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Department of the Environment and Heritage

National Pollutant Inventory

Emission estimation technique manual

for

Gold ore processing

Version 2.0

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Disclaimer

The manual was prepared in conjunction with Australian States and Territories according to the National Environment Protection (National Pollutant Inventory) Measure.

While reasonable efforts have been made to ensure the contents of this manual are factually correct, the Commonwealth does not accept responsibility for the accuracy or completeness of the contents and shall not be liable for any loss or damage that maybe occasioned directly or indirectly through the use of, or reliance on, the contents of this manual.

Erratum for gold ore processing EET manual (Version 2.0 – December 2006)

Page	**Outline of alteration**
1	Referral to the NPI Guide as the first point of reference
2-4	Rewriting of section to reduce repetition and duplication with NPI Guide. Amended figure 1.
5-8	Minor word changes
9	Changed heading and rewriting of section to reduce duplication with NPI Guide
11	Removed reference to worksheets.
	Reporting thresholds section deleted - in the NPI Guide
14-15	Rewritten and information duplicated in NPI Guide deleted
	Elements of the environment section deleted – in the NPI Guide
	Engineering calculations section deleted
	Emission factor section deleted
26-27	Addition of mass balance estimation techniques for elution, electrowinning and carbon regeneration. Definition for seepage added.
28	Volume definition changed
35-36	Amended introductory text and equation on HCN emissions
37	Added text to the effect that the emission factor not recommended for use.
38	Equation amended
40	Sewage treatment estimation technique information deleted, information in another manual.
41	Removed EETs for sewage, referred to another manual.
43	Information on MIRA research projects updated
51-52	Cyanide definitions added
53	References for Health and Simovic updated

Erratum for gold ore processing EET manual (Version 1.1 – October 2001)

Page	Outline of alteration
1	Changed version number, added EA logo and amended footer to make document consistent with other EET Manuals
1	ANZSIC code and some introductory information changed from previous version.

EMISSION ESTIMATION TECHNIQUES
FOR
GOLD ORE PROCESSING
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GOLD ORE PROCESSING

LIST OF FIGURES AND TABLES

1. Introduction

The purpose of all emission estimation technique (EET) manuals in this series is to assist Australian manufacturing, industrial, and service facilities to report emissions of listed substances to the National Pollutant Inventory (NPI). This manual describes the procedures and recommended approaches for estimating emissions from facilities engaged in gold ore processing.

Before reading this document, please read the NPI Guide on the NPI web site at: http://www.npi.gov.au/handbooks/guidetoreporting.html#guide . The NPI Guide gives general information on how to report to the NPI and explains many of the terms, such as reporting thresholds that are used in this document.

The scope of this document is to outline methods that can be used by the gold ore processing industry to:

- identify which substances they are required to report as part of the National Pollutant Inventory (NPI); and
- estimate emissions of NPI substances to air, water and land from their facilities.

This manual covers the processing of gold ore commencing from the delivery of raw ore to the mills, to the production of mine bars (or gold ore)**.**

This manual does not cover the extraction of ore. Extractive mining operations are covered by the *EET Manual for Mining*. This manual also does not cover gold refining which will be incorporated into the Non-Ferrous Metal Manufacture EET manual in the future.

EET MANUAL:	Gold ore processing	
HANDBOOK:	Precious metal manufacturing: gold ore processing	
ANZSIC CODE :	1993	1314
	2006	0804

The scope of this manual is presented diagrammatically in Figure 1.

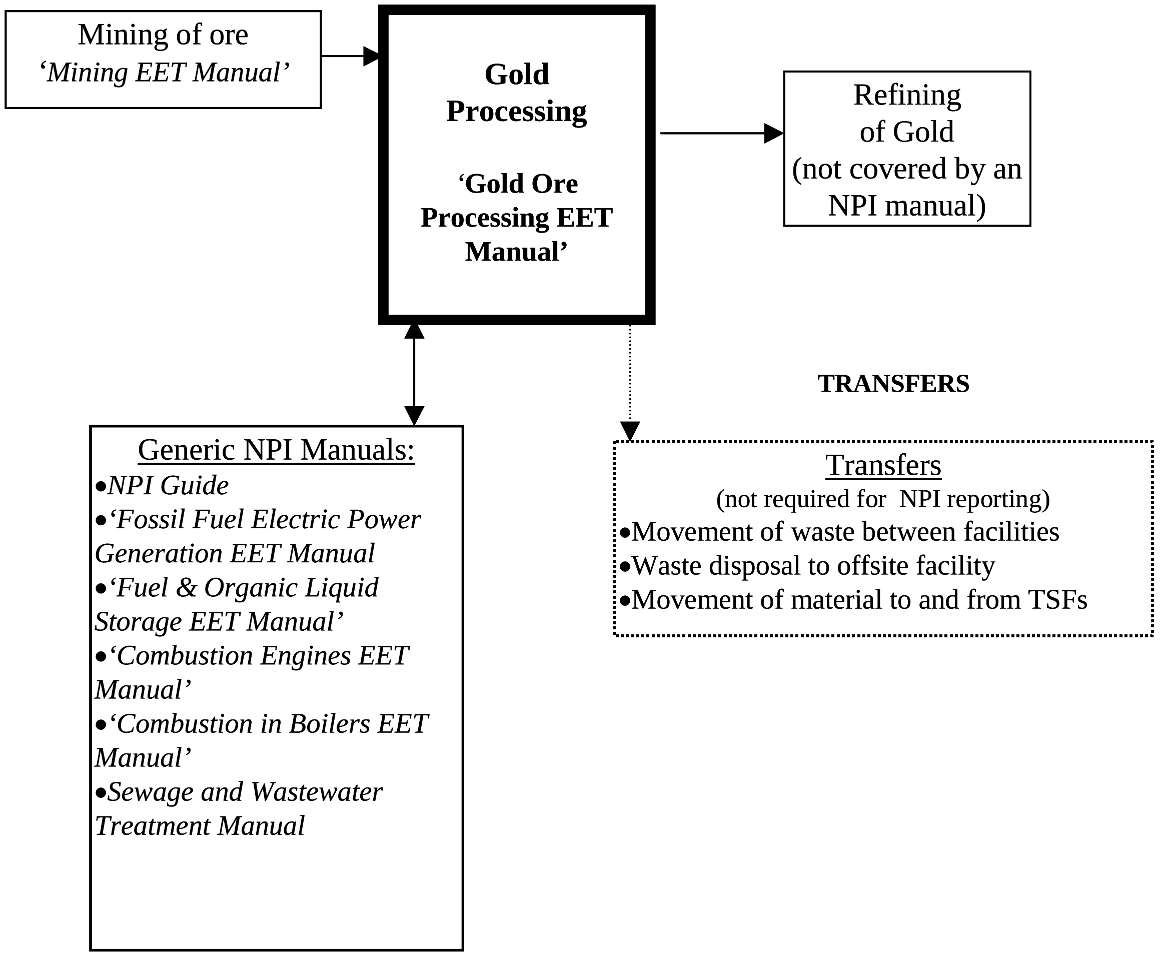


Figure 1 - Scope of the 'Gold ore processing EET manual' and its relationship with other EET manuals

Context and use of the manual

The NPI manual provides a "how to" guide for estimating emissions as required by the NPI. The methods used in this manual will have varying degrees of accuracy with regards to the actual emissions from gold processing facilities. In some cases there will potentially be a large error due to inherent assumptions in the various emission estimation techniques (EETs) and/or a lack of knowledge of chemical processes or site-specific conditions. For example one tailings storage facility may have cyanide moving into groundwater while another one doesn't, due to the different characteristics of each site. For this reason, EET's should be considered as 'points of reference' that are used for guidance purposes only.

The potential errors associated with the different EET options should be considered on a case-by-case basis as to their suitability for a particular facility. Generally it will be appropriate to consider various EETs as alternative options whose suitability should be evaluated in terms of:

- the associated reliability or error bands; and
- the cost/benefit of using a more reliable method.

For example, if emissions of a substance are clearly very small no matter which EET is applied, then there would be little gained by applying an EET which required significant additional sampling.

Facilities are not obligated to use the techniques presented in this manual. They must, however, seek the consent of their relevant environmental authority to determine whether any 'in house' EETs are suitable for meeting their NPI reporting requirements.

NPI emissions in the environmental context

You should note that the NPI reporting process generates emission estimates only. It does not consider the potential environmental impacts, bioavailability of emissions or natural background levels of these emissions.

Outline of manual

The manual is structured to allow facilities to work through the manual addressing issues in a structured and coherent manner.

Likely emissions from facilities are discussed in Section 3, while Section 4 discusses the approach to emission estimation and those elements of the environment where emissions may result.

Sections 5, 6, 7, 8 and 9 address the EETs likely to be used by the gold industry. This approach has been adopted in order to demonstrate how an EET may be applied to estimating emissions of a substance and supported by other EETs. For example facilities may choose to use a mass balance approach to their estimation of cyanide emissions. However, the mass balance EET is likely to be supported by direct monitoring data and emission factors.

This manual has been prepared by PPK Environment & Infrastructure Pty Ltd on behalf of the WA Department of Environmental Protection. Funding for the project was provided by Environment Australia. It has been developed through a process of national consultation involving state and territory environmental authorities, and industry groups.

2. Process description

In Australia, a wide variety of techniques are used to process gold ore. At most facilities, a key step is the extraction of gold from the crushed ore using cyanide and carbon adsorption. This can be done using carbon in pulp (CIP) and carbon in leach (CIL) processes where the gold-cyanide complex binds preferentially to activated carbon. Zinc dust is used as an alternative to carbon at some facilities.

Other processing methods include heap leaching of low-grade ores. Biological oxidation and roasting may be undertaken at some sites where gold is bound up in sulfide ores. These processes free up the gold from the sulfide ores by converting them to oxides.

Figure 2 presents a simplified flow diagram of various gold ore processing technologies used in Australia. The diagram is not intended to represent the processes undertaken at any particular facility. It is intended to provide an understanding of the main gold ore processing technologies and their associated inputs and emissions.

Facilities will have their own process flow diagrams and these should be used to facilitate emission estimation and NPI reporting requirements.

Gold ore processing includes the following steps.

Comminution: The process of reducing the ore to fine particles through crushing and milling. Crushing is the process whereby mined ore is fed through mechanical crushing devices that progressively reduce the size of the ore. Milling is a physical process where the crushed ore is fed into a mill (i.e. rotating drums) and the action of the ore being tumbled (often in the presence of steel balls) reduces the ore to a slurry of fine particles.

Flotation: The process used to separate gold and metal sulfides from the gangue (i.e. waste). Aeration of the milled slurry, and the addition of specific chemical reagents, encourages froth formation, while activators are added to promote flotation of gold-bearing compounds. The froth that floats to the surface contains most of the gold and iron sulfides, and is extracted for further treatment. This material is known as the concentrate.

Thickening: Thickening reduces the water content of the concentrate slurry, separating the water from the heavier mineral-rich solids through gravity.

