The environmental effects of mining waste disposal at Lihir Gold Mine, Papua New Guinea

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Introduction

Mining in its broadest sense is the process of obtaining useful minerals from the earth's crust. A mineral is generally defined as any natural accruing substance of definite chemical composition and consistent physical properties. An ore is a mineral or combination of minerals from which a useful substance, such gold, can be extracted and marketed at a price that will recover the costs of mining and processing, and yield a profit (Encarta 2001).

Mining in developing countries remains controversial since a huge impact on the cultural climate, the physical environs and the socio-economic status of the local people can result (Encarta 2001). Mining operations and their mining waste disposal methods are considered one of the main sources of environmental degradation. Social awareness of this problem is of a global nature and government actions to stem the damage to the natural environment have led to numerous international agreements and laws directed toward the prevention of activities and events that may adversely affect the environment.

Papua New Guinea (PNG) is well endowed with mineral resources and it offers one of the most biologically diverse habitats in the world. On the other hand, the country suffers from a chronic lack of funds with which to properly manage and use its resources (Drogin 1989). Most of the 3.7 million people live as their ancestors did, as subsistence farmers in jungle hamlets outside the cash economy. They have one of the world's highest mortality rates and lowest life expectancies (Mandala Projects undated). During the 1980's PNG experienced a proliferation of mining projects. With the third largest gold reserves in the world, the country has become a magnet for giant multinationals. The development of these mineral resources has been a mixed blessing. Toxic waste from the mines has polluted many areas of the country. In a typical metal mining operation, tailings consist of crushed rock and ore, after most of the target metals have been removed. Mine tailings are often toxic, and if not contained, are harmful to the environment (Mandala Projects undated).

The global economic and environmental climate has progressively changed in recent years. There is growing pressure on mining companies to clean up their toxic tailings. The Lihir Gold Mine is an example of a multinational mining operation that presents its own social, economic and physical environmental impacts. This paper discusses the problem of mine waste disposal at this mine.

PNG 's experience of mining and economics

Papua new Guinea is endowed with a rich natural resource base, including major gold and copper deposits, large oil and natural gas reserves, vast expanses of agricultural land, and extensive forests and maritime fisheries. These rich natural resources provide the foundation for a markedly dualistic economy in which a dynamic, capital-intensive enclave minerals sector dominates, but 85% (Herman 1996) of the population derive their livelihood from agriculture, mainly low productivity labour intensive farming. Much of the population of 4 million remains in the non-monetised subsistence sector and is highly fragmented. There are over 700 distinct languages in the country. At independence in 1975, the tasks of nation-building and sustainable economic development began from a frail base in terms of human resources, administrative capacity, and socio-political structures. Papua New Guinea's per capita income of $1,160 in 1994 (Herman 1996), should classify it as a middle income country, but because the country's wealth is unevenly distributed, the average per capita income for more that 80% of the population is only $350 (World Bank Estimate). For the majority of the population the quality of life and social indicators are no better than those in the average low-income country (Herman 1996). Like many third world nations, Papua New Guinea is dependent on commodity export. Since independence from Australian administration exploration for rich mineral deposits has drawn many international mining companies.

PNG's experience of mining and the environment

The rural communities of PNG depend heavily on nature to sustain their livelihood. Introduction of mining activities in remote areas of PNG affects a lot of people. Waste disposal from process plants and sediment runoffs from open cut mines are dumped into rivers and oceans. Smothering of riverbeds and ocean floors, heavy metal contamination and acid mine drainage are consequences of mine waste disposal into the environment. Toxicity of heavy metals is generally chronic rather than acute, so diseases associated with them are evident only over a long period of time. People's main concerns come from observable changes in say a river – discolouration, odour, taste or feel – rather than chemical quantification of some scientific phenomenon unknown to villagers.

At the end of the 1980's several mine projects triggered major conflicts. In 1989 a guerrilla movement forced the closure of the large copper mine in Bougainville. In 1990, concerned local communities, adversely affected by the Ok Tedi mine, raised environmental issues. Mining disasters and spills in PNG, and their subsequent environmental impacts have been heavily reported in the recent press.

