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Review

Cyanide and society: a critical review

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ABSTRACT

Chemical replacements for cyanide have been investigated for decades; however cyanide remains the exclusive lixiviant of choice in the mining industry due to a combination of its availability, effectiveness, economics and ability to use it with acceptable risk to humans and the environment. About 90% of the significant gold producing operations worldwide currently utilize cyanide for gold and silver extraction. Despite the number of cyanide-related mining operations, there have been no documented accounts during the previous three decades of the death of humans due to cyanide as a direct consequence of major mining-related environmental incidents. Major mining-related environmental incidents have not been concentrated in any geographic location, may occur regardless of the size of the company and do not occur more frequently with a specific type of mining activity. The main aspects of cyanide management that should be addressed at mining operations include transportation of cyanide to site, process solution conveyance, worker health and safety training, water management and treatment, emergency response and preparedness, workplace and environmental monitoring, and community relations. If these aspects of cyanide management are integrated into an overall cyanide management plan, dramatic reductions in risk and potential incidents at mine sites will be realized.

Keywords: Cyanide; Gold; Mining; Treatment; Environmental management

1. HISTORY, SOURCES AND USES

Since its commercial introduction in New Zealand over a century ago, cyanide has been used worldwide in the extraction of gold and silver. Although chemical replacements for cyanide have been investigated for decades, it remains the exclusive lixiviant of choice due to a combination of availability, effectiveness, economics, and an ability to use it with acceptable risk to humans and the environment. As of the year 2000, there were about 875 gold and silver operations in the world, of which about 500 were significant producers. Greater than 90% of gold recovered worldwide relies upon the use of cyanide. There are also about one half dozen major gold smelters in the world.

On shown on Figure 1, gold and silver mines are found throughout the world with an increasing trend toward South American and Australian production and above ground open pit and heap leach mining. About 2,650 tonnes of gold were recovered worldwide in 2003 with the top twenty gold mines accounting for about one-quarter of total production. The distribution of global gold production is presented in Figure 2 (Mining Journal, 1996; Mining Magazine, 2000). Although confidence in and trust of the mining industry has declined, nonetheless the demand for metals, minerals, and other raw materials continues to steadily rise throughout the world by several percent annually.

As shown on Figure 3, about 1.1 million tonnes of hydrogen cyanide (HCN) are produced annually worldwide of which about 900,000 tonnes originates as either primary production or as a by-product from multiple facilities in the United States. There are several smaller primary production facilities in Australia for both solid and liquid sodium cyanide. The demand for sodium cyanide worldwide is about 360,000 tonnes per annum of which about 120,000 tonnes or one-third is used in the recovery of gold and silver. On an equivalent basis only about 6% of the HCN production is converted into sodium cyanide used in the mining industry. There is increasing production and demand for concentrated liquid sodium cyanide both in the United States and Australia (Chemical Market Reporter, 1998; 1999).

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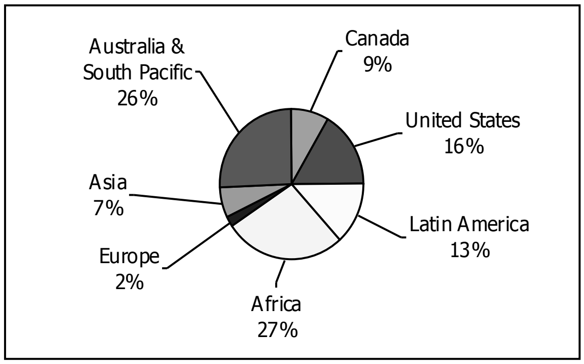

Figure 1. Distribution of World mines that use cyanide

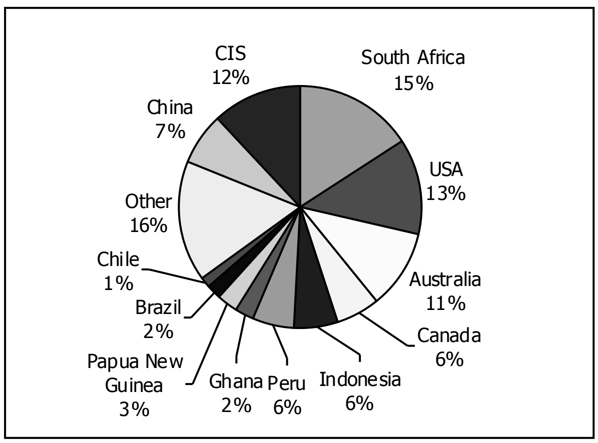

Figure 2. Global gold production by country

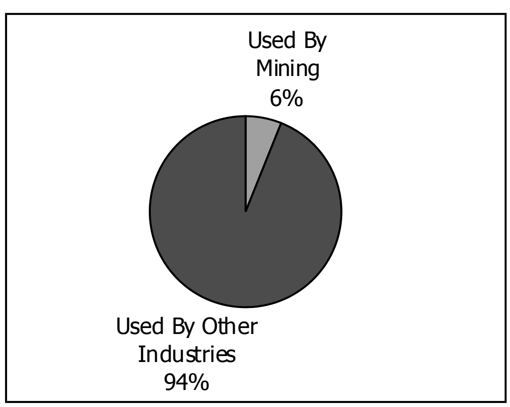

Figure 3. Industrial uses of hydrogen cyanide

The remaining 94% of the hydrogen cyanide is used in the production of a wide range of items such as adhesives, computer electronics, fire retardants, cosmetics, dyes, nylon, paints, pharmaceuticals, plexiglas, rocket propellant, and road and table salts. Nearly 50% of the HCN produced is used in the synthesis of adiponitrile which is the organic precursor to nylon.