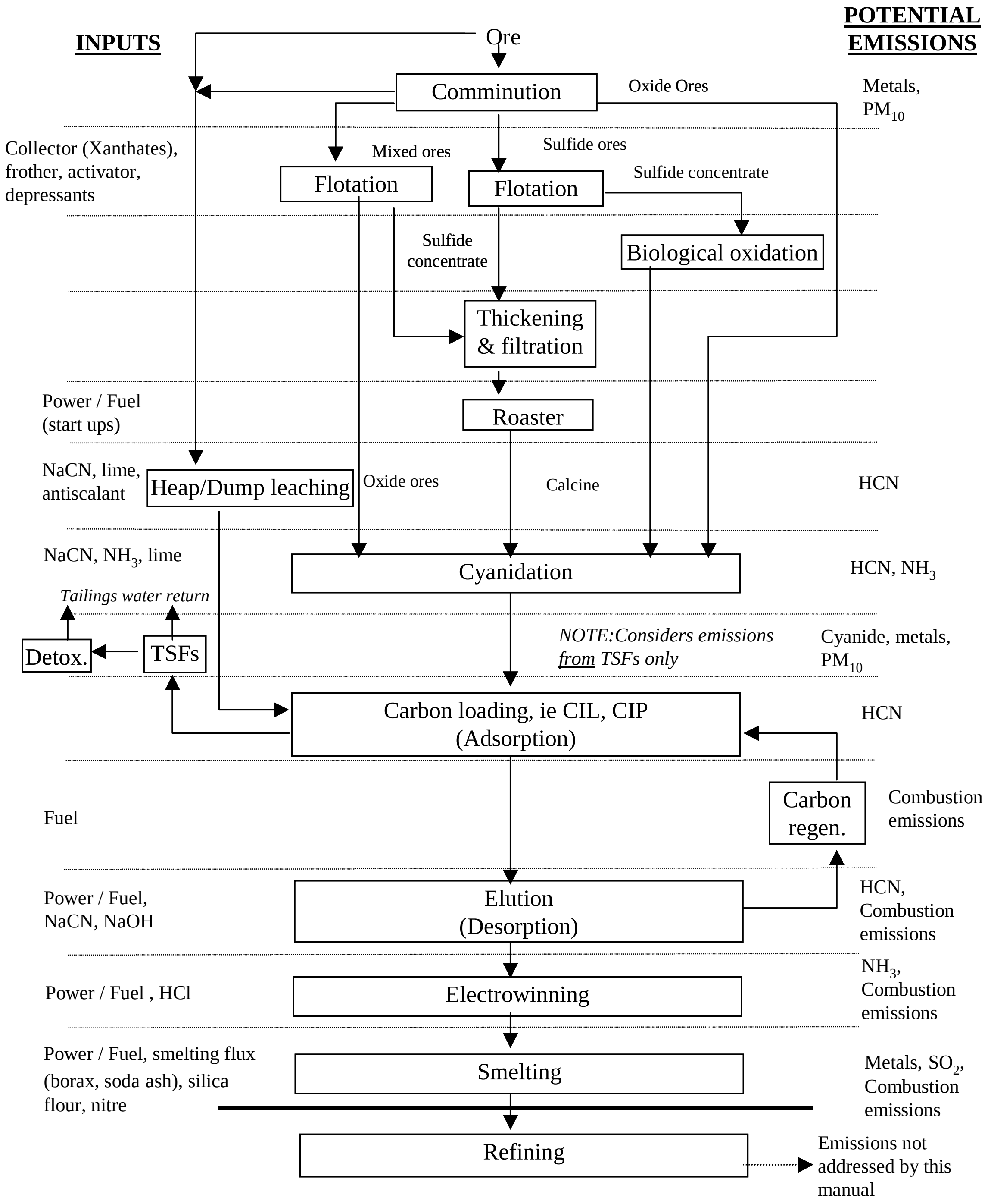


Figure 2 - Gold ore processing: process inputs and emissions

Roasting: Where gold is trapped in sulfides such as pyrite, roasting of the concentrate is required to convert the sulfides to oxides (called calcine), with sulfur in the sulfides liberated as sulfur dioxide. Oxidation is necessary for the subsequent gold leaching and recovery processes to operate effectively.

Biological Oxidation: This is an alternative method for the oxidation of sulfides. Recent advances in technology have resulted in the development of a biological process for the oxidation of sulfide concentrates. In this process bacteria are used to oxidise sulfide concentrates.

Cyanidation: Cyanide is added to the process slurry to promote the dissolution and complexing of the gold. Gold enters solution as a gold-cyanide complex ion.

Carbon-in-pulp (CIP): CIP involves the removal of complex gold ions from solution by adsorption onto activated carbon. Slurry that has undergone cyanidation is passed through a cascade of agitation tanks. As the slurry moves down the cascade, gold is adsorbed onto granular activated carbon that is extracted and pumped to the next tank. The result is a counter-current flow (as Figure 3), where the loading of gold on carbon increases in the opposite direction to slurry flow. Loaded carbon is retrieved from the first tank in the series.

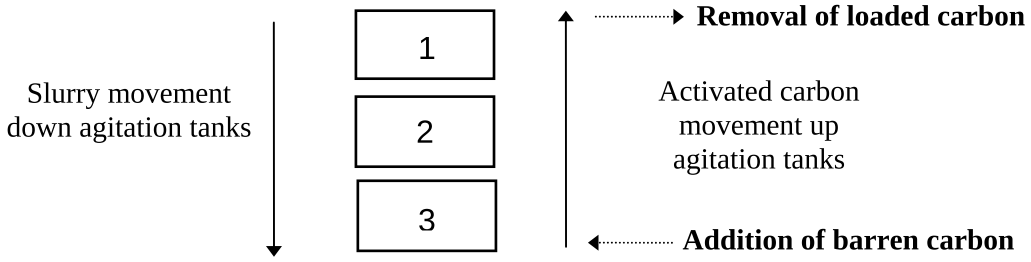


Figure 3 - CIP counter current flow

Carbon-in-leach (CIL): An alternative process to CIP. The main difference between the processes is that the cyanidation and adsorption processes are not staged separately, so that gold dissolution and recovery from the slurry proceed simultaneously in each CIL tank.

Heap/dump leach process. This is an alternative leaching process for relatively low-grade gold-bearing ores. The ore is placed onto pads with the addition of lime (to control pH) and sprayed with weak cyanide solution. The solution slowly infiltrates through the heap to dissolve the gold into solution. Heaps are lined to prevent loss of the solution. The ore may either be crushed or uncrushed, and the leaching process continues for several weeks or months. The gold-bearing solution collects in drains at the edges of the heap and is pumped to a gold recovery circuit.

Elution: The washing of loaded carbon in hot water, caustic and cyanide solution to remove gold to the washing liquor. The resulting liquor is known as pregnant solution. Acid is used prior to elution to remove inorganics.

Electrowinning: The application of an electric current to the pregnant solution to precipitate gold onto steel wool cathodes. Excess steel wool may be dissolved in hydrochloric acid to leave crude gold.

Smelting: The melting of crude gold separates impurities that float to the surface as slag. The slag is poured off and the molten gold is poured into moulds. The resulting mine bars (or gold doré) contain some silver and base metals.

Refining: Refining is the production of gold ingots from doré, and is carried out at a limited number of sites (e.g. the Perth Mint). The Perth Mint refining process involves melting of the gold doré and injecting with chlorine gas under high pressure. Silver and base metals form gaseous chloride compounds, which are ducted via an extractor system to a wet scrubber, where particulates are removed and residual chlorine is neutralised. When the gold melt has attained 99.9% purity it is cast as ingots. Refining is not covered in this manual.

3. Likely reportable substances

Estimates of emissions of NPI listed substances to air, water and land shall be reported for each substance that exceeds a defined threshold value of 'usage' or emission. The reporting list and detailed information on thresholds are contained in *The NPI Guide*.

It is the responsibility of gold ore processing facilities to determine which NPI substances are triggered for reporting. Table 1 indicates those NPI substances likely to be of relevance to the gold ore processing industry and the most appropriate method of determining whether the threshold is triggered.

Within the gold industry trace metals within ore may trigger reporting thresholds, as may the coincidental production of carbon disulfide from the breakdown of xanthates.

Ore handled at gold ore processing facilities may contain a sufficient concentration of NPI metals & compounds to trigger the Category 1 reporting threshold of 10 tonnes per annum. Ore may need to be characterised for all NPI metals & compounds to determine the contribution of ore metal ‘use’ to the total facility ‘use’ of metals and compounds.

Direct measurement by representative sampling is the most accurate means of characterising ore and hence determining ‘usage’ of trace metals as the metals content of ore will vary between and within facilities. In the absence of facility-specific assays, generic ore assays may be used as the basis for reporting of metals ‘usage’. These generic assays are presented in Appendix A. Note that there could be high errors associated with the use of generic assays.

Where substances are ’used’ as a result of coincidental production, such as carbon disulfide from the decay of xanthates or the evolution of ammonia in the electrowinning stage, engineering calculations may be appropriate to determine the amount that is 'used' based on the chemical reaction rates.

Table 1 - NPI-listed substances likely to trigger reporting thresholds, and proposed methods for determining emissions

SUBSTANCE	TRIGGER	METHOD *
Acetone	Usage	INV
Ammonia (total)	Usage (Coincidental production)	INV, E/C
Antimony & compounds	Usage (Ore content)	D/M, G/F
Arsenic & compounds	Usage (Ore content)	D/M, G/F
	and/or fuel/power usage	C
Beryllium & compounds	Usage (Ore content)	D/M, G/F
	and/or fuel/power usage	C
Boron & compounds	Usage (Ore content)	D/M, G/F
Cadmium & compounds	Usage (Ore content)	D/M, G/F
	and/or fuel/power usage	C
Carbon disulfide	Usage (Coincidental production)	E/C
Carbon monoxide	Fuel use	INV
Chromium (III) compounds	Usage (Ore content)	D/M, G/F
	and/or fuel use	INV
Chromium (VI) compounds	Usage (Ore content)	D/M, G/F
	and/or fuel use	INV
Cobalt & compounds	Usage (Ore content)	D/M, G/F
Copper & compounds	Usage (Ore content)	D/M, G/F

SUBSTANCE	TRIGGER	METHOD *
	and/or fuel/power usage	C
Cyanide (inorganic) compounds	Usage	INV
Fluoride compounds	Usage (Ore content)	D/M, G/F
	and/or fuel use	INV
Hydrochloric acid	Usage	INV
	and/or fuel use	INV
Hydrogen sulfide	Usage	INV
Lead & compounds	Usage (Ore content)	D/M, G/F
	and/or fuel/power usage	C
Magnesium oxide fume	Fuel/power usage	C
Manganese & compounds	Usage (Ore content)	D/M, G/F
Mercury & compounds	Usage (Ore content)	D/M, G/F
	and/or fuel/power usage	C
Methyl ethyl ketone	Usage	INV
Nickel & compounds	Usage (Ore content)	D/M, G/F
	and/or fuel/power usage	C
Nickel carbonyl	Fuel/power usage	C
Nickel subsulfide	Fuel/power usage	C
Oxides of nitrogen	Fuel usage	INV
Particulate matter 10.0 microns or less	Fuel usage	INV
Polychlorinated dioxins and furans	Fuel/power usage	INV, C
Polycyclic aromatic hydrocarbons (PAHs)	Fuel usage	INV
Selenium & compounds	Usage (Ore content)	D/M, G/F
Sulfur dioxide	Usage (Coincidental production)	E/C
	and/or fuel use	INV
Sulfuric acid	Usage (Coincidental production)	E/C
Total nitrogen	Discharge to surface waters (sewage plants)	D/M, E/F
Total phosphorus	Discharge to surface waters (sewage plants)	D/M, E/F
Total volatile organic compounds (VOC)	Fuel usage or design bulk storage	INV, C
Zinc and compounds	Usage (Ore content)	D/M, G/F

* A number of methods may be used to determine emissions of NPI substances. The method used will be related to the substance category and available information:

• D/M : Direct measurement	- direct measurement of emissions stream (total N and P) or characterisation of the ore body.
• INV: Inventory	- inventory of material usage (chemicals, fuel), with NPI content of materials identified.
• G/F : Generic factor	- generic factor applies to default concentrations to be used in the absence of facility-specific data.
• E/F : Emission factor	- emission factor to determine content in discharge stream (total N and P).
• C : Capacity	- capacity applies to the storage capacity of a facility, maximum combustion rate, consumption of energy or potential maximum power consumption.
• E/C : Engineering calculation	- engineering calculations may be used for a number of substances such as sulfur dioxide.

The NPI Guide is designed to assist facilities in determining substances that exceed reporting triggers.

You should note that while the reporting threshold for a substance may not be triggered during one reporting period, it may be triggered in another reporting period. As such, it is important to review NPI reporting requirements each reporting period.

4. Emission estimation

Estimates of emissions of NPI-listed substances to air, water and land should be reported for each substance that triggers a threshold. The substance reporting list and detailed information on thresholds are contained in *The NPI Guide*.

The NPI Guide also gives general information on emission estimation techniques (EET) that may be used to estimate emissions from your facility. This handbook will focus on EETs specific to the gold ore processing industry. Table 2 gives a list of recommended EETs for estimating emissions of NPI substances in the gold ore processing industry.

You should note that the EETs presented in this manual relate principally to average process emissions. Emissions resulting from non-routine events are rarely discussed in the literature, and there is a general lack of EETs for such events. However, it is important to recognise that emissions resulting from significant operating excursions and/or accidental situations (e.g. spills) will also need to be estimated. Emissions to land, air and water from spills must be estimated and added to process emissions when calculating total emissions for reporting purposes. The emission resulting from a spill is the net emission, i.e. the quantity of the NPI reportable substance spilled, less the quantity recovered or consumed during clean up operations.

The NPI addresses the total loading, of those forms of a substance required by the NPI to the environment. While the emission estimation takes account of both bioavailable and non-bioavailable forms of a substance (except for total nitrogen and phosphorus emissions), they are not distinguished in reported data. For example the NPI requires that only inorganic cyanide compounds are reported. The form in which cyanide is emitted should be factored into emissions estimation where practicable, although this may be very difficult to achieve where extensive cyanide complexes are emitted. Where this is the case **total cyanide** emissions should be reported.

In reporting emissions it is important to note that while the reporting threshold for a substance may be triggered this does not mean that the emissions will be significant. For example most trace metals in the processed ore are likely to be disposed of to the TSFs. However only emissions from TSFs must be reported within the NPI process.

The NPI has a commitment of not requiring any additional monitoring by facilities in order to estimate their emissions. Appendix B details sources of data that may already be available to facilities. This data may be used to assist in NPI reporting requirements. A combination of these methods may be employed to estimate emissions to the environment from particular process areas, such as emissions from TSFs.