In August 1999, the Asia Times (Pamba 1999) reported an environmental row that was erupting in PNG around plans for a US$38 million nickel mine whose tailings would be dumped into the sea along the country's northern coast. The furore followed the release of scientific reports confirming serious damage to river systems and livelihoods by the 15 year dumping of tailings from the Ok Tedi copper mine. On 22nd August 1999, BBC published a story on the call from World Wildlife Fund to close the giant copper mine of Ok Tedi. Earlier that month Broken Hill Property (BHP), which operates the mine, and has a 52% stake, announced that it was reconsidering its role, saying that waste management procedures at the mine were not working (BBC 2000). On 7th March 2000, the BBC published further urging from the World Bank to the government of PNG that it should shut down the OK Tedi gold and copper mine. The PNG government is caught in a difficult bind between environmental and economic pressures. The Ok Tedi mine experience highlights this. The PNG government has a 30% stake in the Ok Tedi mine (Imhof 1996). The mine contributes up to 10% of PNG's GDP and 20% of the country's export income (Berne Declaration 1999), however it has destroyed over 1000 square kilometers of wetland and virgin forest. Toxic material dumped directly in the Fly River has made it rise 4-5 m in places, causing dieback along the banks. It is killing all life in the river, and all the arable land close to the river – BHP have publicly admitted that about 100,000 people have been affected in the immediate environs with more affected downstream (Oxfam 2000). In The Australian, on 12th Aug 1999, BHP's managing director Paul Anderson was quoted as announcing that the mine is not compatible with BHP's environmental values and the company should never have become involved (RSPAS 2002). Discussions regarding options of terminating mining activity have taken place, but the PNG government has decided, that for the present, the mine must stay open and operational for economic reasons.

The Lihir Gold Mine

Lihir Island is located in Papua New Guinea's (PNG) New Ireland Province, about 700 km northeast of Port Moresby (Fig. 1)

Figure 1 – Location of Lihir Gold Mine (Source: Mining Technology, undated).

Lihir Island is situated off Papua New Guinea's New Ireland Province, about 700 km northeast of Port Moresby. It covers an area of 200 km^2 (Dellar 1995). The Lihir Mine Company operates a gold mine on the north end of the island. The mine's processing plant and the corresponding infrastructure occupies 7.3 square kilometers of land on the island (Berne Declaration 1999) (Fig. 2).

There are 7,100 people living in the Lihir group of islands, 5000 of those on Lihir Island itself (Berne Declaration 1999). Prior to the mine, they survived through subsistence agriculture, supplemented by a few cash crops and fish. To finance the mining operation, 450 million dollars of shares were floated and the Union Bank of Switzerland syndicated a loan for 300 million dollars (Mining Technology undated). The World Bank's Multilateral Investment Guarantee Agency (MIGA) has indemnified the loan against political risks. MIGA's task is to insure private foreign investments against political risks including backlash from environmental issues. On 10th May 1995, the Executive board of MIGA approved guarantees of 76.6 million dollars for the Lihir Island goldmine project. The Swiss representative raised a series of critical questions on environmental and social problems, but reportedly was not supported by the other chairs.

Figure 2 – The extent of the Lihir mine site on the north end of Lihir Island. (Source: Lihir mine brochure)

In 1992, Kennecott Explorations Ltd completed an environmental assessment to the Lihir goldmine project (Kennecott is a wholly owned subsidiary of the Rio Tinto Zinc (RTZ) Corporation, the main investor of the Lihir project). The prospectus that arose from this indicated that further detoxification of the tailings, a safer design of the mine pit slopes and stockpiles, the dumping of waste rock farther ashore and a more reliable monitoring of the submarine environmental impacts would all be technically feasible. The mining company decided to forego such measures, as they are not required in the country of PNG, and for financial reasons (Mining Technology undated). The British RTZ Corporation holds 40 % of the shares, respectively by its wholly owned subsidiary Kennecott Corporation. RTZ is the biggest mining company in the world and currently holds an equity interest in 13 gold producing mines. The company has passed on one fourth of its shares to the Canadian Vengold Inc. RTZ manages Lihir Gold Ltd. through Lihir Management Co., a wholly owned subsidiary. Thirty percent of the Lihir shares belong to Niugini Ltd., a PNG-based corporation. The Battle Mountain Gold Co. in New York holds a 50.3 percent majority of Niugini. The Papua New Guinea government owns a further 30 percent of the shares. The latter will pass on half its shares to the local landowners association of Lihir (Mining Technology undated). Lihirians have signed an agreement that they will not bring any lawsuits of any kind against RTZ for compensation (Berne Declaration 1999). While this is not legally binding, such action serves as a psychological barrier to legal action by the inhabitants. RTZ has stated openly that the PNG government has agreed to exempt the mine if harsher environmental restrictions are applied.