The benefits of cyanide are many, and its products are used safely by hundreds of millions of people worldwide everyday. Only a small portion of the cyanide produced worldwide is used in mining. The elimination of gold and silver mining would not eliminate the risks associated with either cyanide or mining, but would negatively affect the lives of many people depending upon the manufactured goods and economic benefits derived from cyanide production (The Gold Institute, 2000).

Regardless of the perceived or real risks associated with cyanide used at established and permitted mining operations, it is far superior and safer for society and the environment than the impacts arising from the use of mercury amalgamation employed in gold recovery by the millions of unregulated artisanal small scale miners worldwide.

2. THE RISK AND EXPOSURE TO HUMANS

The controversy surrounding mining has more recently focused upon the gold industry and the use of cyanide through environmental campaigns and with documents such as Dirty Metals: Mining, Communities, and the Environment published by Earthworks formally the Mineral Policy Center. The fear of cyanide arises from several historical sources, which are largely non-mining related. It is this fear that is frequently exploited to generate negative public sentiment against mining in general. If cyanide is used improperly, it can be toxic to humans and wildlife. There is no question regarding this matter. There are many myths and misconceptions surrounding cyanide that have accumulated over many decades (Mudder and Smith, 1994; Mason, 1997). However, the same statement applies to driving an automobile or using household products such as bleach containing chlorine, a chemical nearly as toxic as cyanide. Fatal accidents arising from natural disasters and around the home far exceed those associated with industrial cyanide exposure, yet these much higher risks are deemed acceptable and are tolerated in our daily lives (Kahn, 2003).

Some people conclude that mining, as a whole, should be halted due to occasional and regrettable inadequacies of an operation leading to a regrettable environmental incident. Although we do not have to apologize for the existence of risk, we do have to take responsibility for ignoring it. There is an ethical and moral obligation to identify and communicate the level of risk to workers and the public. By acknowledging and being aware of the risks associated with the use of cyanide, the proper level of emergency preparedness and response can be implemented.

Whether or not mining in general should be allowed is not debatable from a practical viewpoint, since humans have been using metals and minerals extracted from the Earth for many millennia and will continue to do so for many more. As the search for ore bodies moves into less developed countries and more remote and sometimes environmentally sensitive regions, a balance must be sought between the struggle to define sustainable development, manage limited resources, and alleviate poverty versus mining every newly discovered metal and mineral deposit.

Public concern regarding the safety and environmental aspects of cyanide is valid and understandable, considering its historical uses and several recent mining incidents, which have involved cyanide. In spite of these concerns, cyanide remains vital to a large number of industries and is handled in a safe and environmentally sound manner at scores of industrial sites worldwide. Nonetheless, cyanide is potentially toxic, and like most chemicals, if it is mishandled or misused can result in severe impacts to humans and the environment. Humans at work and at home come in daily contact with cyanide and its derivatives through foods we eat and products we use. In addition to mining, there are dozens of other occupations in which workers come in frequent contact with cyanide.

Although potential worker exposure to cyanide is comparatively high in the mining industry, there have been about one-half dozen purported accidental deaths worldwide over the last century which translates into one fatality every two decades. There are about 15,000 worker fatalities worldwide each year in the mining industry with more than two-thirds occurring in China. Most of the fatalities occur in the coal and not hard rock mining sector of the industry. A quantitative assessment of risk associated with dying from cyanide exposure in the mining industry would result in a "negligible" designation. This annual number of fatalities compares with 2.9 million due to HIV/AIDS, 1.2 million due to vehicle accidents, 1.1 million due to malaria, and 75,000 from natural disasters.

In the United States, the number of deaths due to cyanide exposure typically ranges from none to two or three on an annual basis, the causes of which are almost always the result of accidents and intentional suicides in the home. Accidental death due to cyanide exposure in the workplace or the home is very low, and thousands of times less than the risk of either dying in a vehicle mishap, from drowning, or from simply falling down. The risk of dying from cyanide exposure at a mining operation is less than that of being in a bicycle accident in Beijing, struck by lighting in Florida, trampled by an elephant in Kenya, or attacked and eaten by a crocodile in Australia. The absurdity of these comparisons underscores the actual negligible risk associated with dying from exposure to cyanide.

The highest exposures of the general population to cyanide in the United States arise from automobile exhaust and cigarette smoking. Most of the cyanide and related compounds entering surface waters originates in effluents from municipal sewage treatment plants and from the iron cyanide used in road salt as an anti-caking agent (Towill *et al.*, 1978).

