Report

Best Management Practices for Cyanide Use in the Small-Scale Gold Mining Sector

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## Abbreviations/Acronyms

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<th>Definition</th>
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<tbody>
<tr>
<td>AC</td>
<td>activated carbon</td>
</tr>
<tr>
<td>ASGM</td>
<td>artisanal and small-scale gold mining</td>
</tr>
<tr>
<td>CIL</td>
<td>carbon in leaching</td>
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<tr>
<td>CIP</td>
<td>carbon in pulp</td>
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<tr>
<td>cm</td>
<td>centimeter(s)</td>
</tr>
<tr>
<td>CN</td>
<td>cyanide</td>
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<td>CN-O</td>
<td>cyanate</td>
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<tr>
<td>Code</td>
<td>International Cyanide Management Code</td>
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<tr>
<td>Cyanide Code</td>
<td>International Cyanide Management Code</td>
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<tr>
<td>DES</td>
<td>deep eutectic solvent</td>
</tr>
<tr>
<td>DMSO</td>
<td>Dimethyl sulfoxide</td>
</tr>
<tr>
<td>EMA</td>
<td>Zimbabwe Environmental Management Agency</td>
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<tr>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
</tr>
<tr>
<td>EPI-EP</td>
<td>Empresa Pública Importadora</td>
</tr>
<tr>
<td>ERP</td>
<td>emergency response plan</td>
</tr>
<tr>
<td>g</td>
<td>gram(s)</td>
</tr>
<tr>
<td>HCN</td>
<td>hydrogen cyanide (gas)</td>
</tr>
<tr>
<td>Hg</td>
<td>mercury</td>
</tr>
<tr>
<td>ICMI</td>
<td>International Cyanide Management Institute</td>
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<tr>
<td>KCN</td>
<td>potassium cyanide</td>
</tr>
<tr>
<td>kg</td>
<td>kilogram(s)</td>
</tr>
<tr>
<td>kPa</td>
<td>kilopascal(s)</td>
</tr>
<tr>
<td>L</td>
<td>liter(s)</td>
</tr>
<tr>
<td>m</td>
<td>meter(s)</td>
</tr>
<tr>
<td>MCP</td>
<td>Merill Crowe Process</td>
</tr>
<tr>
<td>mg</td>
<td>milligram(s)</td>
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<tr>
<td>MSDS</td>
<td>material safety data sheet</td>
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<tr>
<td>NAP</td>
<td>national action plan</td>
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<tr>
<td>NaCN</td>
<td>sodium cyanide</td>
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<tr>
<td>pH</td>
<td>potential hydrogen</td>
</tr>
<tr>
<td>PPE</td>
<td>personal protective equipment</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environment Program</td>
</tr>
<tr>
<td>WAD</td>
<td>weak acid dissociable</td>
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<tr>
<td>ZN</td>
<td>zinc</td>
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Executive Summary

The gap in applicable guidance for CN management for small-scale operators requires urgent attention, especially considering cyanide’s accessibility and effectiveness at gold extraction, and in light of the trend in uptake of cyanidation in the small-scale gold mining sector worldwide. The International Cyanide Management Code (ICMC), which was developed for industrial operators, has limitations on direct transferability to small-scale operations, which are typically undercapitalized and lack formal training and management policies and practices that are adequately structured and enforced.

The purpose of this document is to address this gap, by providing written guidance for ASGM stakeholders on managing the risks of cyanidation where national legal and regulatory frameworks permit its use, in the context of the ASGM sector’s transition from mercury use. However, this document should not be construed or interpreted as advocating for the adoption of cyanidation. Similarly, this document does not aim to sideline or overshadow potentially impactful new and promising mercury-free (non-toxic) mineral processing alternatives.

The guidance contains 4 sections:

(i) Introduction and Context, where the relevant global context and need for this guidance is presented.

(ii) Technical Overview of Cyanidation, which describes in a general manner the CN methods being used in the ASGM sector and may be helpful for readers who will benefit from an improved understanding of working conditions and challenges in the ASGM context.

(iii) Best Practices for CN Management, which recommended better and best practices for small-scale operators. These recommendations are made with reference to the nine Principles of the ICMC.

(iv) Conclusion, which summarizes and provides some generalized risk register tools which can be adapted and applied to help small-scale operators analyze and monitor risks and plan risk-mitigation efforts.

In addition, two national case studies are provided (following section 2) from countries where cyanide has been in widespread use in the ASGM sector, for several decades. Ecuador is presented, representing the South American context, and Zimbabwe, representing the African context. These case studies provide photos and local context which enable readers to contextualize the challenges associated with cyanide management in the ASGM sector.
1. Introduction

1.1. About this Document

Worldwide, cyanide (CN) compounds are used to extract gold from hard-rock ores in the mining industry in a process known as cyanidation. While cyanidation can be conducted safely and without harm to the environment, the entire process (from transport and storage through to use and waste management) presents considerable safety and environmental risks to workers, communities & the environment. While significant progress has been made in the industrial mining sector on the issue of chemical safety, coordinated global efforts are required to ensure CN compounds are being produced, transported and used - throughout the entire mining sector - in ways which minimize adverse effects on human health and the environment.

Unfortunately, there is a lack of accessible guidance materials concerning the safe use of CN for small-scale cyanide operators operating in the Artisanal and Small-scale Gold Mining (ASGM) sector, despite a global need for these materials. The International Cyanide Management Code (hereafter ‘Cyanide Code’) was created in 2002 as an industry-led voluntary initiative to provide best-practice guidelines for the safe use of CN at industrial gold and silver mining operations. Although comprehensive, the Cyanide Code was developed for industrial operators and has limitations on direct transferability² to small-scale operations, which are typically labor intensive and undercapitalized, in many cases lacking formal training, or structured and enforced management policies and practices.

Recognizing (i) the ubiquity of cyanidation for gold processing by the industrial gold mining sector; (ii) cyanide’s accessibility and cost effectiveness, when compared to other conventional gold extraction technologies; and (iii) the present trend in uptake of CN processing systems in the small-scale gold mining sector worldwide, this gap in applicable guidance for CN management for small-scale operators requires urgent attention. Policymakers and regulators, development program directors, and ASGM operators (inclusive of mining associations, miners, ASGM-investors, mineral processing center owners and workers) stand to benefit from improved understanding of responsible and safe CN management.

The purpose of this document is to provide guidance for ASGM stakeholders on managing the risks of cyanidation, in the context of the ASGM sector’s transition from mercury use, and where CN leaching has been identified as an appropriate gold extraction method. It is important to note using cyanidation of mercury-contaminated ASGM tailings constitutes a “worst-practice” as defined in the Minamata Convention. CN operators should not use cyanide on Hg-contaminated tailings without removing/addressing the Hg.

► This document should not be construed or interpreted as advocating for the adoption of cyanidation.
► Similarly, this document does not aim to sideline or overshadow potentially impactful new and promising mercury-free (non-toxic) mineral processing alternatives.

¹ The Cyanide Code is a voluntary regulatory instrument developed by and for the industrial mining sector, which serves to support sound management for the transport, usage, and destruction/disposal of CN at gold and silver mines. The Cyanide Code was developed with coordination support of United Nations Environment Program (UNEP) and is maintained by the International Cyanide Management Institute (ICMI). A history of CN management in the modern era is provided in Appendix 1, which explains the outcomes of major CN releases associated with gold mining (1995–2015) and explains how the mining sector responded through the formation of the Cyanide Code. Understanding the consequences of major CN releases provides important context for this report.

² The Cyanide Code requires that mines have formal management plans for water management, and for waste and tailings management. Due to assumption of competent, well organized management systems (of mining sector operators) the Cyanide Code itself does not specify requirements for “management systems” per se but rather assumes these are in place. Small-scale miners are thus left with little specific guidance regarding (for example) water management systems for CN plants. Nevertheless, the Cyanide Code is a highly accessible and applicable document concerning safe management of CN and should certainly be studied and used by actors in the ASGM sector.
Legal frameworks and regulations establish whether (under which circumstances) cyanidation is or can be authorized, in respective jurisdictions. As part of the sound chemicals and waste agenda, this guidance document acknowledges that some stakeholders have called for bans on the use of CN for mineral processing. In the ASGM development community, for more than 20 years, stakeholders have been strongly advocating gravity concentration, and other non-toxic leaching technologies. While several modern non-toxic mineral processing techniques show promise for applicability in the ASGM sector, clear demonstration on feasibility (proof for cost analysis in scale-up) remains outstanding. This point reinforces the need for stakeholder attention to risks associated with the ongoing proliferation of cyanidation by small-scale operators.

The body of literature on cyanidation and on CNs interacting with the environment is extensive and highly technical. In this report, effort has been made to synthesize critical information without using highly technical language in order to reach a wide audience of professionals encompassing policy makers, mineral sector and development professionals, and civil society. The focus is applicable guidance on safe and responsible small-scale cyanidation systems, in the context of the ASGM sector’s transition away from mercury use.

### 1.2. Context

CN leaching for the extraction of gold (i.e., cyanidation) has been practiced for approx. 150 years, and CN is the primary chemical agent used for modern day gold production. The lion’s share of this extraction is done by large industrial mining companies. In the ASGM sector, mercury (Hg) amalgamation has been and continues to be, a dominant means of gold extraction. In many ASGM regions, however, cyanidation is being used after mercury amalgamation, by extracting further gold from ASGM tailings. In some ASGM regions cyanidation is superseding mercury amalgamation as the dominant gold production technique, in terms of gold production.

The Minamata Convention on Mercury Article 2(a) defines ASGM as “...gold mining conducted by individual miners or small enterprises with limited capital investment and production”. In practice, the legal definition

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4 Alternative gold leaching technologies (to mercury and CN) exist and some are showing promise for application in the ASGM sector, with less toxic profiles than CN. Examples include:
   - Thiosulfate: Aylmore, 2005, 2016; Xu, et al., 2017; Clean GoldTM; and others
   - Dimethyl sulfoxide (DMSO): Yoshimura and Matsuno, 2014; and others
   - Sodium chloride and calcium hypochlorite solutions: Yen, et al., 1995; Carvalho, et al. 2018; and others
   - Iodine-iodide solutions: Liang and Li, 2019; and others
   - Environmental acids, including deep eutectic solvents (DESs): Jenkin, et al., 2016; and others
   - CN reduction by using cyanide-glycine solutions: Barani, et al., 2021; and others
   - Cassava and natural CNs: Torkaman, et al., 2021

For all of these alternative technologies, principal barriers for application and uptake are cost, and expertise required to apply laboratory precision to settings found in the ASGM sector.

5 A collation of influential cyanidation literature available at https://www.911metallurgist.com/blog/list-books-cyanidation illustrates how the majority of CN process research was developed during the beginning of the 20th century, and not much since.

6 In 1887, John Stewart MacArthur, working in collaboration with brothers Robert and William Forrest for the Tennant Company in Glasgow, Scotland, developed the MacArthur-Forrest process for the extraction of gold from gold ores, and CN has been the primary reagent in use for gold processing since.

7 Pact, 2018. ASGM on the African Continent (Briefing Note).

8 The Minamata Convention is an international treaty designed to protect human health and the environment from anthropogenic emissions and releases of mercury. The Convention came into force in August, 2017.
of ASGM varies from country to country with implications for regulatory frameworks. This document considers use of CN as used in small-scale operations, from basic rudimentary vat-leaching through to relatively sophisticated semi-mechanized agitated leaching circuits. Regulatory instruments must govern when and where CN can or should be permitted, and under which conditions. This requires regulators to objectively distinguish between small-scale operators and artisanal mining (most mining regulations do so). CN cannot be recommended (and is not deemed appropriate) for artisanal miners - by commonly held definitions, which generally consider artisanal mining methods as those which are rudimentary and non-mechanized in nature. This document is focused predominantly on the small-scale gold mining sector. Similar to the Minamata Convention, however, this report intends to address conditions and challenges found across the full breadth of ASGM sector, without belaboring a discussion on classification / categorization of mine operations between artisanal vs. small-scale (these definitions generally focus on production scale, depth of excavation, degree of mechanization, etc., and the definitions in mining regulations differ regionally).

Regrettably, CN use in the ASGM sector often occurs in the absence of critical safeguards and responsible management practices. While global awareness of the risks associated with mercury use in the ASGM sector has increased drastically in recent years, improper use of CN is a growing concern as CN systems augment or replace mercury amalgamation and become a dominant gold production methodology in many ASGM regions. CN-associated risks are greatest to people, livestock and wildlife, and inland waterbodies on which they rely, in ASGM regions where CN use is widespread. The health risks associated with CN leaching extend outwards into regional hydrological cycles, including ecological systems and food-webs. Luckily, CN typically is not persistent in the environment and degrades to carbon dioxide, ammonia, and nitrates. In the process, however, toxic metals can be mobilized into the environment and aquatic ecosystems.

The Minamata Convention represents a legally binding global instrument which explicitly targets the use of mercury in ASGM (Article 7). National action plans (NAPs) on ASGM (refer to the convention’s Appendix C) require parties (i.e. country governments) to adopt strategies to reduce & where feasible eliminate Hg use in ASGM, including, where relevant, strategies to adopt and scale up alternatives to mercury amalgamation.

Transitioning to lixiviants (including CN, the most widely used lixiviant) for gold extraction in the ASGM sector represents an important alternative to mercury use. Cyanidation can provide an effective alternative to mercury amalgamation but only if CN operators are effectively regulated and CN operators employ sound chemicals management systems which provide effective risk mitigation for occupational health and safety, and environment (OHSE) hazards. The choice to authorize the use of CN for gold extraction in the small-scale mining sector is a legal and regulatory matter for policy makers. Where regulatory frameworks allow its use, it is imperative that the risks and returns of CN are understood and that CN operators are provided with suitable information, guidance, and training to ensure their compliance with regulations, while also mitigating associated health, safety, social, and environmental risks.

