De-coding Cyanide

An Assessment of Gaps in Cyanide Regulation at Mines

A Submission to the European Union and the United Nations Environmental Programme

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Foreword

Cyanide is a chemical that is both efficient in extracting gold from mined ore, and lethal. Cyanide is a chemical lethal to humans in small quantities; a teaspoon of 2% cyanide solution can cause death.

Processing chemicals such as cyanide have made it profitable to mine ore bodies with low ore grades. Such ore bodies would have been left un-mined in the past. However, this method of mining, using large quantities of cyanide to remove microscopic specs of gold from vast amounts of ore or crushed rock, is generating more and more controversy. Due to a string of spills and accidents, there is growing concern about the environmental, human health, and human rights impacts of large-scale mining operations that use cyanide. Mines that use cyanide as a processing agent often lead to conflicts over the use of land and natural resources such as water. Too often gold mines of this type cause human rights violations like forced evictions and the destruction of land and water, thus depriving communities and people of their very base of existence (clean water, lands for agriculture, forest and fishing). The recent history of cyanide spills is fostering growing public concern about the potential for more spills and accidents, leading to massive water pollution problems. In response, a number of jurisdictions have banned dangerous mining practices and others are seeking to implement similar bans.

Often industry representatives, industry trade associations, and governments attempt to dismiss public concerns about cyanide and its impacts. They argue that modern cyanide process mines can be, and are, well managed. They argue that responsible companies will not pollute. They even argue that responsible companies should be allowed to self-regulate their mine operations. Unfortunately, the record does not support this argument.

Public concerns are based upon mounting evidence that too often things go wrong, even when companies claim to have good management systems in place.

More importantly, as this report will demonstrate, most of what has been proposed by industry and governments in regard to cyanide management misses the mark. These "codes" or regulations fail to address the issues that are of most concern to the public. Issues such as protecting land resources, communities, and water resources. Arguably, current "code" and regulatory proposals amount to *greenwashing* in that they give the appearance that governments and mining companies are addressing environmental issues, when in fact they are not.

At the core of any legitimate discussion of the regulation of mining, must be the issue of community consent. The sponsors of this report (Hellenic Mining Watch, Ecotopia, CEE Bankwatch, FOE Europe, FOE Hungary (MTVSz), FOE Czech Republic (Hnuti DUHA), Food First Information and Action Network (FIAN), MineWatch UK, and Mineral Policy Center support the rights of communities to make their own decisions about whether or not they want to allow large-scale

mining and, if so, under what conditions. In some cases this has led communities and governments to simply ban cyanide process mines. In no instance should a community be forced to accept a project that they do not want, the risks are too high.

Note: The views expressed in this foreword are those of the project sponsors.

Executive Summary

The following recommendations and conclusions are drawn from analysis and evidence provided in the body of this report. Despite assertions to the contrary the evidence demonstrates that regulators, and the industry, have not yet adequately addressed the major issues of public concern that result from the use of cyanide (CN) in mining operations, such as those described below. This is true even of current efforts, sponsored by the United Nations Environmental Program (UNEP) and the now defunct International Council for Metals and the Environment (ICME) to develop a "code" for cyanide management.

- Mining waste should be regulated in the same manner as chemical or industrial waste. Data from the United States Environmental Protection Agency (US EPA) indicate that the mining industry is the largest generator of toxic releases in the U.S.
- The public needs **independent** studies and monitoring. Even the UNEP cyanide code development process is largely funded and driven by industry—hence it gives largely their perspective. As evidence of its shortcomings, the Code makes clear that no suitable emergency response exists for Baia Mare-like accidents.
- At present, we do not know whether numerous cyanide compounds are present in mining wastes, and at what concentrations. Answers to many questions about the presence, persistence, and toxicity of cyanide and related compounds in the environment are lacking.
- Monitoring must be expanded to include several CN forms: WAD-CN, Total-CN, thiocyanate, cyanate, and organic cyanides. Such monitoring should also include an extensive suite of metals and non-metals.
- Long-term, independent toxicity studies are needed to evaluate the impacts to human, plant, and animal communities, especially aquatic species.
- Answers to numerous sampling and analytical problems need to be resolved with respect to cyanide and related compounds.
- Regulators must enforce the need to collect statistically meaningful baseline data (waters, soils, biota) so that changes and impacts can be detected.
- Even with the use of vat-leach procedures, significant problems will continue to exist during post-closure phases. These will require true long-term management and responsibility.
- Efforts should be taken to minimize or prevent the generation of water-saturated mining wastes.
- Many of the accepted conclusions about the geochemistry of cyanide leach systems are true for arid environments, but are largely unproven in wet ones.
- Cyanide destruction processes lower concentrations of many cyanides, but not all; several toxic constituents remain.
- Mining cyanide-leach wastes have the potential to negatively impact municipal sewage and water treatment procedures, potentially causing human intake of several toxic substances to increase.