According to the United States Environmental Protection Agency (USEPA) Toxic Release Inventory or TRI data for 2001, about 50 tonnes of cyanide were released to surface waters of the United States from all mining and metals related sources (USEPA, 2001). In contrast, 10 million tonnes of salt are applied to roads annually in the United States containing about 700 tonnes of iron cyanide as an anti-caking agent. On a comparative basis, the quantity of cyanide released to surface waters of the United States through runoff of road salt exceeds that of industry by as much as an order of magnitude. There are many documented cases of adverse environmental impacts arising from runoff containing road salt entering surface waters with resultant cyanide levels exceeding both acute and chronic USEPA water quality criteria for protection of aquatic life (Paschka *et al.*, 1999; The Salt Institute, 2000).

Cyanide originates from both manmade and natural sources. Ironically, many scientists have postulated cyanide as the first organic compound on earth, from which the chemical building blocks of life evolved (Oparin, 1957; Rawls, 1997). Cyanide is formed, excreted, and degraded naturally by thousands of animals, plants, insects, fungi, and bacteria. The levels of cyanide potentially produced and released upon digestion or cooking of cyanogenic plants can reach several hundreds of parts per million as noted in Table 1 (Eisler *et al.*, 1991). Ingestion of these plants can cause death in animals and chronic poisoning in humans. The list of cyanide producing plants includes almonds, apricots, bamboo, bean sprouts, cassava, cashews, cherries, lentils, olives, potatoes, sorghum, and soybeans. The best-known example of human cyanide poisoning from a natural source involves the ingestion of cyanogenic plants and particularly cassava by hundreds of millions of people living in equatorial countries of the world. If improperly prepared, cyanide can be released at toxic levels resulting in a chronic paralysis of the arms and legs particularly amongst young people. Several thousand cases of Konzo have been documented in African countries.

Although the record regarding cyanide use has been exemplary, and stringent safeguards and standards exist regulating its manufacture, transport, storage, use, and disposal, nonetheless accidents involving cyanide do occur, sometimes with severe impacts. However, reductions in the number of incidents and resultant impacts are possible, with the first steps involving a change in attitude and an increase in awareness. Along with attitude and awareness, comes the realization and acceptance of the fact that no level of regulation can or has eliminated all risk from our daily lives.

Table 1
Background cyanide concentrations in selected plants

Cyanogenic Plant Species	Concentration (mg/kg)
Bamboo (*Bambusa, Arundinaria, Dendrocalamus*)	
Tip	Max. 8,000
Stem	Max. 3,000
Stargrass, *Cynodon plectostachyus*, whole	180
Rose Family, *Malus* spp., *Pyrus* spp.	Max. 200
Cassava, *Manihot esculenta*	
Bitter varieties	
Leaves	347-1,000
Roots	327-550
Dried roots	95-2,450
Stem	1,130
Mash	162
Bark	
Total cyanide	1,351
Free cyanide	102
Peel	
Total cyanide	1,390
Free cyanide	255
Pulp	
Total cyanide	810
Free cyanide	53
Sweet varieties	
Leaves	377-500
Roots	138
Dried roots	46-<100
Mash	81
Lima Bean, *Phaseolus lunatus*	
United States	100-170
Burma	2,100
Puerto Rico	3,000
Java	3,120

continued (Table 1)

Cyanogenic Plant Species	Concentration (mg/kg)
Almond, *Prunus amygdalus*, nut	
Bitter	280-2,500
Spicy	86-98
Sweet	22-54
Seeds, 4 species, Nigeria, whole, frequently consumed by humans	
Phaseolus sp.	381-1,093
Vigna sp.	285-1,223
Cajanus sp.	208-953
Canavalia sp.	285-953
Sorghum, *Sorghum* spp., young plant, whole	Max. 2,500

3. THE TOXICITY OF CYANIDE

Other than humans, there are three basic groups of animals which are of concern with respect to cyanide exposure (Hagelstein and Mudder, 1997a). The first group includes the terrestrial animals like mammals, reptiles, and amphibians. The second group involves migratory birds and waterfowl, while the third group involves aquatic life forms. With respect to the first group, adverse impacts to terrestrial animals resulting from exposure to cyanide solutions at precious metals operations have been limited, due to the proximity to human activities and implementation of exclusion techniques. Ecological impacts resulting from exposure to cyanide arise from both manmade and natural sources of the chemical.

In 1991, the United States General Accounting Office (GAO) conducted a study of 119 active precious metal operations using cyanide in Arizona, California, and Nevada. A total of 31 inadvertent releases of cyanide were reported in generally remote and arid areas. The GAO concluded that the impacts resulting from these releases were not serious and that from a regulatory standpoint, appropriate containment designs and engineering standards are available to protect terrestrial animals (GAO, 1991). In contrast, the United States Coat Guard (USCG) reported release of hundreds of thousands of liters of chemicals and oil into surface waters arising from tens of thousands of reported spills throughout the country during 2003 (USCG, 2003).

