness and implementation within the world gold mining industry.
- Develop funding sources and support for Institute activities.
- Work with governments, NGOs, financial interests and others to foster widespread adoption and support of the Code.
- Identify technical or administrative problems or deficiencies that may exist with Code implementation, and

- Determine when and how the Code should be revised and updated.

Code Signatories and Supporters

Companies with either single or multiple operations can become signatories to the Code; the signature of an owner or corporate officer of the operating company is required. By becoming a signatory, a company commits to follow the Code's Principles and implement its Standards of Practice. Code signatories' operations will be audited to verify their operation's compliance with the Code. A signatory is not required to have all operations certified. When becoming a signatory, a company must specify which of its operations it intends on having certified. A company that does not have these operations audited within 3 years of signing the Code will lose its signatory status.

Cyanide producers, transporters, and other companies or individuals not currently or directly engaged in production of gold by cyanidation can demonstrate their support of the Code's objectives by conducting audits and where appropriate becoming Code Supporters.

Code Verification and Certification

Audits are conducted every three years by independent, third-party professionals who meet the Institute's criteria for auditors. Auditors evaluate an operation to determine if its management of cyanide achieves the Code's Principles and Standards of Practice; the Code's Verification Protocol contains the criteria for all audits. Operations must make all relevant data available to the auditors, including the complete findings of their most recent independent Code Verification, in order to be considered for certification.

During an initial verification audit, an operation's compliance at the time of the audit will be evaluated. Subsequent re-verification audits will also evaluate compliance during the period between the preceding and current audits. Upon completion of the audit, the auditor must review the findings with the operation to ensure that the audit is factually accurate and make any necessary changes. The auditor must submit a detailed "Audit Findings Report" addressing the criteria in the Verification Protocol and a "Summary Audit Report" that includes the conclusion regarding the operation's compliance with the Code to the signatory, the operation and to the Institute. The operation is certified as complying with the Code if the auditor concludes that it is in full compliance with the Code's Principles and Standards of Practice. The detailed "Audit Findings Report" is the confidential property of the operation. The "Summary Audit Report" of certified operations will be made available to the public on the Code website. The operation may submit its comments regarding the Summary Audit Report to the Institute, which will be posted along with the Summary Audit Report on the Institute's website.

Operations that are in substantial compliance with the Code are conditionally certified, subject to the successful implementation of an Action Plan. Substantial compliance means that the operation has made a good- faith effort to comply with the Code and that the deficiencies identified by the auditor can be readily corrected and do not present an immediate or substantial risk to employee or community health or the environment. Operations that are in substantial compliance with a Standard of Practice must develop and implement an Action Plan to correct the deficiencies identified by the verification audit. The operation may request that the auditor review the Action Plan or assist in its development so that there is agreement that its implementation will bring the operation into full compliance. The Action Plan must include a time period mutually agreed to with the auditor, but in no case longer than one year, to bring the operation into full compliance with the Code. The Auditor must submit the Action Plan to the Institute along with the Audit Findings Report and Summary Audit Report.

The operation must provide evidence to the auditor demonstrating that it has implemented the Action Plan as specified and in the agreed-upon time frame. In some cases, it may be necessary for the auditor to re-evaluate the operation to confirm that the Action Plan has been implemented. Upon receipt of the documentation that the Action Plan has been fully implemented, the auditor must provide a copy of the documentation to the Institute along with a statement verifying that the operation is in full compliance with the Code.

All operations certified as in compliance with the Code will be identified on the Code website, http://www.cyanidecode.org/signatories&certifiedoperations. Each certified operation's Summary Audit Report will be posted and operations with conditional certification will have their Summary Audit Report and their Action Plan posted.

An operation cannot be certified if the auditor concludes that it is neither in full compliance nor in substantial compliance with any one of the Standards of Practice. An operation that is not certified based on its initial verification audit can be verified and certified once it has brought its management programs and procedures into compliance with the Code. Its signatory parent company remains a signatory during this process.

An operation that is not yet active but that is sufficiently advanced in its planning and design phases can request conditional certification based on an auditor's review of its site plans and proposed operating procedures. An on-site audit is required within one year of the operation's first production of gold by cyanidation to confirm that the operation has been constructed and is being operated in compliance with the Code.

An operation or an individual cyanide facility at an operation is no longer subject to certification after decommissioning of the cyanide facilities.

Certification Maintenance

In order to maintain certification, an operation must meet all of the following conditions:

- The auditor has concluded that it is either in full compliance or substantial compliance with the Code.
- An operation in substantial compliance has submitted an Action Plan to correct its deficiencies and has demonstrated that it has fully implemented the Action Plan in the agreed-upon time.
- There is no verified evidence that the operation is not in compliance with the Code.
- An operation has had a verification audit within three years.
- An operation has had a verification audit within two years of a change in ownership, defined as a change of the controlling interest of the operating company.

Auditor Criteria and Review Process

The Institute will develop specific criteria for Code Verification auditors and will implement procedures for review of auditor credentials. Criteria will include requisite levels of experience with cyanidation operations and in conducting environmental, health or safety audits, membership in a self-regulating professional auditing association and lack of conflicts of interest with operation to be audited.

Dispute Resolution

The Institute will develop and implement fair and equitable procedures for resolution of disputes regarding auditor credentials and certification and/or de-certification of operations. The procedures will provide due process to all parties that may be affected by these decisions.

Information Availability

The Code and related information and code management documentation are available via the Internet at http://www.cyanidecode.org/. The website is intended to promote an understanding of the issues involved in cyanide management and to provide a forum for enhanced communication within and between the various stakeholder groups with interest in these issues. The site is the repository for Code certification and verification information.

APPENDIX 2: STATUTORY REQUIREMENTS

The regulatory regime relating to cyanide use in mining in Australia is delivered at the State Government level. Different aspects of cyanide use are covered in different pieces of legislation, reflecting the types of risks and activities involved (ie legislation on poisons, dangerous goods, transport, mine safety and environmental protection etc). This situation is common in most jurisdictions around the world, where no legislation specific to cyanide use is provided. Other regulations are applicable to reducing risks related to cyanide, particularly those dealing with water management, water and tailings storage facility design, construction and operation.

An example of legislation covering cyanide management as it relates to the State of Western Australia is in Table 8. Until recently, specific details and advice on how to implement the regulatory requirements were provided in a series of Codes on specific operational aspects which were referred to in the legislation. In order to achieve greater legal authority and allow the practices in the Codes to be enforced, the Western Australian Government has recently written the mining codes directly into legislation. The legislative requirements in other states are similar to those in WA, although the legal authority of the practices described in associated Codes varies. Details of cyanide regulation at a minesite should be clarified with the relevant state or territory authorities.

Obtaining Cyanide

Cyanide is managed under the Poisons Act 1964 (WA) which is administered by the WA Health Department. On request from a potential user, the Health Department may grant a permit to purchase cyanide provided it is satisfied that the potential purchaser can justify using it. For mining companies, this information is cross checked with the Department of Industry and Resources to ensure that the organisation/individual holds the required mining tenements and the company is known to the Department.

Transporting Cyanide

The Explosives and Dangerous Goods Act 1961 (WA) is used to regulate the transport of cyanide (including the identification and labelling).

Storing Cyanide

The storage of cyanide on minesites is regulated by several of the acts listed in Table 8. However, nothing may conflict with the provisions of the Environmental Protection Act 1986 (WA).

Table 8: Regulations governing transport and use of cyanide in Western Australia (after Jones and Kamarudin, 1997)

Applicable Legislation	**Minesite Operation**				
	Obtain Cyanide	Transport Cyanide	Store Cyanide	Use Cyanide	Dispose Cyanide
Poisons Act (1964) (Health Dept.)	X		X	X	
Explosives and Dangerous Goods Act (1961) (Dept Industry & Resources)		X	X		
Mine Safety Inspection Act (1994) (Dept Industry & Resources)			X	X	X
Mining Act (1978) (Dept Industry & Resources)					X
Environmental Protection Act (1986) (Dept Env Water & Catchment Prot'n)		X	X	X	X

In summary, solid cyanide has to be stored in a locked facility that is designed to prevent exposure to water from rain, run-off or flooding. The facility should be ventilated to avoid potential build up of HCN gas within the facility. Liquid cyanide must be stored in tanks that are set in a fully bunded area which allows for effective recovery of any spillage.

USING CYANIDE

The Mines Safety and Inspection Act 1994 (WA) is used to ensure that:

- cyanide is treated as a hazardous substance (see the Hazardous Materials booklet in this series);
- all personnel handling the material or coming into contact with it are adequately trained; and
- manned first aid facilities are available at all times.

DISPOSING OF CYANIDE

Tailings storage facilities are the deposition points of waste cyanide in whatever form. Their design, construction and operation are governed by the conditions detailed in the Mining Act 1978 (WA) according to the requirements of individual sites and of the licensing provisions of the Environmental Protection Act 1986 (WA).

Under section 71 of the Mining Act (granting of tenements) the Minister has wide discretionary powers to impose terms and conditions that are considered reasonable in the management, rehabilitation and decommissioning of a minesite and structure.

This regulatory framework for tailings storage facilities recognises the need for a flexible approach responding to site-specific conditions. It allows for future changes to be made easily. The Guidelines on Safe Design and Operating Standards for Tailings Storages apply. The specific hazards, from construction through to rehabilitation and decommissioning have to be addressed in detail to the satisfaction of the Department of Industry and Resources and, where appropriate, the Water and Rivers Commission and the Department of Environment Protection. Overall, the approach allows for a realistic assessment taking into account variations in climate, geology, surface and ground water. Therefore, regulatory blanket values for acceptable cyanide concentrations have not been set. However licence conditions for discharge to surface water or water drawn from monitoring bores have been set between 0.5 mg/L WAD cyanide and 0.05 mg/L WAD cyanide according to the sensitivity of the respective local environment. There is no guideline value set for cyanide concentrations within the ponded water although most mines strive to have a WAD cyanide concentration of less than 50 mg/L (Section 4.7). All fauna mortalities must be reported.

ARRANGEMENTS AT THE NATIONAL LEVEL

Owing to its toxicity, cyanide is included in the collection of information on significant pollutants gathered by some national jurisdictions, such as Australia (National Pollutant Inventory), Canada (National Pollutant Release Inventory), and the United States (Toxics Release Inventory). These are publicly accessible Internet databases that provide nation-wide information on the type and amount of pollution emitted to the air, land and water across the country.

The Australian National Pollutant Inventory (NPI) provides pollutant emission estimates since 1998 from facilities like manufacturing sites and from other sources such as households, and transport. Facilities estimate their own emissions and 'aggregated emissions' from households and other sources are estimated by government agencies. The desired environmental outcomes are to raise awareness of pollutant levels, sources and distribution to governments, industry and the general public, and through this maintain and improve ambient air and water quality; minimise environmental impacts associated with hazardous waste; and expand the re-use and recycling of used materials. Mining operators can access this database to determine their level of performance in pollutant management, including benchmarking against similar facilities, and assessing likely levels of concern about the performance of their operations from the local community and others. See Case Study: *Reporting Cyanide to the National Pollutant Inventory*.

APPENDIX 3: PROTOCOL FOR FIELD SAMPLE COLLECTION & PRESERVATION FOR CYANIDE DETERMINATION (AMENDED FROM APHA 4500 CYANIDE, 19TH EDITION, 1995)

SUMMARY

Filter sample through 0.45 micron filter (optional if insignificant amount of particulate material). Treat filtrate for oxidising agents by adding sodium arsenite. Treat filtrate for sulfides by adding lead carbonate. Filter and retain filtrate. Add sodium hydroxide to filtrate. Transfer treated filtrate to black 500 mL plastic HDPE screw-top bottles (bottle previously rinsed). Return membrane with particulate material to the bottle. Store bottle at 0-4°C.

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
5. Sodium hydroxide pellets (corrosive)
6. Potassium iodide starch test paper
7. Lead acetate test paper
8. Plastic tea spoons
9. Esky with ice or cold bricks
10. Acetate buffer pH4.

Procedure

1. Rinse a 500-mL black plastic (HDPE) screw-top bottle three times with the water to be sampled. Add sample water to the bottle by holding it beneath the water surface. Fill to nearly the capacity of the container to allow for reagent addition and mixing.
2. If particulate material is present, pressure-filter sufficient sample through a 0.45 micron membrane filter (by hand-operated syringe) into a suitable container and retain the particulate material.
3. Test the liquid sample for the presence of oxidising agents by placing a drop of the sample on a strip of acetate-moistened potassium iodide-starch test paper. If the paper turns bluish, add sodium arsenite (1/4-teaspoon; about 0.1 g/L).
4. Dissolve the sodium arsenite and re-test; continue arsenite treatment until no discolouration of test-paper occurs.
5. Test the sample for the presence of sulfides by placing a few drops of sample on acetate-moistened lead acetate test-paper. If a darkening of the paper occurs, add powdered lead carbonate
   (1/4-teaspoon; 0.1 g/L).
6. After the lead carbonate has dissolved, re-test the solution; continue lead carbonate treatment until there is no darkening of the test-paper.
7. If lead carbonate treatment has been required, pressure-filter the sample (by hand-operated syringe filter) to remove precipitates formed by reaction with lead carbonate. This must be done before sodium hydroxide pellets are added (see Step 8 below).
8. Add three sodium hydroxide pellets to the sample, and then agitate the sample to dissolve the sodium hydroxide*. If the sample was filtered initially, add sodium hydroxide to the filtrate (bottle previously rinsed) and then transfer the retained particulate material to the bottle.
9. Place the sample in the refrigerator within one hour (or chill on ice and keep in the dark). Send to the laboratory and have analysed within 48 hours.

NOTE:

1. If, after several weeks of sampling, no sulfides and/or oxidising agents 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 mg/L), 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!

APPENDIX 4: CYANIDE SAMPLING, MEASUREMENT AND ANALYSIS

This summary is based on Noller (1997). Further information on factors affecting cyanide stability, sample preservation, and selecting the analytical method is provided in Mudder et al (2001).

Cyanide has a complex chemistry (see Section 2), and monitoring it is correspondingly complex. Cyanide exists in soluble and insoluble forms as both simple and complex species. These cyanide species can be modified by other constituents in the sample. They can also be influenced by mining and milling processes. Degradation products containing nitrogen or sulfur may need to be monitored to understand the proportion of chemical forms present.

The chemical forms of cyanide and their degradation products in tailings solution or seepage will determine which monitoring techniques are appropriate. Their nature will also indicate the status of the cyanide present and enable environmental impacts to be the predicted.

WHERE TO SAMPLE

Samples need to be collected from: process water ponds; tailings dams: seepage trenches; recovery drains (heap leach); and groundwater. Appropriate sampling locations at any minesite are best determined by the environmental protection objectives of the site environmental management plan in consultation with experts.

If there is discharge of any cyanide-containing wastewater to external waterways, samples may also need to be taken from surface water upstream of discharge and surface water within and downstream of the mixing zone. Samples may need to be taken downstream to establish when the cyanide concentration indicates complete mixing and/or degradation. Note that in tropical waters cyanide degradation may be very rapid.

REQUIREMENTS AND DESIGN

A sampling scheme according to that of Maher et al (1994) is suggested, taking into account the following: site selection; frequency; and replication.

All aspects of the mine project, and any phenomena that may change with time, must be considered:

- 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 *e.g.* cyanide in tailings dam and heap leach groundwater ;
- environmental effect on biota—birds accessing ponds or beached areas, heap leach; and
- environmental impact of any discharge to surface waters and toxicity testing.

REPRESENTATIVENESS OF SAMPLING

Process water ponds and tailings ponds

Where samples are taken depends on the process and thus sampling 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 profiles sampling will be needed.

For tailings ponds, samples must be taken at the inlet and from decant ponds. These can be expected to be non-homogeneous because of 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 onsite.

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 (use 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. It should also be noted that a grab sample may be representative of flow during a short period and that any other sample shown to be representative of waters being sampled may be applicable.

WHEN AND HOW OFTEN SHOULD SAMPLES BE TAKEN

Samples must be taken at the same time each day to minimise temperature effects. If it is thought that cyanide is being released, samples must be taken during or after such an event. An automatic sampler should be used for fixed time collection (note that losses of cyanide species may occur).

Depending on the aim of the monitoring, frequency of sampling may be at: a fixed time; same time 24 hours or greater; at eight hour minimum; or at one hour minimum.

When sampling at one minute minimum, at least 5 individual samples should be combined.

Replication

A repeat sample should be incorporated every 5 or 10 samples and a blank included in every batch of 10 samples.

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 will most likely not be stable or represented if preserved only as above.

- 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.

Detailed information on collecting and preserving samples for cyanide determination is given in Appendix 3.

SELECTING AN ANALYTICAL METHOD FOR CYANIDE DETERMINATION (MUDDER ET AL 2001)

- Characterise completely sample solutions before analysing them. Place emphasis on species of cyanide present and potential interfering compounds.
- Have a basic knowledge of cyanide chemistry.
- Be aware of method's strengths and weaknesses for specific conditions.
- Understand capabilities of equipment, and operator expertise and experience.
- Have knowledge of treatment techniques to remove interferences.
- Recognise that a treatment to reduce an interference may be an interference itself.

ANALYTICAL METHODS FOR CYANIDE DETERMINATION (MUDDER ET AL 2001)

- Distillation method for total cyanide.
- Cyanide amenable to chlorination with and without distillation.
- Method of WAD cyanide including with distillation.
- Picric acid colorimetric method for WAD cyanide.
- Silver nitrate titration for free cyanide at levels > 10ppm.
- Ion selective electrode for free cyanide and as finish to distillation methods.
- Reactive cyanide for cyanide in potentially hazardous waste.
- Automated distillation with colorimetric finish.
- Ion chromatographic method for individual cyanide species and complexes including thiocyanate and cyanate.

PROCESSING AND PRESERVATION OF MINE SAMPLES

Detailed information is provided in Appendix 3.

EVALUATION OF TREATMENT FOR OXIDANTS

Noller and Schulz (1995) compared various treatments for removing oxidants prior to cyanide analysis (Table 9).

Table 9: 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	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 9: 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	48	84	900
Blanks (all treatments)	< 2	< 2	< 100

SUMMARY OF MEASUREMENTS

An integrated analytical scheme based on APHA 1995, includes some or all of the following (see Table 10 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); and
- Nitrogen species (Total-N, nitrite, nitrate, ammonium).

Confirm WAD cyanide composition by ion chromatography.

REMOTE MONITORING OF DOWNSTREAM WATERS

A state of the art development has sought to incorporate the colorimetric technique for cyanide determination into a field colorimeter in QUALTEL remote monitoring instrument, developed by CSIRO Division of Land and Water. QUALTEL uses satellite transmission of data together with other physico-chemical measurements of water quality.

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

Table 10: 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
$N\text{-}NH_3$	0.49	7.9
$N\text{-}NO_3$	9.4	26
N-Total	100	47
SCN	37	0.6

CYPLUS CORPORATION: BEST PRACTICE IN PACKAGING AND TRANSPORT OF SODIUM CYANIDE

Approximately two-thirds of the worldwide sodium cyanide (NaCN) production is employed in the mining industry where it is predominantly used as a lixiviant for gold and silver extraction. Recent evaluations have concluded that for both technical and ecological reasons, cyanide leaching is the best available technology for the recovery of gold and silver from ores. However, because cyanide exhibits acute toxicity to humans and the environment, the application of adequate safety measures, incident prevention and emergency response systems, are a prerequisite for using cyanide with acceptable and manageable risks. A key to the safe use of cyanide is the implementation of sound management practices through all phases of the product's life cycle, from production through to disposal.

Once the sodium cyanide is produced, the next stages in the product's life cycle come into play, which are packaging followed by transport. Transportation, and disposal of cyanide-containing waste, are the most critical areas for cyanide management in the mining industry. The packaging and transport of hazardous chemicals such as sodium cyanide into areas without sophisticated infrastructure, and the potential for extreme climate conditions, require logistical know-how and special precautions which often go beyond the legal requirements. CyPlus, as a major supplier of sodium cyanide to the mining industry, has focussed its efforts to further improve packaging and transport safety and to ensure that the product is transported in the best possible way to the customers. Once at the minesite, the life cycle continues through the final stages from storage to use/handling, and finally, to disposal. However, even while the product is in the hands of the customer, CyPlus continues to support the product through its commitment to the Product Stewardship aspects of Responsible Care®.

PRINCIPAL GUIDELINES FOR CYANIDE MANAGEMENT

Adopted more than 10 years ago, the *Responsible Care Program* is a voluntary commitment of chemical companies to the public to manage their businesses in such a way that preserves the environment, limits risks to human health, and promotes safe plant operation. The chemical manufacturers also adhere to guidelines ensuring the safe and responsible packaging, handling, transport and disposal of their chemical products under a part of this program called *Product Stewardship,* which means that all health, safety and environmental aspects of a product must be considered throughout the entire life cycle from development to disposal.

Leading producers of cyanides have proven that cyanide can be handled safely, and urge their customers to apply comparable safety standards in their own operations. Based on this expertise, gained over many years, CyPlus and other cyanide producers have developed cyanide safety standards and guidelines for cyanide transport, handling and storage. In Europe, for example, all cyanide producers organised within the European Chemical Industry Council (CEFIC) have established a *Mutual Aid Scheme* where in the case of a transport accident specially trained personnel from the participating companies are sent to the scene to provide technical expertise and assistance.

For the mining industry, CyPlus developed a comprehensive safety and training program that covers the specific issues related to transport, storage and handling, use and disposal of sodium cyanide. The program includes a "site survey" of the customer's operation, as well as training for the operators and personnel from the carrier companies transporting the cyanide to the minesite. Trained CyPlus experts conduct both the training sessions and the surveys. Recommendations of cyanide control for reduced consumption, detoxification, cyanide analytical methods and emergency procedures in case of cyanide poisoning are all part of the product support package that CyPlus provides. The customer is informed of the results of the survey and supplied with concrete suggestions for corrective actions and preventive measures.

Many cyanide suppliers provide training to the operators and the personnel from carrier companies on a regular basis. CyPlus has conducted more than 250 surveys in over 50 countries worldwide over the past three years. Over 2,000 people have attended these safety-training sessions. Customers or carriers who do not comply with the safety standards are refused supply.

PACKAGING

CyPlus is the only manufacturer of sodium cyanide both as a liquid and a solid, therefore covering the complete spectrum of demand from the mining, chemical and surface treatment industries. Depending on the location of the customer and the volumes required, the customer has many packaging choices. All are designed with safety in mind and meet or exceed the requirements for all transport regulations.

Because so many different options are available, customers are given the opportunity to choose the package that best fits their application whether this means drums for a small remote mine-site or bulk liquid truckloads for a larger facility. Many of the packaging options described below are available in similar forms from other cyanide suppliers.

1. Drums

Solid material is typically supplied in 50 kg or 100 kg steel drums. Disposal procedures for this non-returnable variety require thorough rinsing before they can be disposed of (for example, scrap recycling or approved landfill). The manufacturer, as well as the user and the local authorities, monitor the drum disposal procedure.

Returnable drums are typically made from tough puncture-resistant plastic designed to be re-used many times before they are detoxified and recycled. CyPlus encourages the use of recyclable packaging, wherever possible. These special drums are material-tested in order to be able to withstand strong mechanical impacts without the danger of product loss. One criterion, for example, is that the filled drums have to withstand falling from a height of 1.8m.

Drums are the preferred package for most metal-finishing facilities and smaller mines. Also larger mines may keep some on hand as a convenient reserve.

2. Bulk Bags

For most gold mines, bulk bags are still one of the more popular packaging options for solid sodium cyanide. Commonly available in a 1,000 kg size virtually anywhere in the world, bulk bags are also offered as a disposable "bag/box", or the returnable composite bag, unique to CyPlus. With the bag/box system, the sodium cyanide briquettes are loaded into a polypropylene bag then placed in a plywood box lined with a polyethylene bag, which is heat-sealed shut to keep moisture out.

CyPlus's returnable composite bag provides the customer with a returnable alternative to the popular "bag/box" design. The sodium cyanide briquettes are loaded into a polyethylene bag and placed in an outer bag made of polypropylene with rigid side panels. The outer bag is folded flat before being stacked in a shipping container and returned to CyPlus for refilling.

Both bulk bag options are typically transported in shipping containers or enclosed trailers. All of these special bulk bag systems also have to withstand the same material-testing procedure as the drums described above. The manufacturer, the user and the local authorities also monitor the disposal procedure of the non-returnable packaging systems. In this case, after thorough cleaning, combustion or disposal in an approved landfill are the common forms of disposal.

3. Bulk Steel Bins

Often referred to as "bins", this returnable packaging form is commonly used to ship solid product in North America and Europe in relatively close proximity to manufacturing facilities. These containers are returnable and typically hold 1,500 kg.

4. ISO Containers

Unique to CyPlus under the *Advantage SLS ® Solid to Liquid* trade name, these 4,000 gallon (15,140 litre) returnable ISO containers hold approximately 16,000 kg of solid sodium cyanide. The "Solid to Liquid" concept makes this the package of choice for large mines located far from manufacturing facilities and is very well suited for ocean transport. Once the SLS ISO container arrives on-site, the solid sodium cyanide is dissolved by a re-circulating water stream (ie "sparging") directly from the site's storage tank, producing approximately 60 m^3 of concentrated sodium cyanide solution. All the necessary equipment is available from CyPlus and includes the re-circulating/transfer pump skid and the storage. The system is designed to offer a virtually hands-off dissolution system to the site, reducing exposure to cyanide while at the same time reducing manpower costs. Due to the size of each shipment, the economics are further improved by reducing the number of shipments.

Since SLS containers are approved for transport, these ISO containers can be placed directly on a flatbed trailer or chassis. The sturdy frame around the tank acts as a safety cage. After every delivery, each SLS container is fully inspected and pressure checked before being returned to service.

5. Liquid Sodium Cyanide Tank Trucks

Liquid sodium cyanide deliveries are available in areas in relatively close proximity to plants and/or terminal facilities such as Western Europe, South Africa, Eastern Canada, Western Australia and the Western US, particularly Nevada. Liquid product is available both from production facilities designed for this purpose (CyPlus's joint venture Cyanco plant in Winnemucca, Nevada, is an example of this), or from dissolution facilities which dissolve solid sodium cyanide product to ship to the customer as a liquid (such as CyPlus's terminal in Cadillac, Quebec).

The demand for liquid sodium cyanide has increased dramatically over the last 10 years as the number of facilities that can provide a liquid sodium cyanide product has grown. The reason for this demand is the reduction in handling required for product dissolution from other solid delivery options like bulk bags or bins.

Liquid sodium cyanide is transported in semi-articulated trucks specifically designed to exceed stringent safety requirements. They are constructed using double-walled stainless steel with 120 mm of foam insulation in between, which makes them highly puncture resistant. The tankers are built to meet the American Society for Chemical Engineers (ASME) code for welds and general construction integrity. The valves are enclosed to provide rollover protection.

Trained drivers do off-loading in dyked areas. Dripless fittings are also used on all hoses and valves involved in the product transfer process to further reduce the risk of even small spills. The trucks are satellite monitored, and the drivers are provided with two-way communication. As with the SLS containers, each trailer is pressure tested after every delivery to further minimize leakage risks.