- Independent mining environmental economic studies need to be conducted. Such studies must realistically consider long‑term environmental impacts and costs.
- Enforceable financial assurance measures need to be implemented, based on independent economic evaluations.

Introduction

Purpose and Scope
This paper presents technical comments on environmental issues surrounding cyanide use in the metal mining industry. Many of the comments pertain to the various cyanide-leach processes used to extract gold and silver. However, cyanide is also used as one of the flotation reagents to separate various metals in multi-element ores, for example to separate copper from molybdenum and selenium, etc.

Many of these issues have been previously raised in papers by Moran and are cited in the references. The following report, prepared as a submission to the European Union (EU) and the United Nations Environmental Progamme (UNEP), expands on some of these themes.

Background
Mining produces tremendous amounts of solid waste (waste rock, spent ores, tailings), which contain process chemicals, waste metals, and other toxic components. The U.S. EPA states in its Toxics Release Inventory (TRI) for 2001 that the mining industry is the largest source of toxic releases in the USA (U.S. EPA, 2001). In 1999, it released approximately 3.98 billion pounds of toxic materials, more than half of all the toxic releases (7.8 billion pounds) released in the United States that year.

Findings

The Korte Paper
There has been much discussion of the comments prepared by Professor Korte regarding cyanide use in mining. In fact part of the upcoming EU sponsored dialogue is centered on Professor Korte's findings. The author agrees with several important comments made by Professor Korte and his colleagues in the paper the EU will be considering (Korte, and others, 2000). Most importantly, cyanide-leach mining utilizes a combination of <u>chemical</u> as well as physical processes. As such, <u>cyanide should be regulated in a manner similar to other chemical and industrial processes.</u>

The EU and the Public Need "Independent" Sources of Information
One of the greatest barriers to making intelligent regulatory decisions regarding cyanide leach operations is the general lack of <u>detailed</u> analytical data, and the numerous <u>unanswered questions</u> regarding the presence, persistence and toxicity of these very complicated wastes in the environment. To be sure, the available literature contains lots of data, but it generally fails to report the chemical details necessary to adequately understand the issues.

This situation reflects the fact that, in much of the world, mining environmental activities are largely self-monitored and often self-regulated. At the same time, industry has become the main source of research on toxic substances—hence the work is presented from an industry perspective, and not one primarily intended to answer questions focused on protecting the general public or the environment. Prior to the early 1980's it was common to encounter many useful research studies on the presence and toxicity of cyanides, funded with government research money, thus a more balanced environmental perspective was available. The following represent a few examples of early, useful studies that discussed the presence and toxicity of cyanide forms very directly: Doudoroff, P. (1976), Broderius, S.J., and L.L. Smith, Jr. (1980), Heming, T. and R.V. Thurston (1985), Scott, J. S. and J. Ingles (1981). Most of these studies were performed by government agencies. Today, unfortunately, most of the visible literature on mining and cyanides now comes from industry sources, or joint government/industry efforts, performed mostly by scientists and engineers from the minerals industry or affiliated with industry funded ventures. It is now relatively rare to find mining research studies that are truly independent and presented with a broad environmental perspective.

The Industry Cyanide Code
Following the Baia Mare spill and several other environmental incidents involving cyanide, a mining industry-funded research association, the International Council on Metals and the Environment (ICME), together with the United Nations Environment Programme (UNEP) organized a series of meetings in an effort to prepare a cyanide "code", with the objective of describing "best use" practices. Unfortunately, this process has been funded primarily by the industry, and is largely controlled by it. Even the participants from the UNEP staff come largely from industry-sponsored positions. Therefore, the "code" draft (UNEP/ICME, 2002) reflects, predominantly, what is best for industry, not the interest of the environment or the public. The author is concerned that the outcomes of the flawed UNEP sponsored process, will impact decision-making in the EU. (Note: ICME is now defunct and has been replaced by a new industry trade association, the International Council for Mining and Metals—ICMM.)