1.3. Document Scope

The scope of this guidance document is limited to:

- An overview of CN practices used in the ASGM sector, with emphasis on the basic processes and key risks, as well as case studies to help readers understand these processes and risks

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11 A lixiviant is a liquid medium used in hydrometallurgy to selectively extract the desired metal from the ore or mineral.
High-level guidance on minimum requirements for safe and responsible use of CN in ASGM

This guidance document does not provide:

- Comprehensive review of technical aspects concerning CN production or cyanidation for gold extraction
- Technical specifications regarding the extraction process (protocols and controls; precision for chemical and physical operating parameters)
- Comprehensive safety plans, and requirements for CN management

While this guidance focuses on cyanidation systems in general, it does not provide comprehensive guidance on cyanidation issues regarding mercury-contaminated tailings - a process identified by the Minamata Convention as a “worst-practice”. In practice, CN operators regularly process ASGM tailings and it is important to understand that the mercury content/concentration of these tailings will be highest, in regions where “whole-ore amalgamation” is practiced, another “worst-practice” identified by the Convention. To oblige the Convention, such tailings must be processed to remove mercury before or during cyanidation. This topic is briefly addressed in section 3.4, and is also discussed in a recent UNEP report which provides guidance on tailings management in the ASGM sector.12

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**Cyanide Toxicity ABCs**

- A *cyanide* is a chemical compound containing a ‘cyano-group’ which consists of a carbon atom triple-bonded to a nitrogen atom. While carbon and nitrogen are ubiquitous and non-toxic on their own, the ‘cyano-group’ structure produces toxic effects because these molecules can inhibit cytochrome c oxidase – a critical enzyme for oxygen based life, required for oxygen based APT synthesis (i.e. proper functioning of life-sustaining electron transport chain of eukaryotic cells).

- In the ASGM sector water-soluble salts of sodium cyanide (NaCN) and/or potassium cyanide (KCN) are dissolved in water to leach gold and silver from gold ores. These CN salts are toxic and must be managed safely and responsibly. CN chemicals or effluent, if spilled into the environment (especially aquatic systems) can result in lethal consequences to fish and other organisms.

- Hydrogen cyanide gas (HCN) is extremely hazardous; if inhaled by humans, the gas can rapidly inhibit function of cellular respiration leading to asphyxiation. Severe exposure results in headache, coma, seizures, and can result in rapid death.

- If/when aqueous CN solutions have a pH below 9, HCN gas (highly toxic) will be released from the solution. If neutral or acidic conditions are present (<pH of 7) HCN release can be rapid.

- HCN is detectable by bitter smell (similar to almond). Inhalation of HCN fumes can be dangerous even at low levels. At very high concentration the bitter odor of HCN can be undetectable, and this factor compounds the workplace risk factor: odor should not be relied upon as a method to detect, monitor or gauge dangerous HCN levels.

- Because HCN poisoning can occur very rapidly, recovery from poisoning depends upon severity of exposure but also promptness with which antidotes are administered. Common antidotes include amyl nitrite, sodium nitrite, and sodium thiosulfate. Antidotes are typically administered by needle injection, although drug manufactures have elaborated modern CN antidote medications.

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2. Technical Overview of CN Leaching in the ASGM Sector

For the benefit of readers who may not be familiar with technical aspects of cyanidation, the generalized stages of the process are described in this section. This guidance document is not intended to serve as a technical manual, but rather to provide a broad overview of how CN is used, including to describe associated risks. Additional steps/stages which appear in many CN process flowsheets are not discussed here (e.g. flotation\textsuperscript{13}, thickening\textsuperscript{14}, etc.). For comprehensive coursework on technical aspects of CN systems, readers should consult additional resources\textsuperscript{15}, including resources of the International Cyanide Management Institute.

\textsuperscript{13} Flotation is a process of mineral separation to concentrate ores. Most typically, for gold ores containing sulfides and oxides, reagents are added to slurry causing particles of interest (containing gold) to float in a froth on the surface, and this material can easily be separated to form a mineral concentrate. The flotation process was developed in the 20th century to recover fine gold that would otherwise be lost to tailings, in gravity concentrating circuit.

\textsuperscript{14} Thickening refers to the process of adjusting the density of the slurry (mixture of solids with water) by a process of “de-watering” using settling tanks or ponds. In industrial mines, this is achieved using massive circular thickening tanks.

\textsuperscript{15} Online learning institutions such as Universities of Queensland, Camborne School of Mines, University of the Witwatersrand, and private learning institutes such as Edumine - have coursework available online concerning different aspects of Cyanidation, as applied in mineral processing of gold and silver ores.
ASGM Context
In many ASGM supply chains where CN is used, gold extraction occurs in two stages. First, free gold is recovered using gravimetric methods to provide miners with quick pay. Afterwards, CN plant operators process ASGM tailings to recover very fine, and mineralized gold. The CN leaching process can take a week or more, and the revenues generated primarily benefit the CN processing plant owner/operator, in most cases.

2.1. Ore Characterization

Ore characterization is the first step in evaluating appropriate design of gold extraction with CN. In simplest terms, ores can be classified as:

- **Free-milling ores**, where gold is readily extracted by CN leaching
- **Refractory ores**, where the gold is present within other minerals that require the use of special reagents or pre-treatment processes and which commonly contain pyrite and arsenopyrite (sulfide minerals complexed with gold)
- **Complex ores**, usually comprising some mix of free-milling and refractory types and with one or more mineral (or metal) of economic value (e.g., gold, copper, silver), which often results in metallurgical challenges concerning liberation, concentration, or separation of these valuable minerals/metalles.

Figure 2. Ore characterization is necessary to select and optimize cyanide flowsheet design

For efficient treatment of free-milling ores, initial extraction with gravimetric or other concentration methods is usually helpful, because larger gold particles will be slower to dissolve (with CN) than fine particles, as consequence of their surface-area to volume ratio. For this reason, free-milling ore flowsheets usually ensure that free gold is separated and removed as an early step in the gold recovery flowsheet.

For efficient CN leaching of refractory and/or complex ores, pre-treatment before CN leaching is required. When sulfides are present, these often prevent CN in solution from physically contacting gold particles, thus interfering with gold dissolution. Conversely, for ores containing carbonaceous matter, dissolved gold in leach solution can be re-adsorbed by the carbon-containing particles, a process known as *preg-robbing*, which

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16 Adapted from Lunt and Weeks, 2005.

17 In regular conditions for cyanidation the solubility rate of pure gold is 3.25 mg/cm²/hour. Thus, a gold grain of 44 micron (400 mesh) will take ~13 hours to dissolve, while a 150 micron (100 mesh) gold particle requires ~44 hours (Hedley, et. al., 1968).
also interferes with gold recovery. To address these issues, pre-treatments are applied that increase costs and technical requirements of the flowsheet.

Ore characteristics dictate proper design of a cyanidation flowsheet. Gold ores within a geological province/region (even the same deposit) can possess different mineral constituents, varying mineral concentrations, and degrees of alteration or oxidation. Such diversity highlights the need for ore characterization by ASGM mineral processors as a starting point to select the best available grinding and leaching circuit. As such, ore characterization is essential for operators to make informed decisions and ensure process controls are in place so a cyanidation process can operate effectively and efficiently. Improved ore characterization can also help identify risks associated with mining and the environment, such as sulfide ores known to cause acid mine drainage - an environmental concern that results from the oxidation of sulfide minerals and waste piles during and after mineral extraction. Improved ore characterization thus remains an important gap for many/most ASGM operations. In many ASGM settings, technical solutions would be well directed to focus training and support for mineral processors on identifying sulfide-related gold recovery constraints and testing different ore treatment options to mitigate these and improve gold recovery.

### 2.2. Ore Preparation

Ore preparation begins with comminution and gold liberation, accomplished by crushing and grinding (milling). Liberating and/or exposing the gold particles from host rock is critical so they can be separated from other minerals, and/or extracted during the leach. The need for pre-treatment must be determined through mineral test work. Simply following a set recipe or copying what other miners are doing will result in inefficient gold extraction and economic losses. Effective and efficiency gold recovery can be gained by regular ore characterization, which will dictate appropriate ore preparation and cyanidation flowsheet design.

The most widespread challenges in terms of minerology of many gold ores for gold recovery, which can be mitigated through appropriate ore preparation, are caused by the presence of sulfides in the ore. In refractory ores, gold very often occurs in chemically bonded form with these sulfides. Extraction of this gold can be facilitated by decomposing the sulfides into oxides which converts gold to metallic form. Roasting is an accessible method for small-scale operators to accomplish this, and under some conditions and when done properly, can improve gold recovery considerably. Sulfide-rich concentrates can be roasted at temperatures of 400–500°C until a color change is evident from the oxidation process (to grey, red or brown). Care must be taken because roasting can be toxic if certain minerals are present (e.g. sulfur dioxide, mercury, and/or arsenic). Therefore, controls must be in place to ensure that fumes do not endanger workers or communities. Industrial scale roasting mitigates this issue through pressure oxidation, where roasting occurs in controlled chambers in presence of oxygen and elevated pressure. Ores or concentrates can also be pre-treated to actively degrade sulfides by aeration. In the ASGM sector, milled ore can simply be dried under the sun for this purpose, while industrial miners may expose milled ore to pressurized oxygen.

Milled ore can also be pre-treated with hydrogen peroxide or another oxidizing reagent. In some CN flowsheets, removal of magnetic minerals (e.g. pyrrhotite) is prioritized because this mineral will consume large amounts of CN, if not separated. Additional techniques which are not necessarily “pre-treatments” are nevertheless critical for effective design of many CN process flowsheets, including the following:

- **Floatation** is widely used for the separation of sulfide and oxide minerals containing gold. This is a mineral concentration step, after which the concentrate is advanced to CN leaching.

In the case of carbonaceous ores, extra activated carbon (AC) can be added to the leach to offset the preg-robbing effects of carbonaceous materials (refer to carbon-in-leach description under section 2.3).
Another method which can be used to manage sulfides in CN flowsheets is with the application of lead nitrate, which forms lead sulfide and lead sulfite in solution, which can accelerate gold dissolution.\textsuperscript{18} Lead is toxic in some chemical forms, therefore special care must be taken, based on ore characterization.

\begin{quote}
The Minamata Convention defines the processing of mercury contaminated tailings by cyanidation as a “worst practice” that must be avoided. This dangerous practice can lead to the formation of mercury-cyanide compounds that can remain dissolved in solution, in process water and effluent, posing risks to human health and the environment. Thus, it is critical to remove mercury from ASGM tailings contaminated by mercury amalgamation, prior to processing by cyanidation. Numerous methods have been tested to remove mercury from ASGM tailings, including sluicing, centrifugation, floatation, and copper-silver plates.\textsuperscript{19} CN operators need access to appropriate testing instruments or facilities for evaluating mercury contamination in ore or tailings stockpiles/pulps, so that data on mercury concentration and homogeneity in the stockpiles can inform requirements for safe ore preparation (including the removal of mercury, if present) and corresponding CN flowsheet reagents or processes. For further detailed discussion on this issue, the reader is referred to UNEP, 2021.
\end{quote}

2.3. Cyanide Leaching

Leaching methods are dictated by ore characterization but also by capital available and local technical knowledge regarding CN leaching options. The principal types of CN leaching systems employed in the ASGM sector are described in this section. For all CN operators no matter the scale and type, it is critical that workers, technicians are properly equipped and well trained to measure and monitor CN levels and pH – and that workers understand the imperative for doing so. The most common technique for monitoring CN levels is by colorimetry using titration with silver nitrate solution The method requires careful observation of solution color change, during titration using a pipette and flask with solution of silver nitrate\textsuperscript{20} (titration refers to slowly adding measured amount of 1 liquid to another liquid). In practice, pH monitoring can be achieved in several ways, from simple pH paper strips to handheld battery-powered pH meters, to fixed autonomous digital instruments which are programmed to record pH levels at specific time intervals.

2.3.a. Heap Leaching

Heap leaching is generally the most affordable technique for cyanidation and is predominantly used when leaching large volumes of low-grade material. Crushed and milled ore is piled onto impermeable liners (aka a “leach pad”) and alkaline cyanide solution is sprayed or percolated from above (top of slope) and allowed to seep through the material, percolating through the ore and dissolving the gold as it moves. CN solution is continuously recycled using a collecting drain beneath the heap so that the solution can then be pumped back up, over, and through the heap. This cycle is done until the measured gold concentration reaches a given threshold or the solution is no longer increasing in gold concentration. In the ASGM sector, heap leaching is predominantly used for reprocessing of tailings. It is not typically used on virgin ores because ASGM miners typically focus on smaller volumes of higher-grade ore (as compared with industrial mines who often focus

\textsuperscript{18} Refer to Deschenes, et al., 2000.

\textsuperscript{19} Personal correspondence with M. Veiga in August 2021; Refer to Rodriguez et al., 2021.

\textsuperscript{20} Detailed explanation of silver nitrate titration technique for CN measurement is provided at https://www.911metallurgist.com/blog/free-cyanide-vs-total-cyanide-determination.
on large volumes of lower grade ore). For heap leaching, NaCN concentrations around 1:1,000 parts are typically applied: less concentrated than applications for vat leaching or agitated leaching.