No matter which packaging option is chosen, CyPlus uses and often surpasses the best state-of-the-art technologies available to design packaging which provides both a safe and practical way to ship sodium cyanide product. CyPlus continues to develop new packaging concepts in order to continuously optimize the handling safety of the product and to further expand the areas where returnable packaging can be used safely and economically.

TRANSPORTATION

Once the product has left the production plant, much of the responsibility for the safe transfer of the product is in the hands of the carrier. This requires thorough selection, training and monitoring of their procedures, equipment and safety standards by the manufacturer and the mining client in order to ensure safe delivery to the customer site. Only transport companies that have been checked in detail according to the manufacturer's safety and quality criteria are chosen for cyanide deliveries. These criteria often go beyond legal requirements, because of the site-specific nature of the more remote customers. In addition, the transport routes are thoroughly analyzed to minimize the risk of an incident occurring. The Cyplus transport check covers four areas:

1. Risk Assessment

The complete transport route is inspected by CyPlus experts prior to first delivery to determine and check potentially critical risk points. Transport companies are required to take special precautions at these points to avoid accidents. Examples of critical points are populated areas, waterways, bridges, poor road conditions, unloading conditions, and prevailing weather conditions.

2. Transport Companies and Drivers

Carriers used by CyPlus worldwide must have the necessary certifications required by their national and local authorities. In the NAFTA (North American Free Trade agreement) region, for example, drivers must be HAZMAT certified by the relevant authority and have satisfied a federal government background check before being granted a license to haul hazardous materials and use the Cyplus transport protocol. CyPlus uses the American Chemistry Council's (ACC) questionnaire to ensure that adequate levels of driver training, vehicle maintenance and appropriate communication systems are provided (communication systems which can monitor the vehicle's location and allow two-way communication with the driver are required). The carrier is also required to have an emergency response plan in place. CyPlus makes sure that carriers in all other areas of the world follow similar guidelines. CyPlus follows up the questionnaire with an audit of the carrier's facilities to ensure that all the necessary criteria are met; if so, then the carrier is able to become part of CyPlus's logistics team.

CyPlus conducts annual training of the transport company's management staff and drivers, and driver training is conducted by the transport company on a monthly basis. Training includes proper use of protective equipment for the driver, off-load training, emergency procedures and, for mining customers, the drivers must have received their full US Department of Mine Safety and Health (MSHA) training or equivalent for all NAFTA countries. Drivers are typically dedicated to performing just cyanide deliveries. CyPlus hand-picks the drivers from each carrier and continuously scrutinizes their driving records. This is done through special agreements with the chosen carrier.

3. Transport Vehicles

Many factors are involved to determine how the sodium cyanide is shipped to the customer. Obviously the location of the customer plays an important role along with the type of product (liquid or solid sodium cyanide) and the packaging.

Solid sodium cyanide in drums or bulk bags is transported by sea in locked shipping containers labeled with appropriate placards. SLS ISO containers can also be sea-shipped in a similar manner to shipping containers since the sturdy frame is the same size.

Land transport is generally by articulated trucks, although railways are used between the manufacturer's production facilities and terminals. Truck transport of solid product, regardless of the type of packaging, is in enclosed, locked and secured trailers or shipping containers labeled with appropriate placards. During these deliveries the sodium cyanide is shipped alone or, in the case of smaller drum shipments, with compatible chemicals. The prime movers and trailers are inspected thoroughly after each delivery. Vehicles must be well maintained and checked by the transport company and cyanide manufacturer. Inspections and maintenance should be carefully documented and recorded.

4. Emergency Response

CyPlus and other leading manufacturers have developed customer-specific emergency response plans for all customers, including those in more remote areas where infrastructure is not fully developed. These plans help to ensure that proper organizational and communication arrangements, and safety and salvaging equipment, are in place if an incident does occur, and are critical in minimizing impacts in the event of an incident. CyPlus makes sure that all customers are covered by a comprehensive emergency response plan before any product is shipped.

In addition, major European cyanide producers have agreed on a Mutual Aid Scheme (MAS) in case of transport accidents with cyanide within Europe. This system started in July 2000 as a co-operation between Europe's major cyanide manufacturers, enabling the producers to assist one another in case of an emergency. This system provides 24-hour coverage along with telephone assistance in order to dispatch the closest fully equipped cyanide expert team directly to the scene of the incident. The expert team gives technical advice on cyanide in case this is requested and needed by the local emergency response groups (fire brigade, ambulances, and police).

CONCLUSION

The hazardous nature of sodium cyanide demands utmost vigilance at all stages of its life cycle, including the packaging and transport stages where the manufacturer has main responsibility. The integrity of the package, as well as the competence of the transport system, must be maintained at a high level to minimize the potential for individual, public and environmental exposure. If all aspects of *Responsible Care* and *Product Stewardship* are followed, the risks associated with manufacturing, packaging, transportation and use can be reduced to an acceptable level. The systems described in this case study enable sodium cyanide to be delivered safely to any destination in the world.

This case study is produced with the permission of CyPlus Corporation (Mr. Roy Norcross) and is adapted from:

Norcross R, Steiner N, Gos S, and Rubo A, 2000 *The cyanide life cycle - packaging and transport.* Mining Environmental Management 9, 3, pp 19-21.

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GOLDEN CROSS MINE, NEW ZEALAND: CLOSURE AND REHABILITATION

The Golden Cross Mine is on the North Island of New Zealand, 8 km northwest of Waihi. The project was operated as a Joint Venture with Coeur Gold New Zealand holding 80% and Viking Mining Limited with a 20% interest. Open-pit and underground gold and silver production ceased in April 1998 and the reclamation phase took about three years. Although rehabilitation of the site was a regulatory requirement, the Closure Plan was enhanced by a commitment by the Joint Venture to establish a sustainable land use for the site by commissioning engineered facilities designed to last for perpetuity. Cyanide management and community consultation were important issues requiring careful planning and management, beginning before closure planning commenced and continuing throughout the closure phase (MacGillivray et al 2000).

The Golden Cross mine was an open-pit and underground gold and silver operation from December 1991 to April 1998, when 584,000 ounces of gold and 1,675,000 ounces of silver were produced from 5 million tons of ore. The underground vein system was mined at a 4.0 g/t cut off grade and provided 1.7 million tons grading 6.7 g/t, while 3.4 million tons at an average grade of 2.5 g/t, using a cut-off grade of 1.0 g/t, were extracted from the open-pit (Maton, 1999).

The project is situated near the southern end of the Coromandel Range at the headwaters of the Waitekauri River. The minesite rises from around 270 m above sea level to around 480 m on its upper boundary. Surrounding topography is generally rolling to steep farmland with small scattered pockets of native bush and forest. The site is bounded on the west, north, and east by the Coromandel Forest Park and to the south by a private pine plantation.

The mine prior to rehabilitation. Note steep terrain and proximity to forests and farmland. Open pit in foreground; tailings dam beyond; and processing plant right of pit. (photo: Coeur Gold New Zealand Ltd and Viking Mining Ltd).

Long-term mean annual rainfall is 2.9 m, and annual total rainfall varies between recorded extremes of 4.0 and 1.7 m. The intensity of rainfall has dictated the necessity for a stringent water management system and was the key element that determined the planning and engineering goals through operations to closure.

The Joint Venture identified six design features that were key to successful rehabilitation:

- the controlled placement of acid-generating waste rock into engineered disposal sites;
- the design and placement of sealing layers over the waste rock disposal sites;
- the design and construction of diversion drains;
- the establishment and management of vegetation to protect the rehabilitation layers;
- a partial capping of the tailings to accelerate consolidation adjacent to the tailings dam embankment; and
- the implementation of a recovery circuit to recycle cyanide from the tailings prior to disposal.


Above left: The open pit was capped, recontoured, and drainage channels added. Above right: The rehabilitation process almost complete, 2001: the recontoured open pit can be seen in the foreground with the rehabilitated tailings dam in the background. The bush at bottom left is part of the Coromandel State Forest Park. (photos http://www.minerals.co.nz/html/green_from_gold/gx.html)

Another key to success for the project involved genuine consultation with all parties participating in the planning, evaluation, and consenting of the closure process at Golden Cross. The local and regulatory community has been widely represented in the Joint Venture's operating and closure planning throughout the history of the mine. Participants include:

- Regional and District Councillors and staff members,
- Professional peer reviewers;
- Environmental groups;
- Local residents of the valley; and
- Iwi (the Maori people).

This overall commitment to the project has resulted in a world-class rehabilitation program for the first modern metal-mine closure in New Zealand. The work done at Golden Cross sets a new standard for successful environmental protection during mine operation and closure in the extractive industry.

Site works for closure focused on the issues of handling the site stormwater, compacting and sealing acid generating waste, and creating long-term stable structures. The most extensive site works comprised the controlled placement of acid-generating waste rock into engineered disposal sites, the design and placement of sealing layers over the waste rock disposal sites, establishing a vegetative cover to protect the sealing layer, the design and construction of diversion drains, and the partial capping of the tailings impoundment. An important part of the closure process was the procedures and practices adopted through the construction period and mining operation to provide a sound basis for the closure works.

FINAL WATER CHEMISTRY AND CYANIDE RECOVERY IN TAILINGS

A key indicator of performance of the concurrent and closure rehabilitation strategies was the post closure chemistry of the water draining from the site. The aim was to ensure that the best possible water chemistry was achieved at closure, or as soon as possible thereafter, so that direct discharge to receiving water was possible. The experience at Golden Cross was that the runoff and drainage water chemistry met the expectations of the Joint Venture and the regulatory authorities (Russell et al 2000; Kingett Mitchell and Associates 1999; Environment Waikato 2000). Surface water draining from the site can now be discharged directly into receiving water in a high quality stream environment which supports a diverse aquatic community and a small trout fishery, without the need of further treatment.

The key elements of the strategy to achieve the desired environmental outcome of drainage water chemistry which meets receiving water discharge chemistry criteria were:

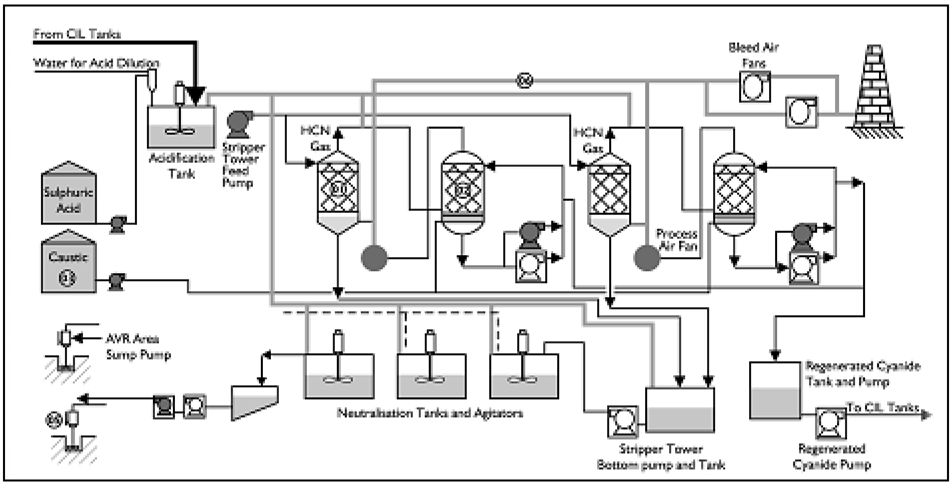
- management of waste rock disposal operations,
- the use of geotechnical and geochemical controls, and
- appropriate design principals.

A significant proportion of the waste generated during the operational phase was process tailings, and one of the key issues with this material was the presence of residual or excess process chemicals - particularly cyanide and the metals that it can continue to leach in the long term and/or keep in solution. During the operating life of the mine this issue was dealt with by a sophisticated water management system and a peroxide oxidation/metals coagulation and removal treatment system on the final discharge. However, to enable the discharge of water without treatment following mine closure and to keep the load off of the water treatment system during operations, a further treatment step was added at Golden Cross whereby cyanide was removed from tailings for re-use.

Cattle graze on rehabilitated pasture in 1999. The process plant in the background, including the cyanide treatment plant, has now been removed and the area has been revegetated for grazing (photo Couer Gold New Zealand Ltd).

There are a number of conventional treatment routes for the destruction of cyanide in gold mill tailings which come with a number of advantages and disadvantages (Smith and Mudder 1991). A principal disadvantage with destruction technology is that cyanide is converted to cyanate and a number of by-products with, for the most part, conservation of cyanide mass, and more significantly the economic disadvantage of loss of excess cyanide from the circuit. At Golden Cross a research and development program was implemented during the earliest stages of mine development which resulted in the development of a system to recover cyanide directly from the tailings stream prior to discharge to the tailings impoundment (the Cyanisorb® system, described in Mudder and Goldstone (1989) and Goldstone and Mudder (1993) - refer to Case study "Golden Cross mine, Cyanide Recovery and Recycling using the Cyanisorb® Process" for further details).

The Cyanisorb® process utilizes the pH dependent chemistry of cyanide by lowering pH and dissociating the cyanide ion from its metal complexes converting the cyanide ion to volatile HCN gas, stripping the gas into air, and then scrubbing the air with caustic, thereby recovering cyanide in the ionic form. The stripped tailings slurry is then re-neutralized to a pH of 9.5, creating a stable environment of carbonate-hydroxide minerals, for disposal into the tailings impoundment.



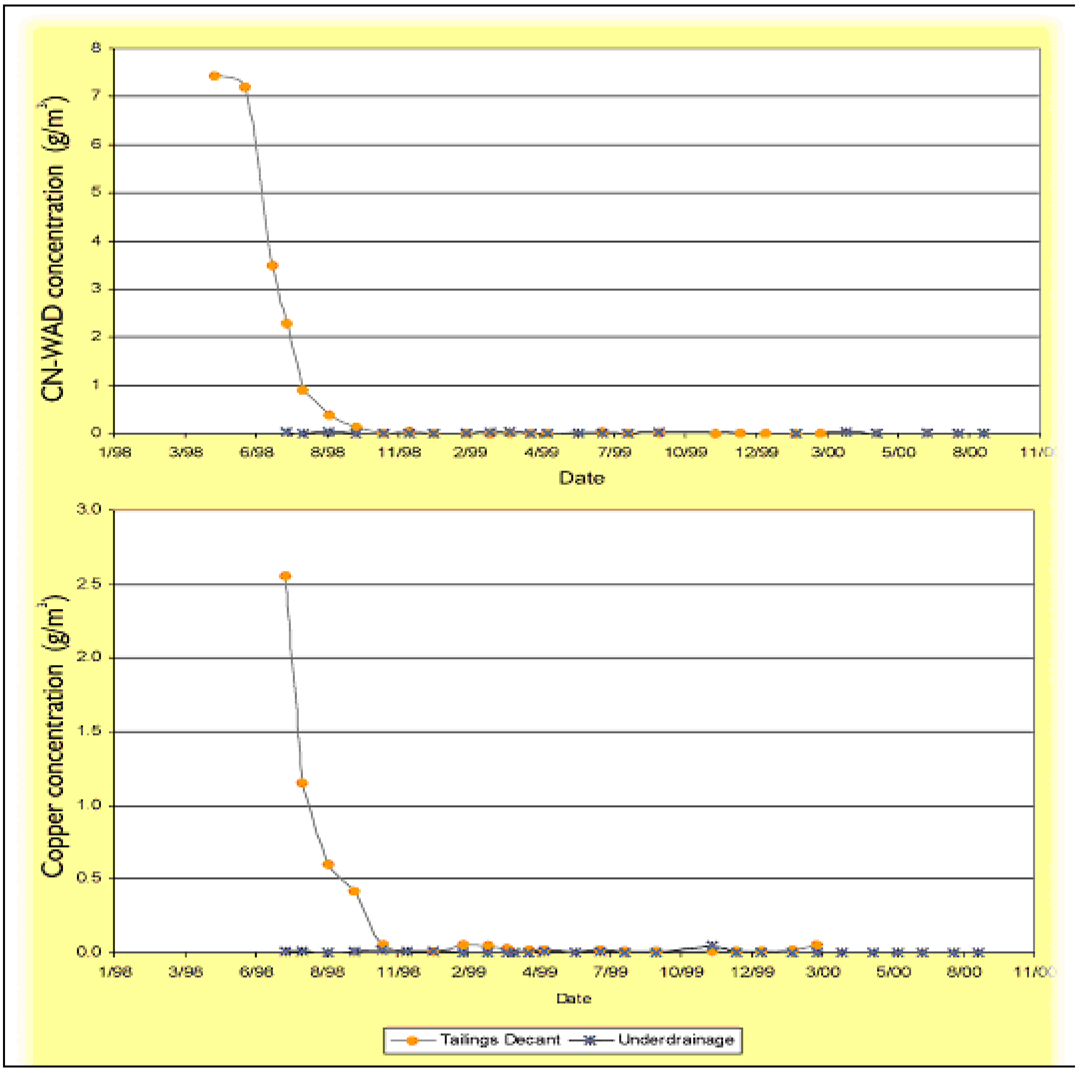
The AVR (Acidification/Volatilisation/Reneutralisation) process used at Golden Cross mine (Coeur Gold New Zealand Ltd).

Tailings discharged to the impoundment generally had solution CN WAD values in the range 15 to 30g/m^3 which represented an 85-90% rate of recovery (Goldstone and Mudder 1993; Russell et al 2000). The drainage water from the tailings area comprised the pond overlying the tailings, and the water collected in the system of drains within the tailings embankment and the under the tailings pile. The key parameters of interest in this area were cyanide and copper.

Immediately following closure, both the decant pond chemistry and underdrainage chemistry began to show signs of rapid improvement and remained very low (see graph showing cyanide and copper concentrations in the tailings pond and the underdrains for the period following closure).

The table shows the chemistry of decant pond and underdrain waters achieved after two years of mill closure, compared with the receiving water criteria established by Environment Waikato and included in closure discharge consents granted to the Joint Venture in September 2000.

Chemistry of decant pond and underdrains (median value January - Sept 2000)			
Parameter	**Typical underdrain concentration**	**Typical decant pond concentration**	**Receiving water criteria (EW 2000)***
WAD cyanide	<0.007	<0.007	0.10
Fe	1.60	0.28	2.0
Mn	1.60	0.043	0.96
Cu	0.002	0.006	0.007
Zn	0.011	0.007	0.037
SO_4	114	123	-
* hardness dependent criteria calculated at 50			



Cyanide and copper decay in tailings decant; seven months from cessation of tailings placement through the closure process. Tailings decant is now direct discharged to the Waitekauri River (Coeur Gold New Zealand Ltd).

Extensive technical analyses were carried out during the closure design and permitting process. This analysis has attributed the success of the closure program for the tailings facility, and the ability to direct discharge water from the tailings to the local receiving environment in closure, directly to the Cyanisorb® system which was used during the operating period.

CONSULTATION

Throughout the history of the operation, the Joint Venture benefited from consultation, conducted through a peer review panel and a local Community Consultative Group. These two bodies were developed during the operational period of the project, but continued through the mine closure phase.

The ongoing review and liaison afforded by these bodies was essential in maintaining confidence in the progress of the closure works during the later periods when the company's presence onsite became minimal. The peer review panel consisted of independent experts whose role was to assess the onsite works being done during reclamation and to provide objective advice to the regulating authorities on whether the works reflected good industry practice. At first the review panel consisted of a consulting geotechnical engineer and an environmental scientist specialising in land rehabilitation. They were advised by two geochemists on water quality and acid mine drainage issues. Later on the panel was expanded to include a landslide expert and a specialist with experience in mine closure when these issues became significant. The panel members were allowed to independently review and advise government regulators on the soundness of the company proposals without any potential of bias from the design engineers. At the same time they provided feedback to the company and contributed to the proposed plans.

The lake above the tailings pile is landscaped to merge with the surrounding terrain and provides a safe habitat for wildlife or farmed animals (photo Coeur Gold New Zealand Ltd).

The Community Consultative Group (CCG) met on a regular basis, starting in the year prior to commencement of decommissioning so that it was able to consider closure planning from the conceptual stage through implementation and subsequent completion. The group comprised Regional Council staff members, District Councillors, environmental groups, Iwi, and the local residents of the Waitekauri Valley. Participation was voluntary and remained consistent, indicating the level of community commitment and interest in mine closure outcomes, and their willingness to contribute in an objective manner when they are given the opportunity to participate. The direct interaction between the peer review panel and the CCG, and routine site visits, were very important in effectively communicating the proposed concepts to the group. This transparent planning strategy, with the help of the regulatory staff members, transformed community concern into informed neutrality and support from those who participated in the ongoing community consultation.

CONCLUSION

Building confidence and support for a project's Closure Plan begins with a commitment to genuine peer review and community consultation. Consultation should begin during the construction phase and continue through the operational and closure phases. The key design features that underpinned the successful operation and closure at Golden Cross in a 3 metre annual rainfall area, included:

- strict engineering rules for the classification, placement, and compaction of mine waste material;
- installation and revegetation of an oxygen diffusion control layer over the waste rock;
- robust design of diversion drains to protect the capping; and
- manipulation of process tailings to reduce and re-use the entrained cyanide, stabilize contained metals, and accelerate improvement in water quality for direct discharge to the sensitive receiving environment.

REFERENCES AND SOURCE MATERIALS

Environment Waikato 2000. *Report of the Waikato Regional Council Hearing Committee in the matter of a series of applications made by Coeur Gold NZ Limited and Viking Mining Company relating to the Golden Cross Mine*. Waikato Regional Council, September 2000.

Goldstone A, and Mudder T, 1993. *Cyanisorb cyanide recovery process design, commissioning, and early performance.* North West Mining Congress Proceedings, Spokane, December 1993.

Goldstone A, and Peterson D, 1991. *Development of Treatment and Discharge Strategies for the Golden Cross Mine.* Proceedings IPENZ Annual Conference, 1991: engineering - choosing our future, Auckland, February 10-13.

Kingett Mitchell & Associates Ltd, 1999. *Golden Cross Mine closure - final resource consent applications: assessment of environmental effects.* Report prepared for Coeur Gold (NZ) Ltd, November 1999.

MacGillivray R, Maton T, and Goldstone A, 2000. *Key mechanisms for successful reclamation - Golden Cross Mine, Coromandel, New Zealand - September 2000*. Proceedings, 2000 New Zealand Minerals and Mining Conference, 29-31 October 2000.

Maton TW, 1999. *The Impact of Resource and Reserve Modelling on the Golden Cross Mine.* Case Study - Masters of Mineral Economics program, Western Australia School of Mines.

Mudder T, and Goldstone A, 1989. *The recovery of cyanide from slurries.* Proceedings of the International Gold Expo Conference, p.107, Reno, Nevada, September 1989.

Russell L, Botz M, Miller S, and Mudder T, 2000. *Life-cycle management of waste at Golden Cross.* Mining Environmental Management, May 2000, Vol. 8, No. 3, p. 7.

Smith A, and Mudder T, 1991. *Chemistry and Treatment of Cyanidation Waste*s. Mining Journal Books Ltd, England.

Williams MPA, and Goldstone A, 1988. *Water management and water treatment at Golden Cross.* Third International Mine Water Congress, Melbourne, Australia, October 1988.

http://www.minerals.co.nz/html/green_from_gold/gx.html

This case study was prepared by Stewart Needham, Neological Consulting from the above source materials and reviewed by Randy McGillivray, Earthworks Technology Inc, Idaho USA.

GOLDEN CROSS MINE, NEW ZEALAND: CYANIDE RECOVERY AND RECYCLING USING THE CYANISORB® PROCESS

The Golden Cross gold and silver mine was a joint venture between Coeur Gold New Zealand Ltd (CGNZ) and Viking Mining Ltd. Construction started in 1990 and production in January 1992. The mine is in the North Island of New Zealand, adjacent to the Waitekauri River, 8 km northwest of Waihi at the base of the Coromandel Peninsula. The terrain is steep to rugged terrain, and average annual rainfall is 3000 mm. After producing 20.5 tonnes of gold and 52 tonnes of silver between 1991 and 1998, the operation became the first modern mine in New Zealand to successfully move into planned closure and final rehabilitation. Rehabilitation was completed in 2001.

The cyanide management procedures used at Golden Cross Mine were integral to the successful implementation of the Environmental Management System (EMS). A key component of cyanide management procedures was the CYANISORB® recovery process.

Aerial view of the minesite showing the open pit, ROM pad and the processing plant (photo: Coeur Gold New Zealand Ltd and Viking Mining Ltd).

CYANIDE RECOVERY PROCESS INSTALLATION

The risk of cyanide losses at Golden Cross mine needed to be minimised because the mine is close to important riverine fisheries. After examining many options, the CYANISORB® cyanide recovery process was installed in 1991. It stripped cyanide from the tailings slurry at a pH of 7.5. The stripped cyanide (as HCN) was reused in the gold treatment plant.

CYANIDE RECOVERY TECHNOLOGY

The CYANISORB® process recovered cyanide directly from gold mill tailings and returned the recovered cyanide to the leach circuit for reuse. The lower cyanide levels in tailings reduced capital and operating costs, because the impoundment and liner design was simpler (as a result of utilising the CYANISORB® process, the 24 ha tailings pond did not have to be lined), and regulatory criteria for water discharge and tailings impoundment closure became less restrictive. Additionally, removing cyanide from the tailings reduced the amount of cyanide entering the groundwater and lessened the risk to wildlife which may have accessed the tailings dam. The water discharged to the environment met stringent New Zealand effluent standards.

PROCESS DEVELOPMENT

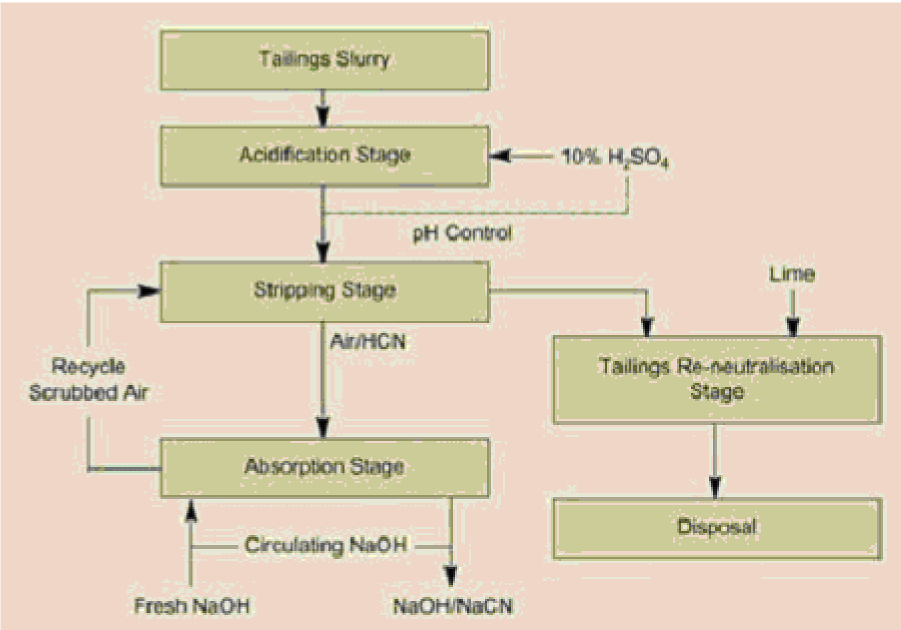
The CYANISORB® technology was developed in response to very stringent permitting and operating requirements for the Golden Cross gold mine in New Zealand. Being near a trout fishery meant cyanide had to be removed from tailings before they were deposited, rather than being removed later on from decant water. Recycling cyanide was favoured over destroying it because it was cheaper and better for the environment. A development program was initiated which culminated in the first CYANISORB® plant being constructed and operating successfully. More recently, processing plants incorporating CYANISORB® technology have come into operation in Idaho USA, Brazil and Argentina.