To be sure, there are some positive practices recommended in the draft UNEP report. However, the draft document continues to recommend environmental monitoring that focuses only on WAD CN, thereby neglecting to evaluate many other toxic forms of CN. Incredibly, the draft (Section: Standard of Practice 4.5, pg. 15) states that direct or indirect discharges to surface waters can contain up to 0.50mg/L WAD CN. Aside from recommending an analytical procedure (WAD) that fails to detect many of the toxic CN species, such a concentration would be lethal to most of the aquatic life in many settings. This is hardly protective and amounts to a UNEP/ICME sanction for the destruction of aquatic systems.

Furthermore, the Code makes recommendations regarding Free CN (again in Standard of Practice 4.5), where they state that a Free CN concentration less than 0.022 mg/L downstream of any established mixing zone is acceptable. In some environments this concentration would be toxic to many sensitive species. More importantly, most objective experts would agree that there is no reliable analytical method to analyze Free CN (C. Johnson, US Geological Survey; G. Miller, U. of Nevada). The authors then add a very self-serving phrase, that "the lower quantification limit (LQL) for free cyanide analysis achievable by most laboratories is 1 mg/l." Most high quality commercial labs can, in fact, reproducibly report to the nearest 5 to 10 μg/L (0.005 to 0.01 mg/L). Thus the report is misleading in its assertion that "most laboratories" cannot achieve this standard.

Clearly the Code is not being particularly protective or accurate when it recommends (Standard of Practice 4.4, pg 14) that WAD CN concentrations up to 50 mg/L in open waters are acceptable regarding safety to wildlife and livestock. There are many examples where numerous birds and other animals have been killed by lower concentrations.

Several Code statements regarding Emergency Response are extremely relevant to the present EU purposes. For example, in Standard of Practice 7.5, pg. 29, if read carefully, one concludes correctly "that there are no safe and effective options to treat cyanide once it has entered natural surface waters such as streams and lakes." Thus it should be the responsibility of a public institution, like UNEP or the EU, to take a precautionary approach to cyanide.

Most importantly, compliance with this Code is intended to be voluntary. Experience shows that the mining industry, with its problematic track record of cyanide management, is unlikely to be able to effectively self-regulate.

Chemical Contents of Impacted Waters and Soils
At present, we do not know whether numerous CN compounds are present in mining wastes (waters, solids), and at what concentrations. Contrary to the common industry refrain, answers to many questions about the presence, persistence, and toxicity of cyanide and related compounds in the environment are lacking—at least to the public.

- **Cyanide-Leach Waste Are Chemically Complex**
  Typical cyanide-leach gold wastes are quite complicated chemically, containing fluids with high concentrations of sediments; cyanide and breakdown compounds (such as free cyanides, metal-cyanide complexes, cyanates, thiocyanates, ammonia, possibly organic-cyanide compounds, cyanogen, cyanogen chloride, and chloramines); numerous metals (for example, arsenic, cadmium, cobalt, copper, iron, lead, manganese, nickel, selenium, silver, mercury, molybdenum, vanadium, zinc); non-metals (sulfates, chlorides, fluorides, nitrates, and carbonates may all be elevated);

radioactive constituents (such as uranium, radium, gross alpha and beta); organic compounds; and high pH (The high pH environment in cyanide leach wastes makes many metals more mobile, hence it is common for such wastes to have elevated radioactivity and metal concentrations). Commonly, neither regulators nor the public are aware of the actual chemical components or concentrations of such wastes.

The publicly available data from the Baia Mare spill reported only total cyanide, and selected determinations of copper, manganese, iron, lead, and zinc—for river samples. No detailed analyses of the actual gold-process waste liquids were made public. No _field_ measurements (temperature, specific conductance, or pH) were reported. Such measurements are, in some ways, the most useful data for understanding such a spill.

- **Routine Analyses May Conceal More Than They Reveal**
  Obtaining reliable data on the various forms of cyanide and related compounds in water and soils can be difficult and confusing. There is disagreement among experts on how samples should be collected and preserved, and even greater uncertainty about what specific cyanide forms are being determined by different analytical techniques. However, if one reads the draft Cyanide "Code", most of these difficulties disappear!