Of equal or greater environmental concern is the exposure of domestic and wild animals to cyanogenic plants and to cyanide containing devices placed in the ground and used to control nuisance predators, like the coyote. Decades ago, the United States Department of Agriculture issued a pamphlet to farmers and ranchers regarding the dangers of their livestock ingesting cyanogenic plants. The United State Fish and Wildlife Service (USFWS) uses a cyanide containing device termed the M44 Injector for coyote control. This devise is buried in the ground and artificially scented to attract coyotes and other carnivores. The USFWS estimates that more than 18,000 coyotes are killed each year using the M44. However, the M44 has also killed scores of additional terrestrial animals and birds of prey as well as protected, threatened, and endangered species.

In addition to the other manmade sources of cyanide entering the environment, there is the widespread use of chemical retardants containing iron cyanide as an anti-caking agent in the fighting of forest fires by the United States Forest Service (USFS). Millions of liters of chemical retardants containing about 400 tonnes of iron cyanide derivatives are being applied in an effort to fight forest fires in the United States each year. Although the toxicity to aquatic life of these chemical reagents containing iron cyanide has been documented through laboratory testing and environmental monitoring by federal government agencies and scientists, their continued application is nonetheless condoned.

With respect to migratory birds and other waterfowl, the primary concern has been exposure of these animals to open solution ponds and tailings impoundments containing elevated cyanide levels. This issue was of serious concern during early part of the last decade, particularly in North America and Australia. Through a cooperative effort between industry and government, this environmental concern has been virtually eliminated either by covering smaller process ponds with nets or floating balls, or by lowering the weak acid dissociable (WAD) cyanide levels entering large tailings impoundments (Hagelstein and Mudder, 1997b). The WAD cyanide contained in tailings slurries discharged into impoundments can be destroyed through treatment or recovered and reused. A level of 50mg/l WAD cyanide in the tailings slurry entering an impoundment has been extensively used as a regulatory guideline providing protection of animals coming in contact with the stored solution. In practice, the resultant WAD cyanide level is reduced well below 50mg/l within the tailings pond due to ongoing natural attenuation.

Several thousand bird mortalities occurred as the result of exposure to cyanide containing solutions at mining operations in Arizona, California, and Nevada in the 1980's. During the same period tens of millions of migratory birds were killed legally by hunters. By the early 1990's due to a reduction in cyanide levels and physical covering of solution ponds, the level of bird mortality had been reduced to less then ten per mine according to the Nevada Mining Association. In contrast, it is estimated that pet cats account for over one billion bird deaths per year in the United States. It is further estimated that as many as 80 million birds die each year through collisions with windows. Nearly, 60 million birds are killed each year colliding with vehicles and one million through collisions with buildings. It has been estimated that several thousand birds can die in one evening by coming in contact with a large radio antenna.

The most vulnerable component of the ecosystem to potential adverse impacts from exposure to cyanide is aquatic life. Aquatic organisms are generally the most sensitive to the toxicological effects of cyanide and cannot physically avoid it upon entering their environment. The primary issue relating to exposure of aquatic life arises from the inadvertent release of solutions containing elevated levels of cyanide into surface waters.

In general, elevated and acutely toxic levels of cyanide are often associated with the extraction of gold and silver, since only very low concentrations of cyanide are sometimes used in the beneficiation of base metals as a flotation reagent. The problem does not extend to excess tailings solutions that have been treated prior to discharge. There are excellent examples of treated process solutions arising from gold and silver operations being discharged into sensitive aquatic ecosystems for many years without adverse environmental impacts.

4. CHEMISTRY, ANALYSIS AND TREATMENT

There are several forms of cyanide potentially present in process solutions associated with the extraction of gold and silver. Related to cyanide are additional compounds formed through interactions with the ore, water treatment, and natural attenuation. Historically, the forms of cyanide most frequently discussed included free, weak acid dissociable (WAD), total, and amenable to chlorination (CAC). Over the years, the WAD analytical procedure has been adopted by industry and the regulatory authorities for measurement of the "toxicological significant" or "ecologically sensitive" forms of cyanide. The WAD analytical procedure measures free and weakly complexed forms of cyanide. Subtraction of the WAD cyanide value from the total cyanide value provides a measure of the essentially non-toxic and stable iron cyanide level present. Applied and conducted properly, the total and WAD cyanide procedures produce reliable and meaningful results that can be used for compliance and monitoring purposes. The sensitivity of these methods is sufficient to quantify the forms and levels of cyanide that could be harmful to humans and the environment.

Problems arise when these analytical methods are extended beyond their capabilities in an attempt to quantify cyanide at levels approaching detection and below which environmental impacts occur. Unwarranted concern and emphasis is placed upon the significance of unreliably low values of cyanide. In order to protect humans and the environment, reasonable levels of protection can be provided through promulgation of standards that not only protect designated uses of surface and ground water, but also can be achieved through treatment and analyzed accurately using approved methods. There is a need for consensus amongst industry, governmental agencies, and commercial laboratories regarding the most appropriate cyanide analytical procedures and their applicability.

It is imperative that the interpretation of cyanide data be tempered with an understanding of the reality of the problems associated with its analysis at levels below which no measurable impacts are occurring. Appropriate criteria and standards can be promulgated for weak acid dissociable (WAD) limits that are both quantifiable and protective of humans and the environment.