2.3.b. Vat Leaching

Until around 2000, vat leaching was the most widespread method in most ASGM regions around the world due to its low cost and relative advantages to heap leaching. In the vat leaching process, milled ore is placed in vats, large drums, tanks, or pools. Below the crushed ore, the vessel is lined with sand and/or filter materials, with a drain below. Quick lime is added to the surface or mixed in with the ore, and alkaline cyanide solution is introduced by hoses to the top of the tanks. The cyanide solution fills the pore spaces, submerging the ore and dissolving gold to form a “pregnant” cyanide-gold solution that passes down through the drain and pumped back around until the solution cannot leach further gold. This point is determined by conducting measurements of CN gold concentrations and determining when the solution is no longer increasing in gold content. The pregnant solution is then directed through a stripping circuit, to deposit gold from solution. This can be done in a few different ways, but typically the solution is passed through a series of tanks or columns containing activated carbon or zinc that “strip” gold from the solution (see section 2.4). The CN solution can be re-circulated through the vats, and this cycling is repeated until gold is no longer being dissolved from ore in the vats.

Vat leaching allows for greater control of the leaching processing resulting in faster, more efficient and targeted leaching when compared to heap leaching. With a vat leach, temperatures, acidity (pH), and solution flow rates can be controlled in the vat, providing significant advantages over heap leaching. Vat leaching can vary in efficiency, based on a number of factors. The process can take 10–40 days, depending on the size and depth of the tanks and other factors. One of the most common challenges for vat leaching as deployed in the ASGM sector is adequate delivery of oxygen into the leaching vats, which greatly limits the rate of gold dissolution.

2.3.c. Agitated Leaching

Agitated leach is more efficient than vat leaching and is quickly becoming the dominant form of cyanide use in ASGM worldwide. Steel (sometimes cement) tanks are used and can vary widely in size but are typically of 2,000 to 20,000-liter capacity. Pumps are used to move solution and slurry between tanks. The most common methods for agitating slurry in the tanks are mechanically driven impeller and injecting compressed air. Lime or caustic soda are added to the slurry to maintain pH between 10 and 12. Slurry is typically maintained at 25–50% solids. Agitated leaching is typically conducted in one of two ways.

► **Carbon in pulp (CIP)** is a sequential leaching beginning with dedicated tanks or vats, where gold is dissolved from ore into solution. CIP leaching systems are generally setup in circuits of 4-6 tanks or vats, so that multiple stages of gold adsorption can be employed (i.e., counter current decantation). This initial leaching stage is followed by a filter stage which separates and clarifies the pregnant leach solution from the pulp. After this, the pregnant solution flows through or is used to submerge activated carbon (AC), and gold is desorbed or “loaded” onto the AC. Finally, the loaded AC is subjected to an elution circuit, where the gold is stripped from the AC using dilute cyanide solution, and then recovered by electrowinning.

► **Carbon in leach (CIL)** is similar to CIP, except that the leach and adsorption process occurs simultaneously. AC is submersed in the agitated leaching tanks, where it adsorbs metals from the leach slurry as soon as they are dissolved. Once the leach cycle is complete, loaded carbon is separated from the pulp by screening, and is then subjected to elution to recover the gold. CIL (i.e., simultaneous leach and absorption) can be more effective than CIP when high levels of silver, copper, or other preg-robbing constituents are present (e.g., carbonaceous ores). Numerous design characteristics can be used to
differentiate CIP and CIL flowsheets from each other, however these characteristics and nuances are not described in detail, here.

Although agitated leach systems have a higher demand for capital and technical knowledge, these methods have higher gold recovery, and as a result are replacing less efficient vat leaching systems in many ASGM regions around the world where cyanidation is common.

2.3.d. Intensive Cyanidation

For some ores it is possible to reduce CN consumption and processing times by leaching a mineral concentrate only, and this method is termed Intensive Cyanidation (IC). Concentrates can be produced using floatation, centrifugation, sluicing, shaking table, etc. IC can reduce the volume of CN and other reagents consumed, as well as the time required time for leaching. Further, IC greatly reduces the amount of CN-affected pulp (tailings) which enters the waste stream, and this comes with large cost saving, because this waste stream must be actively managed (at significant cost to mineral processors).

IC can be operated at a variety of scales, from micro to semi-industrial. Success using ASGM ores from Indonesia and from Ecuador has been demonstrated with concentrate batch sizes between 100 and 200 kg. The objective of concentration is to reduce volume of ore to be processed while preserving gold values. Gold concentrates will generally contain a range of gold size particles, from very fine to coarse. In the event of coarse particles, higher concentrations of CN can be used during leaching (up to 20g/L), along with the addition of oxidizing agents to improve and speed up dissolution of coarse gold particles, thus avoiding the multi-day wait times of conventional leaching methods.

Once a mineral concentrate is ready for IC treatment, the leaching vessel is prepared. The pH of solution must be controlled and monitored during the process. Depending on available tank size, the concentrate is added along with an oxidizing agent, such as hydrogen peroxide. The leaching tank is then subjected to aggressive agitation and/or pressure (10 kPa), which helps to accelerate gold dissolution.

2.4. Gold Recovery after Cyanide Leaching

Gold is most often recovered from cyanide leach solution using AC in a multi-step process beginning with “loading” the AC with gold from pregnant leach solution, followed by “stripping” the gold from the carbon, into a more concentrated “elute” solution, from which the gold is deposited & collected by electrowinning.

2.4.a. Using Activated Carbon

Activated carbon (AC) is highly effective for adsorption of the gold-cyanide compound from solution due to the carbon’s high porosity, large surface area and negative charge. Coconut shell carbon is one of the most widespread types of AC in use by the ASGM sector, worldwide, due to its durability (wear resistance) and effectiveness. AC can typically absorb 5–8% of its weight in gold. The AC is “loaded” with gold through contact with pregnant solution, in either CIL or CIP leach. After loading in the leach stage (by CIP or CIL as described above) the gold must then be stripped (i.e., extracted) from the activated carbon, and this is accomplished by elution, using dilute CN solution with high pH. The result is a highly concentrated gold solution typically containing 1,000–3,000 mg Au/L (PPM). Finally, gold is recovered from the concentrated gold solution (“elute”) by electrolysis or by using zinc. In order for the AC to be used again (i.e., recycled) it must be re-activated, which can be accomplished by washing with acid and/or steam cleaning in the presence of oxidizers.

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21 Refer to Veiga, et al., 2009.
2.4.b. Using Zinc

Zinc (Zn) can also be used to recover gold from pregnant solutions, and it is used on both primary leach solutions, as well as on CN elute solutions (concentrated gold-cyanide solutions). Because zinc metal has a high affinity for cyanide, the introduction of zinc into solution strips cyanide from the gold-cyanide complexes, resulting in gold-zinc precipitate.

The term Merrill Crowe Process (MCP) refers to gold recovery with zinc using specific innovations including counter current decantation (CCD) and the use of filtration techniques which help to reduce oxygen levels in solution at key stages. It is worth noting that many small-scale CN operators use the MCP name rather loosely, while the use of zinc for recovery in the CN flowsheet does not necessarily constitute a formal MCP designation (even though local operators may use the term). However, the MCP presents important improvements over traditional vat leaching with elution to AC or zinc. For example, in the case of ores which contain silver as well as gold, using MCP offers improved gold recovery because silver and other metals also compete with gold for adsorption sites – when AC is used.

Several methods can be used to bring pregnant solution into contact with zinc. One way zinc has been used in the ASGM sector is by allowing the pregnant CN solution to flow through PVC tubes (column filters) filled with zinc shavings (note however that carbon-in-column has become much more widespread – where the PVC tubes are filled instead with activated carbon). In other systems zinc powder or zinc coated roofing materials are added to pregnant solutions or elutes, causing the formation of gold-zinc precipitates, which are then recovered. Regardless of how it is applied, recovery using zinc results in a zinc-gold sludge, zinc-gold precipitate, or metallic plates coated in zinc-gold.

2.4.c. Elution and Electrowinning

Gold can be extracted from the loaded carbon or zinc by elution. This is accomplished using an elution solution comprising dilute cyanide and caustic soda (electrolyte) in which the carbon or zinc is soaked, to extract gold. Heat and pressure can be applied to enhance extraction (optimal eluting temperatures is between 70–90°C). The elute solution - which is much more concentrated in dissolved metals including gold, than the original leach solution, passes through an electrowinning cell, where the gold and other metals are deposited by electrolysis. Gold is deposited at the cathode, where wire wool is typically used to capture the gold as a “metallic sludge”. The elution circuit re-circulates the caustic solution back through the loaded carbon, extracting more gold, and the process continues until the carbon has been fully stripped. Compared to zinc precipitation, this process has the advantage that no chemicals or metals are introduced, and it is selective for gold and silver over copper, thus resulting in a higher purity sludge. The main disadvantages of the elution process (when compared to precipitation using zinc) is slower deposition rates at low gold concentrations (with electrowinning).

In some regions (e.g., Indonesia) it remains common for processors to burn loaded carbon to ash, rather than eluting. The ash is subsequently processed by acid digest to recover the gold. This method emits unnecessary noxious fumes and carbon dioxide and results in less pure doré which requires extra cleaning.

2.4.d. Acid Digest and Smelting Gold Doré

Finally, the metallic sludge resulting from the cyanidation process is digested using acid to make a final separation of gold from other metals (especially copper) before smelting to create the gold doré, using either forced-air burner, forge, or furnace. Concentrated sulfuric acid is used for acid digestion because gold does not dissolve in concentrated sulfuric acid, while other metals are dissolved. The acid digestion releases noxious fumes that contain high metal concentrations; thus, it is imperative that controls are in place to ensure safe and environmentally acceptable practice, which must also account for control of fumes, waste,
and effluent treatment and storage. Unfortunately, fans or fume hoods are often lacking during this process at many ASGM operations, which could help to ensure operator safety. Solutions containing dissolved metals and/or acids should be treated to neutralize the acid in solution and to ensure that dissolved metals are not released to the environment.

In the final stage, the gold mud is carefully placed into a steel or graphite crucible and introduced to a furnace or torch-burner for smelting at temperatures exceeding 1,100°C. Once fully melted, the molten metal is poured into an iron mold or directly into water for cooling. Once cooled, the doré is cleaned by removing slag (glass residue from melted borax or other minerals) and polished.

2.5. Managing Cyanide Effluent

**Mining effluent** refers to mine wastewater that is discharged into the environment. There are numerous sources of wastewater throughout the mining lifecycle and numerous different terms used. In relation to ASGM operations, process water comprises waters that have been altered during mineral processing, including milling, ore concentration, floatation, and gold extraction, including cyanide leaching. **Effluent** refers to mine process waters that are released into the environment, including into holding ponds or neutralization ponds/pools. Unfortunately, poor monitoring and management of effluent by CN operators in the ASGM sector is widespread, which is a critical matter concerning public health in many countries. CN spills have potential to be devastating to environmental receptors when waterbodies are impacted (refer to Appendix 1). Spills to waterbodies result from unexpected and/or uncontrolled release of effluent either to surrounding ground surface (lack or failure of secondary containment) or accidental spillage adjacent or directly into waterbodies. These releases cause rapid poisoning of fish and mammals, including humans. Acute exposures are the most obvious and critical frontline risk associated with CN effluent releases into the environment. The second critical risk concerns the transport of dissolved heavy metals that interact to form cyanide-metal complexes in the environment, many of which are known biological toxins, including mercury, zinc, copper, cadmium, and nickel. Management of mining effluents, with the use of holding tanks or impoundments, tailings facilities, and neutralization of CN within effluent is standard practice within the industrial mining sector industry, but such practices vary widely within the ASGM sector.

There is a wide difference in toxicity of CN to aquatic biota compared with terrestrial biota, with **aquatic biota being more susceptible to harm from CN**. Freshwater tailings storage facilities exhibit greater risk to wildlife and aquatic fauna compared with hyper saline (impoundments). Impacts to wildlife have been demonstrated to be “low” if/when tailings or neutralization ponds contain weak acid dissociable (WAD) cyanide at levels less than 50 milligrams per liter and access to the ponded areas is restricted, and releases of water from the ponded areas or lagoons (into the environment) are avoided.22

2.5.a. Degradation and Treatment of Cyanide Effluents

CN is typically not persistent in the environment23 and degrades to products existing in nature, including carbon dioxide, ammonia, and nitrates. In the environment CN compounds are subject to a variety of natural degradation processes. Most CN compounds hydrolyze rapidly in the presence of sunlight (i.e. they transform into less toxic organic and/or inorganic compounds of carbon and nitrogen). Indeed, all CN complexes are

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22 This level is derived from observations in both the USA and Australia that bird mortalities tend to occur when the WAD CN concentration increases above 50 milligrams per liter (Donato, et al., 2007). Reliable monitoring of CN at TSFs requires specific attention to sampling and sample preservation techniques prior to analysis.

23 There are 3 classes of CN compounds: (i) Free cyanide (HCN/CN-) and cyanide salts (NaCN, KCN), which dissolve in water to form free CN in solution; This is the active form of CN during gold leaching, & free CN is approx. 10,00 times more toxic than other forms. (ii) WAD cyanides, which are CNs that decompose under weakly acidic conditions (e.g., most cyanides of Cu, Cd, Zn, Ag, Ni); and (iii) Strong cyanide complexes, which are stable under ambient conditions of pH and temperature & require pH b/w 2-4 to break down.
subjected to biotic and abiotic oxidation but at differing rates of decomposition (i.e. neutralization). In normal conditions, free CN (the most toxic form, by far) does not remain biologically available after it comes it soils and sediments because CN ions are readily complexed by a wide variety of metals, metabolized by microorganisms, and/or volatilized.24

2.5.b. Natural Degradation

The chemical risks associated with CN leaching extend into the hydrological cycle, including ecological systems and food-webs.25 Luckily, CN is destroyed naturally by oxidation, which can occur without need for additional chemical inputs. Natural degradation is a general term for natural processes26 that reduce the total CN concentration of waste in the absence of human intervention.