Table 2 - Relevant NPI-listed substances for the gold ore processing industry, and recommended EETs

	Processing							
Substance	Comminution	Flotation, Thickening, Cyanidation, Carbon Loading & Elution	Carbon Regeneration Kilns	Power Generation	Smelting	TSFs	Roaster	Sewage
D/M : Direct measurement , M/B : Mass balance , E/F : Emission factors , E/C : Engineering calculations , M : Modelling								
A : Emission to air , W : Emission to water , L : Emissions to land, including groundwater								
Acetone		**A** M/B						
Ammonia (total)		**A** D/M , M/B , E/C						
Antimony & compounds	**A** M/B				**A** M/B	**W ,L** M/B	**A** M/B	
Arsenic & compounds	**A** M/B			**A** E/F	**A** M/B	**W , L** M/B	**A** M/B	
Beryllium & compounds	**A** M/B			**A** E/F	**A** M/B	**W , L** M/B	**A** M/B	
Boron & compounds	**A** M/B				**A** M/B	**W , L** M/B	**A** M/B	
Cadmium & compounds	**A** M/B			**A** E/F	**A** M/B	**W , L** M/B	**A** M/B	
Carbon disulfide		**A** D/M , M/B , E/C	**A** D/M , M/B , E/C					
Carbon monoxide			**A** D/M	**A** E/F				
Chromium (III) compounds	**A** M/B			**A** E/F	**A** M/B	**W , L** M/B	**A** M/B	
Chromium (VI) compounds	**A** M/B			**A** E/F	**A** M/B	**W , L** M/B	**A** M/B	
Cobalt & compounds	**A** M/B				**A** M/B	**W , L** M/B	**A** M/B	
Copper & compounds	**A** M/B			**A** E/F	**A** M/B	**W , L** M/B	**A** M/B	

Table 2 - Relevant NPI-Listed Substances for the Gold Ore Processing Industry, and Recommended EETs cont'

	Processing							
Substance	Comminution	Flotation, Thickening, Cyanidation, Carbon Loading & Elution	Carbon Regeneration Kilns	Power Generation	Smelting	TSFs	Roaster	Sewage
D/M : Direct measurement , M/B : Mass balance , E/F : Emission factors , E/C : Engineering calculations , M : Modelling								
A : Emission to air , W : Emission to water , L : Emissions to land, including groundwater								
Cyanide (inorganic) compounds		**A** D/M , M/B , M , E/F	**A** D/M , M/B , M , E/F		**A** D/M , M/B , M , E/F	**A , W , L** D/M , M/B , M , E/F	**A** D/M , M/B , M , E/F	
Fluoride compounds	**A** M/B			**A** E/F	**A** M/B	**W , L** M/B	**A** M/B	
Hydrochloric acid		**A** D/M , M/B		**A** E/F				
Hydrogen sulfide			**A** D/M , M/B					
Lead & compounds	**A** M/B			**A** E/F	**A** M/B	**W , L** M/B	**A** M/B	
Magnesium oxide fume				**A** E/F	**A** E/F		**A** E/F	
Manganese & compounds	**A** M/B				**A** M/B	**W , L** M/B	**A** M/B	
Mercury & compounds	**A** M/B			**A** E/F	**A** M/B	**W , L** M/B	**A** M/B	
Nickel & compounds	**A** M/B			**A** E/F	**A** M/B	**W , L** D/M , M/B	**A** D/M , M/B	
Nickel carbonyl				**A** E/	C			
Nickel subsulfide				**A** E/F				
Oxides of nitrogen			**A** E/F	**A** E/F				

Table 2 - Relevant NPI-Listed Substances for the Gold Ore Processing Industry, and Recommended EETs cont'

	Processing							
Substance	Comminution	Flotation, Thickening, Cyanidation, Carbon Loading & Elution	Carbon Regeneration Kilns	Power Generation	Smelting	TSFs	Roaster	Sewage
D/M : Direct measurement , M/B : Mass balance , E/F : Emission factors , E/C : Engineering calculations , M : Modelling								
A : Emission to air , W : Emission to water , L : Emissions to land, including groundwater								
Particulate matter ≤10.0 um (PM$_{10}$)	**A** D/M , E/F , M	**A** D/M , E/F , M	**A** D/M , E/F , M	**A** D/M , E/F , M	**A** D/M , E/F , M	**A** D/M , E/F , M	**A** D/M , E/F , M	
Polychlorinated dioxins and furans				**A** E/F				
Polycyclic aromatic hydrocarbons				**A** E/F				
Selenium & compounds	**A** M/B				**A** M/B	**W , L** M/B	**A** M/B	
Sulfur dioxide			**A** E/F	**A** E/F	**A** D/M , M/B		**A** D/M , M/B	
Sulfuric acid				**A** D/M , M/B, E/C	**A** D/M , M/B, E/C		**A** D/M , M/B, E/C	
Total nitrogen								**W** E/F , D/M
Total phosphorus								**W** E/F , D/M
Total volatile organic compounds		**A** E/F , E/C			**A** E/F , E/C		**A** E/F , E/C	
Zinc and compounds	**A** M/B				**A** M/B	**W , L** M/B	**A** M/B	

5. Mass balance

Mass balance provides an estimate of emissions where known quantities of substances are supplied to a process, and the process fate of the substance is both known and quantifiable.

It is essential that the mass balance calculation addresses all losses and fates of a substance and utilises the best available data.

As a result of inherent errors in the estimation of inputs to and losses from a facility or process, and the fates of those substances, the effectiveness of a mass balance approach in estimating minor emissions may be questionable and may contain broad error bands.

5.1 Water balance

Tailings storage facilities (TSFs) represent a significant potential emission source of some NPI substances. A comprehensive water balance will assist in the identification and quantification of emission pathways, allowing the emission pathways of soluble and volatile substances to be more accurately identified and estimated (BPEMIM, Cyanide Management, 1995).

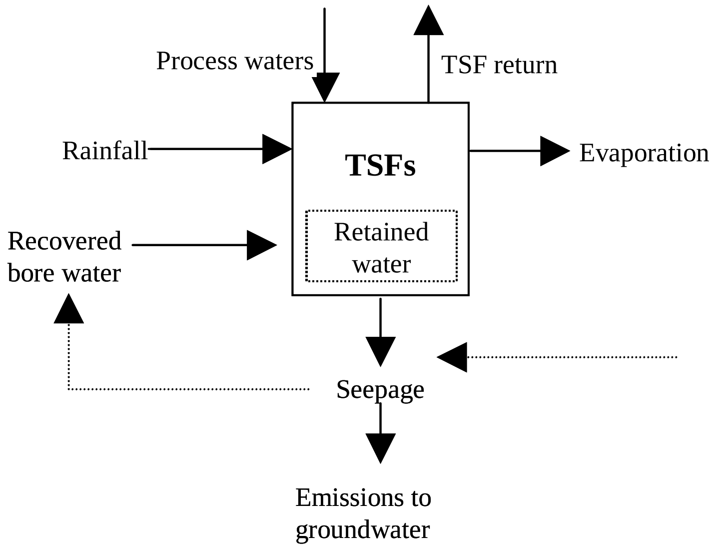


Figure 4 - TSF water balance

A comprehensive water balance, when used in conjunction with EETs, will facilitate the estimation of emissions of soluble NPI substances (e.g. metals) from TSFs.

For example, the difference between known water inputs and losses (including rainfall and evaporation) in the water balance can normally be assumed to represent seepage. Emissions of soluble NPI substances may be estimated through direct measurement of monitored boreholes and relating this data to the known hydraulic conductivity of the soils.

It is noted, however, that estimates of the inputs/outputs of some water balances may have significant associated error bands. Work recently undertaken by MERIWA (MERIWA Project M241, 1998) demonstrates the errors that may be associated with the calculation of evaporative losses from the surface of TSFs. This is well illustrated by the following example from MERIWA Project Report M241, 1998;

For a TSF of 100 ha, an evaporative loss of 100 mm is equivalent to a total volume of 100,000m^3.

Evaporative losses are influenced by a wide variety of factors. Salinity may reduce evaporation by as much as 60 - 95% of the potential evaporative rate. As such estimating to an accuracy of 100 mm may require extensive study and characterisation and any errors in calculating these losses may result in significant inaccuracies.

5.2 Cyanide balance

The NPI requires that inorganic cyanide compounds be reported where the threshold is triggered. As such in the gold ore processing industry total cyanide emissions should be reported.

Cyanide is used in the leach stage of gold ore processing, and is typically added at a rate of 0.5kg NaCN per tonne of ore. The cyanide bonds with gold to form an $Au(CN)_2^-$ complex (as shown below) allowing the gold to be extracted through adsorption onto activated carbon granules or cementation with zinc powder. Lime is used to buffer the slurry pH to optimise cyanide in solution levels and minimise the formation of HCN gas.

$$2H_2O + 2Au + 4CN^- + O_2 \rightarrow 2Au(CN)_2^- + 4OH^-$$

When used in the gold process cyanide may:

- be carried through the system in a dissolved form to be reused in recycle circuits or through TSF return waters;
- seep from TSFs as a ground emission;
- convert to various degradation products such as thiocyanate and cyanate;
- complex with metals such as copper, iron and cobalt;
- decompose to form ammonia and bicarbonate; and
- be released in gaseous form as hydrogen cyanide (HCN).

The behaviour of cyanide within TSFs is extremely complex and has not been accurately modelled to date. Current research projects (such as AMIRA P497a) are being conducted to address this lack of knowledge.

Within the TSFs structure, evaporation, reduction, oxidation, precipitation, adsorption, desorption, exchange reactions are just a few of many possible simultaneous events.

The kinetics of all these reactions is influenced by the general chemistry/geochemistry. This includes variations in:

- pH;
- electrochemical potential (Eh);
- salinity;
- temperature;
- density of solids;
- type of minerals; and
- the individual metal cyanide complexes and their concentration.

While it is accepted that most conventional TSFs facilities seep to some extent (it is only the degree of seepage that varies between structures) into the underlying formations or groundwater, the transport out of the TSF of cyanide compounds can not currently be assumed or calculated due to the above still unresolved complexity. Research data in one case has shown that, despite seepage to groundwater, no cyanide compounds have moved out of a TSF. In another case where seepage rates were similar, significant contamination of groundwater occurred. While total cyanide discharges to the respective TSFs were similar, the cyanide speciation, mineralogy and timing of the TSF of the two sites differed. (Source: Roger Schulz, 1998)

The fate of cyanide within the ore processing stage is relatively complex and cyanide (for the purposes of NPI reporting) may be released to the environment through a number of pathways including as shown in figure 5.

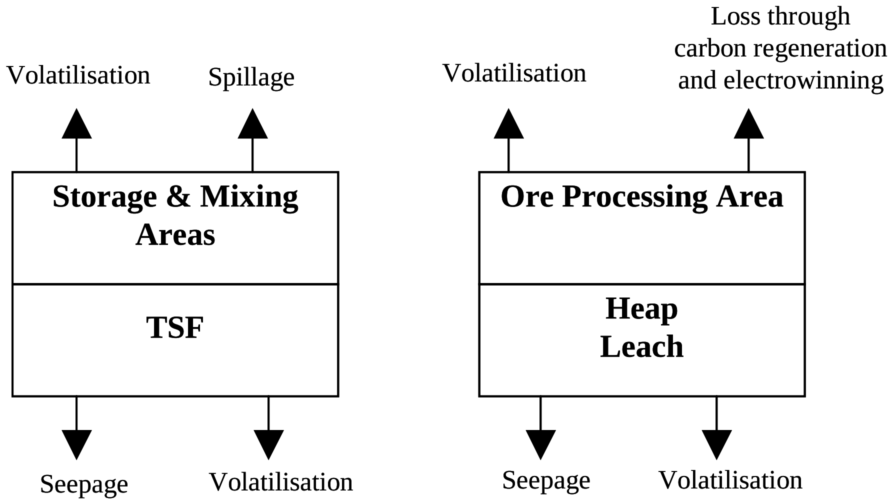


Figure 5 – Loss through carbon regeneration and electrowinning

Regardless, all cyanide is either ultimately emitted to the environment, decomposed or complexed within the TSFs.

When estimating emissions of cyanide to the environment it is important that **total cyanide** is reported. Therefore emissions of HCN should be converted to CN for reporting purposes. Section 9.4 discusses this in more detail.

As a result of losses both within and from the process, cyanide is usually the most expensive reagent cost at a facility. For this reason, in addition to the environmental, health and safety considerations, cyanide fates within the ore processing industry have been extensively studied.

A mass balance approach may be employed to develop a flow diagram of cyanide additions and losses to the process. However, it is likely that the mass balance approach will be supported by other EETs, such as direct measurement and modelling, in order to increase the accuracy of estimated emissions.