Figure 3: (Source: http://www.lihir.com.pg/images/photogallery/)

The island is made up of 5 distinct volcanoes (Berne Declaration 1999; MCA undated a), although there have been no eruptions in recorded history. The presence of hot springs indicates persistent geothermal activity. The gold currently being mined on Lihir Island is located in the heart of the youngest volcano, Luise Caldera. The temperature of the water in the volcano under pressure is 200 °C (Mining Technology undated). The mine is of an open-pit design consisting of 2 adjacent overlapping pits (Fig. 3). With the current reserve, mining will take place for 13 years, during which the higher-grade ore will be fed directly for processing, and lower-grade ore will be stockpiled. This will be processed in the following 17 years, giving a total projected operational life of 30 years (MCA undated a).

The mining and processing of gold ore at Lihir

Gold, the only yellow metal has the chemical symbol Au. It has a very high density, and is an extremely valuable material. It is used extensively in electronic circuits, jewelry, coins and more than half of the world's gold is stored by governments and banks. Common acids do not dissolve gold, but a nitric hydrochloric mixture and alkaline cyanide solutions will (MCA undated a). Processing of the gold bearing ore is complex. In the open cut mine of Lihir, blasting and large capacity earthmoving equipment are used to remove rock from the mountainside. Waste and ore are then blasted to break them into sizes suitable for handling and transport for further processing (Mining Technology undated; Moran 1999). The removed rock is transported one of three directions. Waste rock is transported to barges that continually transport it 1 km out of the harbor, where it is dumped. The low-grade ore is transported to a stockpile where it will be stored for up to 25 years prior to processing. The high-grade ore is transported down to the mill (Fig. 4) for immediate extraction of gold. This ore is ground to a very fine powder by a mill containing numerous steel balls. The fractured ore and water are placed in the mill and the cylinder spins while steel balls bounce around inside and smash the ore. Eventually the ore is ground down to very fine powder with particles less than 0.075 mm across. The powder mixes with the water in the mill to produce mud-like slurry. The slurry passes to one of several giant tanks called leach tanks. It is stirred, aerated and a cyanide solution is added. The gold particles dissolve in the cyanide solution leaving other unwanted minerals and rock material behind in the wet, mud like residue (leach residue). The cyanide solution is pumped to another tank containing activated carbon. The gold comes out of the cyanide solution and forms solid metallic particles that stick to the carbon. These particles are removed and placed in giant furnaces containing a caustic water solution, which is then heated to 350 deg. C under high pressure. The gold re-dissolves in the caustic solution from where it is finally removed by the process of electrolysis, further melted and poured into gold bars (MCA undated b). The waste from this milling process is partly detoxified by reaction with iron-rich counter-current decantation (or CCD) wash water (Mining Technology undated), and is then discharged into the sea by a pipeline at a depth of 125 metres (EMS 2002). 1,785 tons of sodium cyanide are used annually (Dellar 1995; Shearman 2001).

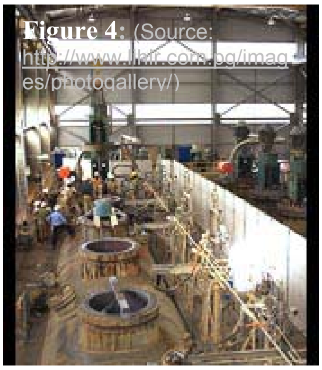

Figure 4: (Source: http://www.lihir.com.pg/images/photogallery/)

Lihir management strategies to manage mining waste

There are 3 categories of waste to be disposed of at the mine site.

1. Dumping of waste rock at sea.
2. Submarine tailing deposition (STD) after processing. STD as an entity will be discussed below followed by a specific discussion on cyanide, the solvent used in processing.
3. Stockpiling of low-grade ore for later processing. Whilst not truly an immediate waste, the stockpile of rock will sit for up to 25 years and will have an effect on water concentrates of heavy metals as it is under the influence of water and weather during this time.