PROCESS DESCRIPTION

The CYANISORB® process relies on the simplest aspects of cyanide and metal cyanide chemistry. It does not use ion exchange or absorption technology. The process involves:

- Tailings pH is first adjusted into a neutral range (around pH 7.5).
- The tailings are brought into contact with high volumes of turbulent air in a packed tower.
- HCN is 'stripped' or transferred to the gas phase, then redissolved in an absorber by a recirculating strong caustic solution.
- Air is recycled to the 'stripper' tower while the absorber solution is recycled to the leach circuit.
- Tailings are adjusted to a desired pH for normal disposal.
- Reagents used are sulfuric acid, or carbonic acid, caustic and lime.

The flow diagram shows one stripping tower and one recovery tower. However, the installation at Golden Cross incorporated two units of each to ensure efficient treatment process operation.



Generalised process flow sheet for the CYANISORB® cyanide treatment and recovery system

THE CYANISORB® PROCESS CONSISTS OF FOUR OPERATIONS:

- converting cyanide and metal-cyanide complexes to HCN;
- stripping HCN from tailings in a packed tower;
- recovering HCN gas into an alkaline solution; and
- adjusting the pH of the stripped tailings.

Two conversion tanks are operated in series with acid being added to the first tank. The conversion section allows sufficient time for metal-cyanide complexes to dissociate into metal cations and free cyanide. Retention time in each tank is approximately 15 minutes with an effluent target pH of around 6.0-8.0. pH is controlled by using multiple pH probes in the second tank and a controller to adjust acid feed to the first tank.

Slurry from the second conversion tank is pumped to the stripping tower where HCN is removed. HCN-laden air from the stripping tower enters the HCN recovery tower where HCN is recovered as sodium hydroxide. Air exiting the recovery tower is recycled to the stripping tower inlet, thus maintaining a closed circuit. One neutralisation tank is used to adjust the pH of stripped slurry to approximately pH 10.5 (using lime). In addition to providing buffering capacity in the tailings slurry, metal cations released through weak acid dissociable (WAD) cyanide dissociation are precipitated as metal hydroxides. Retention time in the neutralisation tanks is not critical, but 30 minutes is usually provided.

The conversion tanks, neutralisation tank, stripping tower and recovery tower are operated as a closed circuit with a negative pressure to prevent loss of HCN gas.

SYSTEM PERFORMANCE

The Golden Cross plant operated with an average recovery of tailings WAD cyanide of 80-90%.

CYANISORB® (AVR) processor at Golden Cross Mine (photo: Coeur Gold New Zealand Ltd and Viking Mining Ltd).

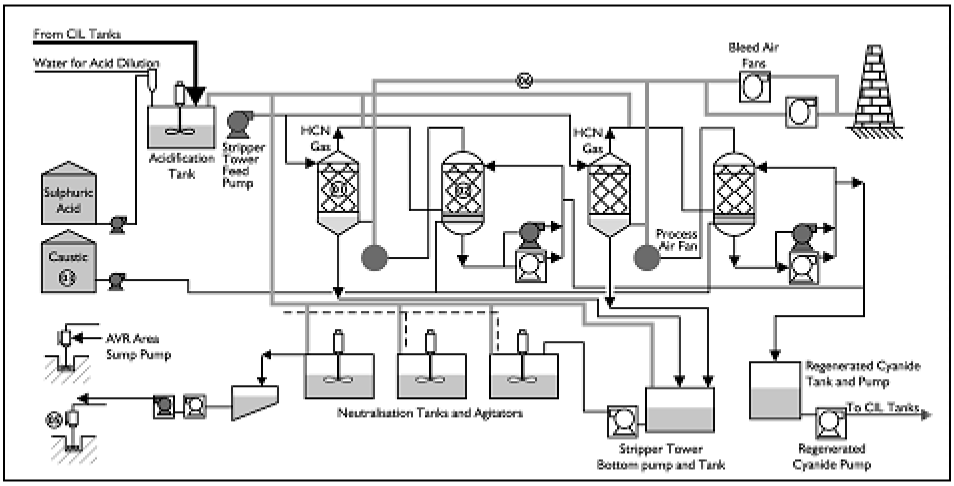
CAPITAL AND OPERATING COST DATA

During its operational life, the cost of the CYANISORB® process was offset by the value of the recovered cyanide alone. The real economic value of the CYANISORB® technology, however, can be seen when the reagent savings from conventional detoxification processes are incorporated into cost calculations. Generally, payback periods of 1.5 to 2.5 years on plant capital cost are possible when all operating cost savings are included. Environmental benefits are a bonus.

METALLURGICAL BENEFITS

The benefits for metallurgy include:

- reduced sodium cyanide (NaCN) purchases and transport/handling; and
- possibility of higher NaCN addition rates and improved gold recoveries without NaCN loss with the tailings.



Cyanisorb installation at the Golden Cross mine

TAILINGS TREATMENT/ECONOMIC BENEFITS

These include:

- reduced sensitivity to NaCN price variations;
- tailings detoxification costs are reduced; and
- cyanide recycling provides an approximately zero net tailings detoxification cost.

Environmental Benefits

These are important as:

- reagent reuse is preferable to reagent destruction or conversion;
- no CN oxidation by-products *e.g.* OCN, SCN, NH_3;
- metals precipitate into the tailings as insoluble hydroxides or carbonates;
- final pH control can accelerate natural degradation in the tailings pond;
- no continued leaching of tailings by residual CN;
- WAD cyanide levels in the tailings dam are reduced from 150 ppm to 20-30 ppm which reduces risk to wildlife;
- cyanide consumption is reduced;
- liability from cyanide leakage from tailings ponds is reduced; and
- requirement for liners for tailings ponds is reduced.

CYANISORB® PROCESS SAFETY

The creation of a safe working environment is a first priority in the design, construction and operation of any CYANISORB® plant:

- Except for tailings slurry, the process is a closed circuit.
- Negative air pressure prevents leakage of cyanide.
- All tanks are air swept with air discharge into the process.
- Plant backup systems minimise the impact of shutdown of process components; interlocks offer complete shutdown at total component failure.
- The section of plant containing HCN gas is relatively small.

This case study was prepared by Randy McGillivray, Earthworks Technology Inc, Idaho USA, and Stewart Needham, Neological Consulting, by updating Case Study 7 in the Cyanide Management booklet 1998 1st edition.

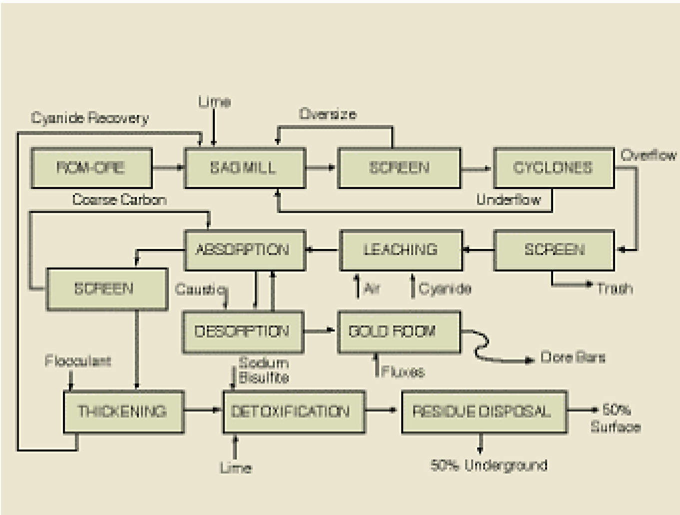
HENTY GOLD LIMITED (PLACER DOME ASIA PACIFIC):
CYANIDE MANAGEMENT IN A HIGHLY SENSITIVE ENVIRONMENT

Cyanide management arrangements at the Henty Gold Mine in Tasmania reflect the site's high rainfall (3.6 m annually) and limited sunlight (average of 4.8 h/day). These conditions restrict natural breakdown of cyanide to a rate lower than for any other Australian mine.

Cyanide use has to be stringently controlled because the gold mine is in a world-renowned, highly sensitive environment. Henty gold mine was the first to open in Tasmania since the late nineteenth century.

To achieve best practice environmental management of cyanide, Henty Gold Mine considered:

- the experience of other Australian gold operations;
- relevant international and national studies and industry standards;
- achievable management goals;
- proven technologies;
- site-specific issues; and
- recommendations by regulatory authorities.



Process Flow Sheet for the Henty mine

CYANIDE TRANSPORT, STORAGE AND ONSITE USE

Henty Gold Mine receives reagents in bulk quantities whenever possible to minimise handling and packaging. All handling and storage of reagents is within a bunded environment. This includes the use of 'drive-on-pads' for unloading.

These pads are contoured to direct hose-down water to two sumps so any reagent spilt during unloading can be contained and reused. Cyanide is received as solid sodium cyanide (NaCN) in containerised one tonne bulk boxes. The boxes are unloaded from the pads and stored in a lockable reagent shed. Cyanide is transferred from the bulk boxes to the 10 m^3 mixing tank within a fully enclosed hood, and spent bags and boxes returned to the supplier for disposal and reuse respectively.

SELECTING THE CYANIDE DETOXIFICATION PROCESS

The need to detoxify cyanide in all leach residue slurries was determined during the feasibility study prior to mine development. The licence conditions, approved by the Tasmanian Government in 1990, stated that a batch detoxification process would reduce residual CN levels before the slurry was discharged from the detoxification circuit. Therefore an INCO SO_2/Air detoxification process was incorporated in the design circuit. Prior to entering the INCO Process, the slurry is thickened and the overflow water that contains most of the residual cyanide is returned to the leach circuit via process water addition.

All gold processing reagents (such as sodium bisulfite) are stored in an undercover bunded area. Cyanide packaging is returned to the supplier as part of the supply contract (photos: Placer Dome Asia Pacific - Henty Gold Ltd).

Process leach residues are detoxified with sodium bisulphite and air (by batch), prior to discharge to leach residue ponds. Discharge occurs when Weak Acid Dissociable (WAD) CN level is below 2 mg/L. WAD CN is reduced further (naturally) in the ponds and once below 0.05 mg/L discharged into the environment.

When the plant process was being designed in 1995, 50 confirmatory WAD CN detoxification tests were done. These used calcium hypochlorite and, for comparison, sodium hypochlorite, which is less hazardous and has physical handling advantages.

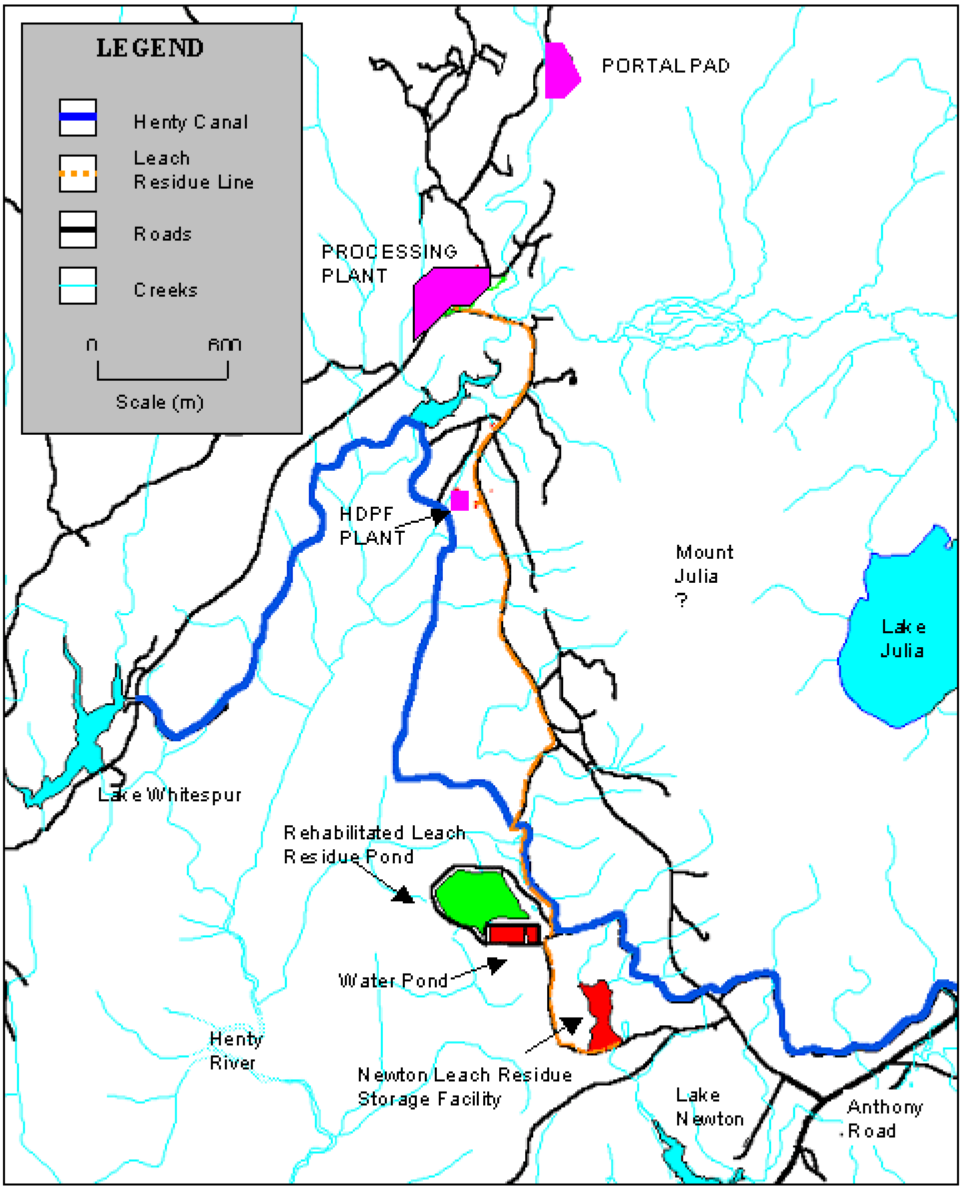
Confirmatory tests showed that, while detoxification was efficient, the very low/undetectable WAD CN levels previously reported were no longer being achieved. Despite more oxidant being added than for the feasibility tests, the residual WAD CN could not be reduced to the levels previously attained. Sodium hypochlorite was less effective than calcium hypochlorite for removing total and WAD CN. Using commercial grade sodium hypochlorite at increased dosages also resulted in increased sodium and chloride concentrations in the leach residue aqueous phase. Therefore, after extensive testwork, calcium hypochlorite was adopted as the most effective batch detoxification process.

In 1997, further detoxification testwork was undertaken to appraise the effectiveness of the new INCO SO_2/Air detoxification process, which was receiving good reviews at some other mines such as the Martha mine in New Zealand. The testing concluded that relative to calcium hypochlorite, the INCO process resulted in better cyanide destruction, employed significantly less reagent at reduced cost, was more efficient in detoxifying cyanide using a continuous process, and resulted in lower concentrations of residual analytes. The INCO SO_2/Air detoxification plant was commissioned at Henty in November 1997, and has now been in full operation for 5½ years with no operational problems.

DETOXIFICATION CIRCUIT OPERATION

In setting an operational WAD CN discharge limit, the effects of continuous processing plant operation and variation in the mineral composition of ore feed must be considered. From the laboratory detoxification testwork and the potential variability in results obtained during operation, an interim internal operational mean discharge limit of 1.0 mg/L WAD CN was proposed. Actual achieved plant discharges since start-up averages 0.48 mg/L WAD CN, which is considered to pose no threat to humans or the receiving environment. Natural degradation and water treatment further reduces the WAD CN levels in the leach residue pond and water pond.

International research on cyanide pollution indicates that WAD CN concentrations less than 50 mg/L will not harm birds. This value is at least one order of magnitude higher than the WAD CN concentration occurring in the Henty residue storage pond.



Henty mine water system plan

Monitoring of water discharges at the mine has shown:

- WAD CN concentrations are generally orders of magnitude below compliance limits;
- average WAD CN concentrations of 0.15 mg/L for discharges from the process plant to leach residue pond after detoxification, with means of 0.1 mg/L WAD CN in the leach residue pond supernatant;
- average WAD CN concentrations of 0.012 mg/L for discharge from the discharge pond to the Henty Canal, ie about one quarter of the 0.05 mg/L regulatory limit of discharge into the Henty Canal; and
- based on dilution ratios, an average WAD CN concentration of 0.0003 mg/L has been achieved for discharge from the Henty Canal to Lake Plimsoll during water pond discharge events (Lake Plimsoll lies 2.5 km east of Lake Julia on the map and is one of the key monitoring points for discharges to the wider environment).

LEACH RESIDUE AND WATER MANAGEMENT

Detoxified leach residue is stored in Newton Dam (commissioned in 2001), the HDPE lined Pond A, and the unlined Pond B about 3.5 km south of the processing plant, adjacent to the Henty Canal. Pond B has been decommissioned and is currently undergoing progressive rehabilitation.

Newton Leach Residue Storage Facility, Tyndall Ranges in the background (photo: Placer Dome Asia Pacific - Henty Gold Limited).

Pond A is a 10 000 m^3 capacity plastic-lined pond holding supernatant solution pumped from the Newton leach residue storage facility. Water pumped to Pond A flows into a discharge pond via a spillway. Water is discharged from the discharge pond to the nearby Henty Canal (part of Hydro Tasmania's Anthony hydro-electric generation scheme) only once all regulatory water quality requirements are achieved. The pond facility has been fenced to exclude fauna. A leachate underdraining system constructed above the liner on the floor of the lined pond A, has a two-fold purpose:

- to collect water from the leach residue material and therefore assist the settlement process; and
- to test the quality of water leaching through the settled solids.

A series of level float alarms in Pond A protects against overfilling. When the pond level approaches the high level mark an alarm is raised in the mill control room and all pumps feeding the water pond automatically stop and interlock to prevent accidental starting. If the level in the pond exceeds the high level float, a higher level float raises a critical alarm.

The pond water is released into the canal following analysis to determine water quality. The pond pumping system has been designed to allow retreatment of the supernatant solution in the event that analysis demonstrates a detoxification circuit failure.

The limits presently imposed on the mine's cyanide discharge from both the gold plant and the leach residue/water pond are orders of magnitude below levels that are likely to cause environmental harm. The predicted ambient free CN level for Lake Plimsoll (0.00005 mg/L) is 100 times less than the proposed Interim Ambient Environmental Quality Requirements (the IAEQR are specific to Henty mine operations and are determined by the environmental regulator, the Department of Primary Industries, Water and Environment (DPIWE). They are termed *interim* to allow for changes to requirements should they be warranted on the basis of continuing research into environmental sensitivity and protection in the region).

Upon dilution within the Henty Canal, free CN levels drop to an average 0.00003 mg/L or 0.03 µg/L, which is an order of magnitude less than the trigger value of 4 µg/L recommended by ANZECC/ARMCANZ for protection of aquatic life. This concentration is derived using average summer-time canal flow rate and average discharge rate. Concentrations will be even lower in the winter, when canal flow rates are higher.

Henty is currently commissioning a new high density paste fill (HDPF) operation. Thickened leach residues, cement and water are blended and used to backfill mined out stopes underground. This process, which may return up to 50% of the leach residue produced underground, has many other advantages including:

- reducing surface storage of leach residue;
- reducing inflow of underground waters thereby reducing water treatment requirements; and
- giving better orebody access.

ADDITIONAL CYANIDE MANAGEMENT CONTROLS

Other cyanide management processes are:

- 4-hourly WAD cyanide determinations of the thickener underflow, reactor tank and batch tailings tank;
- daily inspection of leach residue storage ponds and tailings delivery pipelines;
- incident reporting and a system of emergency procedures;
- systems for data recording, evaluation, interpretation and reporting;
- process technician training and awareness of potential cyanide related problems, including personal safety and impacts on the surrounding natural environment;
- systematic records management and documentation of animal mortalities; and
- incorporating cyanide management procedures into the site Environmental Management Plan, which is currently being updated.

ENVIRONMENTAL OUTCOMES, & FUTURE TRENDS FOR ENVIRONMENTAL PROTECTION

Henty Mine's cyanide discharges from both the gold plant and the leach residue/water pond are orders of magnitude below levels likely to cause environmental harm. WAD CN levels in discharges from the gold plant to the leach residue pond, the water pond to the Henty Canal, and the Henty Canal to Lake Plimsoll, are well below the specified limits. These discharges should pose no threat to aquatic, mammalian, bird or human life.

A very high level of protection against cyanide discharges to the environment has been achieved. It is possible that in the future there may be calls from other parties for the mine to be subject to "zero discharge" limits for CN. However, caution is suggested for such a move because currently available analytical techniques for cyanide are unreliable at very low levels, particularly for free CN. Future water quality requirements for the mine may be based on ambient requirements rather than point source requirements. This further introduces the potential for naturally occurring CN (ie biogenic) CN in the broader environment, which could not be differentiated from very low levels of mine-related cyanide.

This case study was prepared by Arlene Rofe, Sarah Setori, and Bruce Terry Henty Gold Limited, and edited by Stewart Needham, Neological Consulting NSW, June 2003.

KCGM FIMISTON MINE, WESTERN AUSTRALIA:
TAILINGS STORAGE FACILITY WATER MANAGEMENT AT THE "SUPERPIT"

The Fimiston operation at Kalgoorlie in Western Australia, about 600kms east of Perth, includes the Fimiston Open Pit, Mt Charlotte Underground Mine, Fimiston Mill and Gidji Roaster. The Fimiston Open Pit, also known as the "Super Pit", is the biggest gold open pit mine in the country and stretches 3.8 kilometres long, 1.35km wide and more than 500m deep. It takes in several old open pit and underground mines originally along the area known as "The Golden Mile". The operation is a joint venture owned in equal proportion by Newmont Australia Limited and Barrick Gold of Australia Ltd and managed by Kalgoorlie Consolidated Gold Mines Pty Ltd (KCGM). The annual production of about 750,000 ounces of gold is the highest for any Australian gold-producing centre. An overview of KCGM operations can be found at www.kalgold.com.au.

Tailings are discharged to the tailings storage facilities (TSFs) from CIL (carbon in leach - refer Glossary) circuits and contain low levels of Weak Acid Dissociable (WAD) cyanide. The Fimiston TSFs are about 450 ha and receive 12.5 million tonnes per annum (mtpa) of tailings; a WAD cyanide concentration of <50 ppm is maintained. Higher concentrations exist in the smaller Gidji TSF (18 ha, 0.35 mtpa tailings) because of copper concentrations in the calcine which in turn complex with the cyanide. Different strategies are employed at the two facilities to reflect the different physical and operational settings, and the levels and type of environmental risks presented.

Part of the Fimiston II TSF. Embankments are 20-25 m high, constructed by upstream methods. Central gravity decants are used to collect and remove supernatant water.

KCGM has benchmarked the operation of its TSFs against the requirements of the International Cyanide Management Code for the Manufacture, Transport and Use of Cyanide in the Production of Gold. The main environmental risks from cyanide use in the arid environment surrounding the mine are contamination of groundwater, and direct contact with and consumption of water contaminated with cyanide by wildlife. The focus of KCGM has been to devise a comprehensive and reliable water management system for the TSFs which will reduce these risks to acceptable levels.

Key initiatives taken to improve the performance of the water management system with specific reference to cyanide, and to improve understanding of cyanide use, concentrations, locations and loss pathways include:

- working with the metallurgical experts from the joint-venture Owners, CSIRO, and consulting engineers to optimise CN usage and therefore the levels of CN in discharge to the TSFs and in return waters from these facilities;
- monitoring which includes real measurements of emission rates to the atmosphere and modelling to provide information upon which CN usage can be optimised; and
- use of this monitoring data for best possible estimation of CN losses to the environment, which is then used for reporting to the National Pollutant Inventory (NPI).

Achievement of high standards for cyanide management is assisted by the absence of any point discharges of mineral processing effluent to any surface water environment. Also the TSFs have been designed by professional tailings engineers and constructed according to Australian Standards, and WA Department of Industry and Resources (DoIR) guidelines for TSF management (ie designed to withstand the Maximum Credible Earthquake, Compaction control of wall lifts - 95% MDD). KCGM also benefits from the knowledge and affiliation of its engineers and consultants with organisations such as the IEA and AusIMM.

MANAGEMENT INDICATORS

Key indicators for water management at the TSFs relate to background groundwater values, and the quality of mine water within the TSFs.

Background groundwater parameters are:
pH 3
TDS 30,000 -- 50,000 ppm
WAD CN <0.5ppm
Water table 4 - 6m below ground surface.

TSF water quality:
pH 9
TDS 120,000 ppm
WAD CN <50ppm - Fimiston facility
WAD CN >>50ppm - Gidji facility.

Management objectives are therefore to avoid disturbance of natural groundwater characteristics from elevated pH, TDS and cyanide, and to prevent impacts on wildlife through access to cyanide within the TSFs. WAD cyanide values in the Fimiston TSF are managed to remain below 50ppm, but barrier methods must be used to exclude wildlife from high CN concentrations in the Gidji TSF.

The main strategies to achieve the objectives of reliable water management and avoidance of impacts on groundwater and wildlife from cyanide are:

- robust and well-integrated procedures for operational control and environmental protection;
- careful management of supernatant water areas and levels within the TSFs;
- maximum water recycling (make-up water from groundwater bores); and
- comprehensive monitoring tools including remote bore monitoring and control systems.

