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Factors influencing the risk of wildlife cyanide poisoning on a tailings storage facility in the Eastern Goldfields of *Western* Australia

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ABSTRACT

Patterns of wildlife visitation and interaction with cyanide-bearing tailings slurry and solutions at the Fimiston tailings storage facility (TSF) have been reported in a previously published ecological study. The above-mentioned findings are extended in this paper by the examination of additional wildlife survey data, along with process water chemistry data collected during the same study period. Analysis of the combined results revealed that the primary wildlife protective mechanism in operation was effective management of tailings cyanide concentration. Nevertheless, tailings discharge concentration exceeded the industry standard wildlife protective limit of 50 mg/L weak acid dissociable (WAD) cyanide episodically during the study period. Wildlife that interacted with habitats close to the spigot outlet during brief periods of increased discharge concentration were likely to have been exposed to bioavailable cyanide at concentrations greater than the industry standard protective limit. However, no wildlife deaths were recorded. These results appear to support the hypothesis that hypersalinity of process solutions (unique to the Kalgoorlie district of Western Australia) and a lack of aquatic food resources represent secondary protective mechanisms that operated to prevent cyanide-related wildlife mortality during the project. The proposed protective mechanisms are discussed in the context of their potential application as proactive management procedures to minimise wildlife exposure to cyanide.

1. Introduction

Wildlife and livestock that visit and interact with gold mine tailings storage facilities (TSFs) and associated water bodies are at risk of exposure to bioavailable cyanide present in waste solutions (Clark and Hothem, 1991; Henny et al., 1994; Northern Territory Bird Study Group, 1998; Eisler et al., 1999). The primary exposure pathways are feeding, or attempting to feed, in supernatant and wet tailings habitats and drinking from cyanide-bearing water bodies (Resource Assessment Commission, 1991; Minerals Council of Australia, 1996). Specific exposure pathways are unique to each wildlife guild according to its behavioural ecology (Donato et al., 2008; Smith et al., 2007). The importance of these pathways is likely to vary between mine sites according to the relative abundance of different wildlife guilds present in the surrounding region and the amount and type of habitats present within cyanide-bearing water bodies.

Hydrogen cyanide and other cyano-compounds that liberate free cyanide ions are extremely toxic to almost all forms of fauna (Souren, 2000). Once cyanide enters the body it binds to iron, copper and sulfur-containing enzymes and proteins required for oxygen transportation to and utilisation within cells (Barcroft, 1931; Ballantyne, 1987; Minerals Council of Australia, 1996). The principal compound affected is cytochrome oxidase, which is essential for utilising oxygen in cellular function (Minerals Council of Australia, 1996; Ma and Pritsos, 1997; Reece, 1997). Suppression of cytochrome oxidase leads to rapid cell death (Eisler et al., 1999). In vertebrate animals, the major organ affected is the brain, with a rapid decrease in cell function leading to coma and collapse of the respiratory and cardiovascular systems (Barcroft, 1931; Ballantyne, 1987; Department of Mineral Resources, 1996; Minerals Council of Australia, 1996; Eisler, 2000).

Cyanide is a fast-acting poison (Environment Australia, 1998) with a very steep dose–response curve (Kjeldsen, 1999) capable of causing rapid asphyxiation, incapacitation and subsequent death (Wiemeyer et al., 1986; Creekmore, 1999). At lethal concentrations, inhalation or ingestion of cyanide produces reactions within seconds and death within minutes (Eisler, 2000). Extensive field-based observations indicate vertebrate animals (such as birds) that ingest a lethal dose of cyanide within a TSF or other open water impoundment are highly likely to die *in situ* (D. Donato, pers. obs.). If acute exposure is to a sub-lethal dose, cyanides are metabolically degraded (to thiocyanates) by the liver and eliminated from the body with minimal long-term effects (Henny et al., 1994; Minerals Council of Australia, 1996; Smith and Mudder, 1995; Ma and Pritsos, 1997; Donato et al., 2007). The physiological effects on animals that ingest sub-lethal dosages within a TSF remain unresolved (Eisler et al., 1999; Eisler, 2000;

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Brasel et al., 2006) and require further investigation (Donato et al., 2007). For a detailed examination of the factors influencing cyanide toxicity, with specific reference to the gold mining industry, see Donato et al. (2007).

A maximum concentration of 50 mg/L WAD cyanide in solutions ingested by vertebrate wildlife, excluding aquatic organisms, is viewed as safe (Eisler, 2000; International Cyanide Management Institute, 2005), although this is considered an interim benchmark (Environment Australia, 2003; Donato et al., 2007). This protective concentration threshold has been derived from controlled laboratory experiments documenting no-observed impact (mortality) to vertebrate wildlife exposed to cyanide in solution (administered via oral gavage) at concentrations below 50 mg/L WAD (Hagelstein and Mudder, 2001). Further supportive evidence has been provided by intensive field-based wildlife surveys documenting no-observed impact to wildlife interacting (via drinking and foraging in solutions) with fresh tailings systems (using process water with salinity concentrations that are palatable to wildlife) at cyanide concentrations below 50 mg/L WAD (Henny et al., 1994; Donato, 1999).