Dumping of waste rock at sea

The processing of 104 million tons of proved and probable ore reserves from the Lihir mine will create 341 million tons of waste rock. While some rock will be used to extend the land area near Luise Caldera, most material will be disposed of in the ocean about 1 km from the shoreline. Four barges operate 24 hours a day and dump between 1,400 and 4,600 tons of rock per hour (Shearman 2001). Barges operate 24 hours a day to dump waste rock outside the harbor (Fig. 5).

Figure 5: (Source: http://www.lihir.com.pg/images/photogallery/)

The Kennecott environmental report for the mine operators states that it is expected that concentrations of metals [from the waste rock] in the water column are unlikely to exceed the standards outside the immediate dumping area, and that they are likely to be attenuated by the processes of precipitation and adsorption. The prospectus in turn predicts that the main impacts of dumping the rock will be damage to the coral reefs due to increased turbidity of the water, and the smothering of sea floor benthos. In November 1990, the government in Port Moresby asked that the waste rock from Lihir be backfilled into the mine pit, or be dumped farther ashore. These requests were turned down by the mine consortium as being too costly (Mining Technology undated).

It is undisputed that the waste rock submarine mountains cover a large area of the seafloor. What is disputed is whether these bottom deposits affect the fish that are harvested. Many of the fish that local people catch from the PNG waters are caught in the 100-200 m depth range, and they commonly hunt for food down to depths of 800 m or more. Bottom feeders ingesting contaminants are eaten by surface dwelling species with the effect of transporting pollutants to the surface. Microorganisms also migrate up and down the water column on a daily basis feeding at a depth of 12-50 m on single celled plants (Shearman 2001). Even if the deposits cannot be seen in the surface water, further down, these sediments can make fish leave the area, change their habits or can affect their breeding behavior. Alternatively, fish may be attracted by the protection from predators that sediment-filled water provides and in turn can be harmed by toxic components in the deposited material. Research has also shown that fish in sediment-laden water are more susceptible to disease because of the abrasive action of sediments on their skin, and can harmed by sediments blocking their gill filaments (Pearce 2000).

Submarine tailings deposition of waste products after processing

The aim of Submarine Tailings Discharge (STD) is to deposit mine wastes in deep stratified waters where it is likely that tailings will be trapped below the mixed surface layer and flow as a dense slurry to a deposition site on the deep ocean floor. The process has increasingly come into favor throughout the Asia-Pacific region where on-land disposal options are problematic. In comparison to on-land tailings retention, the mining industry has regularly argued that STD is safer both to local people and the environment. It has been stated by mining companies that in the Asia-Pacific Region, the land is unsuited to the construction of tailings dams due to rugged mountains, regular earthquakes and high rainfall. These factors are said to increase the likelihood of a disastrous dam failure (Pearce 2000).

At Lihir, all post processing waste from the mine is channeled by pipeline directly into the sea. Over the life of the mine this will amount to 341,432 tons. The Lihir mining operation discharges this waste directly into the sea to a depth of 125 m, 1.5 km from the island, via a STD pipe. It is hoped that the waste will slide down an ocean trench, the logic being that at such depths, it will fail to affect the surface layer of the ocean (Berne Declaration 1999). The mine's Environmental Plan admits that benthic macro invertebrates will be exposed to high concentrations of cyanide and metals in the area of the tailings sediments. The toxics can be accumulated in the food chain. The degree of metal accumulation, according to the Plan, cannot be predicted with certainty. The prospectus is more straightforward. It states that there may be the potential for bioaccumulation of metals within the marine ecosystem over time, however the potential for bioaccumulation of metals was not assessed in the Environmental Plan. In the monitoring section of the Environmental Plan, it dismisses routine water testing near the tailing deposit as inefficient, logistically difficult and expensive. Instead it proposes a cheaper short-term intensive investigation to validate the assumptions regarding tailings disposal. After this, the Kennecott plan argues, that monitoring can be confined to measurement of key parameters in the tailing or treated sewage effluent prior to discharge. The prospectus refers to the monitoring program as well. It indicates that if a significant increase in metal content develops, mitigation strategies and compensation will be considered (Mining Technology undated).