Netting and gas cannons used to keep birds off the Gidji TSF

ENVIRONMENTAL MANAGEMENT SYSTEM FOR THE TSFS

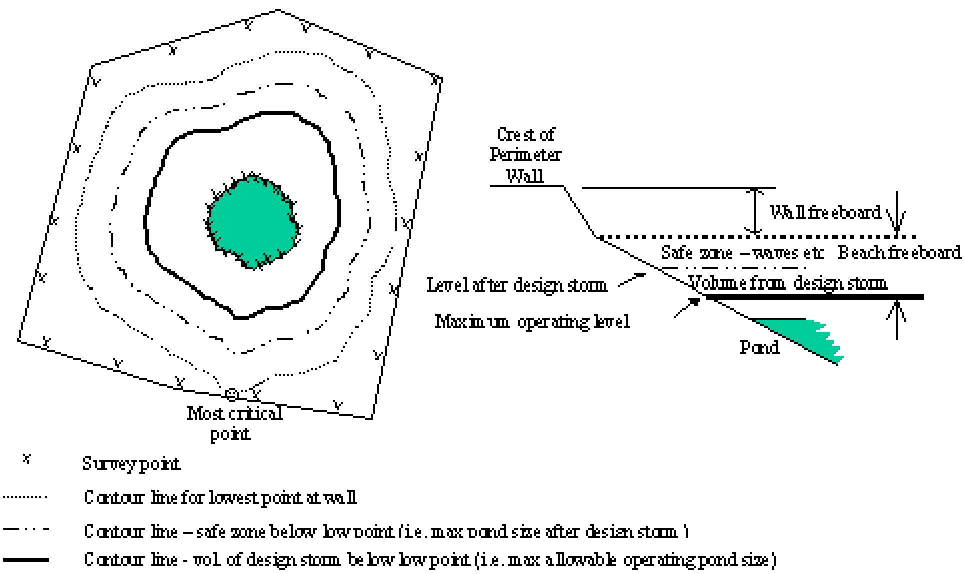
Effective management and operation of the TSFs and the containment of environmental risks associated with cyanide use is achieved through:

- TSF operating manuals;
- Risk assessment;
- Electronic Accident Reporting System;
- Quantitative Risk Assessments;
- Annual Audits;
- 3 hourly inspections; and
- Regular surveys.

The operating manuals have been developed in collaboration with industry experts, and are based on guidelines provided by the regulatory authorities (WA DoIR). Piezometers have been installed to monitor water pressures in the TSFs, and a detailed review of TSF performance is carried out annually. Periodic risk assessment is seen as critical to early identification of possible weaknesses in operating systems and actual or potential failure or poor performance of existing infrastructure; as such, the risk assessments provide a basis for Continual Improvement. Opportunities for improvement are tracked through the risk management software and action register.

MANAGEMENT OF DECANT WATER WITHIN THE TSFS

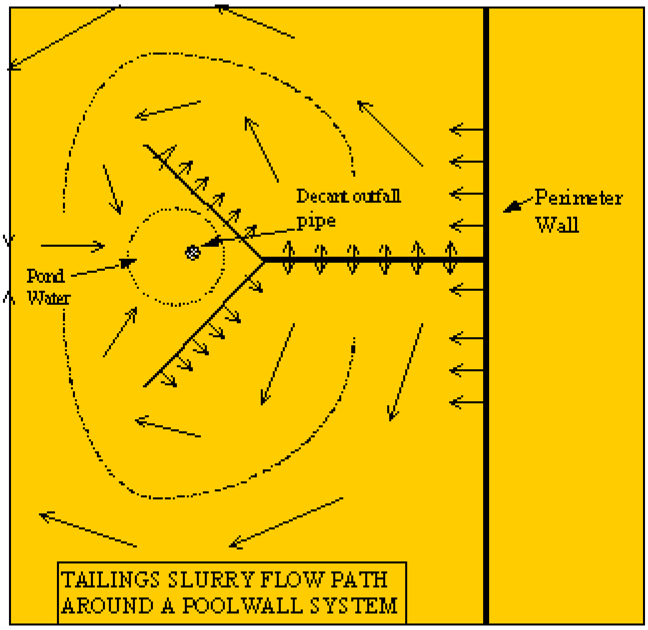
The most important part of TSF management is to maintain freeboard at or below target levels to remove any potential for overtopping. As minor beach slope changes can impact greatly on surface water storage capacity (and hence freeboard), routine surveys are undertaken to provide good indications of required surface capacities and volumes in storage. Surveys are undertaken annually for volume calculation, and minor survey checks of beach slope and pool size are undertaken every two weeks. A smaller pond size will assist in reducing seepage through the tailings core to groundwater. If tailings water interacts with the groundwater, iron cyanate (Prussian blue) will precipitate because of the low pH. To maintain focus on keeping a small pond size, excess water storage is recorded as an environmental *key result indicator* for the Mill Superintendent. This type of event would be reported as a hazard in the electronic Accident Reporting System.



Example of a Major Freeboard Survey of the TSF

A detailed annual survey of freeboard establishes key performance targets for the next year, in particular the *Maximum Operating Level*.

The main mechanism to control pond size is management of the volumes of decant water recycled to the processing plant, and so a general objective is to maximise water recycling without compromising the effectiveness of the flotation process: experience shows that there is limited impact on flotation efficiency with up to a 30% mix of recycled water in the process stream. Given the objective of maintaining a small pool, and limitations on the proportion of recycled water in the process stream, it is normally possible to maintain a typical pond size of 10-15% of operating paddock area.



The spigot system is designed to create flow paths which steepen the beach beneath the supernatant pond and reduce the size of the pond, and to avoid tailings deposition along the access causeway.

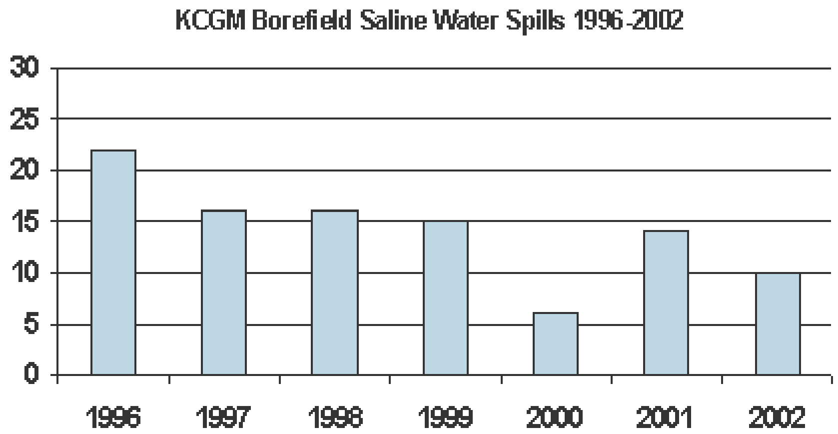
The ideal situation is to have the pool location fixed and the depth maximised in order to improve water clarity and reduce the introduction of solids and TDS into the flotation circuit. A discharge spigot design has been developed which assists in minimising the surface area of the pool (and hence reducing seepage), and maximising pool depth (which helps improve water clarity). The spigot design produces pool walls that act as a glove to contain the dimensions of the pool. Higher strength tailings are achieved (ie higher settled densities), and there is no subaqueous deposition along the access causeway. Pool water depth is increased due to steeper beaches from the spigot discharge along the access causeway.

Groundwater Monitoring and Protection

The system for protecting groundwater and monitoring for impacts comprises 65 monitoring bores, 5.5 km of trenches, and 109 groundwater extraction bores. The bores are linked via radio to a SCADA (Supervisory Control and Data Acquisition) process control package for visualisation, auto control and data recording in a central control room. This system allows for the monitoring of flow rates in individual bores, reporting of faults, leak detection, auto shutdown, and remote stop/start.

The system is also monitored 24 hours a day by site security.

In order to reduce the risk of impacts from spillages along pipelines, saline water and tailings pipelines laid in earthen bund corridors. Flow meters are incorporated to detect differential flows and to alert the control room to spillage potential. Interlocks also prevent continued operation without appropriate action.



The amount of spillage water from the remote borefield system has diminished and the proportion of spilled water lost to the environment has dropped following the increased use of seepage and TSF return water recovered from within the operation.

ENVIRONMENTAL OUTCOMES

The strategies applied in the water management system at Fimiston have resulted in:

- increased CN recovery;
- decreased CN concentration in the tailings;
- fewer spillages;
- lower risk of groundwater impact on vegetation;
- containment of the seepage plume;
- reduced risk of overtopping of TSF; and
- reductions in power, maintenance and reagents costs.

In summary, quality water management practices applied at Fimiston have facilitated significant improvements in quality cyanide management, and major reductions in the levels of environmental risk associated with cyanide use.

This case study was prepared by Stewart Needham, Neological Consulting NSW and checked by Trevor Tyson, KCGM. The case study is based on:

Tyson T, and Bawden J 2003 *Fimiston TSF Water Management.* Presentation to the ACMER Workshops on Cyanide and Management for the Gold Industry, Kalgoorlie/Mt Magnet/Perth WA, 5-9 May 2003. Australian Centre for Minesite Environmental Management, Kenmore, Queensland.

KIDSTON GOLD MINE, QUEENSLAND:
SAFETY ASPECTS OF DECOMMISSIONING OF A CYANIDE PROCESSING PLANT AT A LARGE MINE

Kidston Gold Mine is in northern Queensland about 280 km southwest of Cairns. Gold production from two open pit deposits began in 1984, and ceased in July 2001 when the last bar of gold was poured. Over 3.5 million ounces of gold had been extracted from over 85 million tonnes or ore. The mine was one of the largest gold mines in Australia, being able to process 7,500 ton per day (tpd) of ore when first commissioned. After various upgrades this had increased to over 24,000 tpd at the end of the mine's life. In order to successfully extract the gold, an average 2,800 tonnes of cyanide was used each year.

Decommissioning planning for the milling circuit commenced several years before the plant closed. Key to the closure was to ensure that all activities would be undertaken in a safe manner, and that gold recovery would be maximized from the plant prior to its sale. Pre-closure plant sampling was completed in March 2001 to determine the gold clean-up requirements, and also the hazardous chemical contaminated areas within the processing plant.

CLEANING OUT THE PROCESSING CIRCUIT

The first process was to compile a complete list of jobs that needed to be undertaken to clean out the circuit. This typically started by identifying the hazards for each job, both physical and chemical, and then what sampling needed to be undertaken to determine the extent of the chemical contamination. Particular care was taken with areas that used hazardous chemicals. The process covered both operational and maintenance requirements. This was then converted into Microsoft project format, which allowed proper scheduling and allocation of appropriate resources. It was found that the crushing circuit could be cleaned out in seven days and the remainder of the plant in five weeks. The majority of the work could be carried out concurrently after SAG (Semi Autogenous Grinding) mill decommissioning.

Specific areas that were targeted for special safety consideration included all confined spaces, e.g. ball and sag mills, bulk liquid cyanide tank, and CIL (carbon in leach - refer Glossary) tanks. The initial works involved determining the most appropriate way of decontaminating the plant and pipe work. After carrying out the decontamination, each component was thoroughly flushed and tested for residual cyanide in the flush water to determine how effective the decontamination was. All flush water was discharged to the Wise Pit Tailings Storage Facility. The SAG mill cyanide internal concentration was typically maintained below 150 ppm cyanide during the last 2 weeks of operation; then for the last week of operation, water was used in the cyanide injection line so the circuit had a chance to flush prior to decontamination work being undertaken.

All areas containing cyanide residues were tested for residual HCN prior to work commencing in that area. Gold recovery from the areas where cyanide had been used was important, resulting in scavenging of all sediments from the bottom of tanks and other sumps in the facilities. All pipe work that carried gold-rich ore was cut up into 1 metre lengths and the scale removed, digested, and the gold extracted. In total, an extra 283 000 grams of gold was recovered from the plant during the cleanup phase.

SAFETY PROCEDURES

Safety procedures that were employed as part of the shutdown were similar to those used during operation and planned shutdowns. This included a specific three hour contractor safety induction which went into detailed hazard and risk management, use of tag-out and lock-out procedures for all electrical isolation work, confined space entry permits, and hot work permits for cutting and oxy work. JSA's (Job Safety Analyses) were undertaken for particularly hazardous jobs, and the appropriate controls put in place. A Kidston area supervisor was responsible for all work in that area and for following the deconstruction schedule. Daily meetings were held, so that all employees and contractors knew what activities were being undertaken in what area, and also progress recorded against the plan. All deconstruction work was limited to the day shift.

OUTCOMES

The cleanup of the mill took 5 days longer than the scheduled 5 weeks allocated for the job. Delays were due to more residual gold being found than anticipated, and hence the longer time to recover. The mill was fully decontaminated some 3 weeks prior to the Auction. The work was completed in a safe manner with no serious injury recorded.

Partial plant deconstruction

Ball mill number 2 removal

Sag mill ready for removal

Leach tanks deconstruction

Final Plant Site after rehabilitation
(all photos: Placer Dome Asia Pacific / Kidston Gold Mine Ltd)

This case study was prepared by Nick Currey, Placer Dome Asia Pacific. and edited by Stewart Needham, Neological Consulting NSW.

MPI MINES LTD STAWELL GOLD MINE, VICTORIA:

APPLYING THE INTERNATIONAL CYANIDE CODE AT A MEDIUM-SCALE GOLD MINE

It is critical to ensure that the level of protection against spillage of cyanide, and any impacts on human and environmental health, is are managed at a very high level at Stawell. This is because the underground workings lie directly under the township, the mine infrastructure including cyanide storage and mixing facilities is close to houses and public facilities, and the tailings corridor passes through public land. The town's potable water reservoirs are also included in the mine lease area. The Community at large is aware of reported incidents around the world, at less well managed mines, where damage has resulted from cyanide misuse, poor handling practices, and failure of mine and Tailings storage facilities (TSF) containment systems.

SGM management therefore strives to communicate as effectively as possible to community about the systems in place to prevent cyanide incidents, the level of care taken, and its capacity to respond to any emergency situation. Its procedures to reduce risks from cyanide are described in the case study: *Stawell Gold Mine, Victoria - Managing Cyanide at a Medium-Scale Gold Mining Operation.* As part of the company's efforts to demonstrate its commitment to best practice environmental management of cyanide, SGM has chosen to review the requirements of adopt the International Cyanide Management Code.

WHY THE CODE IS RELEVANT TO SGM

Application of the international cyanide code canwill demonstrate to the local and broader community SGM's ongoing commitment to apply the best possible systems for protecting against cyanide incidents at Stawell, including possible effects on employees, the general public, and to the natural and agricultural environments. Features of the code which are particularly relevant in this regard are:

- The independent evaluation of SGM's operations required by the code will help satisfy community requirements that the systems, commitment and performance are equal to World's best practice;
- The code demands ongoing evaluation of the adequacy of SGM's cyanide management systems, (ie to be a signatory to the code a one-off assessment is not enough) ; auditing by independent external experts is an ongoing requirement for the company to claim compliance with code requirements and standards;
- The code is proactive not reactive; ie under the code any weaknesses in SGM's systems will be identified and the Company will be encouraged to fix those weaknesses within a defined period of time;
- The code provides a structural method to ensure actual compliance. That structure is public information, and SGM's performance and responses to the code's administrative requirements are open to scrutiny;
- SGM's expertise will be further developed through exposure to and interaction with the experts who will undertake the auditing. It is anticipated that these experts will be willing to provide advice and assistance to site staff so that in-house levels of expertise will continue to grow.

There are several issues which SGM is are considering before taking on in order for it to be able to meet the code's requirements effectively and efficiently. These issues probably affect all companies wishing to adopt the code, but are particularly relevant to medium and small-scale operators with relatively limited resources and expertise when compared with the international mining houses:

- Paperwork compliance versus practical compliance: many of the code's demands relate to administrative measures, and a Company must ensure that this is not done at the expense of operational activities and maintenance of appropriate styles, frequency, and accuracy of monitoring;
- The move to "real-time" monitoring usually involves installation of expensive automated scientific equipment (continuous automatic monitoring will detect peaks which may go

unsampled using traditional periodic manual sampling, etc): the value of such a system needs to be considered in the light of available resources and staff, and consideration be given to equally effective alternatives;

- Third party involvement and delegation of responsibility. not sure what the point is here - please explain
- Under the code, certain staff must assume increased responsibilities (ege.g. for administration, data collection, reporting etc). The allocation of responsibilities amongst a small staff team must be made in a manner which avoids potential conflict of interest, too much control of the process invested in one person, or creating unmanageable workloads;
- Statutory compliance vs "non-statutory" compliance: whilst consistent with the principles of best practice, the requirements of the code are may be different to the types of requirements placed on the company by government regulation. A company must ensure that the goal of best practice compliance does not distract from the basic necessity to comply with statutory requirements.

The cyanide code has only recently been developed, and it is the first *international* code of its type. It is not yet fully in place - for example, all of the supporting administrative systems such as auditing protocols, accredited auditors, reporting systems etc are not yet in place. Companies who have stated their commitment to conform to the code are on a steep learning curve because new ground is being broken, and this curve is steepest for smaller companies such as SGM with relatively limited resources. Other issues which have to be sorted out concern the interaction between the code and other systems which are instrumental in achieving best practice:

- How can NATA analytical requirements and ISO certification seamlessly mesh with the code?
- Where does individual duty of care merge with the operational focus of the code?
- How can special company objectives such as support to local community employment be reflected as reasonable constraints to meeting code requirements?
- To what level does demonstrated compliance with statutory regulations satisfy the code (such as the Dangerous Goods Act, OH&S), without the need to duplicate administration to demonstrate the two types of compliance?

SUMMARY

SGM's cyanide management system is continually improvinimproving.g Aas the mine proceeds through its operational phase, closure issues become more apparent, and cyanide/environmental management expertise grows within our staff and closure issues become more apparent. We SGM should want to reviewadopt the code because it will reinforce to the community SGM's the Company's commitment to responsible cyanide management practices. The codeIt will also improve access to external expertise and that way help to solve any cyanide issues that arise. A small to medium scale mine has restrictions on resources and time constraints which means that the management style is more individually based than systems based. A significant challenge for a smaller operator is to bridge the gap between this more individual style of cyanide management, and the more institutionalised, procedural and administrative requirements of the International Code for Cyanide Management.

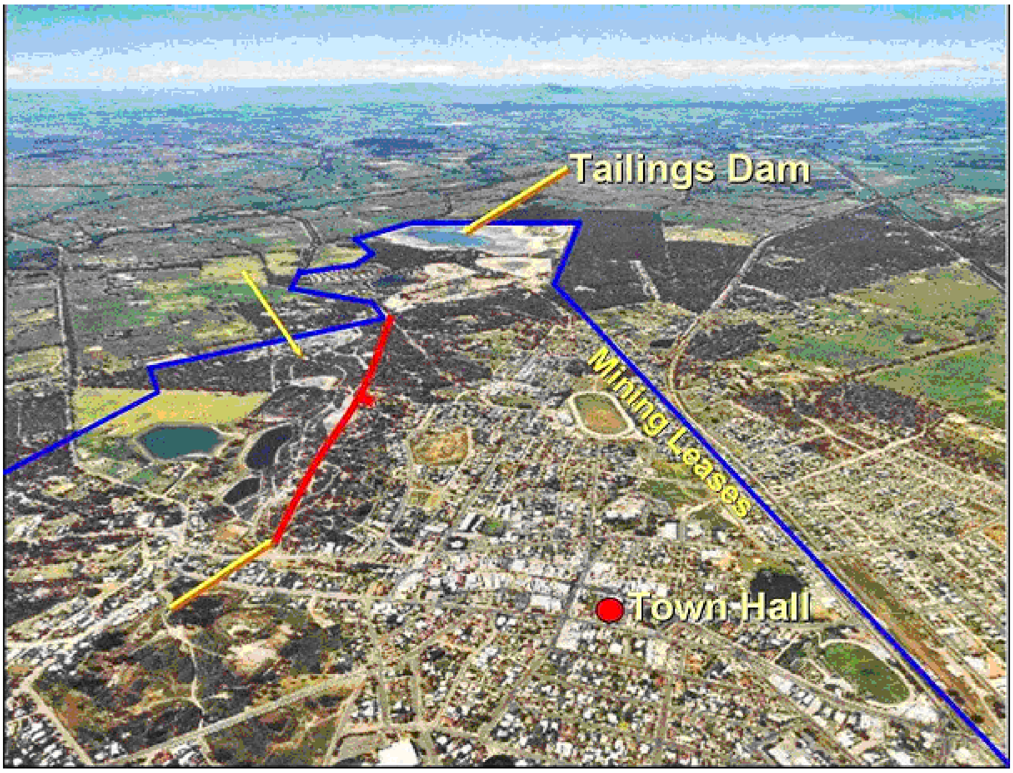
This case study was prepared by John Morgan, Laboratory Manager/Dangerous Goods Officer, Stawell Gold Mine, and Stewart Needham, Neological Consulting. The main source used was:

Morgan J, 2003. *Stawell Gold Mine and the International Cyanide Management Code - a Case Study*. Presentation to the Workshop on Cyanide Use and Management for the Gold Industry. Perth, WA, MAY 2003. Australian Centre for Minesite Environmental Research, Kenmore, Queensland.

MPI MINES LTD STAWELL GOLD MINE, VICTORIA:
MANAGING CYANIDE AT A MEDIUM-SCALE GOLD MINING OPERATION

Gold was first discovered at Stawell in 18553, and 81 tonnes had been produced by 1920 when the mine closed down. The mine was reopened in 1981 by WMC Ltd (as the Magdala mine), and then acquired by MPI Gold Pty Ltd and Pittson Mineral Ventures in 1992. The operation is managed by Stawell Gold Mines Pty Limited (SGM), a wholly owned subsidiary of MPI Mines Ltd (MPI). The current operation is mining from 500m to 900m, beneath the township of Stawell (population 7000). Access is by decline to the Magdala deposit, along which ore is trucked to the surface. Mining is by longhole open stoping. Ore processing entails crushing, gravity separation, carbon in leach (CIL), campaign flotation, and *Zadra* elution. The company supports an on-site assay laboratory.

Annual throughput is up to 850,000 tonnes, with an average recovery of 86% Au or about 3.1 tonnes of gold production. The mine employs 230 people, including 50 contractors. The mine has proven and probable reserves sufficient for a three year mine life at current levels and hasprobable reserves sufficient for a three year mine life at current levels and have exploration targets with the potential to extend mine life beyond 10 years.



Stawell township looking southeast. The mine workings lie under the town. The top left arrow points to the decline portal, close to three potable water storages for the town (photo Stawell Gold Mine Pty Ltd).

Key environmental issues for the mine are:

- proximity of mine infrastructure to the town (500 m from portal to nearest house, <50 m from mine fence to nearest houses);
- town water reservoirs 400 m from mine area;
- mining licence covers much of the town;
- large tailings storage facility (85 ha);
- nearby stands of native iron bark forest with high conservation value;
- use of cyanide in gold extraction, and associated issues related to occupational safety, public safety, environmental risk, and public perception;
- public land adjacent to the 3 km tailings corridor; and
- community attitudes to, and expectations of mining operations.

SGM's response to these issues includes: extensive use of specialists for tailings storage facility management; close liaison with University experts on environmental issues; concentrated training of staff (individuals rather than groups) to grow expertise over time; use existing staff in extensions of their roles; and wide community consultation and communication. In spite of the mine's relatively short life, long-term rehabilitation trials specific to the site are being undertaken to improve the likelihood of a stable and sustainable outcome for site closure.

About 900 tonnes of sodium cyanide is consumed annually. A range of features is incorporated in the mine design and operational procedures to manage risks associated with the handling and use of cyanide. They include:

TRANSPORT

- The transport company delivering the cyanide retains responsibility up to the point of delivery, and stringentand stringent safety requirements are a feature of the supply contract;
- Empty cyanide boxes are back-loaded direct to the supplier by the transport company;
- A dedicated loading bay has been established where activities are restricted to unloading cyanideunloading cyanide containers;
- Emergency response procedures are in place with a local DISPLAN coordinator (DISPLAN is the Victorian State Government's integrated emergency response plan) in case of spillage on route; and
- Trucking routes are selected to minimise potential risks in the case of an emergency.

CYANIDE HANDLING, STORAGE AND MIXING

- The sodium cyanide is received in briquette form in lined and sealed one tonne boxes..
- It is delivered in 20 tonne lots in sea containers to minimize the risk of accidental spillage en route.;
- Tthe product is unloaded by United Transport (transport contractor).

Cyanide mixing area. Level meter, safety equipment, and emergency button are all clearly labelled and easy to access. Bunding ensures any spillage reports to the secure process water pond (photo Stawell Gold Mine Pty Ltd).

- The sodium cyanide is mixed in 2 tonne lots on site to a 22% concentration. Up to 40 m^3 of solution can be held in the Cyanide Storage Tank. Extensive use is made of level controllers to assist in safe management of mixed sodium cyanide. The cyanide concentration in the leaching tanks is automatically monitored by a Chemtronics online cyanide analyser and automatically dosed to maintain a constant concentration of 400 to 450 ppm (depending on ore type) within the leaching tanks. This concentration allows effective leaching and minimal cyanide in the tails.

- Cyanide and pH levels in the circuit are checked manually by the leach operator every hour as a back up to the Chemtronics instrumentation.;
- Dry chemical agent fire extinguishers (4x type) are used in the cyanide storage area rather than fog spray type extinguishers (2x type), to avoid possible cyanide gas emissions being generated during fire fighting as a result of granulated cyanide being mixed with extinguisher water.;
- Cyanide monitors, safety gear and an emergency button are clearly labeled and easy to access.;
- The mixing area is bunded and any overflow reports to the secure process water pond.;
- The process water pond design incorporates sufficient volume to accommodate a major spill from the cyanide mixing area.
- The cyanide storage and mixing areas are close together and adjacent to the processing plant, which provides for economy in construction costs of bunds and piping, keeps most of the cyanide facilities in one area and promotes a more integrated approach to cyanide management by staff. The restricted area facilitates improved security and OH&S control for cyanide handling tasks.

THE ELUTION/ELECTROWINNING CIRCUIT AT STAWELL GOLD MINE

The high pressure Zadra elution process is a well- proven method of eluting gold from carbon and with the addition of an electrowinning pressurised cell, makes for an extremely fast and economical method of gold recovery. As the circuit is completely sealed and the temperature is constant, there is little heat loss and reagent consumption is kept at a minimum. The power, fuel and reagent savings result in the cheapest available elution cost per ounce of gold.

Loaded carbon from the loaded carbon tank is transferred by gravity to the acid wash vessel. The carbon is washed with a dilute hydrochloric acid solution to remove the build-up of inorganic salts on the carbon, which if left on the carbon interferes with its capacity to adsorb gold cyanide. The carbon is then washed free of acid solution, and educted using pressurised water to one of two elution columns. The column of carbon is drained of water and the gold is stripped from the carbon using the pressure Zadra process.

A solution of cyanide and caustic at 120ºC is pumped through the carbon for approximately 16 hours. The strip solution re-leaches the gold from the carbon producing a solution containing gold in concentrations suitable for electrowinning.

Heat is applied to the strip solution by a gas fired Glycol heater and heat exchange is achieved by two plate heat exchangers in series.

The solution is pumped through the electrowinning cell until the gold in solution is reduced to a level below 10 ppm and the final gold loading on the stripped carbon is between 50 and 100 ppm gold. The solution is pumped back to the leach circuit.

The electrowinning cell consists of a series of stainless steel anode (positive) plates and stainless steel stockingwool cathode (negative) in baskets through which the solution flows. The gold is plated onto the stainless steel stockingwools in the cathode baskets. Once the strip is completed, the gold is washed from the stockings using a high pressure water spraysteel wool is removed from the cathode baskets and dissolved in hydrochloric acid. The acid dissolves the steel wool but does not dissolve the plated gold. The gold residue is dried, mixed with fluxing agents, and melted in a gas-fired furnace at over 1200ºC. Most of the impurities separate from the gold into a slag and the heavy molten gold is poured into a mould to form dore bars (dore gold bars contain gold, silver and other base metal impurities). The dore bars are dispatched to a gold refinery where the gold, silver and other impurities are separated and gold bars of high purity are prepared for sale.