**Oxidation** of cyanide-metal compounds typically proceeds in two stages: first, they are transformed to cyanate (CN-O), then cyanate is converted into bicarbonate and nitrogen. A study of natural degradation over a 15-week period in Canada measured a decrease from 68.7 mg/L to 0.008 mg/L,27 but degradation rates will differ based on localized environmental factors. Dependence on natural degradation remains commonplace in the ASGM sector, where CN process effluent is released to ponds or lagoons and these natural processes are allowed to oxidize the residual CN compounds. Natural degradation requires monitoring to be managed safely and responsibly. While natural degradation does not require capital investment or chemical costs, in some cases natural degradation (alone) may not reduce CN levels to permissible levels for release to the environment. Furthermore, while degradation is occurring, neutralization ponds and impoundments continue to pose threats to humans, livestock, and wildlife. Restricting access to these facilities should be required by CN operators, to ensure that critical health and safety risks are appropriately mitigated.

While many CNs can be fully oxidized by natural processes, CNs containing Cu, Ni, and Fe can be particularly resistant to break-down. For this reason, and to ensure that unsafe environmental releases are avoided, it is imperative that CN operators monitor pH, as well as WAD CN concentrations, particularly following release of effluent. Specific guidance and recommendations are provided in Section 3 of this guidance document.

2.5.c. Reagents for Neutralizing Cyanide Effluent

Effective CN neutralization28 can be accomplished using a variety of oxidizing reagents which degrade CN. Chemical neutralization of CN is rapid and effective, and widely implemented within the industrial gold mining sector, so that the principles are well-understood. In the ASGM sector, the most common reagents (additives) used for this process are hydrogen peroxide, chlorine (sodium hypochlorite), sulfur dioxide, and ferrous sulfate. Each of these regents present chemical properties that must be selected based on local conditions and chemical needs.

In some cases, reagents can effectively be added to neutralization ponds to facilitate destruction of CN compounds (e.g., chlorine, hypochlorite, fero-sulfate). Old rubber tires are sometimes left submersed in neutralization pools because rubber containing thiol radicals with sulfur have been shown to help flocculate

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24 Under aerobic conditions, CN salts (in sediment) are microbiologically degraded to nitrites or form complexes with metals. Under anaerobic conditions, CNs denitrify to gaseous nitrogen compounds and enter the atmosphere.


26 Degradation occurs as a result of volatilization, hydrolysis of CN compounds by soil or sediment, microbial generation of cyanate/ammonia in soil (anaerobic biodegradation), and other complexation reactions that break down CN compounds.

27 Refer to Todd, 1986.

fine sediments, thus clarifying solutions and precipitating mercury, which can be associated with these fine sediments.

Each reagent-based method has unique requirements for process controls, and costs vary depending on the neutralizing chemical selected, the quantities of materials needing to be neutralized, and the target CN concentration for the neutralization process. Availability of neutralizing reagents may be limiting in some areas. Effluent release must be treated to ensure that controlled release meet regulatory limits. Most jurisdictions have effluent limit for CN, or have adopted international guidance as limits, such as that of the IFC/World Bank which has established scientific guidance, is 1.0 mg/L total CN. In the context of ASGM, tools such as lifecycle assessment are worth pursuing with the view to identify hotspots for interventions with regards to environmental impacts of the various process steps and effluent treatment options.

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29 The World Bank guidelines developed in 1995 for mine effluent discharge to the environment include Free Cyanide: 0.1 mg/L, WAD: 0.5 mg/L, and Total Cyanide: 1.0 mg/L. The guidelines state that in no case should the CN concentration in receiving waters (outside of a designated mixing zone) exceed 0.022 mg/L and that measures to prevent access by wildlife and livestock are required for all open waters (e.g., tailings impoundments, pregnant leach ponds) where WAD cyanide is in excess of 50 mg/L (World Bank, 1995). Further reading on management of CN effluent and tailings is available in references list, including AGDIS, 2008; EPA, 1994; and Donato, et al., 2007 and 2013.
CASE STUDY #1

Cyanidation in Ecuador’s Small-scale Mining Sector

BACKGROUND

Ecuador’s modern gold mining sector is dominated by small-scale gold mining: production from ASGM is estimated to represent approx. 85% of total gold production. Four types of mining are identified in Ecuador’s mining regulation: artisanal, small-scale, medium, and large-scale mining. Current production levels in the gold sector have been estimated to be around 20 tonnes per year (estimate made for 2018), with approx. 10 t attributed to mercury amalgamation, and 10 t to CN use. The sector provides direct employment to an estimated 20,000 - 32,000 workers, approx. 10% of whom are women, with secondary economic benefits of at least 100,000 people. Districts where the ASGM sector is most active are Zaruma-Portovelo in El Oro province, Ponce Enriquez, in the province of Azuay, and Chinapintza, and Nambija in the province of Zamora. Processing centers are located primarily in the provinces of Zamora, Azuay and El Oro, with a total of 142 legally established processing plants.

REGULATORY SETTING

Regulations concerning cyanide in Ecuador are governed by Ministerial Agreement 003 of the Ministry of the Environment, which regulates permissions concerning cyanide used for mining. The official federal enterprise (Empresa Pública Importadora EPI-EP) regulates authorizations for the import and distribution of CN. The EPI-EP oversees the distribution of CN through qualified and approved companies in the country. Companies and agents granted permission include the association of owners of mineral processing plants (APROPLASMIN), whose representatives are authorized to purchase and distribute sodium cyanide and potassium cyanide to ASGM operators in the country. Previously, CN imports were made predominantly from the USA, but at present imports are also made from Korea, Russia and China.

BUSINESS MODELS

In Portovelo-Zaruma, groups of miners extract ore at numerous sites and transport the ore to processing plants. Most of the processing centers around Portovelo-Zaruma are organized to rent the facilities for crushing, milling, and cyanidation (fee-for-service mineral processing). While various business arrangements are in use, miners often process their own ore at the processing plants with the assistance and oversight of processing center representatives. Depending on mineral characteristics and other factors, the miners often recoup 20-50% of the gold by gravity concentration in the Chilean mills, which is directly submitted to smelting (previously, these mill concentrates were amalgamated with mercury). Following this initial recovery, tailings from the mill centers are collected and processed by cyanide leaching to recover remaining gold.
and silver. Miners pay a rental fee to the owner of the processing center to operate the Chilean mill and the cyanide leaching system, which includes electrowinning for gold recovery. Payout from the processing center typically includes a fee for the chief engineer/technician, as well as costs including lime, lab analysis, and sometimes food for miners/workers. Following CIP cyanidation, tailings which still contain silver are processed by froth flotation, available at several of the processing centers. Plant owners earn profit from fees for the use of their equipment and services, while miners earn profit from gold, silver, and other minerals obtained from the ore. Recently, successful miners are increasingly investing in their own processing equipment, although the fee-for-service model remains in widespread use as well.\(^3\)\(^5\)

ORE CHARACTERIZATION

While alluvial mining exists to limited extent in Ecuador (especially in Zamora Chinchipe and Morona Santiago provinces) the majority of gold production comes from hard-rock deposits. Regional gold occurrences are dominated by sulfide-rich quartz veins with characteristics of both epithermal and mesothermal systems. Most of the epithermal gold occurrences are associated with sulfide minerals, and a portion of these exhibit ‘free-milling’ ore constituents. Processing centers around Portovelo-Zaruma predominantly process local ores from around El Oro but also attract ores from neighboring provinces, including ores with different characteristics and processing requirements (e.g., polymetallic ore from porphyry-type mineral deposits; and sulfide-poor quartz-carbonate vein systems). Gold grades typically vary between 5 and 20 g/tonne but as low as 2 g/t when tailings are processed by cyanidation.

ORE PREPARATION

Most of the processing plants around Portovelo use Chilean mills (also known as pan mill, cone mill), which typically reduce ore to 100 to 140 mesh (approx. 100-150 microns). One of the main benefits of pan mills is that they also act as a concentrator, with heavy minerals including gold settling and remaining in the base on the mill while lighter minerals, which float as the mill is agitated, are removed in suspension to the mill effluent. At several of the independently held small-scale mines and larger processing plants, which do not operate toll milling services, ball mills are used followed by hydro-cyclones which feed into flotation tanks, followed by cyanidation.

LEACHING WITH CYANIDE AND GOLD RECOVERY

Cyanide leaching began in Portovelo around 1990 when processing plant owners learned to build cement tanks for vat leaching, which was locally referred to as ‘percolation leaching’ using zinc to capture the gold from the pregnant solution (Figure E1). The processing time to recover gold was between 20 to 40 days. After 2000, agitation tanks were introduced, which cost more to setup but have the benefit of dramatically reducing processing time (to around 4–5 days for typical 12 ton agitated tank setup, using zinc for gold elution/cementation). Around 2005, some processing centers began using carbon-in-pulp systems to recover gold and silver from the cyanide solution, and this improved processing times further still, to as little as 24 hours in some cases. These most recent system incorporated is the carbon in leach which remain in widespread use around Zaruma-Portovelo and Ponce Enriquez.
Portovelo’s Evolution from Vat Leaching Systems to Agitated CIL systems

As described above, in the 1990's and early 2000's vat leaching systems (locally called “percolation ponds”) were constructed using rectangular cement walled containment structures, and gold recovery from pregnant solution was accomplished using zinc (refer to Figure 1). While these systems were very low-cost to construct and operate, the full leach cycle required between 20 and 40 days. The principal challenge with these systems is the limited presence of oxygen required for the CN to dissolve gold. These rudimentary vat leaching plants have primarily been used for low-cost leaching of tailings -and unfortunately this practice remains in use.

The evolution of cyanide leaching systems in Ecuador occurred through three main drivers: knowledge, cost of operation, and the processing time to recover the gold. The logical and low-cost improvement to the rudimentary vat leaching systems, involved the addition of agitators to the center of existing cement vats (typically 12-15m³), which reduced leaching time. In this way, most owners of processing centres only needed to make small investments to improve leaching efficiency, and many operators still prefer the method due to its simplicity, relative efficacy, and their confidence in managing the process. This simple design became well established and has been replicated in neighboring countries.

While some percolation leaching operations remain, most have been replaced by carbon in leach (CIL), followed by Merrill Crowe Process (MCP) to precipitate gold onto zinc.

In the most typical arrangement, conical steel agitated leaching tanks of 6 m³ are used to leach 6-8 tonnes of milled ore with 8,000–11,000 L of water (per batch; tank slurry capacity 25-40 tonne, i.e. slurry is typically 35-45% solids by weight). Pumps are used to pump pre-mixed slurry into the leaching tanks (a major difference from vat leaching). Depending on ore characterization ~50 kg of sodium cyanide is added into the agitated leach, resulting in leach solution with ~4 to 6 g/L (ppm) of sodium cyanide.
Waste management in Portovelo

Management of ASGM tailings has been a major concern in the Puyango-Tumbes River valley around Zaruma-Portovelo since CN operations became widespread around 2010. Between 2013 – 2019, the Global Environmental Facility (GEF) invested in Integrated Water Resources Management in the Puyango-Tumbes, Catamayo-Chira and Zarumilla Transboundary Aquifers and River Basins,35 drawing attention to the emerging issue of cyanide use in ASGM. Following on these activities and designed to support Ecuadorian stakeholders in addressing ongoing challenges, the University of British Colombia with support from Global Affairs Canada and Ministry of Mines of Ecuador, designed and undertook a project called the Transformation of Artisanal and Small-Scale Mining and Social Learning (TransMAPE project) from 2016–2018, implemented by CIRDI36 with the support of the International Cyanide Management Institute (ICMI). The TransMAPE project began by characterizing mining activities in the region, including cyanide leaching facilities (particularly agitated CIL leach systems which are widely used). This was followed by implementation of an educational and support program, to improve gold production and promote more efficient and sound management practices in mineral extraction and processing, including cyanide leaching systems and cyanidation tailings characterization. Findings from the assessment were used to develop an appropriate educational and training curriculum, including support and education for miners for ore analysis, prior to cyanide leaching. The involvement of miners, owners of processing centers, and representatives of government agencies was invaluable to highlight the need for appropriate policy instruments, regarding cyanide management. The participation of cyanide experts from ICIM provided a strong signal to Ecuador government agents and ASGM operators – regarding the imperative for BMPs to be applied in the ASGM context.

35 GEF Integrated Water Resources Management Project implemented by UNDP (GEF ID: 5328); as well as Integrated Measures for Minimizing Mercury Releases from Artisanal Gold Mining locally executed by UNIDO (GEF ID: 4956).

36 For information about this project refer to Velásquez-López, et al., 2019.
Among the main learnings of the TransMAPE project was that an integrated, multi-prong approach with committed regional partners from both private and public sector is necessary to develop and sustain systematic improvements in regional waste management systems, for ASGM stakeholders. The TransMAPE final report emphasizes that emphasis and support must be directed on education and training, but also on applying political capital and appropriate enforcement mechanisms.

Figure 6. Dam at the edge of the Galera River in Portobelo-Zaruma mining district, Ecuador. This photo illustrates the challenge of ASGM Waste Management; long-term storage and management of tailings is a critical regional priority with important public health implications, in ASGM regions.