The ideal aim of an STD operation is to have the tailings travel from the mouth of the underwater pipe in a continuous current to the sea floor. It is inevitable, however, that substantial quantities of mine waste will separate from the main tailings flow and form plumes of waste that will spread out across the ocean. Different currents can carry these plumes into surface waters. The mine waste that reaches the sea floor does not necessarily stay there. Almost certainly, deep-water currents will move tailings away from the disposal area. The most serious potential problem is related to upwelling. This term is used to describe the movement of deep ocean water to the surface of the sea. This usually occurs along the coastline, and under normal circumstances is one of the most productive marine processes because it provides food, for fish and other animals. Upwellings are often the site of the best fishing. Unfortunately upwelling can also bring mine waste back to the surface of the ocean, where it is most dangerous to marine life.

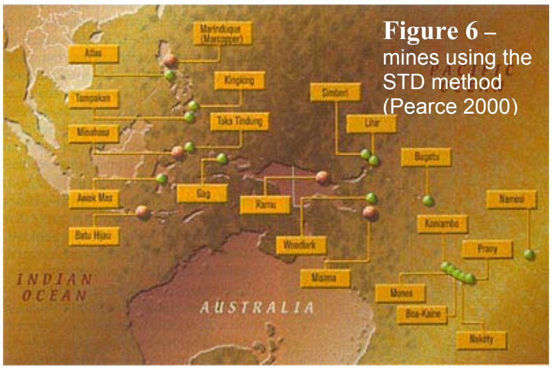

Figure 6 – mines using the STD method (Pearce 2000)

Smothering is another major deep-water impact of STD. It is literally the smothering of hundreds of square kilometers of seafloor under hundreds of millions of tons of tailings. The impact of this can only be guessed since proper scientific research has not been done. Miners admit that those sea floor organisms that do not simply die from being buried under mine waste will instead become contaminated with toxic metals to an unknown extent. Miners dismiss these organisms as unimportant since they live deep under the sea, but they form part of the marine food chain, and more mobile predators that feed on them can carry the toxic metals further and upwards, acting as a biological "pump" mechanism to bring contamination to shallower waters (Pearce 2000).

The alternative to the STD method of disposal is the storage of tailings in dams. These require continuous monitoring and post-mine remediation, so STD is also a cheaper operation for the mining company.

In a global review of mines using STD, the US Department of the Interior concluded that on average, STD use resulted in a 17% reduction in capital costs and a 1.6% increase in operating costs Pearce 2000). STD is used more and more by mining companies from rich countries in their operations in poorer countries, where they can often get around environmental restrictions and are not as accountable to local communities (Fig. 6). STD is effectively illegal in the USA, Canada and Australia. The companies using STD in their host countries would not be permitted to do the same in their home countries. Coastal PNG villages depend heavily on the coastal waters for their livelihood and their health, so whilst there are few independent laboratory or field studies into the environmental impacts of STD, this method remains controversial.

In March 2001, an International Conference on Submarine Tailings Disposal was held in Indonesia. It revealed scientific inaccuracies, threats to marine resources, negative health impacts and devastation of coastal economies. The conference concluded with a declaration calling for an international ban on STD and demanded that mining companies accept liability for the impacts of this environmentally and socially destructive practice on coastal communities.

Cyanide at Lihir

It is difficult to make generalizations about the toxicity of tailings material because they are so varied. Tailings from gold mining operations contain high levels of many types of heavy metal such as arsenic, cadmium, mercury and lead (Pearce 2000). The governments that have banned sea disposal as a method of distributing mining waste have been concerned about the high amounts of heavy metals that are discharged. They have acknowledged that the long-term impacts of this activity are unknown (Berne Declaration). The gold processing and leach solutions are kept at pH levels above 10 because metal extraction is more efficient at this pH. This is accomplished by adding alkaline compounds such as lime or sodium hydroxide to cyanide-containing solutions. These chemicals are all discharged down the pipe after the leaching process (MCA undated b). In its metallic state, gold occurs with sulfide minerals which all become part of the discharge.

Cyanide refers to numerous compounds, both natural and human-made, having the chemical group CN, i.e. 1 atom of carbon and 1 atom of nitrogen (Logsdon et al. 1999). It is a colorless solid with a slight odor of bitter almonds. Cyanide combines with up to 97% of gold, including particles of gold that are too small to be seen by the naked eye, making it one of the most efficient process chemicals for the extraction of a metal. The process of Cyanide leaching is has gained wide use since the 1960's (Anon 2000).