The accuracy of the mass balance approach may be greatly enhanced by the development of a cyanide management plan, regular cyanide audits and the implementation of an environmental monitoring program, such as proposed in the 'Cyanide Management' booklet from the Best Practice Environmental Management in Mining series (1998).

Cyanide mass balance is addressed below for the separate parts of the ore processing sequence.

5.2.1 *Cyanide emissions from storage and mixing areas*

Cyanide emissions from storage and mixing areas may be mainly due to spillage losses and may be estimated through effective record keeping of all spills and inventories of supplies.

Losses to ground and water may be differentiated through effective record keeping of all spills, and the fate of spilled material (washed to treatment process, absorbed and disposed of to licensed site etc).

These emissions shall be reported as CN equivalent masses.

5.2.2 *Cyanide emissions from the ore processing area (leaching and adsorption, flotation & electrowinning)*

Although a recognised procedure, mass balancing for most circuits is potentially highly inaccurate (Staunton et al 2003). For such an approach to be valid, the following prerequisite must be met:

1. The only loss of cyanide is as an emission from the circuit as HCN.
2. All inputs and outputs of cyanide into and from the unit process (es) can be measured with sufficient precision.

For the mass balance presented above it may be assumed that:

- Cyanide addition rates are known;
- Cyanide carry through concentrations are known (Total cyanide);
- Cyanide TSF return water concentrations are known (Total cyanide); and
- Cyanide volatilisation masses from leach and adsorption tanks in the CIP/CIL circuit are estimated as 1% of the total cyanide addition rate where facility-specific data is not available [Heath et al, 1998] (see Section 6.2.1)

Thus the mass balance approach may be used to estimate the emissions of cyanide through the regeneration of activated carbon and loss at the cathode during electrowinning.

Cyanide losses will occur in the carbon regeneration, elution and electrowinning areas. While this cyanide rapidly degrades to form ammonia the original emission form is as HCN and as such is reported as a cyanide emission. No attempt is made to differentiate between the masses emitted from these areas due to the difficulties inherent in their individual estimation.

$$\mathbf{\begin{array}{c}\text{Mass of cyanide lost}\\ \text{during regeneration of}\\ \text{carbon and at cathode}\\ \text{during smelting}\\ \text{(kg)}\end{array}} = \left[\mathbf{\begin{array}{c}\text{Mass of}\\ \text{cyanide}\\ \text{added to}\\ \text{process}\\ \text{(kg)}\end{array}} + \mathbf{\begin{array}{c}\text{Mass of}\\ \text{cyanide in}\\ \text{TSF return}\\ \text{water}\\ \text{(kg)}\end{array}}\right] - \mathbf{\begin{array}{c}\text{Mass of}\\ \text{cyanide}\\ \text{carried to}\\ \text{TSF}\\ \text{(kg)}\end{array}} - \mathbf{\begin{array}{c}\text{Mass of}\\ \text{cyanide lost}\\ \text{through}\\ \text{volatilisation}^{1}\\ \text{(kg)}\end{array}}$$

[1] Assume 1% if specific data is not available.

Unit Processes

a) Elution

Elution may only be considered as a separate unit process when Anglo type elution circuits are used. For Anglo elutions two options are now available:

1. Cyanide emissions can be measured using a mass balance approach, or

2. Cyanide emissions can be assumed to be negligible (<1% of site emissions), relative to other emission sources.

For Zadra elution systems, refer to the section on electrowinning.

b) Electrowinning
Cyanide emissions can be assumed to be negligible (<1% of total cyanide added) relative to other emission sources.

c) Carbon regeneration
For the carbon regeneration circuit, two options are recommended:

1. Cyanide emissions can be measured using a mass balance approach, or
2. Cyanide emissions can be assumed to be negligible (<1% of site emissions), relative to other emission sources.

5.2.3 Cyanide emissions from TSFs

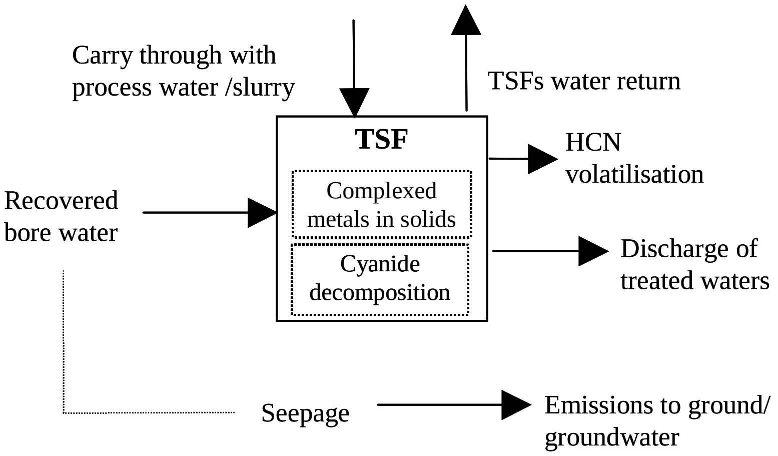


Figure 6 - Mass balance of cyanide emissions from TSFs

The potential for contamination of ground and/or groundwater resources may be a significant environmental risk for the gold ore processing facilities. Seepage from TSFs may be the most likely source of groundwater contaminants within facilities. Industry and regulators have recognised this potential risk and many facilities have seepage control and groundwater monitoring and management systems in place.

These systems include:

- under drainage of TSFs;
- interception trenches and drains;
- groundwater recovery bores;
- groundwater monitoring bores; and
- cyanide destruction technologies.

The total mass of cyanide lost within the tailings circuit (i.e. complexed with tailings solids, decomposed or emitted to the air or ground) may be estimated using the equation:

Mass of cyanide = mass of cyanide - mass of cyanide in

lost to TSFs (kg) **carried to TSF (kg)** **TSF return water (kg)**

Cyanide may be emitted to the environment via the following pathways:

Seepage

It is generally accepted that all TSFs are not impermeable and some seepage will occur, (BPEMIM, Cyanide Management). However, seepage rates will vary considerably between TSFs based on their methods of construction and management regimes. The rate of water movement through underlying soils will again be very site-specific.

The mass of cyanide lost to the environment through groundwater seepage may be estimated using:

- seepage rates; and
- the concentration of total cyanide in TSFs return water.

%seepage = seepage rate (m^3/h)/water flow rate to TSF (m^3/h) x 100

While these seepage rates will be facility-specific, generic seepage rates of between **0 - 10 %** have been quoted within the industry (Mt Keith Nickel 1996, ANCOLD per. comms.). The 10% figure can be used as a point of reference for reporting purposes.

Individual facilities will need to determine the percentage rate of seepage, which is applicable to their facility as a whole, or individual TSFs within the facility, and apply this percentage to the mass balance calculation of seepage losses.

It may be appropriate to use a number of EETs to determine losses.

Cyanide concentrations in seepage may be assumed as being equal to that in the TSFs return water (total cyanide) unless facility-specific data suggests otherwise.

$$M = [V * S] * C \Big/ 100$$

where

M = mass of cyanide emitted through seepage, kg
V = volume of solution (slurry minus solids) to TSF, m^3
S = seepage rate, %
C = concentration of cyanide, kg/m^3

In the absence of facility-specific data the following parameters may be used in calculating seepage;

- 10 % seepage rate;
- total cyanide concentrations equal to that in TSFs return water; and
- no bore water recovery

Borehole recovery may be factored into the estimation technique where cyanide concentration and volumes of recovered bore water are known.

Where seepage rates of less than 10% are used these should be justified.

Volatilisation

In natural degradation most free cyanide is lost through volatilisation (BPEMIM, Cyanide Management, 1998). The cyanide is volatilised as HCN, which ultimately breaks down to form ammonia and carbon dioxide. See Definitions (Section 9) for the meaning of free cyanide.

Volatilisation is enhanced by low pH (acidic) conditions. These conditions will be present in some TSFs storage facilities where the large surface area encourages acidification through increased contact with atmospheric carbon dioxide [BPEMIM, 1998].

At present, there is no reliable method for estimating emissions of cyanide from TSFs using a mass balance. The emissions factors for volatilisation from TSFs presented in Section 6.2.2 may be used to estimate these emissions.

Overflow

Cyanide, and other NPI substances, may be emitted to the environment as a result of TSF overflow. In these circumstances the mass of cyanide emitted may be estimated by multiplying the volume of material lost by the concentration of cyanide in the tailings material.

5.2.4 Cyanide emissions from heap/dump leaches

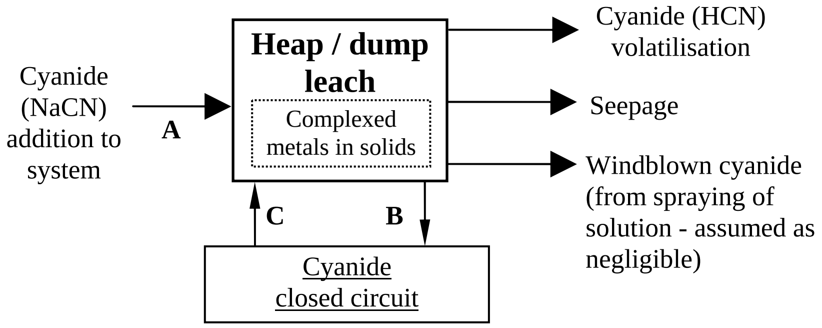


Figure 7 - Mass balance of cyanide from heap/dump leaches

The masses of cyanide added to the system will be known through monitoring of streams A, B and C. Based on this data the mass of cyanide loss within and from the leach system may be assumed to be equal to the masses in stream A. This assumes that a constant cyanide concentration is maintained within the leach process.

This mass of cyanide may be both bound up within the leach system and emitted to the environment via a number of pathways.

Seepage

Seepage from the heap/dump leach pads may be estimated using the equation below:

$$\textbf{mass of cyanide emitted through seepage (kg)} = \left[\textbf{volume of water supplied to heap leach } (\mathbf{m^3}) - \textbf{volume of water intercepted}^{1}\ (\mathbf{m^3})\right] \times \textbf{concentration of cyanide added to heap leach } (\mathbf{kg / m^3})$$

[1] Refers to volume intercepted in cut off trench or other seepage recovery mechanism

<u>*Volatilisation*</u>

Volatilisation would normally be expected to be the most significant cyanide emission pathway from dump/heap leach facilities.

At present, there is no reliable method for estimating emissions of cyanide from leach systems using a mass balance calculation, because volatilisation of cyanide cannot be distinguished from other fates such as natural decomposition.

It is proposed that the mass of cyanide lost to the environment, through volatilisation and other fates, is assumed to be HCN emissions to air. In this way a standard stoichiometry may be applied to these losses.

Cyanide bound to gold (and other recovered metals) and retained in the ore should be included within the mass balance where known.

$$\textbf{Mass of cyanide lost through volatilisation (and other fates) (kg)} = \textbf{Mass of cyanide added to leach system (kg)} - \left[\textbf{Mass of cyanide emitted to the environment through seepage (kg)} + \textbf{Mass of cyanide lost through complexing with recovered gold (and other metals) (kg)}\right]$$

Alternative cyanide EETs include emission factors,
modelling & direct measurement

5.3 Metals

Metals may be emitted:

- through seepage from TSFs and heap/dump leach pads;
- as dust; and
- as a result of TSF overflow.

The mass balance approach may be utilised to estimate emissions of metals in a manner similar to that used to estimate the emission of cyanide through seepage.

The mass of reportable NPI metals lost to the environment through seepage may be estimated using:

- estimates of seepage rate; and
- the concentration of NPI metals in TSFs return water or dump/heap leach liquors

While these seepage rates will be facility-specific, generic seepage rates of between **0 - 10 %** has been quoted within the industry (Mt Keith Nickel 1996, ANCOLD, per. comms.).

Metals concentrations should be assumed as being equal to that in the **TSFs return water** unless facility-specific data suggests otherwise.

$$M = {[V * S] * C_m}/{100}$$

where

M = mass of metal emitted through seepage, kg
V = volume of water and/or slurry to TSF, m^3
C_m = concentration of metal, kg/m^3

In the absence of facility-specific data the following data should be used in calculating seepage:

- 10 % seepage rate;
- metals concentration equal to that in TSFs return water; and
- no bore water recovery.

Borehole recovery may be factored into the estimation technique where metal concentrations and volumes of recovered bore water are known.

$$\textbf{Mass of metal emitted through seepage with bore recovery (kg)} = \textbf{Mass of metal emitted through seepage (kg)} - \left[\textbf{Concentration of metal in recovered bore water } (\mathbf{kg / m^3}) \ \mathbf{x} \ \textbf{Volume of recovered bore water } (\mathbf{m^3}) \right]$$

Alternative metals EETs include direct measurement & modelling

5.4 Chemical usage

The emission of chemicals from facilities from some sources (either as a result of normal operations, spillages or incidents) may be estimated through mass balance.