MILL OPERATIONS

To prevent the exposure of employees to cyanide gas, SGM has installed several systems to ensure a high level of worker safety. These measures include:

- A monitoring and alarm system with elevated siren responses at 10 ppm HCN;
- A combination of personal and fixed cyanide monitors, which have been effective in monitoring for high HCN levels in the plant since the late 1980's;
- Flashing lights and a fixed HCN monitor are used for the transfer of acid wash solution from elution to the tailings tank;
- A red dye and sodium hydroxide areis is added to the solution during the mixing stage to help ensure leaks are noticed, increase pH, and reduce the level of HCN gas produced;.; and
- **Sodium hydroxide is added to the solution during the mixing stage to increase pH, to minimise the level of production of HCN**Sodium hydroxide is added to the solution during the mixing stage to increase pH, to minimise the production of HCN.

Employee awareness and safety around the plant are further enhanced through:

- Clearly labeling pipes containing cyanide solution to allow easy recognition;
- Use of hand- held &and fixed cyanide monitors in the leach and mixing areas;
- Red dye in the cyanide solution gives employees a visual warning that cyanide in solution is present;
- Enforcing procedures for shutdown and maintenance work in confined spaces which address issues relating to cyanide;
- Enforcing welding procedures to avoid the risk of damage to and accidental leaks from pipes carrying cyanide solution (ege.g. hot metal from a welding job should not be allowed to touch plastic pipes carrying cyanide); and
- Regular Safety meetings include both maintenance and mill staff to ensure consistency of awareness, knowledge and behaviour.

The cyanide storage and mixing areas lie close to the plant. Bunding ensures that any unplanned runoff from all these areas reports to the secure process water pond (photo Stawell Gold Mine Pty Ltd).

TAILINGS RETURN WATER

A clear solution (approx 20 ppm sodium cyanide) is decanted from the tailings and is pumped back to the treatment plant for re-use in processing. The water recovery from the tailings is approximately 70%, with the remainder contained in the tailings or lost due to evaporation. Tails return water is mixed with mine and rain water to maintain a closed cyanide cycle. SGM aims for a zero discharge of mine and process water.

TAILINGS STORAGE FACILITY (TSF) MANAGEMENT PRACTICES

Risk assessments are carried out on all aspects of transport and storage of tailings, and - use is made of consultants and contractors for specialist tasks. Piezometers and other forms of ongoing monitoring are undertaken of the TSF, with emphasis on the embankment, to ensure the TSF is operated to design specifications. In-wall, bore and downstream sampling are used to monitor pH and cyanide., Automated flow monitoring and routine visual monitoring is carried out of tailings and return water pipelines (approx 3 kms) from the mill to the TSF. Initiatives installed to reduce risks of environmental damage from failures along the mill/TSF pipeline include use of:

- Larger bore pipes to reduce pressure in the line;
- Hugger clamps to lower the risk of pipe joint failures on the tails line; and
- Offsite pumps and well sited culverts to handle any high rainfall and any potential tails line spills.

The mine and TSF are close to the town of Stawell and local farming communities. , Appropriate attention is given to environmental and safety risks associated with the TSF. , Open communications are maintained with the community through:

Wide-scale education of SGM employees about the importance of responding to any matters of concern to the public;

- Wide-scale education of SGM employees about the importance of responding to any matters of concern to the public;
- Thorough induction system for all staff and contractors;
- Rehabilitation studies of the TSF, using a purpose-built experimental research facility;
- Regular three3-monthly community meetings and distribution of a newsletter to keep the community aware of TSF monitoring results; and
- Pperiodic risk assessments – these involvinge all involved parties, which strive to reach consensus, and identify key criteria and actions to be followed up.

SUMMARY OF CYANIDE MANAGEMENT AT STAWELL GOLD MINE

SGM's experience indicates that the public and regulatory authorities respond positively to proactive information and pre-emptive action to address any identified issues relating to potential risks from cyanide. It is most important to ensure that immediate action is taken should an unplanned event occur. As far as is practicable, SGM seeks to eliminate hazards by a combination of procedural, systems and engineered controls. Appropriate personal protective equipment is supplied at key locations and staff trained in its use. Each issue which arises requires assessment to determine the right level of response, ie meeting the requirements of safety, and environmental standards whilst being practical and cost effective..

Ongoing challenges to cyanide management that remain areremain as:

- Safe transport and use;
- Induction of all employees in the safe handling of cyanide during operations and maintenance activities;.
- Management of the water balance related to the TSF; and
- Maintaining effective communication with the community about the mine's safe use of cyanide.

This case study was prepared by John Morgan, Laboratory Manager/Dangerous Goods Officer, Stawell Gold Mine, and Stewart Needham, Neological Consulting. The main source used was:

Morgan J, 2003. *Stawell Gold Mine and the International Cyanide Management Code - a Case Study*. Presentation to the Workshop on Cyanide Use and Management for the Gold Industry. Perth, WA, MAY 2003. Australian Centre for Minesite Environmental Research, Kenmore, Queensland.

NEWMONT AUSTRALIA LIMITED:
CYANIDE MANAGEMENT STANDARD AND AUDIT PROCESS

As for most gold producers, sodium cyanide is the key reagent used in Newmont Australia's gold production processes. In 2002 some 12,000 tonnes were used across Newmont Australia's seven process plants. Cyanide is an efficient reagent in that with relatively low concentrations, it is possible to achieve very high and selective gold recovery. In certain forms it is however highly toxic and therefore poses a risk to people using it, the environment and communities. Like all hazards, cyanide must therefore be managed with extreme care; otherwise the industry will continue to experience cyanide related incidents that will negatively impact on the reputation of individual companies and the mining industry as a whole.

Newmont Australia was one of the gold mining companies that participated in the development of the concept of an International Standard on Cyanide Management at the inaugural meeting arranged by United Nations Environment Programme (UNEP) in Paris, and at the Steering Committee which set the task of developing the Code. At the same time, it was recognized by Newmont Australia that its own cyanide management practices needed to be improved, particularly in establishing a documented and standard approach across all of its operations. It is for this reason that Newmont Australia has developed an internal standard for the safe and responsible management of cyanide.

DEVELOPMENT OF THE CYANIDE MANAGEMENT STANDARD

Newmont Australia developed a comprehensive cyanide management standard in 2001. The need for this standard was highlighted by an assessment made against a detailed checklist, developed by Anglogold Limited, to review existing practices at all of the Newmont Australia operations. This review demonstrated that there were gaps in cyanide practices and that a prescriptive Standard and Audit checklist were required. The Standard was developed and tested against legislative requirements, Australian Standards, best practice guidelines, hazard identification reviews and the International Cyanide Management Code. Input and review was also sought from the Australian cyanide manufacturing companies.

DESCRIPTION OF THE CYANIDE MANAGEMENT STANDARD

The Newmont Australia Cyanide Management Standard takes the best parts of similar examples from all over the world and puts them together in a document that is specific for cyanide management in Australia. It also fits in with the Newmont Australia safety, environmental and community management systems. The Newmont Australia Standard is also consistent with the International Cyanide Management Code, enabling operations to meet the requirements of the Code by adopting the Standard. Whilst the structure of the Newmont Australia Standard follows that of the Code, it is more prescriptive, includes Australian regulatory requirements and provides a more rigorous approach to assessment of performance.

The Newmont Australia Cyanide Management Standard is a document that defines and sets out fully the way in which cyanide is managed within the group. It includes specific standards for purchasing, transportation, handling and storage, as well as the use of cyanide, in the gold extraction process. It encompasses worker safety, emergency response and training, through to public disclosure of cyanide-related issues and public consultation. The standard is reviewed annually, and updated regularly to incorporate improvements and to ensure that it is consistent with changing community expectations.

ACCOUNTABILITIES AND AUTHORITIES

A key aspect of the Newmont Australia Cyanide Management Standard is the specification of accountabilities in relation to cyanide management. In particular, there is within the organisation a specific senior technical person who oversees all aspects of cyanide management. The following table is an edited extract from the standard, illustrating typical accountabilities within a gold mining company.

Cyanide Officer	Responsible for coordinating the implementation and maintenance of this standard across the Group. Will actively support the sites by providing technical advice and guidance on the contents of this standard. Signs off on all design and modification proposals. Evaluate the implementation of the standard by coordinating the audit process. Make information on the safe management practices for cyanide widely available.
General Manager Supply	Responsible for ensuring procurement contracts is consistent with this standard. Participate in audits of cyanide supplier.
Director - Projects	Responsible for ensuring new cyanide facilities are designed, constructed and commissioned in conformance with the standard.
Standard Controller	Responsible for the preparation of the Standard and for the issuing has updated versions of the Standard.
General Manager Operations	Responsible for ensuring the site complies with this standard. Ensure nominated site managers have sufficient resources to carry out functions described in this standard, and understand their responsibility with respect to this standard. Review all risk assessments with respect to cyanide management and ensure the recommendations are followed through.
Plant Superintendent	Ensure cyanide storage, handling and use practices are consistent with this standard. Participate in risk assessments. Ensure all plant personnel have up to date training in cyanide use and emergency response. Co-signatory (with Maintenance Superintendent) for all repairs, modifications and additions to all areas of plant where strong cyanide solutions are used.
Maintenance Superintendent	Ensure all maintenance personnel have up to date training in cyanide use and emergency response. Co-signatory (with Plant Superintendent) for all repairs, modifications and additions to all areas of plant where cyanide is used.
OH&S Superintendent	Develop and present cyanide use and emergency preparedness training. Record training undertaken and monitor training records to ensure that training is updated at no greater than six-month intervals. Participate in risk assessments. Participate in cyanide management audits.
Environment Superintendent	Participate in risk assessments. Participate in cyanide management audits.
Supply Superintendent	Responsible for ensuring any contractor who supplies and/or transports cyanide to site complies with the requirements of this standard.

AUDIT PROCESS

A key function of the Cyanide Officer is to coordinate audits to ensure that operations are in conformance with the standard. An audit protocol was developed as part of the Cyanide Standard as a tool for use by the audit team and management.

Since Newmont's cyanide standard is multidisciplinary in nature, it is essential that the audit team members are experienced in a range of disciplines. For this reason, the audit team was structured to include an occupational health and safety professional, an environmental management specialist, and a minerals processing expert. Auditors are drawn from a pool of people from within Newmont and from external consultants. Consultants with formal technical audit skills are selected based on their experience, and to provide a more independent viewpoint.

All of Newmont Australia's operations were audited in 2002. The resulting audit reports highlighted major and minor non-conformance with the standard. All operations prepared action plans to address any deficiencies. Areas of below standard performance identified by the audit were:

- emergency response plans not fully documented and/or updated;
- lack of Standard Operating Procedures in some areas;
- faulty or inadequate containment system;
- unsuitable materials for solution pipelines; and
- inappropriate Personal Protective Equipment.

There is an active program in place at each of the sites to resolve the outstanding issues, which is supported and reviewed by Newmont Australia on a group basis. Progress towards correcting deficiencies is periodically monitored by the Cyanide Officer, to ensure that issues are promptly addressed. Exception reports are provided to senior management.

THE FUTURE

Newmont Australia has an active program in place to improve and standardise cyanide management across all of its' operations. This includes:

- identification of the risks related to cyanide including transport, handling and disposal in the areas of worker safety, environmental impact and community effects;
- development of a comprehensive Management Standard consistent with the International Code;
- detailed audits using multi-disciplinary teams, with the aim of identifying opportunities for improvement; and
- implement action plans to address any deficiencies and improve performance.

Newmont Australia does however recognise that it still has to take some steps to be in full conformance with the International Code and satisfy all of the community concerns over cyanide. Newmont Australia sees a requirement for industry wide action on this issue and continues to support industry collaborative activities.

This case study was prepared by John den Dryver and Andrew Minns, Newmont Australia Limited, June 2003.

NEWMONT PAJINGO, QUEENSLAND:
PASTE THICKENER IMPROVES ECOEFFICIENCY AND REDUCES CYANIDE CONSUMPTION

The Newmont Pajingo Gold Mine is 80 km south of Charters Towers. From 1988 to 1995 Pajingo treated ore from the Scott Lode open pit. Operations reopened in 1997 on the Vera Nancy underground, about 10 km away from the Scott Lode Pit. This case study discusses how the introduction of a Paste Thickener has contributed to a more eco-efficient operation. Newmont has developed an eco-efficiency program which is focused on delivering improvements within its operations, whilst also providing an environmental benefit. Cyanide and water are significant inputs to the gold production process. Improved management of these resources leads to improved financial performance and reduces the operation's footprint on the environment.

PASTE THICKENER APPLICATION

Newmont Pajingo has operated a single tailings facility since the mine was commissioned. An expansion of the process plant required additional tailings capacity, and investigations commenced to evaluate the potential of utilising the former Scott Lode open pit.

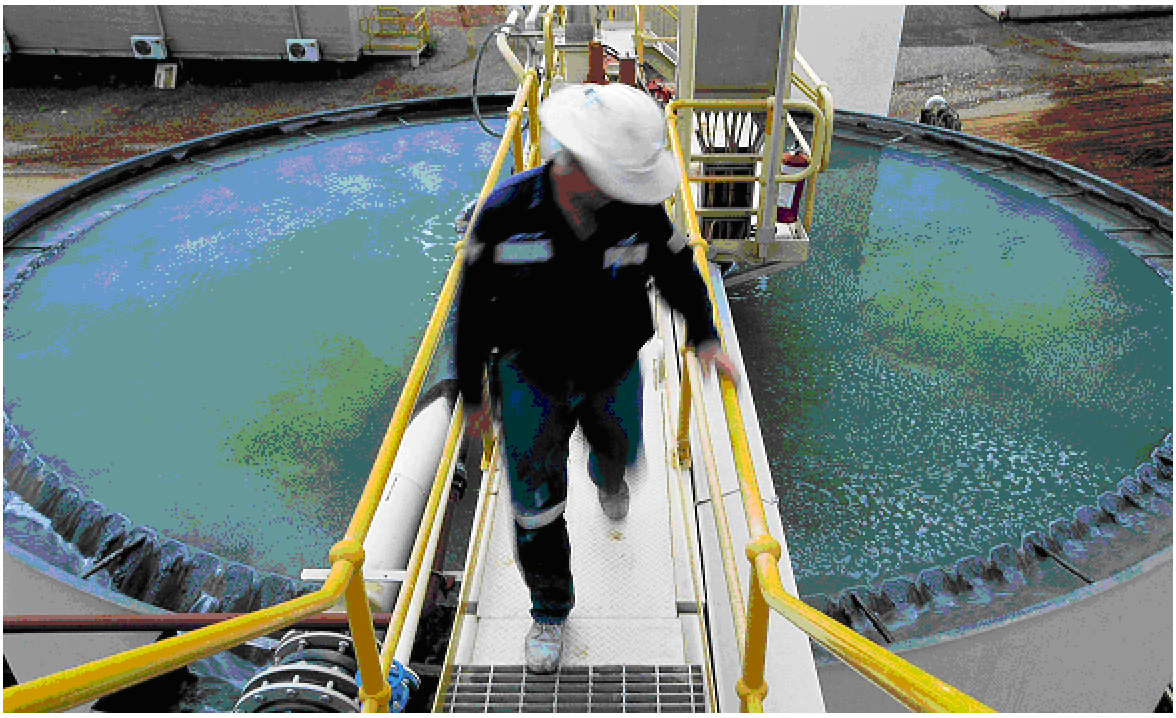
A Paste Thickener was installed in 2002 to treat tailings, prior to discharge into the Scott Lode pit. Utilising the pit void for tailings storage has major advantages of reducing the mine footprint area on the environment, and is cheaper than a conventional tailings facility construction.

The Pajingo thickener was designed for 75 tonnes per hour throughput, with a bed height of 3 m and a diameter of 14 m. The thickener underflow density has exceeded the pilot plant prediction. The thickener treats a tailings feed with a particle size of P80 of 38 um at 50% solids, and thickens it up to 59-61% solids. The thickened underflow is pumped down hill into the pit. The underflow pumping system has proven to be the limiting factor that determines the maximum underflow density at which the thickener can be operated. The thickener underflow density needs to be operated within a certain density range to maintain stable operation. The optimum underflow density range varies due to the ore type rheology, the discharge location in the pit, and the flocculant addition rate.

ECO-EFFICIENCY BENEFITS

A number of eco-efficiency benefits have been achieved from the use of the paste thickener. These benefits include:

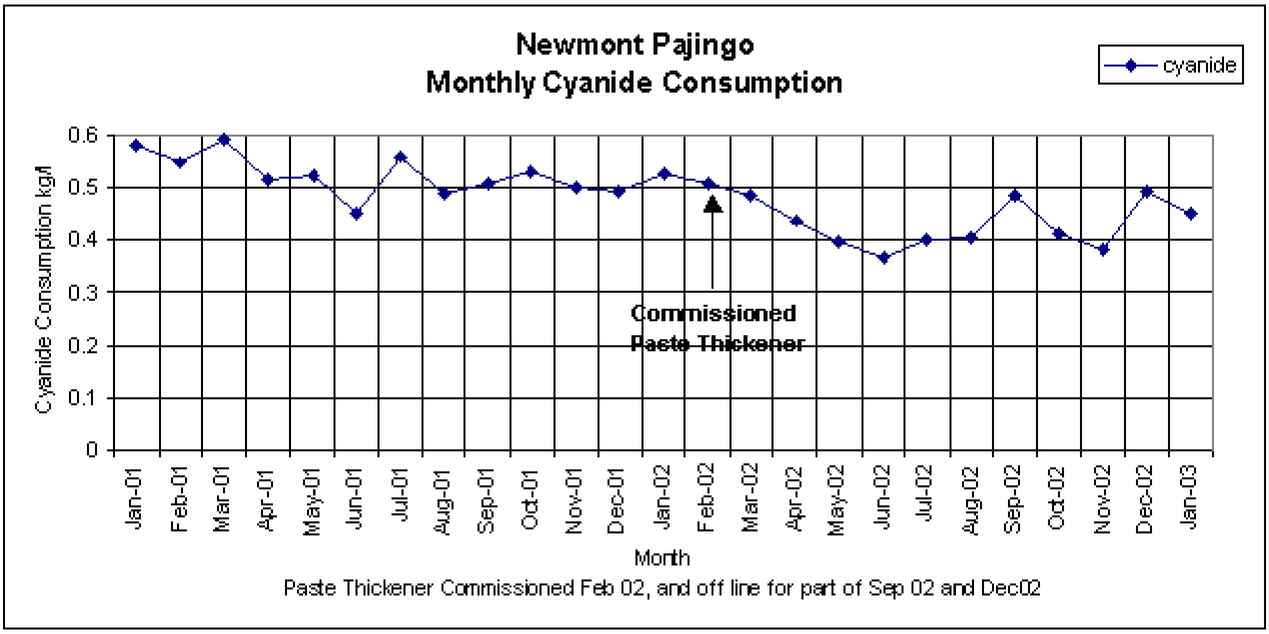
- increase in cyanide recycling and consequently a reduction in cyanide use;
- increase in water recycling;
- higher tailings density; and
- less water stored in the tailings facility.



Dewatering in the cyanide thickener takes place before cyanide leaching

CYANIDE RECYCLING

The operation of the Paste Thickener has increased cyanide recycling. The water, which is pumped from the thickener back to the process plant, contains cyanide and gold. Since the Paste Thickener has been commissioned, cyanide consumption rates in the process plant have reduced from 0.52kg/t to 0.41kg/t, or by 21%.



WATER RECYCLING

The Paste Thickener has increased the volume of water that is recycled, which carries a number of benefits in terms of reagent usage. As the recycled water contains cyanide and lime, less of these reagents need to be added within the process plant. The recycled water also contains traces of gold, and consequently improves process plant gold recovery. Water for the Newmont Pajingo operation is sourced from a nearby borefield and also the Burdekin River about 90 km away. Increased recycling has reduced the amount of water needed from these sources, saving both water resources, and energy required to pump the water.

INCREASED DENSITY OF TAILINGS

The increase in tailings density from 47-52% to 59-61% will result in improved settled densities within the tailings pile. An increase in densities improves the efficiency of the tailings storage, ie more tailings can be deposited in the same area. The improved tailings settled density will also assist at mine closure, as earthmoving equipment will be able to access the tailings surfaces earlier for reclamation of the tailings facility.

Discharge from the mill is regularly sampled to determine paste density

REDUCTION IN WATER STORED ON THE TAILINGS PILE

Paste thickened tailings result in water being removed from the tailings before placement in the tailings impoundment. At Newmont Pajingo this has resulted in increased water recycling and has had the corresponding benefit of reducing the volume of water stored on the tailings surface. Reducing the volume of water stored on the tailings facility reduces evaporation and reagent losses, and further increases tailings density.

This case study was compiled by David Browne, Newmont Australia, and edited by Stewart Needham, Neological Consulting, NSW. May 2003.

NEWMONT WAIHI MARTHA MINE, NEW ZEALAND:
STAKEHOLDERS AND SETTING OF DISCHARGE STANDARDS

The Martha Mine at Waihi, New Zealand, has a history spanning three centuries. Following the discovery of gold in 1878, the deposit was mined by underground methods from 1880 to 1952. In 1987 the modern Martha Mine commenced operations. In contrast to the underground mining that took place historically, the Martha Mine is now an open pit located within Waihi township. Ore and waste are transported about 2 km by conveyor to the Ore Processing Plant and Waste Disposal Area. Excess water passes through a Water Treatment Plant before being discharged into the Ohinemuri River.

The Martha pit (top left) is surrounded by the town of Waihi. A conveyor transports ore to the processing plant (centre), and waste to the tailings storage facilities (centre right). The Ohinemuri River flows between the plant and the TSFs **(photo: Waihi Gold Company Ltd).**

The first cyanidation plant in the world was established close to Waihi, at the Crown Mine at Karangahake in 1889. Prior to the introduction of the cyanide process gold recoveries were low, although the assay value of quartz from the Martha Mine was reasonably high. Gold recovery improved from 40%-50% to 85%-95% once cyanidation of the ore commenced. By 1892 there were six cyanide plants on the Ohinemuri Goldfield, plus others at Thames and Coromandel. The cyanidation process made many operations viable that would otherwise have had to close.

In days gone by, tailings containing cyanide were discharged directly into the Ohinemuri River from various mining operations. This was not an option for the modern Martha Mine. During the original permitting stage which commenced in the 1970's, cyanide management, water management and the long term integrity of the proposed Waste Disposal area were just some of the issues that came under scrutiny by an environmentally conscious public.

STAKEHOLDER INVOLVEMENT AND THE SETTING OF DISCHARGE STANDARDS

Waihi has a relatively high rainfall (averaging over 2000 mm/year) and the site operates with a net positive water balance. Excess water is treated at the Water Treatment Plant prior to discharge to the Ohinemuri River. The Ohinemuri River passes through the Karangakake Gorge which has high scenic and recreation values and supports trout. Stakeholders include iwi (Maoridom), tourism operators and those involved in recreational fishing, swimming, kayaking etc, neighbouring properties including farms, lifestyle blocks and horticulture, environmental groups, Department of Conservation, District and Regional Councils and the general public.

The potential effects of treated water on the water resources and aquatic environment was the focus of lengthy evaluation and hearings for water right applications held in 1987. Stakeholder groups made extensive representations to the hearings and almost certainly influenced the level of standards set for the protection of the Ohinemuri River. At that time, the statutory approval agency (Hauraki Catchment Board) set discharge standards based on the direct use of USEPA national criteria. This resulted in conservative standards being set.

The permitted numeric levels were revised downwards in 1998 following a further permitting round to extend the life of the Martha Mine, making the discharge limits more stringent. The relevant consents include Water Treatment Plant discharge "end of pipe" compliance limits, and an in-river compliance limit that applies to all discharges from the site either separately or in combination with other discharges as follows:

	Concentration Cyanide WAD
"End of Pipe"	Normal Compliance* 0.25 g/m^3
	Maximum* 0.71 g/m^3
"In River"	0.093 g/m^3

** "Normal compliance" values to be met 97% of the time based on all analyses taken during a quarterly reporting period when the WTP is discharging. "Maximum" values are not to be exceeded in any single analysis.*

Note that the discharge of treated water must not exceed 15% of the river flow (15/115 x 0.71 = 0.093 g/m^3)

In practice, levels of weak acid dissociable (WAD) cyanide in the river are well below the in-stream chronic value of 0.1g/m^3 (Smith and Mudder 1991), considered to be safe for aquatic life. Trout continue to be recorded adjacent to the treated water discharge point, both within and outside the mixing zone.

ONGOING STAKEHOLDER INVOLVEMENT

About 12,000 people are shown around the mine operations every year in guided tours by company personnel. This is part of an 'open door' policy to allow the public to view all aspects of the operation and form their own opinions on the many aspects of mining. All operating water rights and resource consents that authorise the mine operation are public documents and are able to be accessed by the public at all times.

Despite fifteen years of modern mining that demonstrates that cyanide can be transported, stored, used and disposed of in a safe manner with no significant adverse effects on the environment, the company continues to receive questions regarding the use of cyanide on site. This is not surprising given the less desirable aspects of its historical use, significant environmental impacts from cyanide incidents reported from time to time at various gold mines around the world, and the myths and misconceptions surrounding its use.

Many people confuse cyanide with arsenic and their questions suggest that they believe cyanide is one or more of the following:

- a heavy metal;
- persistent in the environment;
- toxic in all forms and concentrations;
- teratogenic, mutagenic, carcinogenic or bioaccumulative; or
- a component of acid drainage.

Adverse publicity arising from incidents overseas, e.g. tailings dam failures and bird kills, can often trigger more interest from the public for a period of time. To provide more detailed information to the general public on a number of subjects, the company has produced a website www.marthamine.co.nz.

The website contains general information about cyanide and more detailed information relevant to the Martha Mine Project. The website is visited by approximately 170 people per day and around 7% use the term "cyanide" as a search string for entry to the site. This suggests that stakeholder interest in terms of cyanide management continues well beyond the granting of discharge consents.

REFERENCES

Smith A, and Mudder T, 1991 *Chemistry and Treatment of Cyanidation Wastes.* Mining Journal Books Ltd, London1991

This case study was prepared by Kathy Mason, Waihi Gold Company Ltd, by updating Case Study 2b from the first edition of the Cyanide Management booklet. Edited by Stewart Needham, Neological Consulting NSW. June 2003.

NEWMONT WAIHI MARTHA MINE, NEW ZEALAND:
WATER MANAGEMENT TO REDUCE CYANIDE RELATED RISKS

The Martha Mine in Waihi, New Zealand has a history spanning three centuries. The current open pit operation is however very different to the underground mining that took place from 1880 to 1952 following the discovery of gold in 1878.