A carbon-in-pulp process involving cyanide extracts the gold from the Lihir mine. The investors expect that 1,785 tons of sodium cyanide will be utilized annually. During the mine's lifespan, at least 89 million tons of toxic tailings will be produced. The tailings are partly detoxified by reaction with iron-rich counter-current decantation (or CCD) wash water. After this treatment they are discharged into the sea by the STD pipeline to a depth of 125 m. They are expected to spread on the ocean floor at a depth of between 125 and 1,600 m. The tailings have a free cyanide concentration of 1,220 ug/L at the discharge level, and of 70 ug/L at their equilibrium depth. Within a mixing zone with a radius of 2.3 km, the concentration exceeds the national standards of 10 ug/L (Mining Technology undated).

The Kennecott Environmental Plan argues that there is not enough space on the rugged Lihir Island for a land-based tailings deposit, and that such a deposit would be a hazard for the population and the environment in the case of accidents. (Land-based tailings disposal would be more expensive also.) The Plan argues that submarine tailings disposal should not constitute a hazard for the environment. First, the document indicates, that ocean water is naturally alkaline and the combined tailing stream will be acidic. Therefore, when tailings are discharged to the ocean, the natural alkalinity of seawater would neutralize the acidity of the tailing. Secondly, the density of seawater increases with depth. This will, according to the Plan, prevent any tailings disposed at 125 meters below sea level from entering the [upper range] mixed layer under worst-case conditions.

The CCD wash water process is quoted by the company to detoxify 90 % of the cyanide. Conceptually, the share-offering prospectus indicates, the tailings could be further treated to detoxify the contained cyanide and/or to precipitate heavy metals. Yet this is not being done in Lihir because the PNG government presently requires neither of these procedures (Mining Technology undated).

Cyanide is the most popular chemical used by mining corporations to extract gold from ore, but the use of cyanide compounds in mining is frequently a controversial issue. The quantity of cyanide used by the mining industry is enormous with most being handled without obvious negative impacts.

Nevertheless, several releases of cyanide-bearing mine process wastes, have recently been reported in the news media (Moran 1988; Hynes et al. 1998).

- Failure of a leach pad structure at the Gold Quarry mine in Nevada released about 245,000 gallons of cyanide-laden wastes into two creeks in 1997.
- On 29th May 1998, 6 tons of cyanide-laden tailings spilled into Whitewood Creek in South Dakota resulting in substantial fish kill.
- More than 860 million gallons of cyanide-laden tailings were released into a major river in Guyana when a dam collapsed at the Omai gold mine in 1995.
- On 20th May 1998, a truck transporting cyanide to the Kumtor mine in Kyrgyzstan plunged off a bridge spilling almost 2 tons, about 1,762 kilograms, of sodium cyanide into local surface waters.

Leaks or spills of this chemical are extremely toxic to fish, plant life and human beings. A teaspoon full of 2% solution of cyanide is a lethal dose for a human. Its pathological effects are a blocking of the absorption of oxygen by cells, causing the victim to become progressively hypoxic. Exposure to high levels of cyanide for a short period harms the central nervous system, respiratory system, and cardiovascular system. Short-term exposure to high levels of cyanide (110 ppm) can cause coma and/or death within 30-60 min (Hynes et al. 1998). In recent years communities in Montana and Turkey have successfully challenged the practice of using cyanide leaching, setting standards for the rest of the world Hynes et al. 1998). The mining industry has argued that the dilute cyanide concentrations employed, the methods used, and the rapid decomposition of these compounds make cyanide extraction a very safe alternative (MCA undated b). The most common environmental problems are likely to result from the chronic contamination of surface and ground waters by lower concentrations of cyanides and related breakdown compounds. Such chronic releases are much more difficult to notice and evaluate than are acute, high concentration spills that are often associated with rapid, observable deaths of aquatic organisms. Also, because mining related wastewaters are usually complex mixes of cyanides, metals, organic reagents and other anions; it is difficult to determine which chemical constituents are causing the toxicity problems (MCA undated b).