Process and domestic chemicals used within the facility may be emitted to the environment. The full inventory of these chemicals used within a reporting period, may be assumed either to be emitted to the environment or transferred to an alternative disposal, recycling or reuse facility.

In order to estimate the fate of chemicals, and their component NPI substances, the following approach should be taken:

- Mass of NPI substances within chemicals determined (including coincidental production)
- Inventory (or hazardous substances registers) of chemical usage maintained
- Fate of chemical determined -
  - ⇒ is chemical emitted to the environment or transferred?
  - ⇒ is chemical treated prior to emission from the facility?
  - ⇒ is chemical emitted to air, water or land?

⇒ does chemical undergo partitioning into other forms?
⇒ what are the fates of partitioned substances?

This approach may be applied to chemical usage in areas such as:

- chemical storage areas;
- laboratories;
- workshops;
- kitchens;
- domestic; and
- washdown areas.

Alternative chemicals usage EETs include direct measurement

5.5 Roaster and smelter emissions

Emissions (e.g. sulfur dioxide and metals) from roaster and smelter operations may be estimated through the use of mass balance. Some direct sampling may be desirable to improve components of the mass balance, e.g. sulfur/metals content of process inputs and outputs. Some facilities may choose to estimate these emissions using only direct measurement and this may represent a more accurate EET.

It is important that the fates of component substances are considered within the mass balance and that all assumptions are stated. For example, it may be assumed that all sulfur is converted to sulfur dioxide during combustion, and ash content analyses may suggest that a percentage of some metals are emitted.

The mass balance approach allows fugitive and other emissions to the environment to be estimated.

5.5.1 Emissions estimation for roaster and smelter operations

In a similar manner in which emissions from combustion are estimated, emissions from roaster and smelter operations may be estimated using a mass balance.

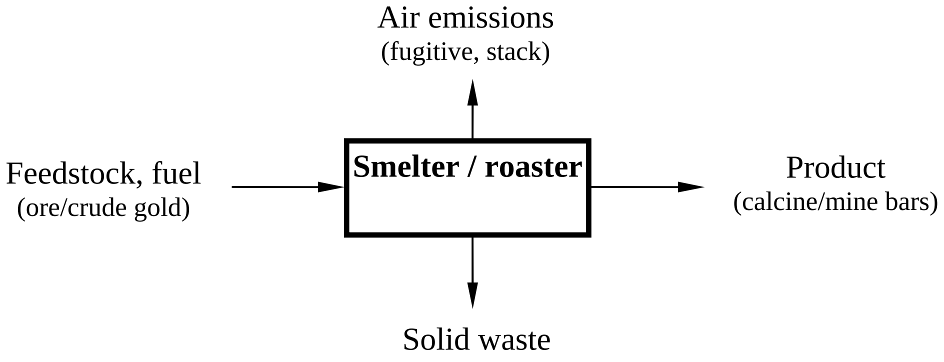


Figure 8 - Mass balance for smelter and converter operations

Air emissions may be estimated where substance concentration of the feedstock, fuel, product and solid wastes has been effectively characterised.

$$\textbf{Emission of substance} = \textbf{Rate of feedstock addition} \times \textbf{wt \%} \times \textbf{MW}_p$$

$$\textbf{(kg/hr)} \qquad \textbf{(kg/hr)} \qquad \overline{\mathbf{100}} \qquad \overline{\mathbf{EW_f}}$$

where:

wt % = weight percent of substance in feedstock.
MW_p = molecular weight of substance emitted, kg/kg-mole
EW_f = elemental weight of substance in feedstock, kg/kg-mole

Alternative roaster / smelter EETs include direct measurement

5.5.2 Emissions estimation for fuel

Fuel analysis can be used to predict SO_2, metals, and other emissions resulting from combustion.

The basic equation used in fuel analysis emission calculations is the following:

$$\underset{\textbf{(kg/hr)}}{\textbf{Emission of Substance}} = \underset{\textbf{(kg/hr)}}{\textbf{Rate of Fuel Usage}} \times \frac{\textbf{wt \%}}{\mathbf{100}} \times \frac{\mathbf{MW_p}}{\mathbf{EW_f}}$$

where:

wt % = weight percent of element in feedstock.
MW_p = molecular weight of substance emitted, kg/kg-mole
EW_f = elemental weight of substance in fuel, kg/kg-mole

SO_2 emissions from combustion can be calculated based on the concentration of sulfur in the fuel.

This approach assumes complete (100%) conversion of sulfur to SO_2. Therefore, for every kilogram of sulfur (EW = 32) burned, two kilograms of SO_2 (MW = 64) are emitted.

$$\textbf{Emission of } \mathbf{SO_2} \textbf{ (kg/hr)} = \textbf{Fuel Usage (kg/hr)} \times \frac{\textbf{wt \% S}}{\mathbf{100}} \times \frac{\mathbf{MW_{SO2}}}{\mathbf{EW_S}}$$

Where:

wt % S = weight percent of sulfur (as elemental S) in the fuel.

The emissions are estimated as kg/hr and as such should be multiplied by the hours of operation in order to determine the total emission load.

Guidance on emissions from fuel combustion may also be found in the following NPI EET Manuals:

- *Fossil Fuel Electric Power Generation EET Manual*;
- *Combustion Engines EET Manual*; and
- *Combustion in Boilers EET Manual.*

6. Emission factors

An emission factor is a tool that is used to estimate emissions to the environment.

In this Manual, it relates the quantity of substances emitted from a source to some common activity associated with those emissions. Emission factors are obtained from US, European, and Australian sources and are usually expressed as the weight of a substance emitted.

Emission factors are used to estimate a facility's emissions by the general equation:

$$E_{kpy,i} = [A \times OpHrs] \times EF_i \times [1 - (CE_i/100)]$$

where

$E_{kpy,i}$ = emission rate of pollutant i, kg/yr
A = activity rate, t/hr
$OpHrs$ = operating hours, hr/yr
EF_i = uncontrolled emission factor of pollutant i, kg/t
CE_i = overall control efficiency for pollutant i, %.

Some emission factors may involve the use of more complex equations and require differentiation of substances fates. Estimation of cyanide fates is an example of a substance that may require the use of more complex EETs.

Emission factors are derived from direct measurement of actual emission loads from a range of similar plants or equipment. While emission factors have an empirical basis they are based on standard equipment and operating practices. As such, the site-specific characteristics of facilities will introduce inaccuracies to the use of emission factors, and with the increasing use of improved technologies and control methods; emission factors may become dated.

Emission factors may be verified at individual facilities by carrying out direct monitoring of emission sources and developing site-specific variations to the standard factors to reflect on-site operational processes and practices.

6.1 Carbon disulfide

In the gold industry carbon disulfide is formed through the breakdown of xanthates which are added at the flotation stage of ore processing.

Xanthate breakdown is influenced by a number of factors. Within the gold ore processing industry the most significant of these factors are:

- pH (below pH 7 the xanthate decomposition rate increases dramatically)
- temperature (10°C rise in temperature may cause a threefold increase in decomposition rates)

[Source: WMC Report Ref 692 634, 1992]

The stoichiometry of xanthate decomposition, and hence CS_2 formation, will also vary according to the pH.

- Hydrolytic decomposition (alkali conditions) of the xanthate ion results in a stoichiometry of 1:0.5 (xanthate to CS_2).

- Hydrolysis decomposition (acidic conditions) of the xanthate ion results in a stoichiometry of 1:1 (xanthate to CS_2).

[Source: WMC Report Ref 692 634, 1992]

The decomposition stoichiometry will vary with the form of xanthate used at particular facilities. Facilities should verify the stoichiometry(s) to be applied based on their use of xanthate types.

The gold ore processing area will generally have an alkali pH (in order to minimise losses of cyanide as HCN). However at some facilities this may be very difficult to achieve.

TSFs are also likely to be alkali, although the geochemistry of the ore being handled may result in TSFs becoming acid.

Available data suggests a wide range of xanthate decomposition rates under varying conditions. Additionally, limited carry over of xanthate may take place with the product and some carry over to TSFs (approx. 2% [Society of Mining Engineers, 1976]) may also occur.

However, as the first point of reference, it can be assumed that 100% degradation of xanthate occurs within the processing area.

On this assumption CS_2 emission may be estimated using the equation:

Alkali conditions (>7) :

$$\textbf{Emissions of } CS_2 \textbf{ (kg)} = 0.5 \times \textbf{Mass Xanthate (kg)} \times MW_{CS2} / MW_{xanthate}$$

Acidic Conditions (<7) :

$$\textbf{Emissions of } CS_2 \textbf{ (kg)} = 1.0 \times \textbf{Mass Xanthate (kg)} \times MW_{CS2} / MW_{xanthate}$$

Example 1 - Carbon disulfide emissions

A facility uses 150kg of Sodium Ethyl Xanthate (SEX), for each mole of SEX used, 0.5 moles of CS_2 are produced (alkali conditions).

Molecular Weight$_{CS2}$ (MW_{CS2}) = 76g
Molecular Weight$_{CS2}$ (MW_{SEX}) = 144g

$$\text{Emission of } CS_2 \text{ (kg)} = 0.5 \times \text{Mass Xanthate (kg)} \times MW_{CS2} / MW_{xanthate}$$
$$= 0.5 \times 150 \times 76/144 \text{ kg}$$
$$= 40 \text{ kg}$$

Alternative CS_2 EETs include direct measurement

6.2 Cyanide

Extensive study has been carried out into the usage rates and fates of cyanide within the gold ore processing industry.

Cyanide fates within the gold process itself are also subject to a range of facility-specific factors including:

- ionic cyanide concentration;
- pH;
- tank geometry;
- aeration;
- agitation;
- wind velocity;
- salinity of process waters; and
- metals content of the ore.

The fates of cyanide will include:

- volatilisation;
- natural degradation;
- metal complexing;
- loss of dissolved fraction in seepage of TSFs water; and
- bound into TSFs solids.

As such the application of generic emission factors is not considered to be reliable in most situations.

6.2.1 Cyanide emissions from the ore processing area

Based on research performed by CSIRO on investigating HCN emissions from process tanks, it was estimated that approximately **1%** of the total cyanide added to the circuit is lost through HCN volatilisation across all tanks (Heath *et al.*, 1998). A figure of 1% of total cyanide added to the leach circuit may therefore be used as a default value for loss of cyanide as HCN from the leach/adsorption train.

Alternatively, a site specific figure for emissions may be calculated using the equation below. The equation estimates the HCN emissions from an individual process tank and is derived from the work reported by Heath et al.

$$\mathbf{E = ([0.013 \times [HCN_{(aq)}] + 0.46\} \times A \times T \times 0.96/10^3)}$$

Where:

E = Emission of CN (kg)
$[HCN_{(aq)}]$ = $[NaCN] \times 10^{(9.2 - pH)}$
$[NaCN]$ = Concentration (as mg/l) of NaCN in the leach/adsorption tank
pH = pH in the leach/adsorption tank
A = Surface area (m^2) of the leach/adsorption tank
T = Period of emissions (hours)

This approach:

- must be applied to each tank individually;
- should be calculated on a regular basis (as required to reflect changing tank conditions) or using mean values based on regular sampling of tank conditions; and
- this equation is of unknown validity at $HCN_{(aq)}$ concentrations below 60 mg/l (as NaCN).

6.2.2 *Cyanide emissions from the TSFs*

In the previous version of this manual, an emission factor for cyanide volatilisation from surface area of the liquor within the TSFs was:

1g of HCN per m^2 per hour for each 100ppm of $HCN_{(aq)}$

(Ref: WMC, Pers. Comm. 1998)

However, this equation is not recommended for use as it based only upon personal communication and cannot be verified.

It has been estimated that volatilisation of HCN accounts for 90% of the natural degradation of cyanide from TSFs (Ellis, 1997; Simovic, 1984). However, volatilisation is extremely pH dependent as a result of the HCN/CN^- flux. A range of other factors also influences the rate of volatilisation although pH is the most significant factor.

This percentage degradation is however dependent on pH conditions. As such, where **‘free’ cyanide** concentration and pH of the TSF return water are known, the percentage degradation may be estimated based on the conditions detailed below;

Table 3 - Effect of pH on the volatilisation of cyanide

pH	Percentage of natural degradation due to volatilisation ($V_{\%}$)
6	90 %
7	90 %
8	80 %
9	60 %
10	20 %
11	0 %
12	0 %

(Based on Ellis, 1997, Simovic, 1984)

This data is applied using the equation below:

$$\begin{array}{c}\textbf{CN from TSFs}\\\textbf{(as kg CN)}\end{array} = \left[\begin{array}{c}\textbf{Titratable cyanide}\\\textbf{concentration in}\\\textbf{water entering}\\\textbf{TSF}\\\textbf{(kg CN / m}^3\textbf{)}\end{array} \times \begin{array}{c}\textbf{Volume of water to}\\\textbf{TSF}\\\textbf{(m}^3\textbf{)}\end{array}\right] \times V_{\%}/100$$

Alternative cyanide EETs include: mass balance, modelling *and direct measurement*

6.3 Dust: PM10 and Total Suspended Particulates (TSP)

Table 4 provides emission factors for PM_{10} and TSP sources within the processing area. The PM_{10}/TSP ratio allows the PM_{10} emission factor to be verified at the facility level where TSP monitoring is undertaken.