Figure 7. Regional topography has important implications in selecting appropriate sites for tailings disposal. (At left) Tailings pond located next to watercourse in steep terrain near an ASGM mining community. Clearly, without berms and secondary containment structures, this is not a well-chosen or executed waste management scenario. (At right) Groundworks using heavy equipment have been undertaken to ensure that tailings are controlled at this site in Ecuador. Unfortunately, however, these types of facilities are often developed without ample engineering studies, and mine wastes can be released from containment as a result of natural causes (e.g., earthquake, or flooding causing liquefaction or flooding), or man made cause (e.g., stacking mine wastes to high (over filling), lack of maintenance and monitoring, etc.).
CASE STUDY #2

Cyanidation in Zimbabwe’s ASGM sector

BACKGROUND

Zimbabwe’s modern gold sector stems from the Rhodesian gold rush of the 1890s. Tolerant and even progressive policies were a hallmark of the Zimbabwean government’s approach to the sector in the 1990s and this resulted in Zimbabwe providing a model of ASGM sector development, for other African nations to follow (Spiegel, 2015). Similar to elsewhere, the ASGM sector was driven by the increase in international gold value. Gold benefaction with cyanide became established in the 1990s, and these were primarily setup as ‘custom milling centers’, where miners would process their ore, and leave tailings behind which the mill owner would take as payment.

Cyanidation leaching plants were most widespread in Midlands, Mashonaland West, and Matabeleland South. Records indicate that annual cyanide consumption in Zimbabwe’s ASGM sector in the late 90’s was on the order of 5000 metric tonnes per annum (UNECA, 2002; Hinton et al., 2003).

Currently (2020-2021), the ASGM sector employs an estimated 300,000 - 500,000 workers and produces on the order of 25 tonnes of gold per year. Approximately 600 milling centers remain in active operation in the country. The majority of modern gold production in Zimbabwe’s ASGM sector is from hard rock mining and production figures are well constrained (as compared to many other ASGM regions) as a result of the Zimbabwean governments’ national gold buying program which has held a monopoly on legal buying from ASGMs for more than a decade. Interestingly in 2021, plans to liberalize gold buying and trading are at an advanced stage as the government plans to sell 60% of Fidelity Printers and Refiners (FPR) to private players in the gold industry. The gold refining unit, which the government is ceding will be called Fidelity Gold Refinery (FGR), and the hope and intention is that the gap between official and black market prices will narrow, resulting in increasing gold flow to FGR.

ORE CHARACTERIZATION

Midlands Province, in the central part of Zimbabwe, has been one of the countries primary ASGM hotspots for more than 20 years and is the geographical focus of this case study. Midlands Province encompasses the mining towns of Gweru (provincial capital), Kwekwe, Shurugwi, Zvishavane, Mberengwa, and surrounding areas. The lion’s share of present-day gold exploited in Midlands are hard rock deposits: mineralized gold, mostly hosted in vein systems; most deposits are associated with shear zones and coincide with quartz, carbonates, and sulfide minerals.
MINING AND ORE PREPARATION PRACTICES

Deposits are mined through vertical shafts, with horizontal and sloping adits and stopes which are used to exploit gold mineralization. Over the past decade, an increasing number of mine operators are investing in steel infrastructure (supported shafts), powered winch systems, and other semi-mechanized advancements - and this is a very positive development in the small-scale gold mines, contributing to improving safety of mine workers.

Once delivered to the surface, initial crushing has historically been done using hammers (manually), but also with stamp mills. Over the past decade, gas-powered jaw crushers are increasingly common. Toll-milling stamp mills were widespread in Zimbabwe since the 1990’s, and in many cases were preferred over ball mills due to more consistent grain size, and because ball mills are more difficult to clean out, and thus less amenable to toll-milling. Miners kept gold from the sluice carpets used beneath stamp mills, while the mill owners would keep tailings for payment, by subsequently recovering additional gold through vat leach cyanidation.40 Currently, the use of small ball-mills remains common, fabricated locally in Kwekwe and Shurugwi from old propane containers or truck wheels, and powered by small gas motors. At other mineral processing sites, miners are deploying mercury free small-scale cyanidation leaching operations, which use cone mills for grinding/milling, followed by sluice boxes and vortex, before tailings are separated to slimes and sands, prior to vat leach cyanidation.
Cyanide Suppliers and Transport

Cyanide used in Zimbabwe's ASGM sector arrives overland by truck, from the marine port at Beira, Mozambique. Import and consumption of NaCN in Zimbabwe's ASGM sector is between 500 and 800 tonnes per month (6000-9600 tonnes per annum). Trucks which are certified for dangerous goods are used for shipping to Harare, where warehouses are used to storehouse the cyanide (approx. 100 tonnes per month is shipped directly to Bulawayo where it is warehoused). Haulage conditions are overseen by respective environmental agencies in Mozambique and Zimbabwe, and transporters are required to have valid licences and training for dangerous goods transport.

In Zimbabwe, CN customers may only buy from EMA-registered and certified sellers. This works in practice, and is quite regulated for large customers, however the system breaks down when large customers allow re-sale of cyanide onwards to small operators, who are often more mobile, and operate with fewer controls, and regularity.

In terms of CN supply chain due diligence, selling companies are required to conduct due diligence with the use of “end user certificates”. These are in widespread use in Zimbabwe and are verified by officers of the Environmental Management Agency (EMA). Cyanide sellers must ensure that these certificates are duly completed, certified, and submitted to international manufacturing companies – which fulfills obligations of the International Cyanide Code.

LEACHING WITH CYANIDE

Vat leaching operations have been in widespread usage in Midlands Province since the early 2000s, usually associated with milling centers. These operators are known locally as ‘static leaching’ operations. Most of these use carbon-in-column elution systems, with PVC columns filled with AC or zinc, to recover gold from pregnant leach solution. Following elution, CN solution flows into barren solution tank, where it is checked (tested), filtered and adjusted for reagent as necessary, and subsequently recycled back through the vat leach. This cycle can be repeated indefinitely, and thus hypothetically there is little demand for solution neutralization, for this type of operation. However, in terms of waste management, these operators represent significant risk for cyanide releases to the environment, due to the fact that these operators typically operate with low capital costs and minimal controls.

Since around 2010, numerous cyanide operators have adopted more efficient CIL and CIP plants, capable of higher gold recovery. Locally referred to as “elution plants”, these sites also use static leaching in vats, but pregnant solution is then loaded onto AC in steel tanks and eluted in specialized steel elution tanks. For these sites, recycling cyanide solution is less efficient, from cost perspective, and therefore barren solutions are sent to neutralization pond, and/or tailings dam. In Zimbabwe, fero-sulfate reagent is added to solution for purpose of neutralizing the CN effluent and tailings.

Since around 2010, numerous cyanide operators have adopted more efficient CIL and CIP plants, capable of higher gold recovery.

REGULATORY ENVIRONMENT FOR CN

Regulatory oversight for CN use in gold mining in Zimbabwe is under the jurisdiction of the Environmental Management Agency (EMA), as explained in the Environmental Management Act (20:27), and Statutory Instrument 12 of the Hazardous Substances, Pesticides and Toxic Substances Regulations (2007). The regulation states that any person who imports, transports, stores, or sells any hazardous substance must have a license for such, and the regulation further requires that cyanide be imported, transported, handled,
and disposed of by trained personnel, and only in certified containers. According to the EMA, the disposal and discharge into the environment at mine sites is regulated using permits and licenses granted by EMA. Specific regulations in Zimbabwe stipulate that total cyanide concentration of effluent leaving mining operations (i.e. if released from holding or neutralization ponds) must be less than 0.07 mg/L (prescribed in Statutory Instrument 6 of the Solid Waste and Effluent Regulations, 2007). Official policy of the Ministry of Mines indicates that CN must only be used in a manner consistent with the International Cyanide Management Code. EMA’s Policy brief on the issue states that any-and-all accidental spillage
CASE STUDY #2 Cyanidation in Zimbabwe’s ASGM sector

of cyanide compounds must be reporting to EMA verbally and in writing, within 8 hours. EMA is responsible to send a team to investigate and direct mitigation or neutralizing, for spilled substances. Costs of cleaning spills are the responsibility of the company responsible for the spillage.

CYANIDE SUPPLIERS AND TRANSPORT

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In terms of CN supply chain due diligence, selling companies are required to conduct due diligence with the use of “end user certificates”. These are in widespread use in Zimbabwe and are verified by officers of the EMA. Cyanide sellers must ensure that these certificates are duly completed, certified, and submitted to international manufacturing companies – which fulfills obligations of the International Cyanide Code.

Figure 12. Steel wool is used for cathode

Figure 16. Gold product, after smelting

Figure 13. Product of Electro-winning: the steel wool cathode is not packed with gold and other metals which have deposited out of the elution solution

Figure 14. Sulfuric acid digest to dissolve metals, while leaving gold undissolved. The acid digest releases noxious and potentially dangerous fumes. Occupational Health and Safety (OHS) measures and personal protective equipment (PPEs) are essential to avoid inhalation of hazardous fumes, or particulates. Afterwards, acid effluents must be managed to ensure dissolved metals are not released to the environment.

Figure 15. Pump-driven air torch for smelting, with wood and oxygen used as fuel
3. Best Practices for CN Management in the ASGM Sector

Risks from CN must be managed throughout CN’s life cycle, from production and sourcing, through transport, usage, and waste management, including final disposal. The Cyanide Code was developed for the industrial mining sector to ensure proper management through this entire life cycle. The Code provides clear guidance regarding the safe management of “…cyanide that is produced, transported and used for the recovery of gold and silver, and on mill tailings and leach solutions.”41 The Code principally comprises two sets of documents:

- The Code document itself, which outlines nine principles for safe management (refer to Figure 3), as well as standards of practice that identify performance objectives that must be met in order to comply with the respective principles.
- Supporting documents comprising primarily verification protocols, which act as a checklist of requirements that must be verified to be in compliance with the Code, and associated guidance documents.

The Code also is very clear that CN operations must comply with regulations and laws of the applicable national and regional legal frameworks.

While miners and regulators often are most concerned with workplace exposures and spills, CN management must encompass sourcing, transport, handling, and storage as well, all of which occur before CN salts are used to leach gold from its ores. Mine operators, CN transporters, policymakers, and enforcement agencies must consider the entire chemical supply chain. Due diligence must be undertaken to ensure safe conditions for production, transportation, and storage.

The Code provides requirements and expectations for operational, safety, and environmental programs and practices for mining operations. However, the exact methods by which those requirements and expectations are met are frequently the responsibility of individual operations, based on site-specific characteristics. For example, while the Code contains requirements and expectations for safety programs, including the use of personal protective equipment and CN antidotes, it does not mandate specific personal protective equipment or specific CN antidotes to be used. This level of detail is left to individual operations based on their specific needs. Likewise, the Code is not an engineering document. While it contains requirements for engineered features such secondary containments or tailings impoundments to be in place, it generally does not stipulate or provide specific guidance regarding all design or construction features of built facilities.

While the Code was not designed to address the ASGM sector, risks to human health and the environment from CN use in the ASGM sector are categorically similar to those that exist in the industrial mining sector, though the number of compounding variables, including the lack of skilled operations management, the

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41 ICMI, 2016.
number of independent parties involved and the high number of individual sites where CN is being used, result in a total aggregate risk profile for CN in the ASGM sector which is more difficult to assess and control.

Detailed and explicit expectations, requirements, and instructions on specific practices and applicable to the ASGM sector is an area where actors in the ASGM sector remain in need of guidance, and support. Below, each of the nine principles from the Code are presented, with specific expectations for ASGM stakeholders as guidance for each principle. The intention here is not to repeat guidance from the Code, which is readily accessible, but rather to provide helpful insights on application of the Code’s requirements, best practices, and guidance within the ASGM sector.

3.1. CN Code Principle 1: Cyanide Production

Encourage responsible cyanide manufacturing by sourcing from responsible manufacturers that operate in a safe and socially and environmentally responsible manner.

Principle 1 of the Cyanide Code ensures responsible CN manufacturing by trustworthy manufacturers that operate in a safe and accountable manner. CN salts are manufactured worldwide, and indeed many manufacturers are signatory to the Cyanide Code.

**Guidance for ASGM stakeholders (CN production)**

i. CN safety and pollution prevention in the ASGM sector should begin by procuring chemicals only from responsible and regulated (Cyanide Code certified) CN manufacturers.

ii. Operators and regulators should avoid informal and unsafe/illegitimate chemical supply networks.

**Highlighting Concerns from the Field: Migori, Kenya**

In Migori, Kenya the use of sodium cyanide in ASGM leaching circuits has drastically increased since 2014. Initially, CN suppliers began sourcing from industrial gold mining regions in neighboring Tanzania through informal trade networks. As the majority of transactions were informal and unregulated, miners lacked receipts, material safety data sheets (MSDSs) or proper labels. However, by 2019, supply licenses for importing larger amounts of CN were being issued through the Mombasa Port with stronger regulatory and permitting requirements. As supply chains shifted, certified suppliers began to distribute CN hazard communication materials, label transport containers (tins), and issue formal receipts with certificates of origin.

3.2. CN Code Principle 2: Transport

Protect communities and the environment during transport.