There are robust and reliable chemical, physical, and biological technologies for removing cyanide and its related compounds operating at dozens of mining operations throughout the world. These processes alone or in combination are capable of achieving effluent levels protective of the environment. In general, there are four chemical oxidation technologies that are currently being used to destroy cyanide (Botz and Mudder, 2000; Akcil and Mudder, 2003; Botz *et al.*, 2004). These technologies summarized in Table 2 include amongst others copper catalyzed hydrogen peroxide, Caro's acid, the sulfur dioxide/air process, and alkaline or breakpoint chlorination.

These processes have been used in full-scale applications throughout the world for decades. In the event a higher quality effluent is needed than can be produced by one of the chemical oxidation technologies, advanced treatment in the form of granular activated carbon can be employed as a polishing process. Cyanide has been successfully treated passively and actively using a variety of aerobic and anaerobic biological treatment processes. As a substitute to cyanide destruction, the recovery of cyanide is again being accomplished at mining operations throughout the world. In this process, about 90% of the WAD cyanide can be recycled through recovery and reuse in the metallurgical process. There are many distinct environmental advantages including a lowering of transportation risks and the potential for contamination of groundwater beneath tailings impoundments.

Table 2
Preliminary guide to selecting cyanide treatment processes

Treatment Process	Iron Cyanide Removal	WAD Cyanide Removal	Slurry Application	Solution Application
SO_2/Air	✓	✓	✓	✓
Hydrogen Peroxide	✓	✓		✓
Caro's Acid		✓	✓	
Alkaline Chlorination	✓	✓		✓
Iron Precipitation	✓	✓	✓	✓
Activated Carbon	✓	✓		✓
Biological	✓	✓		✓
Cyanide Recovery		✓	✓	✓
Natural Attenuation	✓	✓	✓	✓

The success of these processes has demonstrated that cyanide-containing solutions can be treated and discharged into the environment safely and on a continuous basis. The use of treatment facilities and discharge of effluent to maintain site and operational water balances is preferable to attempting to maintain a "zero water balance" with no provision for treatment under extreme climatologic conditions. Incorporating the ability to treat and discharge solution safely into the environment should be encouraged in the initial stages of mine development and design. Many of the major environmental incidents that occur at gold and silver operations have involved the inadvertent release of tailings solutions and slurries containing elevated cyanide concentrations into nearby surface waters. The major result of these releases of cyanide was the acute or short-term toxicological impacts to aquatic life.

The scientific knowledge regarding the chemistry, analysis, environmental fate, toxicity, and treatment of cyanide has increased dramatically over the last two decades (Smith and Mudder, 1991; T.W. Higgs Associates Ltd, 1992; Mudder, 1998; Smith and Mudder, 1998; Botz and Mudder, 2003;). Although cyanide can be toxic to humans and produce adverse effects on the environment, this knowledge of cyanide and its related compounds is of sufficient depth to use it safely. Unfortunately, accidents resulting from human error have and will continue to infrequently occur. The key to limiting environmental impacts from cyanide and mining is to focus on the actual and not perceived sources and causes.

5. ENVIRONMENTAL INCIDENTS AND MINING

Environmental incidents due to mining operations are often attributed to cyanide, whether it is involved or not. This situation arises from the perception that mining and cyanide are synonymous, or a simple desire to portray mining in a negative light.

Cyanide is not generally associated with long-term environmental impacts. The impacts of cyanide are usually acute or short-term in nature, lasting on the order of hours to days. In contrast, long-term environmental impacts from mine sites are generally associated with the release tailings slurries, which once deposited in and along surface waters may be susceptible to oxidation and the slow release of acidic and metals containing drainage. The long-term environmental concerns may often evolve into economic issues associated with the financial surety and stability of the mining companies themselves.

To begin a discussion regarding development of a global code of practice for cyanide management, a review of the major environmental incidents associated with mining and their underlying causes is appropriate. A summary of major environmental incidents associated with all types of mining operations worldwide during the past three decades is presented in Table 3. The information in Table 3 was taken from a variety of published sources (USCOLD, 1994; UNEP, 1996). This review was not intended to be completely comprehensive and was somewhat skewed due to differences in reporting requirements of such incidents in different nations. A major incident was defined as one involving a release of tailings slurry or solution with resultant impacts to humans and ecological systems, in particular aquatic life.