It should be noted that TSP is not a reporting requirement under the NPI and is used to estimate metals content of emitted dust only. Also, while PM_{10} reporting is triggered by fuel usage all sources of PM_{10} emissions must be estimated if the reporting threshold is triggered.

Emission factors for high and low moisture content ores are presented and are for uncontrolled emissions.

Metal emissions can be estimated as a fraction of the TSP emissions, based on available assay data. Where assay data and facility-specific information is not available for metals in dust emissions the concentrations in Appendix A should be used as a default to estimate metal emissions.

Dust emissions from TSFs should only be calculated from those TSFs with the potential to result in dust emissions.

With regards to emission controls for PM_{10}, in the absence of measured data, or knowledge of the collection efficiency for a particular piece of equipment, an efficiency of 90% should be used in the emission factor equation to calculate actual mass emissions. This default should only be used if there is no other available control efficiency.

A range of factors influence the dust generation from TSFs, including:

- moisture content;
- salt concentration;
- vegetation cover and organic matter (lichens, moss etc);
- surface structure (structural & textural cracks & inhomogenity);
- traffic (mechanical and animals); and
- weathering.

(Carras, 1998)

Retaining a wet surface on TSFs will prevent dust generation (BPEMIM, Tailings Containment, 1995), while TSFs with a low salt content (and low moisture content) have a greater potential for dust generation than TSFs with a high salt content. Revegetation of decommissioned TSFs will minimise their potential for dust generation.

The potential for TSFs to generate dust should be assessed on a facility basis. The assessment should be based on known factors, which influence dust generation and observational/monitored results.

In the absence of facility-specific the following assumptions may be made:

- zero dust generation from TSFs where hyper saline water used in process
- zero dust generation from ‘wet’ area of TSFs
- zero dust generation from vegetated TSFs

Alternative dust EETs include direct measurement

6.4 Metals in dust

PM_{10} and TSP may contain a metal fraction, which will represent part of the facility's metals emissions.

The speciation of dust, both PM_{10} and TSP, using an emission factors approach may be achieved using:

- metals content of ore (generic or facility-specific)
- dust generation estimates (either through emission factors, modelling or direct monitoring)

The metals fraction for all processing dust sources may be assumed to be the same as that for unprocessed ore, in the absence of more suitable data. Fractions may be sourced from facility-specific assays of generic ore types (Appendix A).

Table 4 - Emission factors for dust generation

Operation/Activity	**TSP emission factor**	**PM$_{10}$ emission factor**	**PM$_{10}$/TSP ratio**	**TSP emission factor**	**PM$_{10}$ emission factor**	**PM$_{10}$/TSP ratio**	**Units**	**Emission factor rating**
	High moisture content ores			Low moisture content ores				
Primary crushing	0.01	0.004	0.4	0.2	0.02	0.1	kg/t	C
Secondary crushing	0.03	0.012	0.4	0.6	NDA		kg/t	D
Tertiary crushing	0.03	0.01	0.33	1.4	0.08	0.06	kg/t	E
Wet grinding (milling)	0	0		0	0		kg/t	
Handling transferring and conveying	0.005	0.002	0.4	0.06	0.03	0.5	kg/t	C
Loading stockpiles *	0.004	0.0017	0.42	0.004	0.0017	0.42	kg/t	U
Unloading from stockpiles *	0.03	0.013	0.42	0.03	0.013	0.42	kg/t	U
Loading to trains *	0.0004	0.00017	0.42	0.0004	0.00017	0.42	kg/t	U
Miscellaneous transfer points *	0.009	0.0038	0.42	0.009	0.0038	0.42	kg/t	U
Wind erosion (including stockpiles & TSFs) *	0.4	0.2	0.50	0.4	0.2	0.50	kg/ha/h	U

(Source: *EET Manual for Mining*) * High and low moisture content emission factors assumed as equal

Note:

1. NDA - No data available
2. Generally a high-moisture ore is taken to be one which either naturally, or as a result of additional moisture at the primary crusher (usually), has a moisture content of more than 4% by weight.
3. Estimated control efficiencies for various control measures:
    - 30% for windbreaks
    - 50% water sprays to keep ore wet
    - 65% for hooding with cyclones
    - 75% for hooding with scrubbers
    - 83% for hooding with fabric filters
    - 100% enclosed or underground
4. Controls are multiplicative. For example, water sprays used in conjunction with wind breaks give an emission which is which is [(1 - (50/100)) x (1 - (30/100)) = 0.35] of the uncontrolled emission (i.e. 50% of 70% of the total uncontrolled emissions

The metals (and cyanide) content of TSF dust emissions should be based on representative sampling of the TSFs surface matrix.

Alternative metals content of dust EETs include direct measurement

6.5 Sewage

The reporting threshold for Category 3 substances is unlikely to be exceeded at most facilities; however, it is the responsibility of each facility to determine whether they exceed the reporting threshold.

See the *EET Manual for Sewage and Wastewater Treatment* for information on estimating emissions from sewage treatment.

6.6 Combustion emissions

The use of emission factors for estimating emissions from combustion has been extensively studied and may be used to provide a relatively accurate estimate of substance emission.

Reference may be made to the following manuals for combustion emission factors:

- *EET Manual for Fossil Fuel Electric Power Generation*
- *EET Manual for Combustion in Boilers; and*
- *EET Manual for Combustion Engines.*

6.7 Carbon regeneration

Natural gas is generally used as the combustion source in carbon regeneration. The *EET Manual for Combustion in Boilers* may be used to estimate combustion emissions from carbon regeneration activities.

6.8 Fuel Storage

Volatile organic compounds (VOC) may be emitted from fuel storage areas and as a result of incomplete combustion (Section 6.6).

Guidance on the estimation of VOC, and other NPI substances, may be obtained from the *EET Manual for Fuel and Organic Liquid Storage*.

7. Modelling

Modelling may be utilised to determine the fate of substances emitted to the environment, including emissions to air and groundwater.

This EET may be of particular use for estimation of emissions of substances such as PM_{10}, cyanide and dissolved metals through TSFs seepage.

For cyanide and dissolved metals emissions from TSFs, modelling would be likely to have at least two components:

- the fate of the substance within the TSF; and
- the fate and transport of substances within groundwater.

Models may be very simple, based on minimal data and making broad based assumptions, or complex with factors for weather influences, chemical speciation and site-specific factors.

The complexity of a model will influence the accuracy of any emission estimations made using this method. Wherever possible, however, models should be verified by direct measurement under a range of conditions. With effective model verification, models may be factored to allow for site-specific influences, and significant influences may be included within the model itself.

7.1 Groundwater modelling - fates and trajectories

Groundwater movement may be modelled to allow prediction of groundwater fates and that of any associated dissolved substances. Additionally, modelling will allow the temporal prediction of groundwater movement allowing the potential for the breakdown of substances within the groundwater or their in-situ adsorption to be estimated.

Groundwater models may be based on limited data such as calculated groundwater flow rates and direction, or contain in-depth data such as the geology and hydrogeology of the area. The complexity of models should be stated when used to estimate emissions in order to ensure that the error bands associated with the reported data are fully appreciated.

The fate of dissolved metals resulting from TSFs seepage would be suited to this approach.

7.2 Seepage from TSFs

Seepage from TSFs is generally accounted for as part of the design criteria and should not be viewed as a failure of the containment system.

Modelling of seepage from TSFs is recognised as an appropriate means of designing and operating TSFs. Models may be used to estimate emission of dissolved substances such as cyanide and metals.
There are many commercially available models available. Models include PC-SEEP, a two-dimensional unsaturated/saturated groundwater flow model (Mt Keith Nickel, 1996).

7.3 Cyanide

The fate of cyanide within TSFs is subject to continuing research by both industry and academia. Modelling the fate of cyanide within TSFs, including losses due to wind erosion, is an area of primary focus. Models are currently available although caution in their use is advised regarding the assumptions with respect to facility-specific aspects such as geochemistry, operation and construction of TSFs.

Three projects completed under the auspices of AMIRA International studied the fate of cyanide in TSFs. These were P277 (1989-1991) and P497/497A (1997-2000). The development of a model to predict the deportment of cyanide in and around tailings structures was commenced during P497A and the work has continued in the current AMIRA Project P420B. The work program for P420B is scheduled to be completed in April 2004.

Facilities may decide to apply existing models in order to allow estimation of emissions. While there will be inherent errors associated with these models, errors bands may be calculated and stated where data is reported.

8. Direct measurement or source monitoring

Direct measurement (or source monitoring) is one of the more accurate methods of estimating emissions of substances from processes and facilities. A facility may wish to use existing monitoring data for NPI reporting and/or establish additional monitoring. As stated in Section 4.0, the NPI has a commitment of not requiring any additional monitoring.

Facilities may decide to undertake direct measurement in order to:

- estimate their emissions of particular NPI substances;
- verify estimates from alternative EETs; and
- provide supporting data for other EETs.

Where direct measurement is undertaken it is essential to ensure background levels are fully considered. Some areas will have significant background levels of NPI substances either as a consequence of adjacent activities (e.g. TSP and PM_{10}) and as a consequence of the natural background levels (eg. metals in particular geological formations).

Additionally the immediate and long-term aim of the monitoring program should be decided in order to avoid unnecessary ongoing monitoring.

Facilities may have existing monitoring commitments and data that can be applied to the reporting requirements of the NPI. Potential sources of existing data are discussed in Appendix B.

Facilities may also have the analytical expertise on site to enable the monitoring and analysis of NPI substances to be undertaken in a more cost-effective manner.

Direct measurement data may be used to calculate actual loads to the environment by multiplying the concentration of the NPI substances in the final emission stream, by the volume of the final emission stream.

$$\mathbf{\begin{array}{c}\text{mass}\\ \text{emitted}\\ \text{(kg)}\end{array} \quad = \quad \begin{array}{c}\text{substance}\\ \text{concentration}\\ \text{(kg / m}^3\text{)}\end{array} \quad x \quad \begin{array}{c}\text{volume of}\\ \text{total emission}\\ \text{(m}^3\text{)}\end{array}}$$

Where direct measurement is undertaken it is essential that sampling and monitoring procedures are established. The procedures should ensure that all sampling and analyses are undertaken in a standard manner and in compliance with Australian, or other, standards.

8.1 Total nitrogen and total phosphorus

Total nitrogen and total phosphorus loadings may be estimated by direct measurement based on:

- wastewater flows; and
- representative concentrations of total nitrogen and phosphorus in wastewater flows.

Direct measurement is applied to 'end of pipe' emissions ensuring that the facility-specific efficiency of wastewater treatment plants are fully considered.

Alternative total nitrogen and phosphorus EETs include emission factors

8.2 Dust & PM_{10}

PM_{10} emissions are estimated from their point of creation. As such the presence of a buffer zone will not influence the estimated emissions.

Direct measurement may be designed to monitor overall site emissions or emissions from particular processes. In all cases it will be important to ensure background levels are considered and factored into emission estimations.

Alternative PM_{10}, and TSP, EETs include emission factors and modelling

8.3 Metals in dust

PM_{10} and TSP will contain a metal fraction. Speciation of PM_{10} and TSP levels will be necessary to allow estimation of the facility's emissions of these metals.

Periodic analysis of dust samples will allow the speciation of dust with a greater level of accuracy.

The degree of dust speciation required will be determined by the range of substances for which the reporting threshold has been triggered. It is important to note that reporting of metals may be triggered by a number of categories but all triggered substances must be estimated from all sources for reporting purposes.

Alternative metal EETs include emission factors

8.4 Cyanide

In monitoring for cyanide it is essential to:
- clearly define the purpose of the monitoring;
- define the form of cyanide which is to be monitored (free, total, WAD, complexed);
- develop an appropriate sampling regime (including replicates and blanks); and
- ensure samples are effectively preserved and treated appropriately.

(Source: BPEMIM, Cyanide Management; Minerals Council of Australia, 1996)

A flow diagram detailing the fate of cyanide within the facility, and its form at all fate pathways, should be developed to ensure that:

- monitored data is appropriate; and
- cyanide stoichiometry is valid.

In-depth guidance in the development of a cyanide monitoring program should be sourced from the references above, process technicians and specialist laboratories.

Cyanides comprise a large class of organic and inorganic chemical compounds, which contain a chemical group comprising a nitrogen atom triply bonded to a carbon atom.

Of this class of chemicals only the inorganic cyanides are relevant to the mining industry (NPI reporting is for inorganic cyanide compounds).