CN transport by land, water or air results in related risks for communities, ecosystems, and wildlife. Once CN compounds are sold by a manufacturer, the product enters an extensive international supply chain network, and transport to remote ASGM communities certainly increases transport-related risks. Modes of transport must adopt mitigation measures to avoid contaminating food supplies and/or consumer goods. This is done by isolation (i.e., physical separation) of hazardous chemicals from cargo. In the industrial mining sector, miners have strict CN transport compliance regulations, and use only Code-certified transport companies and supply chains, whose systems, such as vehicle maintenance and inspection programs, and emergency response programs have been audited. In the international ASGM sector, with less formal trade networks and supply lines, it is more difficult to ensure legitimate, certified transporters; but, here this is even more
important. Safe management measures must be implemented by transporters and audited by regional and local regulators to ensure responsible transport of CN used in the ASGM sector.42

**Guidance for ASGM stakeholders (CN transport)**

i. Due diligence measures on safe and environmentally responsible CN management should extend throughout the entire CN transport chain from CN purchase centers at international ports and city warehouses through distribution and final sale.

ii. Transporters should be aware of CN hazards and risks during transportation and implement controls for safe transport and unloading.

iii. Small-scale mine operators should only use transporters with appropriate safety practices and due diligence procedures in place.

iv. Local regulators should audit CN carriers to ensure that appropriate transport conditions and safety precautions are in place.

v. Regulators and supporting stakeholders should hold chemical suppliers accountable if/when uninsured, unlicensed, or unsafe transporters are identified in their product supply chains.

### Highlighting Concerns from the Field: East Africa

Each month, 500–800 tonnes of sodium cyanide are imported and transported over land to Zimbabwe from the Beira port in Mozambique. Trucks that are certified for dangerous goods are used for shipping to Harare, where warehouses are used to storehouse the CN (approximately 100 tonnes per month is shipped directly to Bulawayo). Haulage conditions are overseen by respective environmental agencies in Mozambique and Zimbabwe, and transporters are required to have valid licenses and training for dangerous goods transport. In Zimbabwe, CN customers may only buy (legally) from Zimbabwe Environmental Management Agency (EMA)-registered and certified sellers. This works in practice and is quite regulated for large customers; however, the system breaks down when large customers allow resale of CN onwards to small operators, who are often more mobile and operate with fewer controls and regularity.

The increased use and transport of CN throughout Africa and elsewhere is a major public safety concern that requires appropriate oversight. Poorly regulated transport routes and transporters of cyanide are a growing concern in some areas. In some cases, truck-transport of CN to ASGM operations have been known to mix shipments with livestock and/or agricultural products and in vehicles not permitted for CN transport. According to some ASGM operators, safe CN transport is a blind spot. ASGM stakeholders must ensure that dedicated trucks with adequate training and safety measures be mandated and enforced.

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43 Detailed CN supply chain analysis provide by T. Chinyowa, Zimbabwe (July 2021).
3.3. CN Code Principle 3: Handling and Storage

Protect workers and the environment during cyanide handling and storage.

Improper storage and handling of CN compounds can result in serious injury, disability, or death. Acceptable storage spaces and facilities must be used when storing CN, with due consideration for spill prevention and containment measures and regular inspections.

**Guidance for ASGM stakeholders (CN handling and storage)**

i. CN users should have **dedicated facilities for storing CN compounds**. Storage facilities should be dry and well-ventilated with impermeable flooring, be lockable, and have an inventory tracking system that is maintained to monitor shipments and usage of CN compounds.

ii. Transporters and CN handlers should be trained on assessing workplace hazards and risks, as well as avoiding adverse impacts on communities, agricultural lands, livestock, surface waters, and wildlife. Detailed emergency response plans must be in place and well understood (rehearsed) by CN handlers and site operators.

iii. Small-scale gold mining facilities should ensure that CN storage facilities are fenced and secured to avoid unwanted or unlawful entry and the possibility of related accidents.

iv. CN salts should never be stored with or near incompatible substances, such as water (wet conditions can result in CN salts releasing hydrogen cyanide gas) or oxidizing agents.

v. CN mixing and storage tanks and areas where mixing and storage occurs should have impermeable liners and secondary containment adequate to capture spillage and prevent contamination of soil and water.

vi. Procedures should be in place for **appropriate disposal of CN containers**.

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**Highlighting Concerns from East Africa (Kenya) and West Africa (Mauritania)**

The gold mining communities of Chami, Mauritania, and Migori, Kenya, share a common concern: assurance and oversight concerning safe application and responsible use of CN. Personal accounts in both cases recount recent instances of community protests concerning CN. Inadequate management and poor waste management practices have become a controversial issue in gold mining areas.

In the Kenyan account, an unattended two-year-old boy fell into a leaching pool and suffered major health issues due to CN exposure. This tragic event caused outrage in the local community and prompted ASGM operators to improve safety infrastructure, such as fences to keep children and livestock out of high-risk areas and storage areas to house CN compounds. In the account from Mauritania, community protest led to protesters torching vehicles during a protest demanding transparency and accountability concerning cyanide operators.

These strongly held community concerns point to the strong need for increased assurance, enforcement, and transparency measures are urgently needed to avoid preventable accidents associated with CN use.
3.4. CN Code Principle 4: Operations

Manage cyanide process solutions and waste streams to protect human health and the environment.

Principle 4 of the Code presents nine operational standards of practice that are critical to ensure responsible CN use on active mineral processing plants or mine sites.44

Guidance for ASGM stakeholders: Establishment of standard operating procedures (SOPs)

i. Operations are expected to have operational plans and SOPs to ensure that activities involving CN are conducted safely for workers, the environment, and the communities in which they operate. The exact format, structure, and definitions of “plans and procedures” and other documents are not mandated and may vary depending on the facility. The importance of plans and procedures lies in their content and whether the documents specifically and adequately address the systems and activities required at an ASGM operation to safely manage CN.

ii. Operating plans and SOPs should address activities such as inspections and maintenance, water and effluent management, spill prevention and response, and environmental protection and monitoring.

iii. Operating plans and SOPs should be specific to the facilities and CN processes at an operation, practical, and written at a level to facilitate understanding & implementation by the workers who will use them.

iv. Operating plans and SOPs should provide clarity concerning roles and responsibilities of personnel. Workers should be trained to the plans and procedures prior to the worker beginning the activities described, and refresher training should be conducted on plans and procedures at least annually.

v. A variety of SOPs should be documented and understood by site workers, including the following:
   - SOP describing how CN-related tasks, such as unloading, mixing, plant operations, entry into confined spaces, and equipment decontamination (e.g., prior to maintenance); SOPs should emphasize how systems and controls are designed to minimize risks and hazards.
   - SOP regarding how CN concentrations are established, adjusted, and monitored - in the leaching process, including to minimize CN use and loss. Limiting CN use to the greatest extent practicable has both environmental and economic benefits. Lower CN concentrations reduce risks to wildlife from exposures to tailings and to water quality from potential seepage. Lower CN use reduces a mine's costs for the reagent and its transport to the site and limits the potential for releases and exposures during transport.
   - SOP regarding protocols and process for maintaining appropriate pH which is critical to limit the production of hydrogen cyanide gas during mixing and leaching activities.

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44 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 CN 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 & wildlife from direct & 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.
Further recommendations for operating plans and SOPs associated with specific operational topics, are provided below.

vi. As described in Section 2.2 of this report, Annex C of the Minamata Convention defines the processing of mercury contaminated tailings by cyanidation as a “worst practice” which must be eliminated. CN operators must be aware of the associated risks and must deploy controls to avoid CN leaching of mercury-contaminated waste piles to ensure the safety of workers, biota, and surrounding communities.

Example of Removal of Mercury from ASGM Tailings Prior to Cyanidation

Numerous methods can be used to remove mercury from ASGM tailings, including sluicing, centrifugation, floatation, and copper-silver reaction plates. One method is the use of reaction plates. Reaction plates can be made from copper or tin and are most effective when coated with silver, using silver nitrate solution. The method is a simple variation on the practice of sluicing, which ASGM stakeholders are already familiar with. Slurry of tailings is passed over sloped plates, and mercury is deposited by chemical reaction onto the surface of the plates. Afterwards, the oxidized mercury is removed by scraping the surface. Before using again, the plates must be cleaned using vinegar. The efficiency of the mercury removal depends primarily on the mercury oxidation state in the tailings or ore; however, mercury removal/recovery > 95% has been demonstrated in some cases. Once mercury is removed, it can be mixed with cement and sulfur to form a solid, inert waste product.

Guidance for ASGM stakeholders: Effluent and water management

i. Operating limits for freeboard must be identified and maintained on all impoundments, based on factors such as design and operating and environmental conditions. Ponds and impoundments must be constructed and managed to ensure that rainfall or local flooding do not result in release of CN contaminated effluent.

ii. Ponds for process water and effluent should be designed and managed with volume capacity to accommodate storm events and should also have secondary containment capacity, and these

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containment structures must be monitored and maintained in state of readiness - to prevent release of CN effluent and/or contaminated solutions, under all foreseeable environmental conditions.

iii. Ponds and impoundments should be designed and actively managed where practical to take advantage of natural CN degradation processes.

iv. CN effluent lagoons should be constructed with adequate measures to contain seepage (sealed base or liner) to protect the beneficial uses of ground water (including agriculture and community drinking wells). Ponds used to receive effluent with high concentrations of CN or metals should have liner systems and should be monitored regularly.

v. Operating plans should consider emergency preparedness and preventative maintenance on all related infrastructure (e.g., transport and storage facilities, tanks and vessels, piping). Such maintenance needs and mitigation events should be recorded in an operations logbook.

Guidance for ASGM stakeholders (Protection of birds, wildlife, and livestock)

i. Controls to restrict access to effluent or tailings ponds containing CN must be in place. At minimum, process water and effluent ponds must have fences with locked gates and signage identifying the presence of CN.

ii. Open waters in effluent ponds are particularly hazardous for water birds, such as ducks. Operations having open effluent ponds should manage them so that WAD cyanide concentrations in the effluent discharge to the ponds are less than 50 mg/L, levels that are considered safe for avian life.

Guidance for ASGM stakeholders (Protection of surface and groundwater)

i. Process solution and effluent ponds should be constructed with adequate measures to contain seepage, such as a liner or sealed base, to protect the designated or actual beneficial uses of ground water, such as for agriculture or drinking water. Such ponds should be lined with double membrane liner systems and contain an inter-liner leak/seepage monitoring system to identify if a liner is compromised.

ii. Routine monitoring of surface and groundwater in the vicinity of a plant are essential to detect contamination and to assess the effectiveness of control measures, such as secondary containment, pond linings, and other practices.

iii. Secondary containment measures should be in place for all CN unloading, storage, mixing, and process solution tanks such as leach tanks.

iv. Containment measures should also be provided for all CN process solution pipelines to collect leaks and prevent releases to the environment.

Guidance for ASGM stakeholders (Inspection and preventive maintenance programs)

i. Inspection programs are critical to ensure safe performance to internal and external standards and plans. Inspection programs should use site-specific checklists/forms, and the inspection and maintenance program must be monitored on a weekly basis. Inspections should cover:
   • Tanks containing CN, such as mixing, storage, and leach tanks, pipelines, and tailings impoundments; check for signs of corrosion and leakage
   • Secondary containments provided for tanks and pipelines; check for physical integrity (e.g., cracking), leakage, and available capacity; ensure that any drains are closed to prevent accidental releases to the environment
   • Pipelines, pumps, and valves; check for deterioration and leakage
- Ponds and impoundments for capacity: check for freeboard, seepage, and signs of loss of integrity, such as erosion or cracking
- First aid and emergency response equipment: check to ensure is available and ready

### 3.5. CN Code Principle 5: Mine Decommissioning

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

Decommissioning activities treat, neutralize, or otherwise manage CN in process solutions and waste materials, around CN facilities in preparation for closure so these do not endanger people, wildlife, or the environment. Decommissioning is an aspect of mine closure which addresses remaining CN contamination at a site once gold production has ended. Best practices in the industrial mining lifecycle aim to ensure that decommissioning costs are planned for in advance of closure. Unfortunately, in the ASGM sector, weak enforcement and a lack of financial planning often results in site abandonment and/or sudden closures without financial assurance required for decontamination of equipment, removal of residual CN reagents, rinsing heap leach pads, and installation of measures necessary for management of surface or ground water, such as pumping and treatment systems during the facility's closure period.

Various methods exist for detoxify CN solutions, spent leached ores, and tailings. Physical separation into smaller waste deposits, washing and chemical treatment to oxidize residual CN, and biological treatment or natural degradation are types of decommissioning strategies employed. While this guidance document does not provide an exhaustive summary of CN treatment technologies, refer to section 2.5 for guidance on widespread and available CN neutralization technologies appropriate for the ASGM sector.

**Decommissioning of Heap Leaching Operations**

According to the EPA, there are three fundamental approaches to the decommissioning of CN-contaminated ore heaps (heap leaching):

- Leaving the heap alone and allow the CN to degrade without any human intervention (natural degradation)
- Dismantling the heap and treating the ore in smaller batches (physical)
- Rinsing the heap to flush out CN, with rinse solutions then treated by chemical, biological, and natural degradation processes

For example, ore heaps may be rinsed with fresh water or recycled rinse water that has been pre-treated so that it contains little CN. The rinse medium may or may not contain chemicals designed to oxidize the remaining CN as it trickles through the heap. Mines using CN heap leaching will already have equipment to supply rinse solution, and the same system used to apply the CN solution can also be used for rinsing of the heap. In summary, treatment methods depend on the type of facility and range from rinsing heaps with water to more complex techniques (e.g., alkaline chlorination, sulfur dioxide processes), which treat both solutions (spent CN solutions) and slurries (tailings) to recover residual CN.

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46 This process does not include physical stabilization of tailings storage facilities or heaps, revegetation of degraded land, or the long-term management of effluent seepage from leaching facilities or tailings storage facilities and does not include environmental monitoring, as defined by the Cyanide Code.