Table 3
Chronology of major mining-related environmental incidents since 1975

Year	Location	Cause	Type of Operation	Description		Cyanide Present? Yes	Cyanide Present? No
1975	USA	Dam Mishap	Lead/Zinc	Size of Release: Human Fatalities:	150,000m^3 0		✓
1976	Yugoslavia	Dam Mishap	Lead/Zinc	Size of Release: Human Fatalities:	300,000m^3 0		✓
1977	USA	Pipe Failure	Uranium	Size of Release: Human Fatalities:	30,000m^3 0		✓
1978	Japan	Dam Mishap	Gold	Size of Release: Human Fatalities:	80,000m^3 1	No Data	
1978	Zimbabwe	Dam Mishap	Gold	Size of Release: Human Fatalities:	30,000t 1	No Data	
1980	USA	Dam Mishap	Copper	Size of Release: Human Fatalities:	2,000,000m^3 0		✓
1982	Philippines	Dam Mishap	Copper	Size of Release: Human Fatalities:	27,000,000m^3 0		✓
1985	USA	Dam Mishap	Gold	Size of Release: Human Fatalities:	25,000m^3 0	No Data	
1985	Chile	Dam Mishap	Copper	Size of Release: Human Fatalities:	500,000m^3 0		✓
1985	Chile	Dam Mishap	Copper	Size of Release: Human Fatalities:	280,000m^3 0		✓
1985	USA	Dam Mishap	Sand & Gravel	Size of Release: Human Fatalities:	11,000m^3 0		✓
1985	Italy	Pipe Failure	Fluorite	Size of Release: Human Fatalities:	200,000m^3 268		✓
1986	Brazil	Dam Mishap	Iron	Size of Release: Human Fatalities:	100,000t 7		✓
1988	USA	Pipe Failure	Coal	Size of Release: Human Fatalities:	250,000m^3 0		✓
1988	China	Dam Mishap	Molybdenum	Size of Release: Human Fatalities:	700,000m^3 20		✓
1991	USA	Dam Mishap	Gold	Size of Release: Human Fatalities:	39,000m^3 0	✓	
1992	Philippines	Dam Mishap	Copper	Size of Release: Human Fatalities:	80,000,000t 0		✓
1994	South Africa	Dam Mishap	Gold	Size of Release: Human Fatalities:	600,000m^3 17		✓
1995	Guyana	Dam Mishap	Gold	Size of Release: Human Fatalities:	4,000,000m^3 0	✓	
1995	Australia	Dam Mishap	Gold	Size of Release: Human Fatalities:	40,000m^3 0	✓	
1995	Australia	Dam Mishap	Gold	Size of Release: Human Fatalities:	5,000m^3 0	✓	
1995	Philippines	Dam Mishap	Gold	Size of Release: Human Fatalities:	50,000m^3 12		✓
1996	Philippines	Pipe Failure	Copper	Size of Release: Human Fatalities:	1,500,000t 0		✓
1996	Bolivia	Dam Mishap	Lead/Zinc/Silver	Size of Release: Human Fatalities:	400,000t 0		✓
1997	USA	Dam Mishap	Copper	Size of Release: Human Fatalities:	230,000m^3 0		✓
1998	Kyrgyz Republic	Transportation Accident	Gold	Size of Release: Human Fatalities:	1,800kg sodium cyanide 0	✓	
1998	USA	Pipe Failure	Gold	Size of Release: Human Fatalities:	Several tonnes 0	✓	
1998	Spain	Dam Mishap	Lead/Zinc/Copper/Silver	Size of Release: Human Fatalities:	5,000,000m^3 0		✓

continued (Table 3)

Year	Location	Cause	Type of Operation	Description		Cyanide Present?	
						Yes	No
1998	Spain	Dam Mishap	Phosphate	Size of Release: Human Fatalities:	50,000m^3 0		✓
1999	Philippines	Pipe Failure	Gold	Size of Release: Human Fatalities:	700,000t 0	✓	
2000	Romania	Dam Mishap	Gold	Size of Release: Human Fatalities:	100,000m^3 0	✓	
2000	Romania	Dam Mishap	Base Metals	Size of Release: Human Fatalities:	22,000m^3 0		✓
2000	Papua New Guinea	Transportation Accident	Gold	Size of Release: Human Fatalities:	150kg sodium cyanide 0	✓	
2000	USA	Dam Mishap	Coal	Size of Release: Human Fatalities:	950,000m^3 0		✓
2000	Sweden	Dam Mishap	Copper	Size of Release: Human Fatalities:	2,500,000m^3 0		✓
2001	Ghana	Pipe Failure	Gold	Size of Release: Human Fatalities:	650m^3 0	✓	
2001	China	Transportation Accident	Gold	Size of Release: Human Fatalities:	11t liquid cyanide 0	✓	
2002	Australia	Transportation Accident	Gold	Size of Release: Human Fatalities:	400 liters liquid cyanide 0	✓	
2003	Chile	Dam Mishap	Copper	Size of Release: Human Fatalities:	50,000t 0		✓

As indicated, there have been more than 30 major incidents over last 29 years, or about one incident per year. These incidents have involved junior, intermediate, and large mining companies. As shown on Figure 4, the incidents have occurred throughout the world and have involved transportation accidents, pipe failures, and tailings dam related causes.