There is a confusing assemblage of terms used in connection with cyanide toxicology. The commonly used generic names to describe the inorganic cyanides are listed and explained below:

Free cyanide - the cyanide ion (CN^-) and molecular hydrogen cyanide (HCN) which in aqueous solution may dissociate to form the cyanide ion, the degree of dissociation being pH dependent.

Simple cyanides - represented by the chemical formula $A(CN)_{x,}$ where A is an alkali (e.g. sodium) or metal and x is the valance of A. Those simple cyanides which dissolve in water, particularly alkali cyanides, dissociate to generate cyanide ions and molecular hydrogen cyanide in aqueous solution.

Complex cyanides - the complex alkali-metallic cyanides generally represented by the formula $A_yM(CN)_{x,}$ where A is the alkali or metal, y the number of alkali or metal atoms, M is the heavy metal (iron, cadmium, copper. etc) and x is the valance of A multiplied by y, plus the valance of the heavy metal. Complex cyanides which dissolve release the complex ion $M(CN)_x$ rather than the cyanide ion. The complex ion may then undergo further dissociation releasing the cyanide ion.

Total cyanide - an analytical quantity determined by digesting a sample at high temperature and low pH, conditions which effectively break down most metal cyanide complexes. Total cyanide includes cyanide from: free cyanide (CN^- and HCN) and all metal cyanides (e.g. Zn, Ni, Fe, Cu, Au, Co). Note that some of the very strong complexes (e.g. Co) may not be broken down. Total cyanide does not include cyanide from cyanate or thiocyanate.

Some analytical methods for Total Cyanide will break down the thiocyanate, with the cyanide component reporting with the other cyanide species. In such procedures, thiocyanate should be determined separately, and subtracted from the first result to give a correct value for Total Cyanide.

Titratable cyanide – Cyanide species which are determined by titration with a silver nitrate solution, typically using rhodanine as an indicator. This method determines the cyanide ion (CN^-), and cyanide weakly bound to metal complexes (including cyanide bound to zinc and some of the cyanide bound to copper). In most process solutions it will not measure all of the molecular hydrogen cyanide (HCN) that is present.

Weak acid dissociable (WAD) cyanide - an analytic quantity determined by using less harsh conditions than for Total Cyanide determinations. The WAD determination includes cyanide from free cyanide (CN^- and HCN); and cyanide contained in the weaker metal cyanide complexes (zinc, nickel and part of the cyanide from copper and cadmium complexes). Cyanide contained in iron and cobalt complexes is not collected.
(Source: Minerals Council of Australia, 1996)

The NPI requires that inorganic cyanide compounds are reported. As such, **total cyanide** should be reported from the gold ore processing industry. However, as shown by the example in Appendix D, a number of different forms of cyanide may need to be monitored in order to achieve an estimate of emissions.

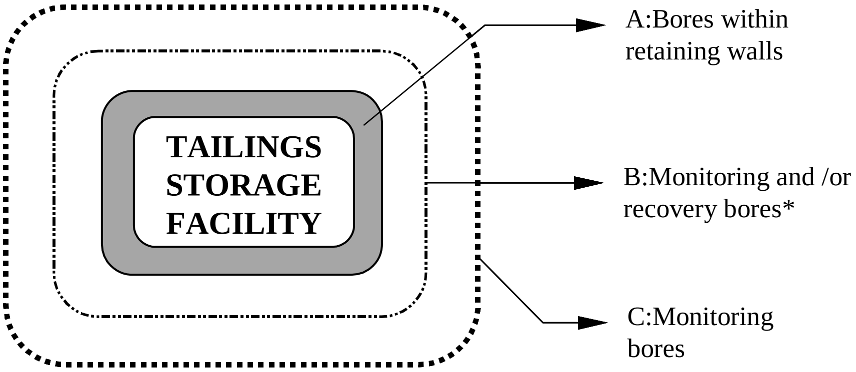
Alternative cyanide EETs include mass balance,
emission factors and modelling

8.5 TSF seepage

Seepage from TSFs may be estimated through the use of a system of monitoring bore holes.

Bore hole layout and depths will be dependent on facility-specific conditions, such as hydrogeology, depth to groundwater and groundwater flow direction. However, in order to achieve an accurate estimation of emissions, such as cyanide and metals, boreholes should:

- intercept known preferential flow paths; and
- be located at a range of distances from the TSFs.



* Alternative recovery systems, such as trenches, may also be used.

Figure 9 - TSF bore hole monitoring approach

NPI substances detected (above background levels) at bores 'B' (monitoring and/or recovery) will not be considered as emissions to the environment if recovered water is treated, for example pumping back to the TSF. The substances contained in the volume of water not recovered will be considered emissions to the environment.

NPI substances detected (above background levels) at bores 'C' (monitoring) will be considered as emissions to the environment.

The mass of NPI substances emitted will be estimated by multiplying the detected concentration at bores 'B' by the known hydraulic loading beyond bores 'B' (from the zone of influence and hydraulic conductivity of the soil) and the monitoring interval.

The hydraulic loading around the TSF is estimated using the equation below. The equation may be used to estimate the hydraulic loading from all ‘faces’ of the TSF (north, south, east and west) as a single entity or in distinct areas where the hydraulic gradient is known to differ significantly.

The hydraulic gradient is based on the hydraulic head produced by the TSF and the physical gradient between bores 'A' and 'B'.

$$\begin{array}{c} \textbf{TSF} \\ \textbf{hydraulic loading} \\ \mathbf{(m^3\ /\ day)} \end{array} = \begin{array}{c} \textbf{Cross sectional area} \\ \textbf{of zone of influence} \\ \mathbf{(m^2)} \end{array} \times \begin{array}{c} \textbf{Hydraulic} \\ \textbf{conductivity} \\ \mathbf{(m\ /\ day)} \end{array} \times \begin{array}{c} \textbf{Hydraulic} \\ \textbf{gradient} \\ \ \end{array}$$

The emitted hydraulic loading is estimated by subtracting the volume of recovered water from the TSF hydraulic loading.

$$\textbf{Emitted hydraulic loading } (\mathbf{m^3 / day}) = \textbf{TSF hydraulic loading } (\mathbf{m^3 / day}) - \textbf{Volume of recovered water } (\mathbf{m^3 / day})$$

The emission of NPI substances is then estimated

$$\textbf{Mass of substance emitted } (\mathbf{kg/period}) = \textbf{Concentration of substance in bores 'B'* } (\mathbf{kg / m^3}) \times \textbf{Emitted hydraulic loading } (\mathbf{m^3 / day}) \times \textbf{Period } (\mathbf{Days})$$

* Where ‘total cyanide’ concentration is not available from bores the ‘total cyanide’ concentration from TSF return water should be assumed.

Alternative seepage from TSFs EETs include emission factors, modelling & mass balance.

9. Definitions

Reference should be made to the National Pollution Inventory and *The NPI Guide* for definition of terms used within the NPI system.

Term	Definition/description
Boundary	Boundary is defined in varying ways depending on the emission type. For emissions to air boundary is the point of creation (such as the surface of a liquid during evaporation, or the wheels of a vehicle for dust generation). For emissions to land and water, boundary is the point at which a substance is no longer contained (such as a spill to ground from a process vessel, or a discharge to surface waters from a treatment works).
Direct measurement	Technique used to estimate emissions to the environment through the sampling and analysis of emission streams.
Emission	Any release of substances to the environment whether it is in a pure form or contained in other matter. Emissions may be solid, liquid or gaseous.
Emission factor	A number or equation that may be applied to raw data from a facility to estimate emissions from that facility without the need for emissions sampling and analysis. This technique is most often used to estimate gaseous emissions to the environment.
Fugitive emissions	Emissions not released from a vent or stack.
Inventory	Means of recording usage and stores of all materials, and product, held on a facility or utilised by a process.
Mass balance technique	Estimation of emissions to the environment through equalisation of inputs and outputs to a particular process or facility.
Power generation	Production of power for the operation of facilities and use in processes.
Free cyanide	The cyanide ion (CN^-) and molecular hydrogen cyanide (HCN) which in aqueous solution may dissociate to form the cyanide ion, depending on pH.
Simple cyanides	Represented by the chemical formula $A(CN)_{x,}$ where A is an alkali (e.g. sodium) or metal and x is the valance of A. Those simple cyanides which dissolve in water, particularly alkali cyanides, dissociate to generate cyanide ions and molecular hydrogen cyanide in aqueous solution.
Complex cyanides	The complex alkali-metallic cyanides generally represented by the formula $A_yM(CN)_{x,}$ where A is the alkali or metal, y the number of alkali or metal atoms, M is the heavy metal (iron, cadmium, copper. etc) and x is the valance of A multiplied by y, plus the valance of the heavy metal. Complex cyanides which dissolve release the complex ion $M(CN)_x$ rather than the cyanide ion. The complex ion may then undergo further dissociation releasing the cyanide ion.
Total cyanide	An analytical quantity determined by digesting a sample at high temperature and low pH, conditions which effectively break down most metal cyanide complexes. Total cyanide includes cyanide from: free cyanide (CN- and HCN) and all metal cyanides (e.g. Zn, Ni, Fe, Cu, Au, Co). Note that some of the very strong complexes (e.g. Co) may not be broken down. Total cyanide does not include cyanide from cyanate or thiocyanate. Some analytical methods for Total Cyanide will break down the thiocyanate, with the cyanide component reporting with the other cyanide species. In such procedures, thiocyanate should be determined separately, and subtracted from the first result to give a correct value for Total

Term	Definition/description
	Cyanide.
Titratable Cyanide -	Cyanide species which are determined by titration with a silver nitrate solution, typically using rhodanine as an indicator. This method determines the cyanide ion (CN-), and cyanide weakly bound to metal complexes (including cyanide bound to zinc and some of the cyanide bound to copper). In most process solutions it will not measure all of the molecular hydrogen cyanide (HCN) that is present.
Weak acid dissociable (WAD) cyanide	An analytic quantity determined by using less harsh stripping conditions than for Total Cyanide determinations. The WAD determination includes cyanide from free cyanide (CN- and HCN); and cyanide contained in the weaker metal cyanide complexes (zinc, nickel and part of the cyanide from copper and cadmium complexes). Cyanide contained in iron and cobalt complexes is not collected. (Source: Minerals Council of Australia, 1996)

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Technical Guidelines for the Environmental Management of Exploration and Mining in Queensland, Department of Minerals and Energy, January 1995

Waste Management: Solutions and Opportunities in the Mining Industry, 26th August 1993

The following emission estimation technique manuals referred to in this manual are available at the NPI web site and from your local environmental protection agency (see the front of the NPI Guide for details):

- Emission Estimation Technique Manual for Combustion in Boilers;
- Emission Estimation Technique Manual for Combustion Engines;
- Emission Estimation Technique Manual for Fossil Fuel Electric Power Generation;
- Emission Estimation Technique Manual for Fuel & Organic Liquid Storage; and
  Emission Estimation Technique Manual for Sewage & Wastewater Treatment.

Appendix A: Generic ore assays

Table A1: Generic ore assays

Element	Symbol	Basalt	Granite	Coal	Soil	Earth's crust	Marine clays	Marine carbonates	Shale	Limestone	Sandstone	Sediment
Antimony	Sb	0.69	0.2	3.5	1	0.2	1	0.05	1.5	0.3	0.05	1.2
Arsenic	As	1.5	1.5	6.5	6	1.5	13	1	13	1	1	7.7
Beryllium	Be	0.3	5	1	0.3	2.6	2.6		3	<1	<1	2
Boron	B	8	12	70	20	10	230	55	130	20	30	100
Cadmium	Cd	0.13	0.09	0.2	0.35	0.11	0.21	0.23	0.22	0.028	0.05	0.17
Chromium	Cr	200	4	20	70	100	90	11	90	11	35	72
Cobalt	Co	35	1	5.4	8	20	74	7	19	0.1	0.3	14
Copper	Cu	90	13	15	30	50	25	30	39	5.5	30	33
Fluorine	F	510	1400	-	200	950	730	550	800	220	180	640
Lead	Pb	3	24	30	35	14	80	17	23	5.7	10	19
Manganese	Mn	1500	400	41	1000	950	6700	1000	850	620	460	770
Mercury	Hg	0.12	0.08	0.23	0.06	0.05	0.08	0.46	0.18	0.16	0.29	0.19
Nickel	Ni	150	0.5	15	50	80	225	30	68	7	9	52
Selenium	Se	0.05	0.05	2.9	7	0.05	0.17	0.17	0.5	0.03	<0.01	0.42
Zinc	Zn	150	240	31	90	190	150	20	160	20	220	150

(Source: EET Manual for Mining)

1. All figures in mg/kg (or g/tonne)
2. Extracted and adapted from Bowen, H.J.M. 1979. *Environmental Chemistry of the Elements*, Academic Press and generally checked against Berkman, D.A. 1989 *Field Geologists Manual*, The Australasian Institute of Mining and Metallurgy.
3. The figures listed above are average or median concentrations of the particular element within the rock or material specified.
4. The NPI requires the reporting of emissions of the elements listed in this Table provided appropriate thresholds have been tripped. As noted in the body of the Manual, it is recognised that trace metal analyses are not routinely undertaken for mining operations. In these situations, it is likely that the trace metal concentrations would be average to below average. Thus, where data on particular elements is not available, the average concentrations listed above for the particular material type should be used. In most cases, it would be expected that a low reliability would be attached to the emission estimate.
5. Further to Note 3, trace metal concentrations will be significantly greater than average where the reportable metal occurs at the site. For example, at a silver, lead and zinc mine, the concentrations of lead, zinc and probably cadmium in waste rocks, TSFs and soils will be significantly greater than the average concentrations listed in the above Table. It is expected that where it is necessary to use an assumed trace metal concentration to estimate emissions from a site, the facility will nominate a credible figure, which can be justified to the administering authority. The reliability attached to the estimate will generally depend on the available data sets from which the estimate has been calculated.