47 See definition of “decommissioning” in ICMI, 2021a, page 3.

48 Means of demonstrating that sufficient funds will be available upon cessation of operations to implement the proposed decommissioning measures.
Guidance for ASGM stakeholders (mine decommissioning)

i. The decommission process is technically complex and may exceed the capacity of small-scale operators without training, assistance, and support.

ii. Decommissioning plans should be developed for all CN processing plants/centers, and at a minimum these should include targets and indicators with reference to regulatory references, management and monitoring plans, and a schedule for these.

iii. There is no standard template for decommissioning because the decommissioning plan is specific to the type of process used, access to equipment, technical competence, ecosystem sensitivity, and proximity to communities or infrastructure.

iv. Governments, ASGM stakeholders, and financial institutions should work to develop financial assurance mechanisms for CN plant operators, which should be designed to support and ensure funds are available for plant decommissioning.

v. ASGM regulators must enforce mine closure and CN plant decommissioning policies and regulations, and these should be tailored for the ASGM sector.

3.6. CN Code Principle 6: Worker Safety

Protect workers’ health and safety from exposure to cyanide.

Protecting workers from hazardous exposure to CN is one of the primary motivating principles of the Cyanide Code, and all CN safety regulations, for that matter. In the ASGM sector, which is prone to conditions of informality, it is critical to ensure that basic engineered controls (e.g., barriers and other physical controls) and systems (e.g., procedures, training, regulations) are in place to protect workers and ensure a safe work environment. In this instance, the Code’s standards of practice and associated requirements can directly be applied to the ASGM sector, as summarized below.

Guidance for ASGM stakeholders (worker safety)

i. Conduct regular trainings (at least annually), where workers discuss and learn about CN hazards, safe CN management, potential CN exposure scenarios, first aid for CN, emergency response, and measures required to mitigate risks to worker health. These trainings should involve all workers who enter sites where CN is used.

ii. Have clear operating and monitoring procedures that ensure that worker health and safety are protected. These should include identification of personal protective equipment (PPE) necessary for the specified tasks, and requirements for pre-work inspections of the areas in which tasks will be conducted.

iii. Routinely conduct checks, tests, or other assessments to ensure that health and safety measures are well understood by workers and are fully implemented and effective.

iv. Ensure that an emergency response plan (ERP) is developed that clearly explains exactly what should happen if an accident concerning CN occurs. The ERP ensures readiness to respond to potential incidents of worker exposure to CN (also see Principle 7).

v. Post warning signs where CN is used advising workers that CN is present, of any necessary PPE that must be worn, and that smoking, open flames, and eating and drinking are not allowed. Workers should be alerted to the presence of CN and reminded of the various prohibitions regarding its use.
vi. Provide showers, eye wash stations, or other water in areas where CN is used to enable
decontamination of exposed workers.

vii. Have oxygen, a resuscitator, antidote kits, and a radio, telephone, alarm system, or other means of
communication or emergency notification readily available for use at CN unloading, storage, and
mixing locations and elsewhere in the plant.

viii. Ensure the mandatory use of PPE to mitigate risks to workers associated with CN. Refer to the Table
1, on the next page, for a list of recommended and commonly used PPE for mitigating workplace risks at
CN operations.

### Table 1. Recommended PPE for cyanide use in leaching of gold ores

<table>
<thead>
<tr>
<th>Objective</th>
<th>CN Workplace hazard</th>
<th>Suggested PPE</th>
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<tbody>
<tr>
<td>Eye and face protection</td>
<td>Liquid chemicals, CN salts or compounds, gases or vapors</td>
<td>Safety glasses with side shields, chemical splash goggles, or full-face shield</td>
</tr>
<tr>
<td>Respiratory protection</td>
<td>Fumes, mists, gases, smokes, vapors</td>
<td>Facemasks with appropriate filters for air purification for CN compounds, dust, vapors, and gases</td>
</tr>
<tr>
<td></td>
<td>Oxygen deficiency</td>
<td>Portable or supplied air (fixed lines) and on-site rescue and spill response equipment</td>
</tr>
<tr>
<td>Hand protection</td>
<td>CN compounds and liquids</td>
<td>Impervious gloves (PVC, butyl rubber)</td>
</tr>
<tr>
<td>Foot protection</td>
<td>CN compounds and liquids</td>
<td>Impervious boots</td>
</tr>
<tr>
<td>Body/leg protection</td>
<td>CN compounds and liquids</td>
<td>Impervious apron</td>
</tr>
</tbody>
</table>

3.7. CN Code Principle 7: Emergency Response Plans

Protect communities and the environment through the development of emergency response
strategies and capabilities.

As introduced under Principle 6, ERPs form a critical element of the responsibility of operations involved in
the use of CN, whether they be a CN plant owner/operator, or a transport company which is making CN
product shipments. ERPs should be in place and should be mandated by regional ASGM authorities. The
primary purpose of the ERP is to clearly outline exactly what should happen if an accident concerning CN
occurs, including human exposure to an accidental release or spill of CN product or process solution
containing CN. The ERP ensures readiness to respond to potential incidents of worker exposure to CN.

Numerous examples of ERPs for industrial mining operations can be found online. These are frequently
written to include the emergency response requirements of the Cyanide Code and, as such, may be used as
outlines or templates for ASGM-specific ERPs. These ERPs frequently are part of more comprehensive cyanide
management plans included in environmental impact assessments.

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49 Adapted from MSDSs by CN certified producers of sodium cyanide (NaCN), Harvard lab safety on CN use, and International
Finance Corporation occupational health and safety guidelines.
Guidance for ASGM stakeholders (ERPs)

i. The ERP should be customized based on the operation’s nature, extent, CN use, and infrastructure and on environmental factors, such as proximity to water bodies and communities.

ii. The ERP should be reviewed and updated on a set frequency, such as annually, and further updated with any changes to site processes and facilities.

iii. Managers should involve site personnel and stakeholders in the emergency response planning process and ensure that the active ERP is shared with all implicated parties.

iv. At a minimum, the ERP should fulfill the Code’s expectations for emergency response and emergency response planning:
   - Prepare detailed ERPs for potential CN releases.
   - Involve site personnel and external stakeholders in the planning process.
   - Designate appropriate personnel and commit necessary equipment and resources for emergency response.
   - Develop procedures for internal and external emergency notification and reporting.
   - Incorporate into response plans monitoring elements and remediation measures that account for the additional hazards of using CN treatment chemicals.
   - Periodically evaluate response procedures and capabilities and revise them as needed.

3.8. CN Code Principle 8: Training

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

Training and education may be the most essential ingredient to bring about behavioral change and systems improvements, after financial considerations are accounted for. Technical and safety training for the ASGM sector remains a critical need, including guidance and accessible training for safe and responsible use of chemicals including CN. All workers interacting with CN must be trained and educated on its use, toxicity, and related hazards. Basic training on safe CN management should also be extended to local and regional authorities in areas where CN is used for gold recovery.

Guidance for ASGM stakeholders (training)

i. While technical and safety trainings for CN operations are fundamentally the responsibility of the CN operations, support for such training should be a high priority for responsible development of the SSGM sector. Trainings could be developed and delivered in partnership with international CN experts (e.g., ICMI, University of British Colombia, EPA), regional authorities, (local/regional) institutes of higher learning, non-governmental and civil society organizations, and local ASGM associations, with support from industrial mining sector partners (individual mining companies, industrial mining associations).

ii. CN-related training materials emphasizing safe CN management specifically directed at the ASGM level should be produced and disseminated in applicable learning formats and local languages, with clear examples that are amenable to rapid dissemination (video, audio) and in formats that miners and CN plant operators are likely to digest, learn from, and share.

Protect communities and the environment through the development of emergency response strategies and capabilities.

Principle 9 of the Code emphasizes the shared responsibilities that mining companies must carry (i.e., proactively engage on), with other stakeholders, such as government authorities and regulators, mining associations and chambers, environmental organizations, and community interest groups. Official avenues that allow for community awareness must be addressed by actors in the ASGM sector, just as they are in the formal industrial mining sector. This can be accomplished through multi-stakeholder dialogue led by ASGM agencies and regulators and designed with ASGM-affected communities.

Guidance for ASGM stakeholders (dialogue)

i. Stakeholder engagement and awareness-raising are essential to ensure the risks and potential benefits associated with CN use in small-scale gold mining are accurately communicated to develop appropriate emergency response strategies.

ii. ASGM operations and associated regulatory entities, such as mining and environmental ministries and agencies, should work with ASGM associations and chambers to establish multi-stakeholder dialogues to disseminate information about safe and responsible CN use in gold mining and processing.

iii. The regional ASGM agencies and regulators should lay out clear operational and reporting regulations and expectations, aligned to respective regulatory frameworks.

iv. The regional ASGM agencies and regulators should ensure and enforce that business parties implicated in regional CN supply chains understand regulations, and operational requirements.

v. ASGM agencies and associated regulators should engage regionally affected communities to actively grant opportunities to learn about regional CN use, operationally, and concerning the environment. The regional dialogue process should ensure that concerned ASGM communities have opportunity for their voices to be heard. The process should consider if a whistle blowing and/or complaint mechanism is warranted.

4. Conclusion

4.1. Stakeholder Responsibilities

Developing CN management strategies for the ASGM sector is a shared responsibility among sector stakeholders. Regulating and enforcement agencies must take the lead in developing sound guidance and ensuring that regulations are enforced. The CN code can be used as a frame of reference for actors to make concrete commitments and steps towards fostering safer and more responsible CN use in the ASGM sector. Strong emphasis must be made by Regulatory and Enforcement agencies to ensure that all CN operators (not only the largest ones) have sound chemical management systems in place. Regulatory review should be conducted, along with enforcement measures, to ensure that regulations effectively mitigate risks to humans and the environment. Regulatory and legal frameworks can create an enabling environment through positive incentives to safeguard human health and promote environmental stewardship regionally and globally.
Mineral processors and CN operators must ensure the safety of their workers and the surrounding environment, including host, neighboring, and downstream communities. This starts with applying basic principles of risk identification and mitigation and must be sustained by being prepared with appropriate controls in place to avoid risk and routine monitoring using effective tools for taking routine measurements. Section 3 of this document should be reviewed and understood by CN operators and site personnel responsible for operations.

Dedicated support of civil society groups, including mining associations, NGOs, chambers, environmental advocacy groups, and international ASGM coordinating and development agencies (e.g. ICMI, UNIDO, UNEP, etc.), is needed to provide capacity development, technical support, and international coordination regarding best practices and to ensure logical and consistent messaging and prioritization of resources associated with relevant international instruments and development funding opportunities (e.g., Minamata Convention, corresponding ASGM development programing under PlanetGOLD).

Private sector actors from all corners of the global gold supply chain must bear responsibility for ensuring safe and responsible gold production. Socially and environmentally responsible mining operations are becoming an expectation of downstream markets, and this trend among gold consumers is expected to strengthen in resolve. Likewise, industrial gold miners: the world's operational experts in managing and deploying CN systems, have an opportunity to contribute to finding ways to support accessible education and training on CN systems, which can be adapted safely by small-scale gold mining operators. CN production and transport companies have an important responsibility, as stipulated by the Code, to ensure that end-users are managing CN risks adequately.

### 4.2. Risk Registration

Simple and practical tools designed to promote and ensure sound chemical management and effective risk mitigation must be shared, adapted (based on national CN regulations), and deployed widely. One example of such a tool is presented in Table 2, below. This generic risk register tool can be used to provide basic education and training to all CN site workers, regardless of their job or training. The table can easily be adapted as a risk monitoring tool by reformatting to add columns to provide space for routine monitoring checks. Printed copies can then be deployed for daily or weekly site monitoring checks, which would include new rows, indicating location specific measurements (e.g., for recording CN WAD concentration levels, pH, water levels, at specific site locations).