  For example, one may collect waste water samples which, when analyzed, show less than detectable amounts of WAD or total cyanide. Nevertheless, if the same waters are analyzed using specific techniques for determining, for example, cyanate, thiocyanate, metal-cyanide complexes, etc., significant concentrations can be detected (Moran, 1999, Johnson, _et. al., 2000a and b_). Thus, if only total cyanide determinations are performed—as in the Baia Mare report---the actual cyanide decomposition products may be missed (see Moran 1998, 2000, 2001a, and Johson, _et.al,_ 2002 for details).

  Also, it is important to note that thiocyanate and many of the metal-cyanide complexes can convert to free cyanide when exposed to sunlight. Because sunlight can decompose metal-cyanide complexes, releasing free cyanide and metals, measured concentrations can vary depending on what time of day the samples were taken (Grimes, _et.al,_ 2000; Johnson, _et. al._, 2002). Higher concentrations have been observed under conditions of greater light. Thus, the choice of sampling time can be quite important.

  As mentioned previously, there is no reliable analytical technique for determining free cyanide.

  Clearly there is a great need to expand monitoring of mining wastes to report additional forms of CN. These should include: WAD CN, Total CN, thiocyanate, and cyanate. Additional monitoring needs to be conducted to determine the presence of metal-cyanide complexes and organic-cyanide

compounds in mining wastes. Obviously these studies would also need to monitor for an extensive suite of metals and non-metals. Such information must come from sources independent of industry influence.

High-quality, local analytical laboratories may not exist, making regulatory oversight and assessment of mine wastes incomplete. Local labs may not be able to perform many of the required determinations. Also, "complete" analyses are expensive. Hence, regulators often fail to require companies to perform such monitoring—thus we really do not understand the complexities and risks associated with such wastes.

- **Geochemical Behavior is Poorly Known**

How do these wastes "behave" geochemically? Many aspects of the geochemical behavior and toxicity of such complex mixtures are poorly known. For example, mining literature frequently states that cyanide naturally breaks down quickly, in the presence of sunlight, into relatively harmless, non-toxic substances. A recent report sponsored by the mining and cyanide manufacturing industries (Logsdon, M.J., *et. al.*, 1999) states: "Since cyanide oxidizes when exposed to air or other oxidants, it decomposes and does not persist. While it is a deadly poison when ingested in a sufficiently high dose, it does not give rise to chronic health or environmental problems when present in low concentrations." This statement is misleading and presents a falsely benign picture.

First, cyanide also tends to react readily with many other chemical elements and molecules to form, as a minimum, hundreds of different compounds (Flynn and Haslem, 1995). Many of these breakdown compounds, while generally less toxic than the original cyanide, are known to be toxic to aquatic organisms, and persist in the environment for significant periods of time. In addition, there is evidence that some forms of these compounds can be accumulated in plant tissues (Eisler, 1991) and may be chronically toxic to fish (Heming, 1989; and numerous other studies discussed in Moran, 1999). Nevertheless, regulatory agencies do not require mine operators to monitor for these toxic cyanide-related compounds. Therefore, while much of the cyanide used at mineral processing sites does break down fairly readily, either as a result of natural degradation or the various treatment processes *sometimes* employed, significant amounts of the original cyanide form other potentially toxic compounds that may persist for long periods of time and remain unaccounted for in the monitoring.

Second, there is considerable disagreement about the percentage of cyanide that actually volatilizes into the air. Recent studies by the U.S. Geological Survey (Johnson, *et.al,* 1999, 2000a and b *, 2002)* indicate that most of the original cyanide in spent (leached) ores has been converted to other toxic forms, such as cyanide-metal complexes, cyanate, and thiocyanate. Many of the metal-cyanide complexes can remain stable in leached ores for decades.