Modern mining at Martha Hill started in 1987 and the current operation has produced (to June 2002) 37 tonnes of gold and 218 tonnes of silver by open pit methods. Ore and waste are transported approximately 2 km by conveyor to the Ore Processing Plant and Waste Disposal Area. Excess water passes through a treatment plant before being discharged into the Ohinemuri River.

The Martha pit (top left) is surrounded by the town of Waihi. A conveyor transports ore to the processing plant (centre), and waste to the tailings storage facilities (centre right). The Ohinemuri River flows between the plant and the TSFs (photo: Waihi Gold Company Ltd).

The current Martha project was the first major hard rock mining operation to be commissioned after the resurgence of the mining industry in New Zealand. Operated within the environs of the township at the southern end of the Coromandel Peninsula, the operation received, and continues to receive, a high level of public scrutiny in many areas including cyanide and water management.

WATER MANAGEMENT

Waihi has a relatively high rainfall (averaging over 2000 mm/year). Where possible water is reused and recycled, although the site operates with a net positive water balance. Excess water is treated at the Water Treatment Plant prior to discharge to the Ohinemuri River.

WATER TREATMENT

Downstream of the mine the Ohinemuri River passes through the Karangakake Gorge, which has high scenic and recreation values and supports trout. The discharge limits imposed for treated water reflect the need to provide protection for aquatic life (refer the case study entitled "Stakeholders and the Setting of Discharge Standards").

Prior to building the existing Water Treatment Plant, substantial laboratory trials were undertaken to develop the optimum treatment process design. This work looked at maximising the oxidation of cyanide in the form of free cyanide and weakly bound complexes of copper, nickel and zinc (WAD cyanide) which are recognised as the forms having most potential to affect aquatic biology.

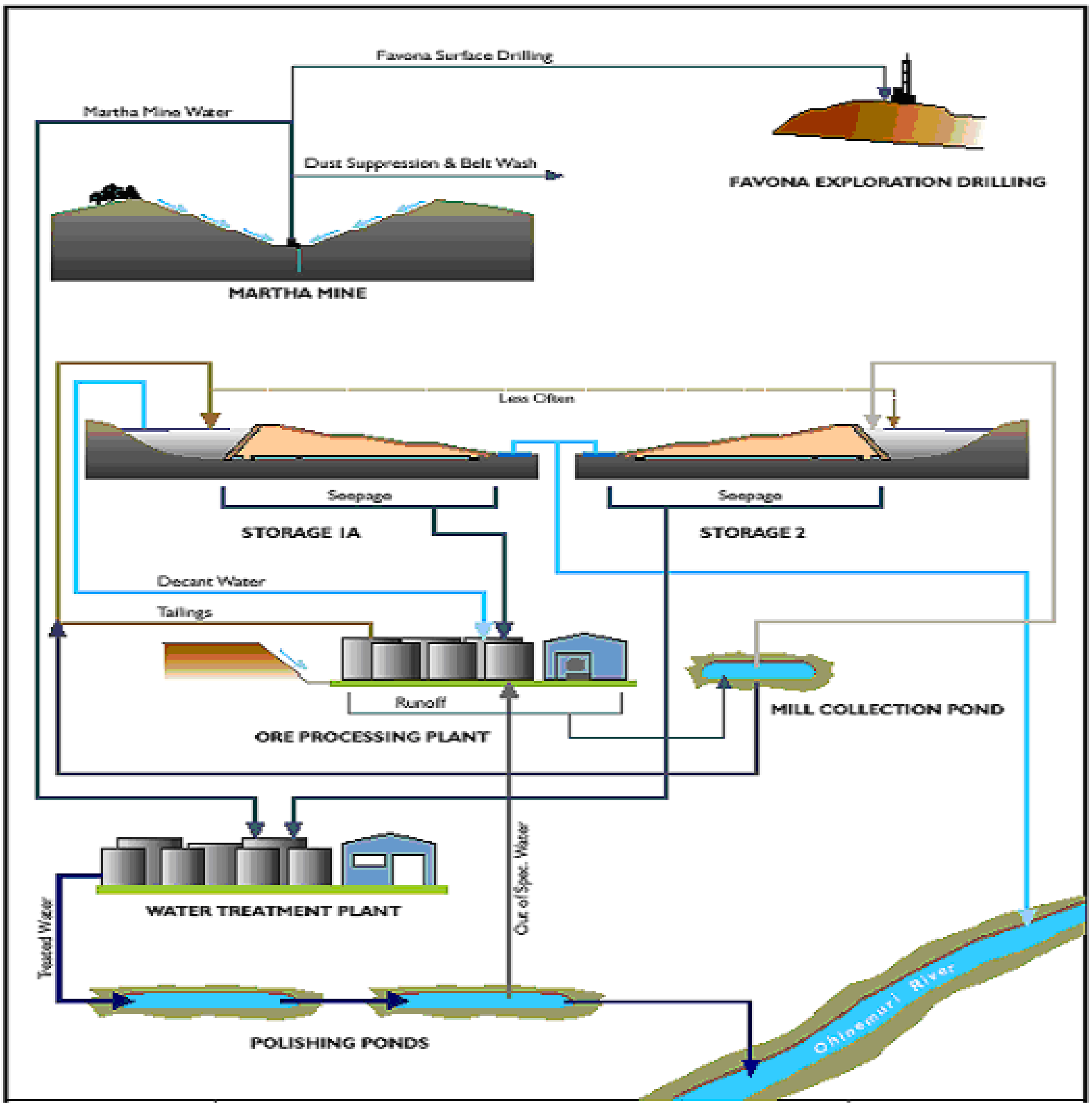
Biological Monitoring in the Ohinemuri River: artificial substrates are deployed for several weeks and then retrieved. The substrates consist of Perspex plates bolted together and then bolted on to a steel post in the river. A net is placed around the artificial substrate before it is removed from the post. In the photo you can see the waratah and the net. (Photo: Waihi Gold Mining Company Limited)

The Water Treatment Plant was constructed and commissioned in 1989, and has performed well, with a very high level of compliance with the consent conditions. In 1999 the plant was upgraded to provide sufficient capacity to cater for the predicted increase in water requiring treatment arising from the Martha Mine Extended Project. The upgraded plant presently has the capacity to treat up to 15,000 cubic metres per day of non-cyanided water and 5,000 cubic metres per day of cyanided water.

Excess water on site can be derived from a number of sources; some of which contain cyanide. To manage this, the Water Treatment Plant incorporates two distinct treatment stages:

- a cyanide destruction process using hydrogen peroxide - a strong oxidising agent - to destroy the cyanide, and copper sulphate as a catalyst to speed up the reaction; and
- a metal and trace ion removal process, using ferric chloride, lime and flocculants.

The water treatment plant removes suspended solids and reduces the concentrations of cyanide and metals to satisfy resource consent conditions and ensure receiving waters are not adversely affected.



Martha mine Water Management System

Pipeline Risk Management

The tailings and decant lines cross the Ohinemuri River (see photo). As cyanide is present in tailings and decant water, management of these pipeline systems is a crucial part of the Martha operation.

There is bunding at both the Ore Processing and Water Treatment Plants and, as an added precaution, all runoff from these areas is channelled into collection ponds. Decant and tailings pipelines are contained in lined trenches if there is a risk of seepage. Associated with the trenches are contingency ponds which have been sized to contain the maximum conceivable spill.

Tailings line crossing the Ohinemuri River
(Photo: Waihi Gold Mining Company Limited)

The tailings line has a flow differential system and alarm to indicate a pipeline rupture. Where the pipelines cross the river, they are carried in fully enclosed concrete culverts to provide secondary containment against possible pipeline rupture. Woven synthetic shadecloth has been trialled at strategic areas to contain spray from a possible pipeline rupture.

Pressure testing is carried out six monthly and after maintenance to ensure pipeline integrity. The tailings disposal, decant and dam return pipelines have flow differential systems which sound an alarm on the computer control system if a significant leak were to occur. All pipelines are visually checked routinely every two hours.

TAILINGS AND CYANIDE RISK MANAGEMENT

In contrast with many Australian gold mining operations, waste rock is used to build an engineered embankment behind which the tailings are placed. Under the tailings are drains to collect seepage. The cyanide concentration and flows recorded in the tailings underdrains were initially relatively high, but after ten years they had dropped significantly as the tailings consolidated.

Tailings are discharged to the dam at levels up to 250g/m^3 WAD cyanide, and investigations carried out onsite indicate that cyanide decay is occurring rapidly after tailings deposition. Only low residual concentrations are found in the decant pond. The maximum cyanide level (WAD) in the tailings decant water has been as high as 35-40 g/m^3 and averages approximately 15 ppm. This is well below the level of 50 g/m^3 which is the safe level for birdlife (Mudder 1997). A large number of birds are regularly observed on the tailings pond, and no deaths attributable to cyanide have been recorded.

Various trials have been conducted on cyanide degradation and the long-term fate of cyanide within the tailings. Cyanide decay and transformation processes observed in the tailings ponds are very effective in reducing cyanide concentrations in the decant and entrained liquor. Transformation processes produce very stable compounds, preventing long term leaching of WAD cyanide from the ponds. When processing stops, WAD cyanide will rapidly decay and residual cyanide within the tailings ponds will not be a concern for closure or final rehabilitation.

In 1993, trials were established on oxidised tailings to see if grass and native species would establish and grow. Very good growth was recorded for all species. Shortly after deposition, it was found that the tailings contained 150g/m^3 of total cyanide. Assuming that the tailings bulk density is 1t/m^3, and that all of the cyanide nitrogen mineralises to ammonium and nitrate nitrogen, this is equivalent to 81kgN/ha/10cm. This provides substantial nitrogen for plants.

SITE SPILLAGE PLAN AND CYANIDE MANAGEMENT PLAN

The Company has a good record with respect to cyanide management, spanning fifteen years of operation. A specific Cyanide Management Plan is an integral part of the Environmental Management System. In addition, the Site Spillage Plan documents the necessary procedures should a spill occur. These documents ensure that cyanide related risks continue to be identified, managed and provided for where necessary in accordance with best practice.

REFERENCE

Mudder T, 1997 *The Sources and Environmental Significance of Low Levels of CN*. In "Short Course on Management of Cyanide in Mining", Perth WA 1997. Australian Centre for Minesite Environmental Research, Kenmore Qld.

This case study was prepared by Kathy Mason, Waihi Gold Mining Company Ltd, by updating Case Study 2a in the 1998 edition of the Cyanide Management booklet. Edited by Stewart Needham, Neological Consulting NSW. June 2003.

NORTHPARKES, NEW SOUTH WALES:
THE 1995 BIRD KILL ON THE NORTHPARKES TAILINGS DAM

Northparkes gold mine, which is 27 km north-west of Parkes, New South Wales, was operated by North Limited until December 2000 and is now operated by Rio Tinto Australia. In Stage 1 of the project, gold bullion was produced by open pit mining and Carbon-in-Pulp (CIP) processing of the oxide gold ore. Towards the end of Stage 1, transition gold ore with a higher copper content was being processed. This led to a build-up of soluble copper-cyanide complexes in the tailings dam which resulted in bird fatalities. These fatalities were attributed to the formation of moderately strong copper cyanide complexes which are toxic to animals, especially birds.

Owing to exhaustion of the oxidised ores with higher gold grades, and the transition to sulfidic copper ore with low gold grades, the CIP processing plant was decommissioned in September 1995. Stage 2 of the operation entails open pit and underground mining and processing of copper-gold ore by flotation methods. The copper-minor gold concentrate is transported offsite for further processing.

Because the management groups involved did not recognise the environmental implications of processing copper enriched gold ore, the increasing copper concentrations in the lower levels of the oxide orebody complexed with free cyanide to form moderately strong cyanocuprate complexes. To re-establish optimal cyanide levels in the mill to dissolve gold, additional cyanide was added to the leaching circuit. Monitoring the free cyanide (for process purposes) at tailings discharge from the plant indicated that levels of free cyanide in the tailings were normal. Thus it was incorrectly assumed that there was no overall increase in cyanide levels. The copper cyanide compound formed was, however, a Weak Acid Dissociable (WAD) cyanide species. As there was no statutory requirement to routinely monitor WAD cyanide, the increase in WAD cyanide levels in the tailings was not detected.

The first dead birds were seen on the dam in May 1995. The increasing cyanide levels quickly led to an increased number of bird deaths, estimated by mine staff to be about 100. This was noted by government officials who were on a study visit to Northparkes. When the nearby Lake Cowal project team (proposed mine) met with these officials eight days later, a decision was made to count and identify the birds. From the count, 2,700 dead birds were recovered from the tailings dam.

Tailings Dam No.1, Hydrogen peroxide dosing equipment on the central causeway. Photo: North Limited

On the day these birds were counted, an intruder into the Northparkes tailings dam obtained footage for the '60 Minutes' television program which later had an episode on the Northparkes mine and the environmental damage it was causing. This episode caused considerable public outrage and had a significant although largely indeterminable impact on North's image. The loss of 2,700 birds also contributed to sustained collateral impacts, with possibly the worst of these being the negative influence on the decision to refuse North's development application for the Lake Cowal Gold project. There was also damage to North's environmental reputation.

The incident also had a significant impact on mine employees, the North Board and the way in which the company appraised its environmental performance and prepared for environmental emergencies.

In response to this incident, the company initiated the following remedial actions:

- Tailings Dam Management Procedures - aimed at bird management, monitoring, cyanide detoxification, compliance and reporting, safety, security and information gathering.

- Community Information Sharing - aimed at informing employees and the wider community of the incident.
- Improvement and Recovery Actions - aimed at correcting deficiencies in management practices and conducting research into cyanide management.

Cyanide detoxification was considered to be the most effective means of reducing the risk to bird and other wildlife. Cyanide detoxification commenced on 22 August 1995 and by early October, the levels in the tailings storage facility were lowered from 350 mg CN(WAD)/L to <50 mg CN(WAD)/L. During this time, bird mortality and cyanide levels were closely monitored with the overall trend showing that by controlling cyanide levels to below 50 mg CN(WAD)/L there was a corresponding and dramatic decrease in bird mortality.

The incident at Northparkes has highlighted the need to carefully analyse and assess all potential hazards before a mine is commissioned. Such an analysis would have ensured that management systems and contingency plans were in place to either eliminate, control or mitigate risks. As a consequence, Northparkes Mines has implemented an extensive program to assess all of the significant environmental risks posed by its operations.

The incident at Northparkes was not unique, as there have been significant bird kills attributed to cyanide at other mines in Australia. The further impact of the Northparkes incident however, will be measured by the resultant changes in regulations and reviews for new mine proposals, and, probably more importantly, by changes and improvements to cyanide management practices at mines.

Tailings Impoundment No. 1, floating decoys in foreground, gas 'scare' gun in the background and hydrogen peroxide dosing equipment in decant and on floating structures in the foreground/centre. Photot: North Limited

This case study was prepared by Claire Silveira, Rio Tinto Australia, by updating Case Study 5 in the Cyanide Management booklet 1998 1st edition.

ORICA AUSTRALIA: CYANIDE HANDLING AND MIXING PROCEDURES

INTRODUCTION

ORICA Australia provides all consumers of their cyanide products with handling and mixing procedures that follow the principles of Environmental Best Practice. These procedures include all appropriate environmental management and safety standards for cyanide to be used efficiently and safely.

This case study does not discuss the transport of cyanide to a minesite, handling and storage on site, nor the handling of cyanide-contaminated solutions after processing. It covers the safety aspects of cyanide handling before it is used in the processing plant and should be read with another booklet in this series 'Hazardous Materials Handling, Storage and Disposal'.

CYANIDE HANDLING AND MIXING PROCEDURES

The following personal protective equipment is the minimum required when handling or mixing cyanide:

- Hard hat
- Long PVC gloves
- Safety boots
- Full face canister mask
- Disposable 'poly' overalls with hood.

The protective equipment must be regularly maintained and in particular:

- The canister is to be replaced every month and the date should be marked on the canister when it is first used.
- Gloves should be worn external to the arms of the overalls.
- A full face mask is to be worn with the appropriate and approved canister when undertaking cyanide duties; and there must be an air tight seal between face and mask. To ensure a tight seal, personnel are required to be clean shaven. The mask must be dismantled and cleaned regularly. The mask is to be stored in the plastic bag provided.
- Overalls are to be worn over normal work clothes. The full face mask is to be worn under the hood and the hood pulled securely around the mask.

Any spills or leaks of cyanide must be reported immediately to the supervisor.

JOB TASKS

The following tasks must be carried out by two trained people in line with ORICA's current safety policy. One operator is to perform the tasks while the other is posted as a safety watch. The person on safety watch is to have communication with the control room or emergency services at all times.

Full protective equipment must be worn for steps 8 to 21 and 26. Normal minesite protective equipment (hard hat, safety glasses, safety boots) must be worn for steps 1 to 7 and 24 to 25.

Step 1	Obtain the key to the cyanide storage compound from the Shift Supervisor.
Step 2	Determine in conjunction with the Shift Supervisor the number of boxes of cyanide required per tank for mixing.
Step 3	Transfer the required number of boxes for mixing, one at a time from the storage compound to the mixing shed using the designated fork lift. Position the box as close to the point of discharge as possible. Full boxes are NOT to be stored at the mixing shed for any later mix. Employ a system of stock rotation in the storage shed to ensure stock is regularly turned over.
Step 4	Check that the safety showers are operating correctly.
Step 5	Check that the mixing tank agitator(s) are operational and running.
Step 6	Position a chain across the entrance to the reagents mixing area.
Step 7	Fill the mixing tank(s) to the required level with water.
Step 8	Add a scoop of sodium hydroxide (caustic soda) to the tank(s).
Step 9	Add dye to the tank(s).
Step 10	Cut the strapping from the cyanide box, remove the lid and place it to one side.
Step 11	Slit the heat sealed polythene liner in the four corners of the box to gain access to the inbuilt lifting loops.
Step 12	Take the four lifting loops and position them on the lifting frame of the overhead crane. All four lifting loops MUST be used when lifting each cyanide bag.
Step 13	Using the overhead crane, slowly lift the bag clear of its box.
Step 14	Position the bag over the hopper cutting frame of the mixing tank.
Step 15	Carefully lower the bag on to the hopper cutting frame (which ultimately will allow the cyanide to discharge into the mixing tank).
Step 16	When cyanide discharge from the bag ceases, lift the bag slightly and move to within arm reach by using the overhead crane. Carefully shake the bag to clean out any briquettes or dust which may be lodged in the bag. Personnel should not lean over the hopper cutting frame at any time.
Step 17	Place the empty bag into the waste rubbish bale provided.
Step 18	Replace the plastic lid securely on the empty box and return to the outside storage area. Stack two high. Carefully position the top box to fit squarely onto the bottom box. The transport operator will remove the empty boxes at the time of the next delivery.
Step 19	Repeat steps 10 to 18 for each of the required number of boxes.

Step 20	After the required number of boxes have been emptied into the mixing tank(s), wash down hopper cutting frame and chute with water from the hose provided.
Step 21	Collect all plastic strapping and place in the waste rubbish bale.
Step 22	Wash PVC gloves at the safety shower before removing safety equipment. Remove canister mask and wipe down with cleansing napkin.
Step 23	Wash hands and face and return re-useable safety equipment to its dedicated locker.
Step 24	Record the number of boxes used in the mix on the log sheet with the date and time of mixing.
Step 25	Ensure the cyanide storage compound is locked at all times.
Step 26	When the waste rubbish bale is full, tie the neck of the bale. Place in an industrial bin for disposal. The handling of the waste rubbish bag must be carried out in full protective safety gear.
Step 27	Any cyanide box delivered to site in a damaged condition must be used immediately. If the product cannot be discharged safely, it is to be placed to one side and removed from the site at the time of the next cyanide delivery.

If the above steps are followed and the required personal protective equipment used, there should be no safety problems during the handling and mixing procedure.

This case study was prepared by Chris Avramopoulos, Orica Australia. May 2003.

PORGERA JOINT VENTURE, PAPUA NEW GUINEA:
WASTE CYANIDE TREATMENT CIRCUIT

Placer Dome Asia Pacific is currently mining gold at Porgera in Papua New Guinea and operates as the Porgera Joint Venture. The method of tailings disposal at Porgera is an environmentally sensitive issue and an important component of the mining operation. Since operations began in 1990, treated tailings (containing low levels of cyanide) have been discharged to the riverine environment, which extends 1000 km downstream to the Gulf of Papua.

The annual rainfall at Porgera is high at more than 3.6 metres and the region is prone to earthquakes. When stability and design considerations for a tailings impoundment were examined in 1986, it was determined that such a structure was not feasible because it could fail and threaten the lives of people living downstream.

Even if a tailings impoundment had been able to satisfy safety requirements, significant amounts of effluent from storage would still need to be discharged due to the high rainfall. The concept of tailings impoundment was discarded in favour of tailings treatment followed by riverine disposal.

THE WASTE CYANIDE TREATMENT CIRCUIT

The Waste Treatment Circuit provides an environmentally safe discharge in three ways:

- reduces free cyanide levels in tailings to less than 2 ppm;
- raises the pH to 7.0 prior to river discharge to ensure precipitation of heavy metals and making them unavailable to downstream biological communities; and
- precipitates mercury by adding sodium sulfide to the circuit, thereby reducing its bio-availability.

The Waste Treatment Circuit achieves these results by combining the three main effluent streams of the process at the beginning of the Waste Treatment Circuit. Very little additional reagent is needed to produce treated tailings that can be safely discharged to the river.

The acidic liquor tailings of the pressure oxidation process contain many dissolved metal species (including ferrous and ferric ions). Free cyanide at a concentration of 80-100 ppm is also contained within the basic CIP tailings stream. When these two streams are combined, free cyanide reduction is maximized when insoluble metal complexes are formed with most metals including iron. The neutralisation process also reduces cyanide levels by volatilisation. Also added at this point in the circuit is sodium sulfide (Na_2S), which reacts to form the highly insoluble mercury species HgS, or synthetic cinnabar.

Next, the flotation tailings are added to the circuit to begin neutralisation through the formation of metal hydroxides and calcium sulfate. The most important component of the flotation tailings is its calcium carbonate content.

With sufficient residence time, the three streams reach neutral pH and a pH of 4 - 5 is achieved before reaching the precipitation section of the circuit. Lime from a small mixing tank is added to the tailings before entering the precipitation tanks to raise the pH from 4 - 5 to the river discharge pH of 7. Remaining metal ions are then precipitated mainly as metal hydroxides and calcium sulfate.

TAILINGS DISPOSAL

The net result is a final treated tailings fit for riverine disposal. The targets for the discharged tailings are pH 7.0, free cyanide less than 2 ppm, and mercury complexes less than 0.05 ppm. The treated, but undiluted tailings, have been toxicity tested by Australian Nuclear Science and Technology Organisation (ANSTO) using internationally accredited tests. The fingerling trout used in the test were found to have a 100% survival rate.

Porgera has an extensive water quality and downstream biological monitoring program to detect any impacts from the mining operation. Dissolved metal levels are very low at the downstream compliance monitoring station, where the compliance criteria for dissolved metals set by the PNG government must be met at all times. Environmental monitoring shows that metal levels in fish are not elevated significantly over background levels. In addition, no adverse health impacts have been found downstream of the mine.

An independent review of the downstream impacts conducted by the CSIRO was undertaken in 1996. Their review confirmed that PJV had been in compliance with downstream water quality criteria since start-up, and that the original impact predictions had proved to be reasonably accurate. The review also included recommendations for improvement. Many of the recommendations were concerned with risk assessment and reduction, with emphasis on the health risk to downstream villagers. Most of the review recommendations have been implemented. Ongoing medical checks and dietary surveys continue to demonstrate no ill-effects to people living downstream.

MANAGEMENT

The procedures detailed in this case study for the management of cyanide at the site are part of the company's environmental operating framework.

View across 4 of the 5 waste treatment circuit tanks at Porgera, where cyanide is precipitated as insoluble metal complexes. Looking towards discharge end; lime tank on left; Mt Paiam in distance **(photo: Placer Dome Asia Pacific).**

This case study was prepared by Jim McNamara, Placer Dome Asia Pacific, and edited by Stewart Needham, Neological Consulting NSW, June 2003.

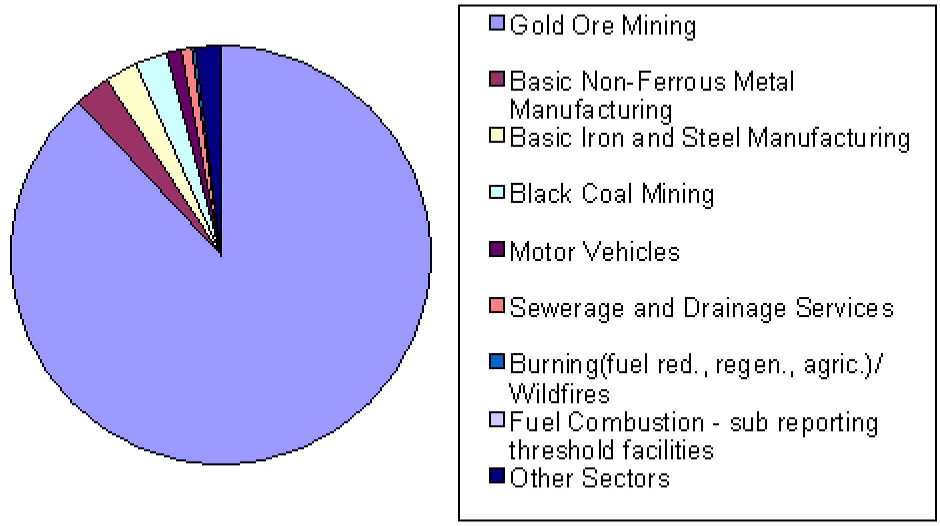
REPORTING CYANIDE TO THE NATIONAL POLLUTANT INVENTORY

The National Pollutant Inventory program (NPI) is a cooperative program between the Commonwealth, State and Territory governments of Australia, promulgated as a National Environment Protection Measure (NEPM) agreed to by the relevant Government Ministers from each jurisdiction. States and Territories are responsible for liaising with facilities and assessing facility reports, and the Commonwealth is responsible for collating and publishing the data.

The NPI requires industry to annually estimate and report a range of substances (currently 90) emitted to the environment for which NPI reporting thresholds are exceeded. The information is collated into a publicly-accessible Internet database of estimated pollutant emissions from industry and diffuse sources. Current details in relation to NPI reporting are at www.npi.gov.au.

One of the 90 NPI substances is cyanide (ie the cyanide component (CN) of inorganic cyanide compounds). Emissions of cyanide to air, land and water must be estimated and reported if the use of cyanide compounds is more than 10 tonnes per year.

The graph shows the distribution of Australia-wide cyanide emissions reported to the NPI in 2001-2002, and includes diffuse sources from airshed regions that cover major cities and some rural areas. The gold mining sector accounts for 90% of total reported emissions, compiled from data provided by 46 of the estimated 133 gold mining operations within Australia.