<table>
<thead>
<tr>
<th>Risk</th>
<th>Severity of Risk</th>
<th>Mitigation Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturing and Sourcing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CN was not produced by a Code-certified producer and lacks MSDSs.</td>
<td>High</td>
<td>Mine operators should implement a policy to only purchase from Code-certified or, at a minimum, registered CN suppliers.</td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport vehicles carrying sodium cyanide from supplier are poorly regulated and drivers are unaware of the risks hazardous</td>
<td>High</td>
<td>Invest in secure truck transport with dedicated driver, purchase from responsible, Code-certified CN suppliers with proper labelling of containers, certificates of origin, and responsible transport tendering.</td>
</tr>
<tr>
<td>Risk</td>
<td>Severity of Risk</td>
<td>Mitigation Measure</td>
</tr>
<tr>
<td>------</td>
<td>----------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>Road infrastructure is limited and has poor road quality that might result in increased frequency or intensity of accidents results in chemicals spills.</td>
<td>Substantial</td>
<td>To avoid accidents or disasters, only work with Code-certified CN transporters who manage risks and logistics in a responsible manner.</td>
</tr>
<tr>
<td>Handling and Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staff lack ability to safely handle chemicals on site and manage spills or emergencies.</td>
<td>High</td>
<td>Staff must be trained to properly handle chemicals and to access to PPE and on-site emergency first aid and eye wash stations. An emergency protocol for spills should be clearly posted.</td>
</tr>
<tr>
<td>Insufficient fence security to minimize livestock and small children entering the processing site.</td>
<td>High</td>
<td>Secure the perimeter fence, add chain links, ensure security on site, and consider motion-activated spotlight to enhance night security.</td>
</tr>
<tr>
<td>Lack of storage facility where chemicals are centralized and secure.</td>
<td>Substantial</td>
<td>Construct safe storage facility for all chemicals for authorized staff only. Staff should fill out and manage inventory sheets. Chemical monitoring protocols should be developed, implemented, and audited.</td>
</tr>
<tr>
<td>Contamination of surface or ground water due to poor chemicals management.</td>
<td>Substantial</td>
<td>Reduce the likelihood of chemicals spills through improved laboratory spill response, training for staff to safely transport chemicals from lab to barren tank, and constructing a concrete reinforcement around barren tank to collect chemical spillage.</td>
</tr>
<tr>
<td>Operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator does not have physical barriers or access controls which prevent unwanted human or wildlife access to critical areas, such as leaching tanks and neutralization ponds.</td>
<td>High</td>
<td>Secure perimeter fence, add chain links, ensure security on site, and consider motion-activated spotlight to enhance night security.</td>
</tr>
<tr>
<td>Operating plans and on-site technicians are not adequately monitoring and adjusting leach system pH and CN levels, resulting in unsafe formation of hydrogen-cyanide gases.</td>
<td>High</td>
<td>Site operating plans and site technicians must ensure that regular measurements are made of CN levels and pH. Measurements should be recorded in site logbook that clearly indicates place and time of all measurements and that can be used to monitor the entire site, including issuing corrective actions.</td>
</tr>
<tr>
<td>Operators must be able to confirm (have systems to ensure) that reactors, storage tanks, and/or neutralization ponds are not resulting in seepage to ground water.</td>
<td>Substantial</td>
<td>CN Operators should be able to demonstrate regular ground water checks (measurements) from test pits or wells, which confirm CN and dissolved metals are not draining into the water table.</td>
</tr>
<tr>
<td>Waste Disposal: Solid Waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site lacks a comprehensive waste management plan for management and disposal and of solid waste and CN-contaminated containers.</td>
<td>Substantial</td>
<td>Site managers must proactively identify the risks associated with solid waste streams and interim storage containers of CN compounds. Solid waste management facilities should be developed.</td>
</tr>
<tr>
<td>Waste Disposal: Effluent Management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insufficient protective measures in place for sound management of CN solution.</td>
<td>High</td>
<td>Construct trenches or other drainage and containment features to prevent runoff from contaminating surface and ground water.</td>
</tr>
</tbody>
</table>
4.3. Risk Control and Mitigation

To address risks from CN use, it can be useful to analyze risk avoidance and mitigation by considering risks from the highest level of protection and reliability to the lowest, then applying a hierarchy of controls. In so doing, the goal is to avoid or eliminate a hazard and associated risk as a first option, then, if not possible to avoid or eliminate), to focus on appropriate mitigation and risk controls. High and substantial risks should be prioritized with this approach, whereby risks are minimized through avoidance, followed by appropriate controls and mitigation measures.

### Table 3. Control hierarchy for evaluating cyanide risk control and mitigation options

<table>
<thead>
<tr>
<th>Hierarchy</th>
<th>Control Measure</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elimination</td>
<td>Eliminating CN use in flow sheets</td>
<td>– Select an alternative processing solution, rather than cyanidation</td>
</tr>
<tr>
<td>Substitution</td>
<td>Substituting CN use in flow sheets with a less hazardous chemical(s) to minimize risk</td>
<td>– Substituting sodium cyanide solution with alternative technologies, such as improved grinding and gravity concentration, amino acid leaching, or Gold Dressing Agent</td>
</tr>
<tr>
<td>Mitigation: isolation</td>
<td>Isolating CNs from other chemical substances to avoid dangerous reactions that could generate hazardous gases</td>
<td>– Transporting CN and its compounds in dedicated vehicles to avoid contact with food products, livestock, consumer goods, and reactive substances, such as water to produce harmful gases</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Constructing dedicated a facility for storing, handling, and mixing CN compounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Storing CNs away from acids, oxidizing agents, and other reactive substances to avoid unintended chemical reactions; Nitrates, nitrites, peroxides, and chlorates can</td>
</tr>
<tr>
<td>Hierarchy</td>
<td>Control Measure</td>
<td>Example</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Mitigation: engineering      | Technical equipment installation, and physical infrastructure investments      | − Installing a local exhaust ventilation system to reduce workplace exposures during handling, storage, and mixing  
− Digging a trench surrounding leaching tanks to contain possible spills or natural hazards (i.e., floods)                                        |
| Mitigation administrative    | Adopting management protocols to address identified risks                      | − Investing in human capacity development and training (Cyanide Code Principle 8)  
− Providing workers with relevant information, training, and instruction regarding potential hazards and risks associated with CN work, safe use, handling, storage, and disposal  
− Making sure containers are labelled, and CN is kept in original containers with a documented inventory, with oldest products organized for immediate use  
− Working in pairs to reduce exposure risks; All mine workers or technicians should have a thorough understanding of CN hazards, risks, and mitigation measures alongside emergency protocols. |
| Personal Protective Equipment (PPE) | Protection for skin and for lungs, from chemicals, gases and vapors              | − Respiratory protection  
− Eye and face protection  
− Impervious gloves, aprons, boots, etc.                                                                                                                                                               |
Appendices

Appendix 1. CN Spills which garnered international attention and led to development of the CN Code

The Cyanide Code was developed by a multi-stakeholder Steering Committee under the guidance of the UNEP and the International Council on Metals and the Environment in response to identified risks associated with its use by industrial mining operators. In the 1990s, a series of accidents involving CN that occurred throughout the CN use cycle and in both developed and developing countries made international news and sensitized public opinion to the use of CN in the mining industry. These included spills of CN-containing solutions at the Zortman-Landusky and Summitville Mines in the United States and the Omai Mine in Guyana and the release of reagent CN being transported to the Kumtor Mine in Kyrgyzstan. The most notorious event was the Aural Gold Mine spill in Baia Mare, Romania, in January 2000. That accident released approximately 100,000 m³ of gold mill tailings into a tributary of the Danube River. Fortunately, no human lives were lost, but the spill resulted in a massive fish kill and focused the world’s attention on the risks of CN used in the gold mining industry. The accident in Romania prompted UNEP and the former International Council on Metals and the Environment (then headquartered in Ottawa) to convene an international workshop in Paris to discuss ways to improve the management of CN in gold mining. The workshop, involving nearly 40 individuals from a wide variety of professional backgrounds, led to the development of the Cyanide Code.

Creating a code to encompass an entire industry on a global scale was difficult. Nevertheless, despite the host of complex issues requiring resolution, the multi-national, multi-stakeholder steering committee (established after the Paris Workshop) took just 13 months to complete its work on developing the structure and content of the Cyanide Code in early 2002. The Cyanide Code was formally announced at the World Mine Ministries Forum in Toronto in March 2002. Two more years were needed to finalize the substantive and procedural documents for the Cyanide Code’s implementation and along the way to create the ICMCI in 2003 to oversee the Cyanide Code’s implementation. Throughout this process, growing awareness of the Cyanide Code led to a change in attitude which, resulted in the implementation of more stringent management procedures by the mining industry worldwide. Importantly, the Cyanide Code serves to give a common framework to this process of change. Around the same time the UNEP helped to coordinate the international mining community’s development of the Cyanide Code, an additional report titled “Guidance for the Mining Industry in Raising Awareness and Preparedness for Emergencies at Local Level” was also developed.50

The Cyanide Code was one of the earliest standards and certification programs developed for the minerals sector. It remains largely in use primarily by large industrial miners and uptake by small mining companies remains lacking. As of Jan. 2021, the number of signatory companies to the code, is 195 (representing 290 mine operations, globally, in 55 countries).

The International Finance Corporation (IFC), a part of the World Bank that provides funding for mining projects, applies the Cyanide Code in lieu of its own requirements in its Environmental, Health and Safety (EHS) Guidelines for Mining. Important industry certification standards such as the Responsible Jewelry Council, and the Initiative for Responsible Mining Assurance (IRMA), require adherence to the CN Code.

## Appendix 2: CN Code Principals & Standards of Practice

<table>
<thead>
<tr>
<th>Practice</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mining Principal 1: Production and Purchasing</strong></td>
<td>Encourage responsible CN manufacturing by sourcing from responsible manufacturers that operate in a safe, socially, and environmentally response manner.</td>
</tr>
<tr>
<td>1.1</td>
<td>Source cyanide from responsible producers who employ appropriate practices and procedures to limit workplace exposures and prevent released into the environment.</td>
</tr>
<tr>
<td><strong>Mining Principal 2: Transport</strong></td>
<td>Protect communities and the environment during transport.</td>
</tr>
<tr>
<td>2.1</td>
<td>Establish clear lines of responsibility for safety, security, and release prevention training and emergency response in written agreements with producers, distributors, and transporters.</td>
</tr>
<tr>
<td><strong>Mining Principle 3: Handling and Storage</strong></td>
<td>Protect workers and the environment during cyanide handling and storage.</td>
</tr>
<tr>
<td>3.1</td>
<td>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.</td>
</tr>
<tr>
<td>3.2</td>
<td>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.</td>
</tr>
<tr>
<td><strong>Mining Principal 4: Operations</strong></td>
<td>Manage cyanide process solutions and waste streams to protect human health and the environment.</td>
</tr>
<tr>
<td>4.1</td>
<td>Implement management and operating systems designed to protect human health and the environment including contingency planning and inspection and preventive maintenance procedures.</td>
</tr>
<tr>
<td>4.2</td>
<td>Introduce management and operating systems to minimize cyanide use, thereby limiting concentrations of cyanide in mill tailings.</td>
</tr>
<tr>
<td>4.3</td>
<td>Implement a comprehensive water management program to protect against unintentional releases.</td>
</tr>
<tr>
<td>4.4</td>
<td>Implement measures to protect birds, other wildlife, and livestock from adverse effects of cyanide process solutions.</td>
</tr>
<tr>
<td>4.5</td>
<td>Implement measures to protect fish and wildlife from direct and indirect discharges of cyanide process solutions to surface water.</td>
</tr>
<tr>
<td>4.6</td>
<td>Implement measures designed to manage seepage from cyanide facilities to protect the beneficial uses of ground water.</td>
</tr>
<tr>
<td>4.7</td>
<td>Provide spill prevention or containment measures for process tanks and pipelines.</td>
</tr>
<tr>
<td>4.8</td>
<td>Implement quality control/ assurance procedures to confirm that cyanide facilities are constructed according to accepted engineering standards and specifications.</td>
</tr>
<tr>
<td>4.9</td>
<td>Implement monitoring programs to evaluate the effects of cyanide use on wildlife and surface and groundwater quality.</td>
</tr>
<tr>
<td><strong>Mining Principal 5: Decommissioning</strong></td>
<td>Protect communities and the environment from cyanide through development and implementation of decommissioning plans for cyanide facilities.</td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>Practice</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Plan and implement procedures for effective decommissioning of cyanide facilities to protect human health, wildlife, livestock, and the environment.</td>
</tr>
<tr>
<td>5.2</td>
<td>Establish a financial assurance mechanism capable of fully funding cyanide-related decommissioning activities.</td>
</tr>
</tbody>
</table>

**Mining Principal 6: Worker Safety**
Protect workers’ health and safety from exposure to cyanide.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Identify potential cyanide exposure scenarios and take measures as necessary to eliminate, reduce, and control them.</td>
</tr>
<tr>
<td>6.2</td>
<td>Operate and monitor cyanide facilities to protect worker health and safety and periodically evaluate the effectiveness of health and safety measures</td>
</tr>
<tr>
<td>6.3</td>
<td>Develop and implement emergency response plans and procedures to respond to worker exposure to cyanide.</td>
</tr>
</tbody>
</table>

**Mining Principal 7: Emergency Response**
Protect communities and the environment through the development of emergency response strategies and capabilities.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>Prepare detailed emergency response plans for potential cyanide releases.</td>
</tr>
<tr>
<td>7.2</td>
<td>Involve site personnel and stakeholders in the planning process.</td>
</tr>
<tr>
<td>7.3</td>
<td>Designate appropriate personnel and commit necessary equipment and resources for emergency response.</td>
</tr>
<tr>
<td>7.4</td>
<td>Develop procedures for internal and external emergency notification and reporting.</td>
</tr>
<tr>
<td>7.5</td>
<td>Incorporate remediation measures and monitoring elements into response plans and account for the additional hazards of using cyanide treatment chemicals.</td>
</tr>
<tr>
<td>7.6</td>
<td>Periodically evaluate response procedures and capabilities and revise them as needed.</td>
</tr>
</tbody>
</table>

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

<p>| | |</p>
<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>Train workers to understand the hazards associated with cyanide use.</td>
</tr>
<tr>
<td>8.2</td>
<td>Train appropriate personnel to operate the facility according to systems and procedures that protect human health, the community and the environment.</td>
</tr>
<tr>
<td>8.3</td>
<td>Train appropriate workers and personnel to respond to worker exposures and environmental releases of cyanide.</td>
</tr>
</tbody>
</table>

**Mining Principal 9: Dialogue and Disclosure**
Engage in public consultation and disclosure.

<p>| | |</p>
<table>
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<tr>
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</tr>
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<tbody>
<tr>
<td>9.1</td>
<td>Promote dialogue with stakeholders regarding cyanide management and responsibly address identified concerns.</td>
</tr>
<tr>
<td>9.2</td>
<td>Make appropriate operational and environmental information regarding cyanide available to stakeholders.</td>
</tr>
</tbody>
</table>
References


Eisler R., and S.N. Wiemeyer. 2004. Cyanide Hazards to Plants and Animals from Gold Mining and Related Water Issues. *Reviews of Environmental Contamination and Toxicology* 183. [https://doi.org/10.1007/978-1-4419-9100-3_2](https://doi.org/10.1007/978-1-4419-9100-3_2)


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