The cyanates and thiocyanates are stable in the process liquids for undefined periods of time, but industry observations suggest they can be present for at least weeks to months—depending on the temperature, amount of sunlight, and presence of selected microbes. [Plumlee, et. al., 1995, discuss samples that still contained significant thiocyanate concentrations at least one to two years after active cyanide use had ceased.] They are much more likely to persist if released into the environment during winter when lakes and rivers may have snow and ice cover, less available sunlight, and lower temperatures. Areas with high rainfall and persistent cloud cover also have restricted rates of natural cyanide destruction (Environment Australia, 1998). Most of the assumptions about the geochemical and hydrogeologic processes taking place in cyanide-leach wastes come from studies performed in arid regions. Leach facilities operated in wet environments often create very different problems.

The toxicity of cyanide and decomposition products at gold mining sites is most significant to aquatic organisms, especially fish. For example, fish are killed by cyanide concentrations in the *microgram per liter* range, depending on the specific fish species. Bird and mammal deaths generally result from cyanide concentrations in the *milligram per liter* range. Additional details on the toxicity of various cyanide forms are presented in Moran (1999) and its associated references.

The UNEP Baia Mare report indicates that elevated total cyanide concentrations were detected for, as a minimum, hundreds of kilometers downstream, for up to four weeks after the Baia Mare spill. Clearly the total cyanide in the Tisza River did not decompose quickly.

An approved release of heap leach solutions from the Beale, Montana, U.S. site provides an illustrative example of the uncertainties. Here, the State regulators gave permission to dispose of these fluids on nearby lands, believing that they were non-toxic based on the low WAD CN concentrations (which complied with regulations). Within four days, toxic effects began to be noted in the exposed plants (verbal communication, C. Russell, US EPA). Plant toxicity testing indicated that the most toxic constituent in the discharged leach solutions was thiocyanate, which was present at between 200 to 400mg/L (Dr. G. Miller, Univ. of Nevada). Of course, using the WAD CN data to approve this release was useless, because the data fail to provide an indication of the presence of toxic thiocyanates. [The use of ammonium thiocyanate as an extremely toxic weed killing agent was noted in the literature as early as 1948 (Frear, 1948).] These conclusions are clearly relevant to mine sites near agricultural zones, forested areas or any lands containing sensitive vegetation.

There is a great need for "independent" studies to define the bio-geochemical "behaviour" of the compounds in and near these wastes.

For example, almost nothing is publicly available on the existence of organic-cyanide compounds in mining wastes. These efforts also should further investigate the extent to which free cyanide is released from various other cyanide-related compounds, like the metal complexes and the thiocyanates.

- **Long-term Toxicity Studies Are Largely Lacking**

It is common to read statements such as: "No evidence exists to demonstrate that cyanide (and other toxic substances) results in chronic toxicity in aquatic organisms (or humans)." Several such statements are often made regarding chronic toxicity of cyanides (and many metals). In most cases, what this actually means is that the long-term studies have not been performed, so, it is technically true that the evidence does not exist. Even the cyanide "code" (Appendix F) mentions chronic toxicity in humans from the long-term ingestion of cyanogenic plants. Why would one make the simplistic assumption that long-term exposure of mine workers or nearby-residents (or other organisms) to inorganic cyanides would be harmless?

What incentive does the industry have to perform such expensive, and potentially detrimental studies? Do mine wastes (solid and liquid) result in long-term toxicity impacts to aquatic and terrestrial plants and animals and humans? Truly long-term, independent toxicity studies need to be conducted before the public can be assured that cyanide-leach wastes are benign.

Heap Versus Vat (or Tank)-Leach Technologies

The two dominant techniques that use cyanide to recover precious metals are the heap-leach and vat-leach procedures. The process details of each are described in numerous technical documents (i.e. Logsdon, *et.al.* 1999). In general, the major environmental impacts from the two processes are quite similar, especially when the long-term is considered. Both processes are subject equally to unforeseen spills of concentrated cyanide and other reagents.

During the **operations** phases, the major environmental weaknesses of heap leaching involve leakage or spills of process fluids from the process facilities (heap leach piles and solution ponds), and toxicity and danger to living organisms if they contact the liquids in these open ponds. Leakage and unregulated discharges or spills present the most significant, and most expensive problems, causing contamination of surface and ground waters.