The table below presents the concentrations within the ore that will trigger the reporting threshold for Category 1 NPI substances.

Metal conc. in ore (ppm)	Annual tonnage (millions of tonnes)
0.1	100
0.2	50
0.3	33.3
0.4	25
0.5	20
0.6	16.7
0.7	14.3
0.8	12.5
0.9	11.1
1	10
10	1
100	0.1

Appendix B: Existing data

The emission estimation methods proposed in this manual require best available data. This data may be available within a corporation or facility in a range of forms and sharing this data between facilities will aid reporting and allow for a greater level of accuracy in the estimation of emissions.

This data may be used to:

- directly estimate emissions;
- provide guidance on the most appropriate estimation methods to be used; and
- provide guidance on where direct monitoring may be most beneficially carried out.

It is not intended that facilities disclose proprietary or sensitive information, rather that this information is used in-house to assist in the NPI reporting process.

Data sources may include the following.

Existing Data & research

Research projects of interest to industry are often sponsored, such as university PhDs and final year projects. These may be much directed areas of research, such as slag content and leachability or hydrogeological contamination, and may not be widely available within a facility or may be held at a corporate level.

Some mine sites currently address their dust emissions as three distinct components:

- the monitoring of ambient dust levels:
- the assessment of dust sources; and
- the implementation of dust control strategies.

Mine sites may also sponsors CSIRO dust research projects including that generated from TSFs.

Data of this type may be applied to emission estimations methods to increase their accuracy either directly through the development of emission factors or indirectly by identifying additional process within mass balances.

Mines may also have carried out discrete monitoring studies to determine the health or environmental impacts of particular substances. While these studies may have shown that minimal health or environmental risk is posed and hence ongoing monitoring is not required, it may also be used to allow more accurate estimation of NPI substances.

Many mines will have access to geotechnical data and groundwater data for the mine site from exploration work carried out in the past. This data may provide information on groundwater flows, the location of palaeochannels and other geological formations, and provide useful data for deciding the location and depths of any monitoring boreholes.

Process monitoring

Elements of the process may be monitored regularly in order to optimise recovery of the product. This data may be applied to emission estimation methods such as mass balance, serving as a verification of the mass balance to that stage of the process and raw data.

Monitored areas may include:

- ore;
- concentrate; and
- TSFs water input and return

Monitoring may also be undertaken for health and safety requirements and may include:

- ammonia;
- cyanide;
- acids; and
- carbon monoxide

Licenses & reporting

Mine sites may be required to carry out monitoring which can be applied to the requirements of the NPI. These data may include the following parameters:

- sulfur dioxide;
- sulfuric acid fumes;
- arsenic (As);
- dust and particulates;
- metals; selenium, antimony. beryllium, cadmium. lead, mercury, chromium, manganese, cobalt, copper, nickel, zinc;
- chemical spills, including cyanide; and
- dangerous goods licensing.

Facilities may monitor TSFs and storage ponds at regular intervals to ascertain reuse potential and treatment methods such as neutralisation. Where seepage from ponds and TSFs is suspected monitoring of bore holes may also be undertaken. Parameters may be expressed as soluble or total, and may include:

- pH;

- conductivity and TDS;
- standing water level; and
- metals.

This data may be used:

- directly where NPI substances are being monitored and reported;
- indirectly such as dust monitoring where speciation of the dust component may be required; and
- relationally where the ratio of a monitored parameter can be related to the emissions of an NPI substance.

Approvals data

Gold mines may have Consultative Environmental Reviews (CERs), Public Environmental Reviews (PERs), Notifications of Intent (NOIs) or other approval documents, which contain a range of facility characterisation and operational efficiency data. This may be applied to emission estimation methods to provide greater accuracy in reported data.

For example from March 1993 all proposal submitted to WA DoME require a detailed summary and list of commitments. The range of information must be reported under the guidelines (NOI Guidelines, 1993) including:

- properties of TSFs;
- TSF construction parameters;
- decant or under drainage systems;
- liner type; and
- monitoring.

Regulatory data

Regulatory and government departments may hold extensive data relating to individual facilities, state and territories, or national and international sources. This data may be accessed to provide a more extensive database of available information with which to develop facility or corporate emission estimation strategies.

Suppliers

Suppliers should be able to provide in depth data regarding the fates of supplied chemicals within the process. A good example of this would be xanthates which breakdown to form carbon disulfide. Suppliers should be able to provide data relating to the proportional breakdown of xanthates, environmental stability, and potential for carry through in the gold process and to TSFs.

Inventory

A facility inventory may be used to identify all inputs to the gold process and the usage rates in relation to ore treated and product achieved. The inventory should be used as a tool to assist in the estimating and reporting process and will not need to be submitted with estimated emissions.

An *example* of an existing facility inventory is presented below.

INPUTS	*Units*	Jan	Feb	Mar	...	Dec	TOTAL
Tonnes of ore treated	*tonnes*						
Gold production	*kg*						
Sodium Cyanide	*tonnes*						
Quicklime (78% CaO)	*tonnes*						
(88% CaO)	*tonnes*						
Oxygen	*m3*						
Carbon	*tonnes*						
Flocculant	*tonnes*						
Antiscalent	*tonnes*						
Diesel	*litres*						
Grinding balls	*tonnes*						
Electricity	*kWh*						
LP Gas	*tonnes*						
Caustic soda	*tonnes*						
Hydrochloric acid	*tonnes*						
Potable Water	*kl*						
Bore Water Total	*kl*						
Decant Water from TSFs	*kl*						
TSF dewatering system	*kl*						
TSF decant return	*kl*						
TSF underdrainage	*kl*						

In addition to its use within the NPI framework a facility inventory may also be used to determine material usage across the site assisting in:

- financial planning;
- resource planning;
- waste minimisation; and
- environmental reporting.

It is likely that most facilities will have an inventory of some type and reference to this may enhance the accuracy of emission estimation and be applied to all emission estimation methodologies.

Appendix C: Transfers

Transfers are the movement of NPI substances from the facility for ‘processing’ at another facility or onsite. For the gold industry these may include:

- all material sent to another facility for processing or use;
- all material sent to a tailings dam facility;
- all material to managed landfill or waste treatment sites outside of the facility; and
- all material leaving the facility to be reused, recycled, recovered, treated reprocessed or destroyed.

The reporting of transfers is not a requirement of the NPI at this stage. However, the concept of transfers is being trialled and may become a requirement of the NPI following the 1999 review. If transfers are to be estimated the appropriate EETs detailed in this manual should be used.

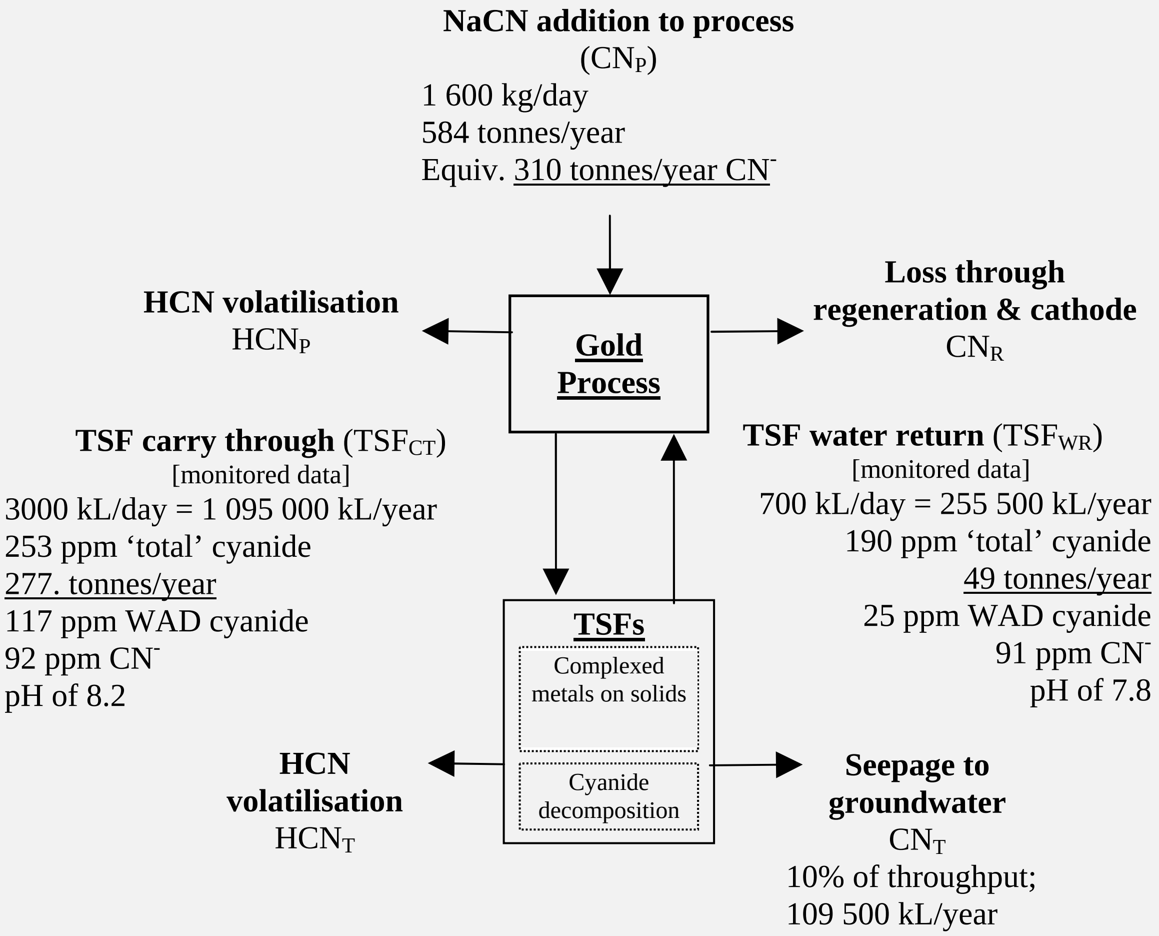
Examples of transfers of relevance to the gold industry, if included in the NPI, may include:

- management of arsenic waste through its disposal at intractable waste sites
- transfer of sulfide concentrate between facilities. This may include transfer of material from the processing to an offsite roaster. In the same way the transfer of calcine from the roaster back to the processing plant is also a transfer. Where internal transfers take place, close liaison is likely to be required between facilities to prevent double accounting of emissions
- off-site disposal of wastewaters and sludge from treatment processes will represent a transfer; and
- off-site disposal of solid wastes will represent a transfer.

Appendix D: Example emissions calculations

Example - cyanide emission

This example considers cyanide losses throughout the facility. The approach is largely based on mass balance, although emission factors and direct measurement are applied to provide an estimate of emissions.



HCN volatilisation ***[Air emission]***

HCN_P: 1% of total cyanide (CN^-) addition
310 x 0.01 = 3.1 tonnes of HCN
= 3 tonnes of CN^-

Loss through regeneration & cathode ***[Air emission]***

$CN_R = (CN_P + TSF_{WR}) - (TSF_{CT} + HCN_P)$
$= (310 + 49) - (277 + 3)$
$= 359 - 280$
$= \underline{79 \text{ tonnes}}$

Example - Cyanide emission cont'

Cyanide loss to TSFs

TSF_{CT} - TSF_{WR} = 228 tonnes

Seepage to groundwater ***[Land emission]***

CN_T = 109 500 kL/ year x 190ppm

= 21 tonnes

HCN volatilisation ***[Air emission]***

HCN_V = (0.091 x 255 500) x 0.8

= 18 600 kg

= 19 tonnes

= 18 tonnes CN^- equivalent

Cyanide emissions for reporting period

Inorganic Cyanide Compounds Emissions to Air: **100 000 kg**

Inorganic Cyanide Compounds Emissions to Land: **21 000 kg**

Inorganic Cyanide Compounds Emissions to Water: **NIL**