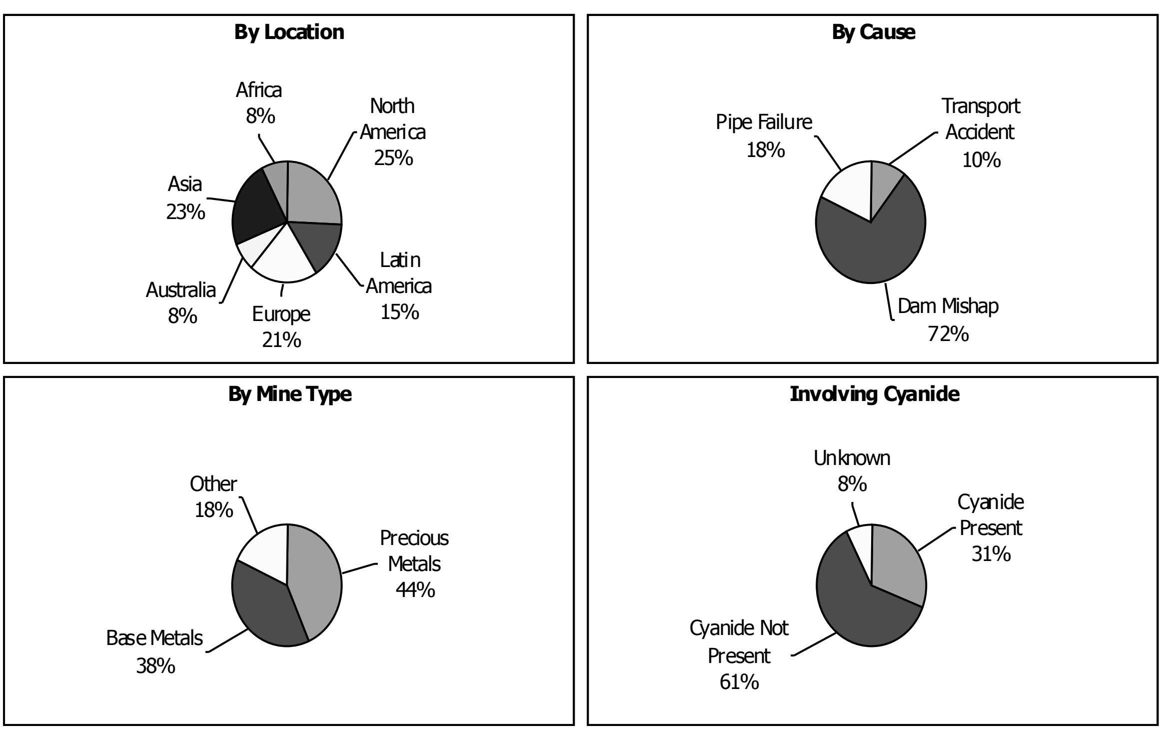

Figure 4. Summary of major mining-related environmental incidents since 1975

The tailings dam related causes, which accounted for the majority environmental incidents, have included overtoppings and geotechnical failures due to design flaws and earthquakes. Based upon the antidotal information associated with these incidents, the release of cyanide has not been directly responsible for any of the human fatalities. It appeared that human fatalities have been the result of physical inundation by the tailings themselves, such as washing away of homes. The major environmental impacts of cyanide have been associated with short-term effects leading to injury and mortality of aquatic life.

A more detailed examination of the environmental incidents related strictly to gold and silver mining operations is presented on Figure 5. As with all mining related environmental incidents, they have been distributed throughout the world with the major causes having been related to a water management or engineering aspect of tailings dams. The percentage of incidents related to transportation has been slightly higher for the gold and silver operations than mining in general. In both transportation related incidents, non-traditional methods were employed to bring the cyanide pellets to the mining operation.

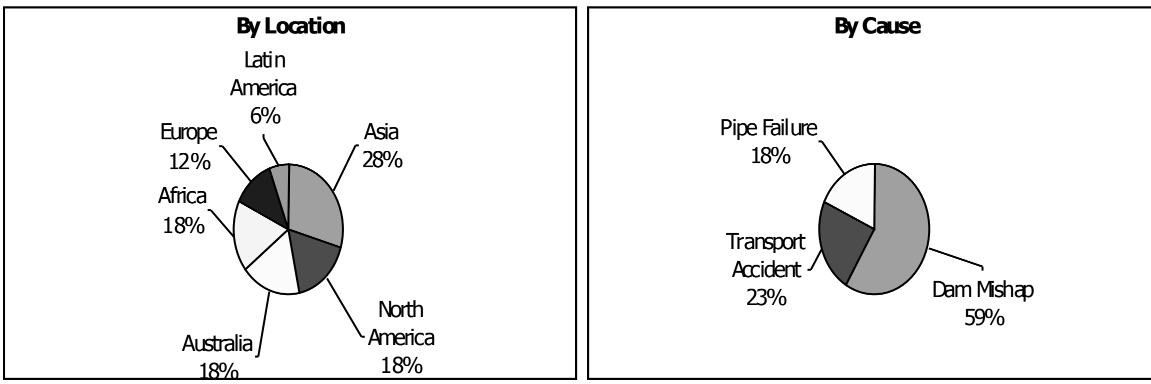

Figure 5. Summary of major mining-related environmental incidents since 1975 in the gold industry

As is discussed in the next section, adherence to the many codes of practice and management plans that exist for cyanide throughout the world could reduce a portion of the incidents that have occurred. One specific area not addressed in the various codes and management plant relates to the levels of cyanide allowed in tailings impoundments. The lowering of WAD cyanide levels in tailings impoundments could dramatically reduce the risk of adverse short-term impacts to aquatic life. With respect to environmental impacts, aquatic organisms are the most frequently affected component of the ecological system. A recommended target level of less than 50mg/l WAD cyanide for tailings slurries entering impoundments would not only protect wildlife but also lower the risk of adverse impacts to the environment in the event of an inadvertent release.