Vat leaching, on the other hand, is carried out inside enclosed containers, gold is extracted in a plant, and a mixture of solid and liquid wastes, tailings, are discharged into a tailings impoundment system, which is usually lined. Some of the tailings solution is recycled for reuse, and at many facilities these solutions receive some form of treatment. Thus, when vat leaching is operational, the sensitive environmental issues usually involve seepage from the tailings impoundment, and toxicity to birds or other organisms if they contact the waters *ponded* on the tailings. From an environmental point of view, there may be some

preference for vat-leach approaches, mostly because there are no open process solution ponds, and some of the tailings liquids may be treated. However, higher concentration cyanide solutions are often used in vat-leach facilities. Vat-leach approaches could be improved through requiring that tailings be deposited essentially dry.

The mining industry often says that there will be no leakage from modern tailings facilities because they will be lined with synthetic membranes. Thus, they are often called "zero discharge facilities"—implying to the average citizen that there will be no leakage. Unfortunately, this is an obvious exaggeration; all liners leak to some extent. This is well recognized within the professional community. Such leakage can be very significant if the liners were not installed correctly. Synthetic liners for such leach facilities are normally emplaced using heavy mechanical equipment that passes over the liners, creating holes in the synthetic materials. Even when correctly installed, small amounts of leakage can produce significant impacts if they occur over long periods of time. The management of potential leakage becomes even more difficult once the mine closes. It may require that some form of water management activities continue *in perpetuity* after mine closure.

After closure of the facilities, regardless of the leach processes utilized, tremendous masses of potentially toxic solids remain on the site. These solid wastes are a combination of tons of metals, non-metals, salts, and chemical reagents, together with largely inert rock particles. The wastes contain massive amounts of constituents that are potentially *leachable* into the environment if adequate amounts of water contact the wastes. These leachates can be either alkaline or acidic, depending on the geochemistry of the ores. In the long run, it is likely to be much more difficult to successfully prevent the release of unacceptable leachates in high rainfall areas as opposed to arid regions.

Clearly there are options that will minimize the tendency to form toxic leachates, such as capping, rerouting of water sources, construction of discharge collection systems, etc. However, it must be emphasized that these may require essentially perpetual waste management---despite the fact that the operations may be active for only 10 to 15 years, often less.

Commonly Used Cyanide Destruction Techniques: How clean is the treated water?
The more commonly used destruction processes are described in Smith and Mudder (1993), Mudder (1998), and Flynn and Haslem (1995). Only two of the processes are discussed below.

A cyanide destruction technique of interest in Greece and at other sites is the **INCO** process. This process is often used to treat ores containing iron sulfides, or where iron cyanide complexes are present in the effluents in significant concentrations. It involves the addition of SO_2, air, and a copper catalyst to

breakdown cyanide. While this process does greatly reduce free cyanide concentrations, it results in the formation of several other byproducts that may be toxic to aquatic organisms, such as: cyanate, thiocyanate, sulfate, ammonia, nitrate, some free cyanide, and elevated copper concentrations. Such treated effluents may also contain elevated concentrations of other metals. The INCO process also results in the formation of large volumes of calcium sulfate-rich sludges, which increase the process and disposal costs. Most Canadian gold sites that use the INCO process are able to generate effluents that meet the discharge standards. However, many of these effluents are still toxic to organisms in bioassay tests (Dr. George Dixon, toxicologist, U. of Waterloo, personal communication, 1999). Thus, these complex solutions produce toxicity effects we do not understand, probably as a result of synergistic effects, or they contain toxic constituents that are not being detected or regulated.

Like cyanate, thiocyanate is normally not monitored or regulated at most mining sites. Nevertheless, it is reported to be toxic to fish at concentrations between 90 and 200 mg/L (Ingles and Scott, 1987). Heming and Thurston (1985), and Heming and others (1985), report thiocyanate toxicity to be between 24 to 70 mg/L thiocyanate, SCN⁻, for brook trout. Heming and Blumhagen (1989) report that thiocyanates cause "sudden death syndrome" in trout, partly as a response to stress, and because thiocyanate is accumulated—contrary to much previously published literature. Lanno and Dixon (1994), report that juvenile fathead minnows showed numerous negative effects after chronic (124 days) exposure to thiocyanate: thyroid tissue changes started as low as 1.1 mg/L; reproduction effects were noted at 7.3 mg/L and above; overt goiter was noted as low as 7.3 mg/L. Many of these effects are believed to be controlled by the antithyroid activity of thiocyanate.