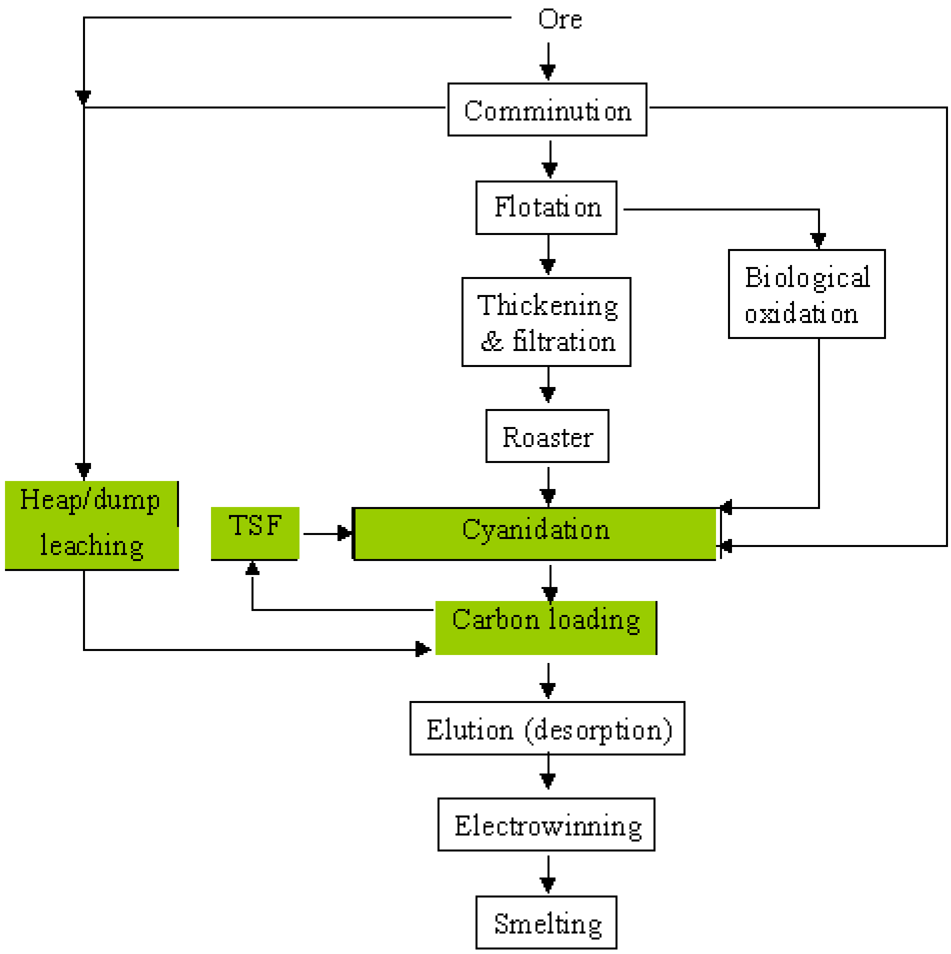
Distribution of cyanide emissions in Australia from most recent NPI data for 2001-2002 (as at May 2003)

The NPI allows four broad techniques to be used for estimating emissions. Often more than one technique is available for estimating emissions, and the most appropriate technique for a facility should be chosen. The four approaches are:

- mass balance;
- emission factors;
- engineering calculations; and
- direct measurement.

Handbooks detailing these techniques have been developed in consultation with industry and are available on the Internet (www.npi.gov.au). Also available is the NPI Guide, which provides details about determining whether reporting thresholds are exceeded. The handbook for the gold processing industry is titled 'Precious Metal Manufacturing: Gold Ore Processing' (the main manual in the handbook (Gold Ore Processing) is to be updated in 2003-2004, and input from will be sought industry prior to publication of the new version). Before undertaking estimates of cyanide emissions for the NPI, the NPI Internet site (www.npi.gov.au) should be checked for the latest information.

The flowsheet shows the major units in gold processing and highlights the components, which are the main sources of cyanide emissions.



Simple flowsheet of typical gold processing facilities, with main possible sources of cyanide emissions highlighted

An example is given here of how CN emissions from a Tailings Storage Facility (TSF) can be estimated for the NPI. For other parts of the process refer to the most up to date material on the NPI Internet site (www.npi.gov.au).

TAILINGS STORAGE FACILITIES

There are cyanide emissions to land from seepage and emissions to air by volatilisation. The example below uses estimation techniques from version 1.1 of the Gold Ore Processsing Manual (published on 9 October 2001).

SEEPAGE - EMISSIONS TO LAND

From section 5.2 of the manual the seepage from a TSF is dependent on the seepage rate (volume% per year) using the following equation:

M = [V x S] x C/100
M = CN emissions to land by seepage, kg/year
V = volume of solution to the TSF, m^3/year
S = seepage rate/solution discharge rate as a percentage
C = CN concentration in TSF, kg/m^3

Using the following parameters as an example:

V = 10,000 m^3/year
S = 10 %
C = 0.12 kg/m^3,

the estimated emission of CN to land from the TSF is 120 kg/year.

VOLATILISATION - EMISSIONS TO AIR

Section 6.2.2 of the manual provides detail on estimating emissions from the TSF due to volatilisation. The following equation applies:

CN = [Free cyanide concentration x Volume of water to TSF] x $V_{\%}$*/100*

The free cyanide concentration refers to the concentration in the water discharging into the dam.
$V_{\%}$ is the TSF pH-dependant degradation factor for CN

As an example, for a pH of 10 in the TSF the value of $V_{\%}$ is 20%.

Free cyanide concentration = 0.12 kg/m^3

Volume of water to TSF = 100,000 m^3/year

From the above equation the CN emissions to air from the TSF are 2,400 kg/year.

If there are no other sources of CN emissions, the above estimates should be transcribed to the electronic reporting tool or paper reporting form. Details of the electronic reporting tool and a copy of the paper reporting form are on the Internet (www.npi.gov.au). Completed NPI reports should be forwarded to the jurisdiction where the facility is located.

This case study was prepared by Chris Mill, Environment Australia.

SGS LAKEFIELD ORETEST: PROCESS FLOWSHEET SELECTION METHODOLOGY FOR CYANIDE DETOXIFICATION AND RECOVERY

Responsible cyanide management has become a major consideration both in the development of new gold projects and in the operation of existing ones. Detoxification of tailings and other waste streams from gold plants has become an integral part of the process flowsheet in most new operations. This case study illustrates a generic cyanide detoxification flowsheet selection process that is typically developed at SGS Lakefield Oretest for gold prospects and operations alike.

CYANIDE REMOVAL PROCESS SELECTION ISSUES

There is a wide variety of cyanide detoxification and recovery processes available to operators. Selection of the most appropriate process technology for a specific tailings cyanide speciation chemistry, rheology and climate can be a substantial task. Local regulations may impose site-specific restrictions and may change periodically. Also the mine plan and the water balance around the plant as a whole must be carefully considered.

Economic factors such as capital and operating costs are often the key drivers in the selection of a process. There is often a strong temptation to terminate the testwork component prior to adequate data collection, and so force a premature decision.

Current cyanide recovery processes for tailings at the production or feasibility stage are listed below. Natural degradation in tailings ponds is the most common approach for free-milling ores, but this approach is often inadequate when polymetallic and transition sulfide ores are being treated, which is now a common occurrence at many gold mines.

Typical Cyanide Recovery Processes for Tailings

As HCN - AVR, Cyanosorb, CRP, SART
As CN^- - Hannah, High-Rate Thickening, Reverse Osmosis

Typical Cyanide Detoxification Processes for Tailings

Oxidation - SO_2/Air, H_2O_2, Caro's Acid, Activated Carbon, Biodegradation
Immobilisation - Prussian Blue Precipitation
Volatilisation - Pregnant Pulp Air Stripping, Acidic Effluent Co-Disposal

Further considerations include the presence of copper in solution, which is a prerequisite for several of these methods and may result in a saleable copper by-product, such as in the SART process (Sulfidisation-Acidification-Recycle-Thickening). Certain of these processes require a relatively clean solution, which eliminates them if a typical tailings slurry is presented.

GENERIC CASE STUDY

As part of a sound cyanide management system, every aspect of cyanide use is typically considered prior to final selection of a cyanide detoxification process. Several steps are involved, and these are summarised below.

CYANIDE LEACH OPTIMISATION

The approach that is considered best practice is one that entails the minimisation of cyanide use without compromising gold recovery. This is best achieved by means of a systematic testwork programme to determine the optimal set of conditions that achieves this outcome.

Several leach strategies have been successfully applied to specific cyanide leach circuits, and the selection of the most appropriate one is made based on an evaluation of the mineralogy and chemistry of the ore and process water. Several leach strategies may be applicable and evaluated in the course of the optimisation testwork programme.

CYANIDE ASSAY AND SPECIATION

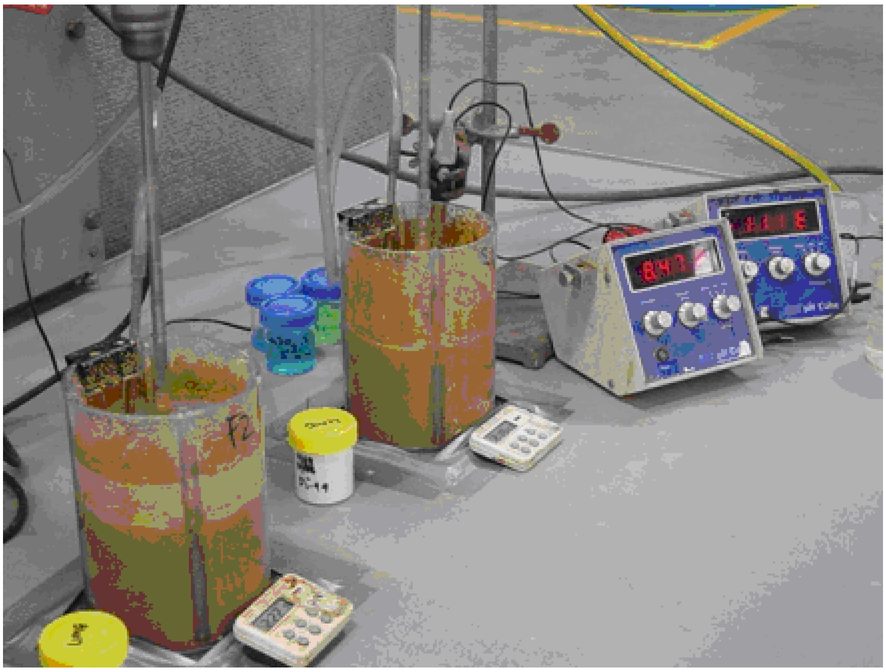
A sample of the tailings under optimal conditions is subjected to a variety of assays, to enable meaningful cyanide speciation analyses to be carried out. The output covers the range of $M(CN)_x^{y-}$ complexes for Cu, Fe, Ni, Co, Au, Ag, SCN^-, OCN^-, CN^-, HCN, as well as solid-bound forms of cyanide and thiocyanate. The methodology developed at SGS Lakefield Oretest cross-validates the result via several different assay methods (Adams, 2001).

CYANIDE DETOXIFICATION SHORT-LISTING AND SIGHTER TESTWORK

The cyanide speciation results are combined with other relevant data to produce a preliminary short-list of potential processes that may be appropriate for cyanide removal for the specific case. Well-controlled batch sighter tests are conducted to provide an initial estimate of the viability of the short-listed processes. The tests are typically designed to maximise the yield of data pertinent to every stage of processing of the tailings stream.

CYANIDE DETOXIFICATION OPTIMISATION TESTWORK

There may be one or two potential processes that are selected as a result of the sighter tests and subjected to a series of small-scale batch and semi-continuous tests. The results add confidence to the process selection and provide preliminary engineering data to facilitate development of preliminary cost models.

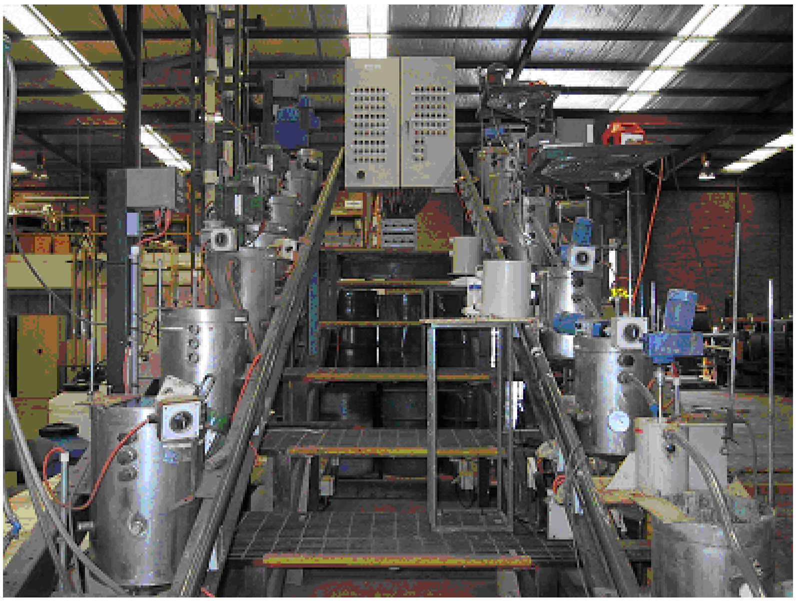


Typical bench-scale cyanide detoxification set-up (photo: SGS Lakefield Oretest)

CYANIDE DETOXIFICATION PILOTING TESTWORK

The final process flowsheet requires pilot-scale testing to adequately determine impurity build-ups, recycle and bleed stream flowrates, and final engineering data for scale-up purposes. A final operating and capital cost model is prepared from the pilot-plant results, which are communicated to the client on an ongoing basis during the piloting campaign, culminating in a comprehensive bankable report.

Pilot-scale testing is particularly important in the case of cyanide recovery process routes, where separation of free cyanide from base metals is a key aspect ensuring usability of the recovered cyanide in the leach.



Typical pilot-scale cyanide detoxification set-up (photo: SGS Lakefield Oretest)

IMPLEMENTATION OF CYANIDE DETOXIFICATION OR RECOVERY PROCESS

On-site commissioning typically entails an initially more rigorous sampling and assaying protocol, augmented by additional tests such as cyanide speciation. Close attention to practical details during commissioning may help avoid ongoing problems during subsequent operation.

A SART (sulfidisation-acidification-recycle-thickening) plant (Macphail *et al* 1998) was successfully commissioned at Telfer Gold Mine by plant staff with some assistance from SGS Lakefield Oretest, including cyanide assays and speciation on various plant streams. The SART plant only ran for a short while prior to Telfer going on to a care-and-maintenance phase; however, the results were sufficiently encouraging to warrant further development and possible installation of a larger plant.

The SART process has been successfully operated at several full scale plants, such as Alumbrera copper-gold mine in Argentina.

SART cyanide recovery plant at the pre-commissioning stage, Telfer Gold Mine WA, mid-2000 (photo: SGS Lakefield Oretest)

REFERENCES

Adams MD, 2001 A methodology for determining the deportment of cyanide losses in gold plants. Minerals Engineering, vol. 14, no. 4, pp. 383-390.

MacPhail PK, Fleming CA, and Sarbutt KA, 1998 Cyanide Recovery by the SART process for the Lobo-Marte Project - Chile. Randol Gold Forum '98, Denver, Colorado, April 26-29.

This case study was prepared by Mike Adams, SGS Lakefield Oretest WA, and edited by Stewart Needham, Neological Consulting NSW. June 2003-06-15

SGS LAKEFIELD ORETEST: EMISSIONS ESTIMATION AND REPORTING METHODOLOGY FOR CYANIDE REPORTING

The Australian gold mining industry is currently required to report all emissions of substances listed in the National Pollutant Inventory (NPI). The Emission Estimation Technique (EET) Manual (Environment Australia 2001) gives some options for the estimation of cyanide emissions from both the plant and the tailings storage facility (TSF). However, these estimation techniques have been the topic of much discussion since the manual was first published in 1999.

A further development that calls for responsible cyanide management, monitoring and reporting has been the International Cyanide Management Code for the Manufacture, Transport and Use of Cyanide in the Production of Gold.

The need for consistent and accurate reporting of emissions to meet the expectations of NPI and the code has prompted the development of several methodologies to achieve this outcome.

CYANIDE EMISSIONS ESTIMATION

The main task building up to cyanide reporting is the estimation of cyanide emissions. Several methods have been used.

CYANIDE MASS BALANCING

The approach that is considered best practice is one that entails the monitoring of various parameters by the plant, for input into a plant-specific spreadsheet for calculation of a cyanide balance across the plant. There are variations to this approach that may be applicable to suit individual minesite requirements, but this is the one generic approach that has seen consistent application over a relatively long period in Australia, North America and other regions.

The methodology developed at SGS Lakefield Oretest is discussed below in a generic setting to illustrate the practical application of cyanide mass balancing to cyanide emissions estimation.

Key features of the successful application of a cyanide mass balancing approach are:

- involvement of site personnel from the outset, to minimise any perceived increase in operators' workload;
- utilisation of existing plant control data to eliminate seasonal, operational and orebody related fluctuations in plant performance;
- use of meaningful cyanide speciation assays to determine and quantify the range of cyanide complexes and reaction products present in plant samples. The methodology developed at SGS Lakefield Oretest cross-validates the result via several different assay methods;
- periodic updates to the data to ensure currency and consistency; and
- correlation of assay data with cyanide inventory change.

CHEMICAL MODELLING

The application of known thermodynamic data for the volatilisation of HCN gas from the dissolved state has been considered for use in cyanide emissions estimation. Widespread practical application of this technique has yet to be proven. Aspects that may impact on this include:

- unpredictable variations in water quality and temperature at minesites;
- possible frequent variability in orebody and operation strategy; and
- frequent plant assays are still required as inputs into the model.

DIRECT MEASUREMENT OF HCN EMISSIONS

While the total capture of volatilised HCN above a leach tank could feasibly be achieved with appropriate equipment, this approach is impractical at best and the cost is not easily justified. Measurement of scrubbed cyanide from a pipe suspended in the leach tank at a gold plant has previously been made. Practical translation of this data to obtain meaningful emissions estimates would present difficulties, given that the influence of variable climatic factors such as wind velocity, humidity and temperature would have a significant impact on the flux of cyanide.

ESTIMATION FACTORS

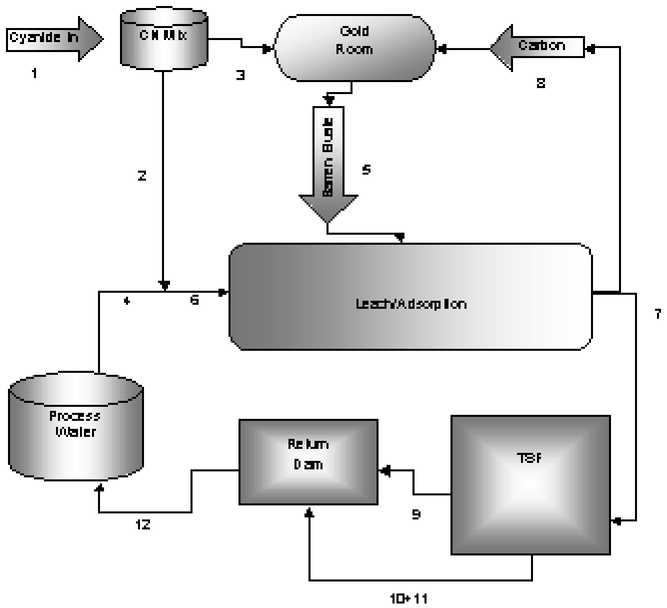
The majority of minesites are currently using the simple estimation factors suggested in the EET Manual. The lack of available comprehensive data on which to base these factors may result in over-estimations of cyanide emissions in some cases. Best practice would be to strive for the reporting of as meaningful a result as possible, which again points to the mass balancing approach.

GENERIC APPROACH TO CYANIDE MASS BALANCE ESTIMATION

The typical approach taken by SGS Lakefield Oretest at several Australian gold recovery plants comprises the following stages:

1. Preliminary Discussions and Data Collation

Development of a preliminary cyanide balance typically takes place prior to the site visit. The process flowsheet and other relevant information are evaluated to determine the likely initial sampling points and areas around the plant that may require particular inspection during the site visit.



The cyanide balance for a gold plant must be tailored around the site-specific characteristics of the plant and take into account all site components where cyanide reports.

2. Site Visit

The site visit covers the following essential areas:

- discussions with plant metallurgists, environmental officers and operators to identify any specific issues and future plant strategies;
- capture of the relevant plant control and logsheet data as well as any other pertinent information;
- evaluation of existing plant sampling, assaying and monitoring protocols for use in future cyanide-balancing exercises; and
- obtaining and stabilising the necessary samples for off-site assay.

3. Cyanide Assay and Speciation

The samples are subjected to a variety of assays, to enable meaningful cyanide speciation analyses to be carried out. The output covers the range of $M(CN)_x^{y-}$ complexes for Cu, Fe, Ni, Co, Au, Ag, SCN^-, OCN^-, CN^-, HCN, as well as solid-bound forms of cyanide and thiocyanate.

This information is useful in its own right, both from a plant metallurgical and an environmental point of view. The results can help define a cyanide minimisation strategy, and hence lower operating costs for the plant, as well as help solve operational issues. The speciation results can also assist in the selection and development of the most appropriate cyanide detoxification or recovery strategies for the minesite.

4. Cyanide Balancing

The cyanide speciation results are combined with the plant control assay and logsheet data to produce a preliminary cyanide balance. This is cross-checked against the relevant information gleaned from the site visit and the appropriate assumptions are introduced to produce a simple, robust cyanide balance that can be applied to future ongoing monitoring efforts by the plant. Correlations within the balance are also cross-checked.

5. Cyanide Emissions Estimation

Once a reliable preliminary cyanide balance has been generated based on the initial data, a preliminary calculation of cyanide emissions can be made, covering by way of example the following areas:

- plant - HCN volatilisation, NH3 volatilisation; and
- tailings storage facility (TSF) - HCN volatilisation, NH3 volatilisation, seepage, run-off, discharge.

There may be other areas that require attention, depending on the site specifics.

6. Ongoing Cyanide Monitoring

Once the preliminary cyanide balance is set up, plant personnel continue the monitoring process as a small part of their daily plant control and logging responsibilities. Periodic assaying of a reduced suite of samples for a simplified matrix of assays is then undertaken. These results are incorporated into the balance to build a robust balance for the plant that after a period covers seasonal and plant variations to a greater degree.

Major changes to the orebody mined or modifications to the circuit may necessitate a somewhat more comprehensive sampling and assaying exercise for a short period, as the quest to obtain meaningful data is sought. For these reasons the balance is best reviewed periodically to maximise continuity.

References

Adams MD, 2001 *A methodology for determining the deportment of cyanide losses in gold plants.* Minerals Engineering, vol. 14, no. 4, pp. 383-390.

Environment Australia, 2001 *Emission Estimation Technique Manual for Gold Ore Processing,* Version 1.1, National Pollutant Inventory, 9 October 2001. www.npi.gov.au/handbooks/approved_handbooks/pubs/gold.pdf

This case study was prepared by Mike Adams, SGS Lakefield Oretest WA, and edited by Stewart Needham, Neological Consulting NSW. June 2003.

TAILINGS SPILL ACCIDENT IN BAIA MARE, ROMANIA

AURUL was established in 1992 as an Australian - Romanian joint venture company to process tailings from old mining operations in order to recover gold The planned project was designed to reprocess tailings from three and silver. impoundments:

- Sasar (Meda dam): 4.43 million tonnes with a recoverable gold grade of 0.60 g/t gold;
- Central Flotation: 10.05 millions tonnes with a recoverable gold grade of 0.48 g/t gold; and
- Old Bozanta: 8.5 million tonnes with a recoverable gold grade around 0.30 g/t gold.

A new treatment plant was constructed at Aurul with an annual capacity of 2.5 million tonnes per year and annual production of about 1.6 tonnes of gold and 9.0 tonnes of silver, over a life span of at least 10 - 12 years.

Operations began in May 1999 to process material from the 30-year old "Meda" tailings dam located near the town of Baia Mare. The new operation entailed installation of a closed-circuit CIP leaching plant (the first CIP plant in Romania) using about 120 mg/l CN solution, with the tailings deposited in a new 94 ha tailings dam, 6 km downstream of Baia Mare close to the villages of Sasar and Bozinta.

Prior to 30 January 2000, 60-70 cm of snow and ice had accumulated in the tailings dam. On that day 30mm of precipitation (rain and snow) fell, and temperatures rose above 0^{o}C causing the snow and ice in the dam to melt. As a consequence of the rapid rise in water level within the dam, the inner embankment materials became saturated, lost strength, and at 10 pm collapsed to form a breach 23m wide and 2.5m deep (down to the crest of the original starter dam). The area between the inner and outer embankments quickly filled with water and slurry, which then overtopped the outer embankment. About 100,000 m^3 of water and tailings containing an estimated 50-100 tonnes of cyanide, as well as heavy metals, particularly copper, escaped into the Somes, Tisza and, ultimately, Danube river systems. Nearby tailings were used to fill the breach and reduce the discharge to 40-50 L/s, which was neutralized with sodium hypochloride until the breach was completely sealed two days later. On the same day (2 February), decontamination began of the 14 ha land area flooded by the spill, and the first report of dead fish was recorded.

The impact of the incident included:

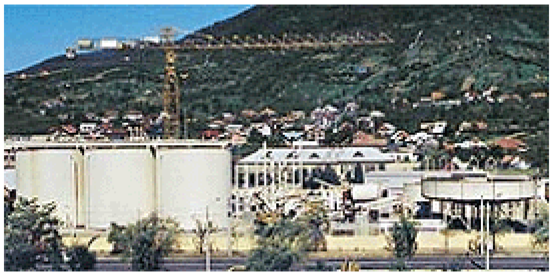
- extensive contamination of a major river system, from the Somes/Szamos streams and the Tisza River, to the Danube River - contamination was detected for 2000 km downstream of the spill;
- contamination and interruption of the drinking water in 24 towns and of 2.5 million people;
- massive fish-kill and destruction of aquatic species in the river systems;
- severe negative impact on biodiversity, the rivers' ecosystems, drinking water supply and socio-economic conditions of the local population; and
- major clean-up and remediation costs.

The scale of the impact alerted the gold mining industry to the urgency of improving cyanide management in the gold mining sector, and was a key factor leading to development of the International Cyanide Management Code.