A comparison of the recent environmental incidents related to the tailings dam failures in Spain, Guyana, and Romania provides additional insight into this issue. The large dam failure in Spain did not involve cyanide, although severe short-term and potentially long-term impacts to humans and the environment occurred. In this incident, a large release of tailings entered a large river system. In the case of the dam failure in Romania, a large release of tailings containing elevated cyanide levels entered a major river system resulting in severe impacts to aquatic life hundreds of kilometers downstream. In contrast in Guyana, release of a large quantity of tailings into a small stream resulted in significantly less impacts to aquatic life due to the much lower WAD cyanide levels.

From the information available regarding major mining related environmental incidents, a dramatic reduction in the risk of short-term adverse impacts could realized by lowering WAD cyanide levels to below 50mg/l prior to discharge into a tailings impoundment. However, in order to achieve a major reduction in impacts resulting from mining operations, there must be increased emphasis on water management practices and tailings dam safety.

6. REGULATIONS, MANAGEMENT AND CODES

The manufacture, transport, storage, use, and disposal of cyanide can be managed safely and are strictly regulated in many countries worldwide (E.I. du Pont de Nemours and Company, 1988; Degussa AG, 2000). Countries throughout the world have stringent narrative and numerical standards and criteria limiting exposure of humans, livestock, wildlife, and aquatic organisms to cyanide. Many countries have severe civil and criminal penalties arising from the accidental and intentional violation of these standards and regulations.

Nonetheless, there are risks associated with the use of cyanide, and accidents do occur. Not all countries regulate cyanide to the same degree. When environmental impacts do occur from cyanide in less regulated countries, these incidents are sometimes exploited in an attempt to justify the need for more controls and legislation worldwide, when adoption, acceptance, implementation, and enforcement of existing regulations, standards, codes of practice, and management plans are the solution.

The mining of metals and minerals has become and will remain a global industry with companies operating on six continents. In order to remain a sustainable worldwide industry, mining companies in association with governments, environmental organizations, and other stakeholders and stockholders must adopt an attitude and code of practice toward environmental stewardship that incorporates the concepts of transparency and verification.

Many mining companies and operations worldwide are continuously updating and improving their environmental monitoring, reporting, and compliance programs through internal and external employee training and audits. In response to concerns raised by the public, mining companies have instituted environmental mission statements, guidelines, and codes of ethics. However, no degree of legislation and planning can eliminate completely risks or impacts to the environment. If an accident occurs, responsible mining companies have established rigorous emergency response procedures.

There are both general and specific codes of practice and management plans that have been developed for cyanide around the world. The goal should not be to create more regulations but to utilize the operational experience and technical expertise associated with the various cyanide management and codes of practice to formulate a single unified document for global application. Adherence to that code and management plan is essential and requires acceptance of an alliance and association of many stakeholders and stockholders. This experience and expertise can be combined with a wealth of new scientific information to produce a consensus for cyanide management in the precious metal mining industry (Rouse, 1988; U.S. Bureau of Land Management, 1991; Department of Mines and Energy, 1992; Duffield and May, 1998; Logsdon *et al.*, 1999).

7. CONCLUSIONS

About 90% or 450 of the significant gold producing operations worldwide currently utilize cyanide for gold and silver extraction. Despite this large number of cyanide-related mining operations, there have been no documented accounts during the previous three decades of the death of humans due to cyanide as a direct consequence of major mining-related environmental incidents. All published accounts of human deaths due to mining-related environmental incidents have been the result of physical inundation with tailings materials.

It appears that major mining-related environmental incidents have not been concentrated in any geographic location, are likely to occur regardless of the size of the company and do not occur more frequently with a specific type of mining activity. Furthermore, most major incidents have been the result of some sort of dam overtopping, breaching, geotechnical failure, or earthquake. The banning of cyanide from mining will not eliminate the risk of environmental impacts due to mining. The other two primary causes of major cyanide related incidents include pipeline ruptures and transportation accidents related to shipments of cyanide.

Several cyanide treatment and recovery technologies have been widely demonstrated to reliably control cyanide levels in mining solutions. With proper use of these technologies, tailings cyanide concentrations can be maintained at levels protective of wildlife while reducing the potential for severe environmental incidents. The development of a written cyanide management plan should take into consideration adoption of a WAD cyanide standard that maintains the levels entering an impoundment below 50mg/l. In conjunction with lowering of the WAD cyanide levels, further review of dam design and water management practices should be undertaken. The main aspects of cyanide management that should be addressed include transportation of cyanide to site, process solution conveyance, worker health and safety training, water management and treatment, emergency response and preparedness, workplace and environmental monitoring, and community relations. If these aspects of cyanide management are integrated into an overall cyanide management plan, dramatic reductions in risk and potential incidents will be realized.

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