It seems important to mention **alkaline chlorination**, an older destruction process, less favored at modern sites, because it was apparently used in desperate attempts to treat portions of the Baia Mare and Kumtor spills. Alkaline chlorination involves the addition of chlorine or hypochlorite to decompose most of the cyanide into cyanate. This process, however, causes the production of a highly toxic intermediate compound, cyanogen chloride, which then converts to cyanate. In addition, alkaline chlorination allows the formation of several stable metal-cyanide complexes and is likely to result in the formation of toxic ammonia and chlorinated ammonia compounds—chloramines. Free cyanide can be released when the metal-cyanide complexes break down in sunlight. Cyanates are toxic to trout in the range of 13 to 82 mg/L (Ingles and Scott, 1987).

Chloramines are normally indicated via analysis for total residual chlorine. The U.S. Environmental Protection Agency (1986) states that freshwater aquatic organisms should not be exposed to total residual chlorine concentrations exceeding *11 to 19 micrograms per liter*, and that ammonia is toxic to fish at concentrations between 0.083 and 4.6 mg/L. Thus, ammonia is roughly as toxic as free cyanide to fish.

Hypochlorite is frequently applied to cyanide leach spills in developing countries—at least surreptitiously. Thus, it is likely that undetermined amounts of toxic cyanates, ammonia, chloramines, and metal-cyanide complexes are formed as a result of such shortsighted attempts at cyanide decomposition.

Long Term Impacts
Mining geochemical reactions may take many years to develop water-quality impacts. While gold cyanide-leach wastes are normally alkaline (pH 10—12), acid rock drainage (ARD) problems can develop later.

Because gold-cyanide process fluids are kept alkaline (as are copper mill circuits), the potential to develop acid rock drainage may be overlooked. Spent ores or tailings that contain significant sulfide concentrations may become acid after the original buffering compounds and minerals react. These processes may require decades to become visible, and standard geochemical predictive techniques will often underestimate this potential. As a result, some modern mining situations may appear to be without impacts, when in fact it may simply be too early to judge. Once such impacts do develop, however, they may continue for centuries if not adequately and continuously managed.

A technical team from the U.S. Environmental Protection Agency made an assistance trip to the Baia Mare sites in April 2000. They specifically noted (see Trip Report, Larry Reed, June 21, 2000) that the tailings were generating acid rock drainage. In the long-term, the ARD probably presents a much more costly contamination problem than do the cyanide and related products. Remediation of long-term ARD problems at U.S. mine sites usually requires the construction and operation of an active water-treatment plant. In many cases, these plants must be run in perpetuity, and may cost $500,000 to several million U.S. dollars per year to operate, depending on the volumes of water involved.

One of the greatest shortcomings in most mining studies involves underestimating the length of time the public should consider when attempting to evaluate future impacts. For example, acid drainage has continued for hundreds and even thousands of years at sites originally mined in ancient Scandinavia, Spain, and Greece. Also, it is an unproven assumption that buried wastes will remain "contained" even a hundred years in the future. As evidence of these concerns, the State of New Mexico (U.S.) recently recommended that mining companies provide financial bonds adequate to pay for treatment of contaminated waters for a period of 100 years following mine closure (*Moran, R.E. and McLaughlin Engineers, 2001*). Thus we need to begin thinking of mining waste management in the same way that we think about the risks posed by radioactive waste. That is, we need to fully assess, and account for, the potential need to treat, remediate, and manage these sites for decades or centuries.

Where are the Baseline Data?
Mining or re-mining often begins without adequate *local* baseline water-quality data. This is consistently a problem at almost all sites I work at, especially in developing countries. The operators may have contracted for seemingly-sophisticated computer simulations of various impacts, but they invariably lack a usable baseline data set. <u>Thus, it is frequently not possible to assess responsibility for present or future impacts.</u> This was clearly the case for the Baia Mare spill, where no recently collected baseline water-quality samples, surface or ground water, were available. As a result, no actual "yardstick" existed against which the spill data could be compared.