In its application within the gold mining industry, such as by operations that are signatories to the International Cyanide Management Code (the Code) (International Cyanide Management Institute, 2005), the prescriptive concentration limit is not applied exclusively to the discharge spigot point, but rather to any area within a TSF (or other open water impoundment) where wildlife can access tailings-derived water to drink and/or forage (International Cyanide Management Institute, 2007). The authors stress that the cyanide concentration limit should not be viewed as a universal toxicity concentration threshold for wildlife, but rather as a spigot discharge management trigger figure. By adopting such a management strategy, natural degradation of cyanide occurring post discharge to the tailings dam will result in concentrations at habitats downstream of the spigot (i.e. supernatant and wet tailings) being reduced to below 50 mg/L WAD (Donato, 1999; Donato et al., 2007).

This paper relates directly to site-specific research undertaken to examine the factors that influence the risk and impact (if any) of wildlife exposure to cyanide at Kalgoorlie Consolidated Gold Mine (KCGM). The Fimiston Operation is managed by KCGM for joint venture partners Newmont Gold Corporation and Barrick Gold Corporation. The operation is located in the southeast corner of the city of Kalgoorlie-Boulder, which is approximately 600 km east of Perth, Western Australia. For a detailed description of the study site, including the Fimiston TSF system, see Smith et al. (2007).

An ecological study of the KCGM Fimiston TSF system revealed that a range of birds (waterbirds, waders and passerines) inhabited, and to varying degrees interacted with, supernatant and wet tailings habitats (Smith et al., 2007). The supernatant pond within Fimiston II TSF was deemed to be essentially abiotic, containing no aquatic macroinvertebrate food resources for waterbirds (Smith et al., 2007). This finding is consistent with the literature, where it is stated that cyanide and heavy metals are highly toxic to aquatic biota (Eisler et al., 1999; Cain et al., 2000; Eisler, 2000; Battaglia et al., 2005). Filter-feeding waterbirds are, however, likely to dip their bills in solutions searching for food resources even if no aquatic macroinvertebrates are present (Smith et al., 2007).

Food provisions within Fimiston II TSF were apparently limited to aerial insects flying over the TSF and landing on or becoming embedded in the surface of supernatant and wet tailings. This represented a regular food source for some birds. Waders of the families Charadriidae and Scolopacidae were observed foraging by picking aerial and terrestrial macroinvertebrates from the surface of supernatant and wet tailings. Inadvertent ingestion of supernatant and tailings slurry through this foraging method was identified as the primary cyanide exposure pathway for wildlife interacting with the Fimiston TSF system (Smith et al., 2007).

Insectivorous bats (Microchiroptera) were also recorded in the airspace above the TSF supernatant pond where presumably they hunted for aerial insects (Churchill, 1998; Smith et al., 2007). Whether or not insectivorous bats were exposed to cyanide in mine waste solutions through foraging has not yet been determined.

Smith et al. (2007) also proposed that drinking mine waste solutions at the Fimiston TSF system was not possible due to hypersalinity and as such was not an exposure pathway to cyanide; indeed no drinking of mine waste solutions by wildlife was observed within the Fimiston TSF system during the study period. The salinity tolerance of Australian wildlife that interact with tailings systems is not well known, however, it seems very unlikely that any non-marine mammal or avian species can drink water with a salinity concentration equal to, or greater than, sea water (Smith et al., 2007; Adams et al., 2008).

The research results of Smith et al. (2007) are extended in this paper by the examination of additional wildlife survey and process water chemistry data collected during the same study period. On analysis of these combined results we propose that during the period of this research project, several protective mechanisms operated within the Fimiston II TSF to prevent cyanide-related wildlife mortality.

The proposed protective mechanisms are discussed in the context of their potential application as proactive management procedures to prevent wildlife exposure to cyanide. This is an explicit requirement for the KCGM Fimiston TSF system to be deemed compliant with the Code (International Cyanide Management Institute, 2006).

2. Methodology

Cyanide chemistry, salinity and wildlife monitoring were conducted concurrently by KCGM personnel over a period of approximately 6 months, from 13 September 2006 to 14 March 2007, at both the Fimiston I and Fimiston II TSFs. Monitoring procedures are ongoing. Additional intensive wildlife monitoring was conducted by third-party experts for 100 h between 4 September and 17 November 2006.

2.1. Cyanide monitoring

Cyanide samples were taken from Fimiston I and II TSFs on a daily basis from Monday to Friday. Tailings liquor (at spigot discharge) and supernatant samples (from the supernatant pond next to the central concrete decant tower) were collected and transported in a white polypropylene bucket (sealed with a screw top lid) to a National Association of Testing Authorities (NATA) accredited laboratory. Sub-samples were then decanted into black polypropylene screw top bottles and sodium hydroxide added to adjust pH to approximately pH 10.2 to preserve the cyanide in solution. All tailings liquor and supernatant samples analysed during this study were delivered to the laboratory, and cyanide preservation conducted, within approximately one hour of the sample being collected in the field. Once preserved, sample bottles were immediately transferred to a refrigerator (maximum temperature set at 4 °C) for storage. All samples were analysed within 2–3 days for WAD, Free and Total cyanide concentration using the American Society for Testing and Materials (ASTM) Standard D2036 laboratory test method for cyanide in water (American Society for Testing and Materials, 1998).

2.2. Salinity monitoring

Tailings liquor and supernatant salinity samples were taken (at the same sampling locations as for cyanide monitoring) from within Fimiston I and II TSFs every 1–2 weeks. Samples were collected in 250 ml clear polypropylene bottles and stored at 4 °C before being sent to a NATA accredited laboratory for analysis of total dissolved solids (TDS).

2.3. Wildlife monitoring

All field-based (observational) surveys of wildlife behaviour were conducted in accordance with national and international guidelines for the protection of animal welfare (National Health and Medical Research Council, 2004).