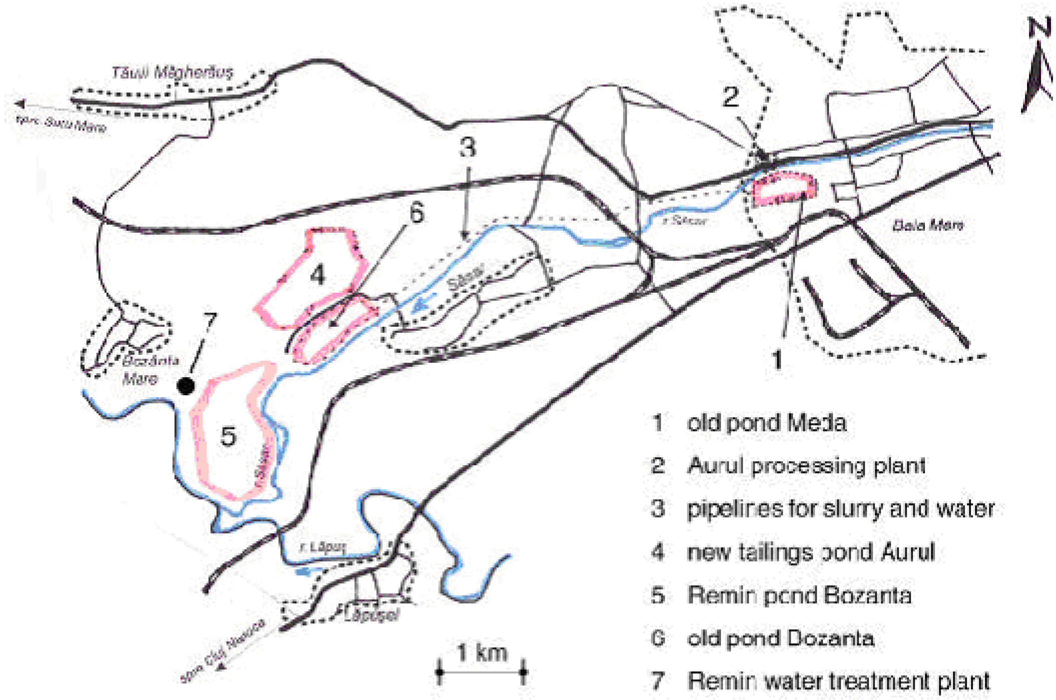
DESCRIPTION OF THE AURUL PROJECT

Urban development in the Baia Mare area is restricted in some areas by the presence of old tailings ponds which are less than 50 m from houses, and amenity is reduced through associated contamination of soil, water and air. Air pollution includes heavy metal-contaminated dust blowing from unremediated tailings pile surfaces. In the early 1990s it was agreed that three impoundments ponds should be cleaned and recovered to allow areas for development, through the reprocessing of tailings for gold by the Aurul joint venture. The reprocessed tailings were deposited in a plastic lined dam, which promised to be a major environmental improvement to the old impoundments which are an ongoing, long term pollution source. The company received all necessary permits under

Romanian legislation before obtaining an Environmental Agreement to proceed. The old Meda impoundment contained 4.43 million tonnes of flotation tailings, which were mixed with water to form a slurry to enable pumping to the processing plant where cyanide was added to the mixture (see map). Around 700 mg/L cyanide was used in the process to extract the gold and silver. The resultant tailings, containing about 400 mg/L total CN, were then pumped through a pipeline to the new pond 6.5 km downstream and away from the city.


The Aurul processing plant at Baia Mare

Plan of Baia Mare and Aurul plant and tailings impoundments



The new 94 hectare impoundment had a final design height of 20 m high, and was constructed on gently sloping terrain by forming an embankment surrounding a central decant well where ponded decant was re-circulated to the plant. The pond was lined with a plastic membrane to prevent loss to the ground, and drains were fitted in the dam wall to collect seepage which was added to the decant water fed back to the processing plant. Thus the design aimed to completely contain process water, with no loss to the surrounding environment. Observation wells were installed along the perimeter of the impoundment to monitor for possible groundwater pollution.

The tailings dam embankment was constructed as a low "starter dam" from the coarse fraction cycloned from the tailings. A low perimeter embankment about 2 m high around the toe of the main wall provided some protection against accidental release from the main impoundment. The embankments were progressively raised through addition of more cycloned tailings. The finer fractions (slimes) were discharged from the hydrocyclones into the impoundment and a decant pond was allowed to form in the center. This method of construction is very economical as it avoids the use of borrowed material to form the embankment. Formation of "beaches" of slimes against the inner side of the embankment is encouraged to increase embankment stability and reduce lateral and downward percolation. The decant water level was designed to be managed to ensure that a large dry beach remained formed to assist in maintaining the strength and integrity of the embankment. The dam was designed to have sufficient capacity between operational water level and maximum allowable water level) to accommodate storm run-off from extreme rainfall events up to 118 mm.

Decant water with high cyanide levels was returned to the old Meda tailings pile and re-used in the pumpable slurry to reduce the quantity of new cyanide which was added at the processing plant to attain the required CN concentration for effective gold-silver removal.

CHEMICAL AND BIOLOGICAL IMPACTS

The spill initially entered the Sasar river near Baia Mare, then travelled at 2.1 - 2.4 km/h along the Lapus and then the Somes river into Hungary; then into the Tisza river reaching Yugoslavia (800 km in 14 days). The Tisza is a tributary of the Danube, where the pollution continued for a further 1200 km at 2.4 - 2.9 km/h before entering the Black Sea.

The maximum cyanide concentrations measured in the rivers within Romania and Hungary varied depending on the time, location, and sampling and analytical procedures, with values ranging from 7.8 - 32.6 mg/L. By the time the plume had reached the Yugoslavian border 800 km from Baia Mare, the cyanide concentration had dropped to 1.5 mg/L. Once in the Danube river, the cyanide plume followed the left bank of the river, and concentrations dropped to about 0.07 mg/L at the Iron Gates 160 km downstream of Belgrade. Elevated CN was still measurable in the Danube Delta on the edge of the Black Sea four weeks after the spill (maximum concentration of 0.058 mg/L).

The plume also carried elevated heavy metals including copper, lead, zinc, iron and magnesium; Cu and Fe concentrations still exceeded maximum permissible levels by between 13-20 times in Yugoslavia, over 800 km downstream of the spill.

Fish kill along the Tisza River

The Romanian and Hungarian authorities reported a total loss of phyto- and zooplankton communities in the Somes and Tisza rivers during the plume. Recovery was relatively quick due to the inflow of unaffected water from upstream. The Hungarian authorities also ran biological tests in the Tisza river during the cyanide plume using Daphnia and fish; 100 % mortality was reported during the highest cyanide concentrations (Tisza water is normally toxic, with mortalities between 0 - 30% shown in routine monitoring data). These catastrophic impacts on benthic organisms were limited to the upper reaches of the system, and much less marked effects were recorded in the lower reaches of the Tisza river in Hungary and Yugoslavia. Massive fish kills were reported in the Tisza river in Hungary and Yugoslavia, but no fish kill was apparent in the Danube.

POSSIBLE CAUSES OF THE FAILURE

The breach in the retention dam was probably caused by a combination of inherent design deficiencies in the Aurul tailings dam, unexpected operating conditions, and bad weather. Where the walls of tailings dams at operating mines are constructed of cycloned tailings, they are normally under continuous construction, so that wall height is continually raised to maintain sufficient freeboard above the water level within the impoundment. This freeboard should cater for extreme events at all times. However, at the Aurul tailings dam, embankment construction had stopped because sub-zero temperatures did not allow the hydrocyclones to operate. Whilst the addition of new slurry was stopped because of the shutdown of the cyclones, the water level continued to rise because of high rainfall and meltwater from the snow and ice within the dam. There were no provisions, such as water pumps, for coping with situations of a rise of pond water level due to uncontrollable input into the reservoir system. The climatic winter conditions aggravated the situation leading to an uncontrolled rise of pond level resulting in the overflow of the dam.

A number of factors contributed to this accident:

- inadequate identification of risk factors and incorporation of these into the design parameters for the site, in particular dam capacity, dam design, and dam construction;
- poor water balance modelling, and inadequate assessment of risks under severe climatic and meteorological conditions;
- inadequate design of the Water Management System, such as lack of provision for emergency pumping;
- inadequate fail-safe measures in case of unusual operating conditions;
- deficient emergency response plans; and
- weak and inappropriate permitting of the facility, and inadequate monitoring and inspection.

Although the system was described in the EIS as incorporating a "closed system" for cyanide, clearly inadequate measures were provided to ensure containment in both the Meda and Aurul impoundments. Emphasis was put on maintaining high CN concentrations throughout the system so as to improve the effectiveness of uptake of gold and silver within the slurry and enhance recovery in the treatment plant. No measures were taken to reduce CN levels in the tailings dams to levels less toxic to plants and animals in the event of animals accessing the ponds, or accidental spillage. It appears that the criticality of design for a high-cyanide impoundment close to urban areas and a major river system was overlooked during the mine planning, mine approval, construction and operational phases of this operation.

When the spillage occurred, water with total CN of around 120 - 400 mg/L escaped and flowed into nearby rivers. Fish are approximately one thousand times more sensitive to cyanide than are humans. Dose levels as low as 0.03 mg/L HCN can be ultimately fatal to sensitive species, while 0.2 mg/L is lethal to most species. In each case, levels less than lethal promote physiological and pathological responses that reduce swimming ability, interfere with reproductive capacity and can lead to seriously deformed offspring, and also leave fish more vulnerable to predators. Cyanide toxicity in fish increases 3-fold with a 12 °C decrease in temperature. Hence the high-CN, near-freezing, plume of tailings water proved extremely lethal to the river ecosystem. Gloomy winter weather and temperatures below 0^{o}C also strongly reduced the rate of CN decomposition through photodegradation, evaporation, and interaction with river sediment.

RECOMMENDATIONS FOR IMPROVEMENT

Recommendations made by the UN Mission which investigated the Baia Mare incident included:

- Re-assessment of the relationship between environmental "benefits and risks" of the mining scheme. In particular, a risk assessment study of the entire system of remining the old tailings.
- Assessment of whether hydromining of the old tailings material using cyanide - containing effluent can be avoided and replaced by an environmentally less risky process (like dry excavation and transport to the processing plant).
- Assessment of whether materials less toxic than cyanide can be used for gold extraction.
- Development of a sound emergency plan in collaboration with all partners and stakeholders involved.
- Integrated examination of risks from all mining and related industries in the region, including abandoned sites, as a basis for better accident prevention and improved emergency preparedness and response measures.
- Revision of on and off-site contingency plans to ensure prompt early warning and response.
- Organizational roles and responsibilities off-site for dealing with a dam breach and the ensuing water pollution should be clarified. The plans should be practical, targeted to the site and fully accessible by workers and local stakeholders. The APELL process (Awareness and Preparedness

for Emergencies at Local Level) as developed by UNEP can be a useful model on which to base such a review.

- In the light of a number of earlier accidents with tailing dams, construction methods and operation procedures should be reviewed. More attention should be paid to better integrating the construction and operational aspects of the design.
- Special attention is needed for emergency preparedness where cyanide is used.
- Special monitoring and inspection regimes should be implemented by the authorities where cyanide is used.
- Process water ponds should, wherever possible, be reduced in quantity and to sizes which can be handled in emergencies. They should have secondary retention systems for overflow or breaches.

Sources: this case study was prepared by Stewart Needham, Neological Consulting, using the following reference materials:

Bernstorff A & Kanthak J, 2000. The Face of the Golden Kangaroo. Greenpeace.

Brauns J, Ratzenhofer M, & Schiess M, 2000. *Report on the circumstances leading to the spill in connection with the accident at the new tailings pond (of S.C. Aurul S.A.) at Baia Mare/Romania.* UNEP.

Hynes TP J, Harrison E, Bonitenko TM, Doronina, Baikowitz H, James M, and 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.

UNEP/OCHA, 2000. *Spill Of Liquid And Suspended Waste At The Aurul S.A. Retreatment Plant In Baia Mare, Romania.* United Nations Environment Programme/Office for the Co-ordination of Humanitarian Affairs, Assessment Mission on the Cyanide Spill At Baia Mare, Romania. 23 February - 6 March 2000. UNEP, Geneva, March 2000.

Hungarian environmental NGO website: http://www.zpok.hu/~jfeiler/baiamare/impacts.htm

Romanian EPA website: (http://www.apmbm.ro/index-eng/about/about.html)

TELFER GOLD MINE, WESTERN AUSTRALIA:
DEALING WITH CYANIDE ISSUES AT TELFER

The Telfer Gold Mine operated by Newcrest Mining Limited is located 485 kilometres south-east of Port Hedland, within the Great Sandy Desert, where mining is the sole industry.

The mine started producing in 1977 and grew to become one of the nation's largest, producing more than 5 million ounces of gold. Telfer ceased operations in October 2000, and was placed on care and maintenance. A new resource has been identified, and once again Telfer will rank amongst Australia's major gold producers.

Gold was initially mined at the Telfer Gold Mine using Merrill Crowe zinc precipitation. This was replaced in the mid 1980's by the Carbon-In-Leach (CIL) process. Both of these processes use cyanide. A sulfide circuit, which concentrates the sulfide ore by flotation, was commissioned in 1987.

The tailings from both the CIL and flotation plants were discharged to six separate tailings storage facilities (TSF). TSFs 1,2 and 3 have been decommissioned. TSFs 5 and 6 were used alternately to store the oxide tailings while TSF 4 was the sole sulfide storage facility.

In 1988, Telfer commissioned the first in a series of five dump leach pads. More than 95 million tonnes of ore has been leached by this process. In the leaching process, cyanide solution is sprayed over the surface, percolates through the dumps, dissolves minerals and releases gold into the liquor. The liquor is collected by gravity (drainage), stripped of gold, re-charged with additional cyanide and returned to the dumps.

All cyanide used at the Telfer mine site was in the form of solid sodium cyanide (NaCN) pellets and was transported to site by road trains. Cyanide was stored onsite in three separate locked areas adjacent to the mixing facilities. On average, 1200 tonnes of NaCN per annum was consumed by the processing plant. In contrast, the Dump Leach Operation used around 8,000 tonnes of NaCN per annum.

CYANIDE MIXING AND TRANSFER FACILITIES

There were three separate cyanide mixing facilities at Telfer. One of the mixing facilities was within the gold treatment plant with the other two adjacent to the dump leach pads. The mixing process was automated with the operator only required to attach cyanide bags to a hoist. The cyanide bags were opened over the mixing tank via an external spike. The mixing and transfer to the leach tanks was automatically regulated by the level of cyanide in the leach tanks.

CYANIDE ISSUES AT TELFER

The cyanide issues considered significant at the Telfer mine site were:

- potential for groundwater pollution;
- bursting of pipes containing cyanide solution; and
- fauna deaths via access to cyanide solutions.

POTENTIAL FOR GROUNDWATER POLLUTION

The biggest cyanide issue at the Telfer mine site was the potential for groundwater pollution (there are no surface water bodies near the minesite). Therefore, leach pads at the mine site were constructed under strict quality control. The pad bases were designed to have the lowest practicable permeability and construction methods were reviewed with the building of every new pad. The leach pad base was constructed in a number of steps:

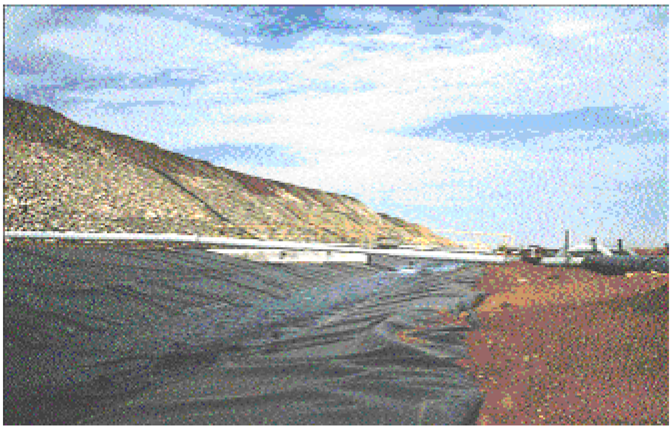
1. A layer of waste was initially placed over the pad area in 2 m high lifts compacted by machinery.
2. A compacted layer of low permeability clayey laterite material was then placed to form a sub-base.
3. A 1.0 mm High Density Polyethylene (HDPE) membrane was placed on top of this compacted layer.

4. A cushioning layer of soil/sand was then placed over the liner to provide protection from mechanical impact and puncture.

Finally a filter layer was placed on the pad, followed by the dump leach ore.

To ensure nearby vegetation and groundwater resources were not contaminated by excess storm runoff from the dumps, stormwater ponds designed to contain a 1:50 year rainfall event were constructed adjacent to the dump leach pads. Any additional runoff during the wet season was retained by the ponds and re-used in the gold treatment process.

Approximately 20 monitoring bores surround the tailings storage facilities and dump leach facilities. Groundwater pollution from the tailings dam facilities has not been an issue. The deposited tailings act as an impervious base layer to restrict solution flow to the groundwater. Monitoring during operations, and during the subsequent care and maintenance period, has not detected cyanide in any of the monitoring bores.



Intermediate and pregnant solution channels surrounding Leach Pad 7 were lined with HDPE designed to contain a 1:50 year, 72 hour rainfall event, ensuring overtopping of channels did not occur Photo: Newcrest Mining Ltd)

BURSTING OF PIPES CONTAINING CYANIDE SOLUTION

All cyanide lines within the mill operation were located within bund walls to contain any spilled material. Within the dump leach operation, every effort was made to contain cyanide lines within bunded areas. Those pipes that could not be contained (such as the header lines) were within the hardstand areas and therefore any cyanide spillage was easy to contain.

Upgrades of the cyanide pumping/pipe system in both cyanide circuits included the installation of automatic shut off valves on the header lines should pipe pressure fall suddenly. An alarm would sound on the process monitoring system prior to this shutdown to alert the operator and solution flow along the pipe line would cease. Operators undertook at least four inspections of the above facilities per shift so any pipe failures/leaks were promptly observed and remedial action taken.

FAUNA DEATHS VIA CYANIDE SOLUTIONS

There was a potential for fauna deaths at the Telfer minesite and therefore cyanide levels within the tailings storage facilities and the dump leach processes were frequently monitored. Any fauna deaths identified as being caused by access to cyanide solution were reported to the relevant authority.

MONITORING

DUMP LEACH OPERATIONS

A series of monitor bores were installed around the dump leach facilities and the water levels were measured monthly to detect any changes to the water table level. Every quarter, samples were bailed from these bores to measure the Weak Acid Dissociable (WAD) cyanide levels, heavy metals, pH and total dissolved solids. All results were reported annually to the Department of Environmental Protection (DEP) and were also reviewed frequently by qualified site personnel.

TAILINGS DAM OPERATION

Because of high evaporation and low rainfall in the area, and careful management of the beaches, the consolidation of tailings at Telfer Gold Mine was very high. These controls, and high ambient temperatures, have maximised the natural degradation of cyanide.

Monitoring bores were installed around the tailings storage facilities and results reported annually to Government. In addition, site samples were taken of the tailings solution and decant water every month and analysed for free and total cyanide in the site laboratory. Additional samples were taken less frequently and sent to an independent laboratory where they were analysed for free cyanide, WAD cyanide and total cyanide. These results were used by site personnel to monitor any changes in cyanide levels within the dams caused by changes in the process. For metallurgical purposes, free cyanide samples were taken every four hours by the plant operators for site analysis.

The tailings facilities were inspected every shift by operators and any fauna deaths recorded. The number of fauna deaths over the years has been low.

Groundwater monitoring has continued during the care and maintenance period according to our licence requirements. These results confirm that the cyanide management strategies implemented at Telfer have been effective in protecting the surrounding environment.

This case study was prepared by John Allan, Newcrest Mining Ltd, June 2003, by updating Case Study 1 in the first edition of the Cyanide Management booklet 1998.

USING A RISK MANAGEMENT APPROACH TO ESTABLISH REGULATORY LEVELS FOR CYANIDE IN MINING

Environmental regulators are generally obliged by legislation to give priority to the need for environmental protection, while still recognising economic sustainability. Whilst there is information available on the toxicity of cyanide to the environment, this information is not complete for all situations and for all species that are likely to be affected. Therefore, there is a level of uncertainty which must be considered when setting standards for cyanide use for environmental protection. Full consideration of the potential environmental impacts must recognise (a) the significant uncertainties and data gaps on both fauna exposure to cyanide and cyanide toxicity; and (b) the fauna protection values and goals adopted for each site for which regulatory standards are to be set.

The following aspects are critical in the effective management and regulation of cyanide at mine sites:

- the need for **feedback loops** that provide effective adaptive management of risk;
- **control of cyanide concentration** as the critical method for effective fauna protection;
- the need for rigorous **consideration of risk** at each site; and
- **point of measurement** of cyanide levels for tailings dams.

Further, these measures should be supported by action to maintain a continuous improvement philosophy within the gold mining industry. There is also the potential for the gold mining industry to investigate cost effective, sustainable alternatives to extraction of gold by cyanidation, and carry out comparative environmental risk assessment of these alternatives.

FEEDBACK LOOP: ADAPTIVE MANAGEMENT AND REGULATION MUST LINK BACK TO THE ENVIRONMENTAL GOAL

The history of cyanide management clearly demonstrates the high risk of assuming that a certain practice will achieve a goal, without taking active, ongoing measures to test the assumptions on which the practice is based. It is essential to have adequate feedback loops in place that continually test assumptions and levels of confidence.

Adaptive management must be effectively built into both industry best practice and regulatory processes. A flexible approach is required so that new information can be assessed and management and/or regulatory arrangements amended if it becomes evident that operational practices are inappropriate, or the tools are inadequate. It is essential that an effective site monitoring and reporting program is used to inform cyanide management decisions.

CONTROL OF CYANIDE CONCENTRATION FOR EFFECTIVE FAUNA PROTECTION

The literature, industry and regulatory experience on tailings dams, cyanide and fauna protection overwhelmingly suggests that control of Weak Acid Dissociable (WAD) cyanide level has been found to be the most effective strategy to achieve fauna protection goals. 'Hazing' and scaring techniques to control fauna access (particularly birds) to tailings dams have not been shown to be consistently effective. Whilst the use of the most effective fencing available to exclude terrestrial fauna is advocated, the critical method of fauna protection remains the control of WAD cyanide levels.

CAREFUL CONSIDERATION OF RISK AT EACH SITE

Clearly, environmental risk associated with cyanide will vary between sites and also between different designs of mining operations. This must be considered in the context of an evaluation of the risk of fauna exposure. Planning and Licensing Approvals should ensure adequate assessment of site specific risks and appropriate actions to reduce risks to appropriate levels.

POINT OF MEASUREMENT

The point of measurement is critical to:

- controlling the risk of cyanide to fauna;
- providing industry with an effective indicator of risk that is clearly related to its environment protection goal; and
- providing an effective regulatory limit.

The point of monitoring is critical in the approach to managing the risk to fauna from cyanide at tailings dams. In recent years, the industry has generally cited experience that maintaining a concentration in the decant pond of 50 mg/L WAD cyanide minimises fauna deaths, but anecdotal evidence and written reports indicate deaths do occur at this level on mine sites and in laboratory toxicity tests. The industry and the research are inconsistent on whether the 50 mg/L WAD cyanide figure should be an average or a limit, but generally require this value to be applied to decant pond cyanide concentration. Maintaining either an average or a limit of 50 mg/L *in the decant pond* implies that significantly higher concentrations can be discharged to the tailings (on the assumption of degradation of cyanide as the liquid flows over the beach to the decant pond), thus increasing the risk to fauna. Fauna may be exposed to these higher levels through ingestion of sediment from pore water and surface flow.

In 1995, the incident at Northparkes NSW (ACMRR, 1997) indicated the need to take a precautionary approach and to choose an effective indicator of the risk to fauna. Whilst cyanide levels at that incident were much higher than those now widely recognised to protect fauna, the levels were found to vary widely across the tailings dam. It was found that measured levels of free cyanide in the decant pond were not an effective indicator of the WAD cyanide levels to which fauna were exposed across the tailings dam.

The environmental exposure risk begins at the point of discharge of process water to the tailings dam. This is the place where risk is most effectively quantified and controlled. It is recommended that at this point a clear limit, that provides confidence of achieving the fauna protection goal, must be specified.

CYANIDE LIMITS AT MINE TAILINGS DAMS

Currently, Australia has no nationally accepted or consistent guidelines for cyanide for the protection of fauna accessing minesite facilities, such as tailings dams. However, a water quality limit of 50 mg/l WAD cyanide for wildlife protection is being promoted widely within Australia and overseas by some industry representative bodies and some regulators, and in the new International Cyanide Management Code (ICMI 2002). This limit is based on field observations of a general absence of wildlife mortality where WAD cyanide concentrations are below this level at the site of exposure *(It should be noted that this limit applies to mine facilities and NOT to discharges to the broader environment, for which regulatory agencies may set more stringent conditions. In setting those limits the agencies may consider environmental sensitivity and may consider monitoring results and research data and guidance material such as the ANZECC 2000 guidelines).*

Developing risk management objectives to achieve the goal of preventing fauna deaths from cyanide in tailings storage facilities and similar structures requires a precautionary approach. A precautionary approach accounts for such factors as -

- the range of fauna that may inhabit or use these facilities;
- the proximity to sensitive environments e.g. wetlands;
- general agreement that techniques for fauna (and particularly bird) exclusion or 'hazing' have not been consistently effective or reliable;
- the absence of toxicity data for fauna that inhabit these facilities, as well as information on fauna drinking behaviour; and
- the potential for exposure to mixtures of various forms of cyanide (free and compounds), for which toxicity data are limited.

NSW ENVIRONMENT PROTECTION AUTHORITY APPROACH

To reflect the need for a precautionary approach, the NSW Environment Protection Authority (EPA) has recently reviewed its overall approach to limits where cyanide-rich process water is discharged to tailings dams at mines in NSW with high likelihood of fauna access. After consideration of the factors listed above, a two tier approach of setting limits was derived. The limits are necessarily conservative because of the paucity of toxicity and fauna exposure data.

For more sensitive sites, a very high level of confidence is necessary. An example is the Lake Cowal project, where the approval process established limits for the discharge point of tailings of 20mg/L (90th percentile) and 30mg/L (never to be exceeded) WAD cyanide, consistent with a goal of zero fauna deaths and a precautionary approach.

For less sensitive sites, limits at the discharge point to the tailings dam of 30mg/L (90th percentile) and 50mg/L (never to be exceeded) WAD cyanide, provide an appropriate level of confidence of achieving the goal of zero fauna deaths.

The limits do not apply to heap leach facilities or to 'thick concentrate' tailings. The application of the limits to existing mines is considered on a site-by-site basis, in the context of the risk of fauna access.

Application of the limits will continue to be subject to a stringent monitoring regime of both cyanide levels and fauna deaths, as well as investigation of the cause of any deaths. Should fauna deaths occur that are caused by cyanide then current management practises would be reviewed in the first instance. If the desired aims of fauna protection cannot be achieved through revised management practises then cyanide limits would then come under review.

The application of reasonable, available technology that can achieve lower levels than the above, is also considered in the derivation of licence limits. The NSW EPA advocates that lower levels be achieved, where reasonable technology is available, to further increase the confidence of prevention of fauna death.

REFERENCES

ANZECC, 2000 *Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 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

ICMI, *2002 International Cyanide Management Code for the Manufacture, Transport and Use of Cyanide in the Production of Gold.* International Cyanide Management Institute, May 2002

Short Course on the Management of Cyanide in Mining (1997) The Australian Centre for Minesite Rehabilitation Research (ACMRR) in association with the Office of Supervising Scientist (Environment Australia).

This case study was prepared by Stewart Needham, Neological Consulting NSW, in consultation with the NSW Environment Protection Authority. May 2003.