Regulators can sometimes be reluctant to require costly monitoring before a mine has any cash flow. Failure to collect adequate baseline data is becoming an increasingly common problem—especially where re-mining of previously worked sites is involved. The common justification is that any modern activity will improve the previously contaminated situation therefore regulators need not be vigilant in developing a baseline. Of course, the scale of the modern activity usually dwarfs the historical operation, thus its potential impact may be much greater. <u>Regulators must enforce the need to collect statistically meaningful baseline data (waters, soils, biota) so that changes can be detected.</u>

Indirect Impacts to Municipal Waste and Drinking Waters
Using cyanide in mineral processing will produce indirect environmental impacts, especially where mine facilities are located near populated areas. Because some of the cyanide compounds will inevitably be released into the environment, they will eventually end up in municipal waters—both sewage and drinking waters.

These mine wastes will add to the normal industrial sources of wastes arriving at sewage treatment works (STWs). The details of such consequences are beyond the scope of this paper, but they have been nicely summarized in Wild, *et. al.* (1994). The paper makes clear how these added cyanide (especially the dissolved simple cyanide-metal complexes) and metal loads can destabilize STWs and make operation significantly more costly. It also indicates how many aspects of cyanide chemistry are still unanswered as regards this arena.

Additional cyanide and metal loads can also aggravate the operation of public water systems where chlorination is involved. In fact, the U.S. EPA issued a Public Water System Warning in 1994 indicating that chlorination of waters containing more than 0.2 mg/L cyanide can lead to the formation of the highly toxic byproduct, cyanogen chloride. [This compound was used as a chemical warfare agent in the First World War.] Interestingly, U.S. EPA reports that they would not regulate cyanogen chloride because they have no direct data on its toxicity in drinking water. They further state, however, "chronic exposure to cyanogen chloride may be as harmful as chronic exposure to cyanide at and above the MCL."

The oxidation of cyanide to cyanogen chloride occurs instantaneously at all pHs. If the pH is 8.5 or above, the cyanogen chloride then rapidly converts to cyanate (see earlier discussions on toxicity). In the presence of excess chlorine, cyanate rapidly converts to harmless bicarbonate and nitrogen gas. However, at pHs less than 7.1, oxidation of cyanogen chloride to cyanate proceeds very slowly.

These same oxidation processes can release free CN from metal-cyanide complexes, and possibly from thiocyanate compounds.

This U.S. EPA Public Water System Warning also reports that contamination from one cyanide heap leach operation had maximum reported CN concentrations of 2.7 mg/L in the receiving stream. [It is not reported what analytical procedure was used to determine the CN concentration---WAD, Total, etc.] The U.S. EPA has also published documents warning of similar concerns about the generation of toxic chloramines (chlorinated ammonia compounds) in drinking water via the chlorination of cyanide compounds (U.S. EPA, Expedited M-DBP Rules, Notice of Data Availability, November 1997 Update).

Thus, it is possible that increased cyanide and other mine wastes can elevate the amounts of CN ingested by humans in treated drinking water.

Environmental Economics Studies
As with so many topics previously discussed, I know of no studies that evaluate mining economics that also realistically consider long-term environmental costs. There are numerous industry studies that purport to investigate such issues, but these are unreasonably biased. In mining Environmental Impact Assessments, I have even seen economic evaluations that consider the process water to have no value. Such environmental economic studies are crucial to making reasonable decisions about the viability of cyanide-leach operations in the EU.

Financial Assurance
Financial assurance measures are usually inadequate or lacking, thus mining companies may avoid paying for potential environmental impacts. Such measures often include financial bonds held by the government or possibly environmental liability insurance. Several international mining companies have now been required to provide bonds greater than $100 million for mine remediation and long-term operation of water treatment facilities. This is a special concern where foreign-owned companies use bankruptcy and international laws to avoid financial responsibility. In such situations, citizens subsidize environmental impact costs.

Conclusion
It is recommended that any EU or UNEP discussion of cyanide impacts or management in mining must take into account all of the above issues. The only

reasonable conclusion to draw from this brief summary of technical issues is that governments and industry, to date, do not have sufficient research or data to demonstrate that cyanide process facilities can be considered best available technology. The only reasonable way forward is to take a precautionary approach, one that puts the burden of proof on those proposing these facilities or these standards.

In regard to the current draft of the ICME-UNEP sponsored cyanide "code," it is clearly deficient. Any "code" that is supported by public agencies such as UNEP must address all of the major issues of public concern in relation to cyanide process technology. The current "code" draft fails miserably in this regard. It was not developed with adequate non-industry input, it is not independent, and fails to establish an independent mechanism. It even fails as a technical guidance document for the reasons described in this report.

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