The cyanide used in processing the ore is sodium cyanide, NaCN. The white solid dissolves readily in water, yielding sodium ion, Na+, and cyanide ion, CN-. Some of the CN- then converts into HCN, hydrogen cyanide or hydro cyanic acid. The cyanide ion, and hydrogen cyanide are often collectively called free cyanide and the relative amounts present are largely controlled by the pH of water with the percentage of HCN rising as the pH falls (MCA undated b). At a pH of 7, about 99.5% of the cyanide exists as HCN. At lower pH levels than this, essentially all dissolved cyanide is present as HCN. In natural waters most free cyanide present is present as HCN since the natural pH range is between 6 and 8.5. Cyanide impacts fish at far lower concentrations than humans. Five ug/L concentrations have been found to inhibit fish reproduction, and adverse impacts have been reported at levels of 10 ug/L. The toxicity increases with falling dissolved oxygen concentration, and increases 3-fold with a 12 °C decrease in temperature (MCA undated b). It will therefore be more toxic at depth than at surface, warmer temperatures.

Cyanide is known to impair enzyme systems that facilitate oxygen metabolism (e.g. cytochrome oxidase) and other physiological functions in fish and invertebrates, and to damage the liver, spleen, heart, and brain of the fish (Demster and Donaldson 1974; Dixon and Leduc 1981; Rubec 1986; Hanawa et al. 1998). Heming et al (1985) coined the term Sudden Death Syndrome to describe the delayed mortality of fish after experimental exposure to thiocyanate ion (SCN-) (Rubec et al. 1999).

Although cyanide solution eventually breaks down in the presence of sunlight and air at pH neutral conditions, it will not do so when it seeps underground, under cloudy or rainy conditions such as are seen in tropical countries, or at the bottom of the ocean. Many of the substances that cyanide breaks down into are still toxic to aquatic organisms and may persist in the environment for significant periods of time. Some of these toxic breakdown forms include the free cyanides, metal-cyanide complexes, organic-cyanide compounds, cyanogens chloride, cyanates, thiocyanites, chloramines, and ammonia. Cyanite especially is a by-product of mineral process sites. It and ammonia have a synergistic and amplifying toxic effect on marine life. Thiocyanites have been shown to cause a “sudden death syndrome” in trout (MCA undated b; Hynes et al. 1998). HCN readily forms a gas, some of which is released into the air. (This is the same gas used in execution gas chambers). Studies by the US Geological Survey (Johnson 1999) indicate that this may be a minor cyanide loss pathway only, within some process wastes. The studies indicated that the majority of the mass of free cyanide is converted to other forms, and retained within the heap leach piles by adsorption or precipitation (MCA undated b). Free cyanide forms readily react within a few hours to a few days with almost any other chemicals they contact, producing a wide variety of new compounds. These compounds can be grouped – simple cyanide compounds, cyanide complexes, and cyanide related compounds (MCA undated b).

There are official standards set by the United States Environmental Protection Agency (EPA) for cyanide. The levels are 5.2 ug/L for freshwater aquatic life and 1 ug/L for aquatic life and wildlife. No criteria exist for the other toxic cyanide-related compounds (Hynes et al. 1998). A low-grade ore suitable for cyanide leaching may contain only 0.5 to 1 gram of gold per ton (0.5 to 1.0 ppm gold). The same ore may also contain other metals such as copper, zinc, and nickel in concentrations ranging from 10's to 1000's of ppm. So the cyanide leach solutions now contain numerous metal-cyanide complexes. These complexes are generally much less soluble than are free cyanide (Environment Australia 1998). The decomposition of these complexes is affected by pH, water temperature, concentration of dissolved solids, CO_2 concentration, and UV exposure. Some are degraded by the action of bacteria on them and when they are filtered through soil. Other complexes are very stable and persistent; especially iron cyanide and cobalt-cyanide complexes. These 2 complexes were found in samples of bricks, concrete, plaster and mortar from buildings at the Auschwitz-Birkenau concentration camps collected about 45 years after cyanide use ceased (MCA undated b; Markiewicz et al. 1994). The cyanide in gold mining solutions can undergo several types of reactions to form various toxic cyanide-related compounds. These compounds are toxic to aquatic organisms.

National and international regulatory and financing agencies do not require monitoring for many of these chemical substances (MCA undated b)[17] so many of these substances are not detected in the routine analyses normally performed on mining related waters. Thus it is often assumed that they do not exist. Total measured cyanide and weak-acid-dissociable cyanide when routinely measured, may be quite low, however when more specifically analyzed, they may have quite high levels of cyanates and thiocyanites (not routinely measured for). Numerous research and regulatory documents describe these compounds as toxic, but generally do not state at what concentrations (MCA undated b).

Stockpiling of low-grade ore for later processing

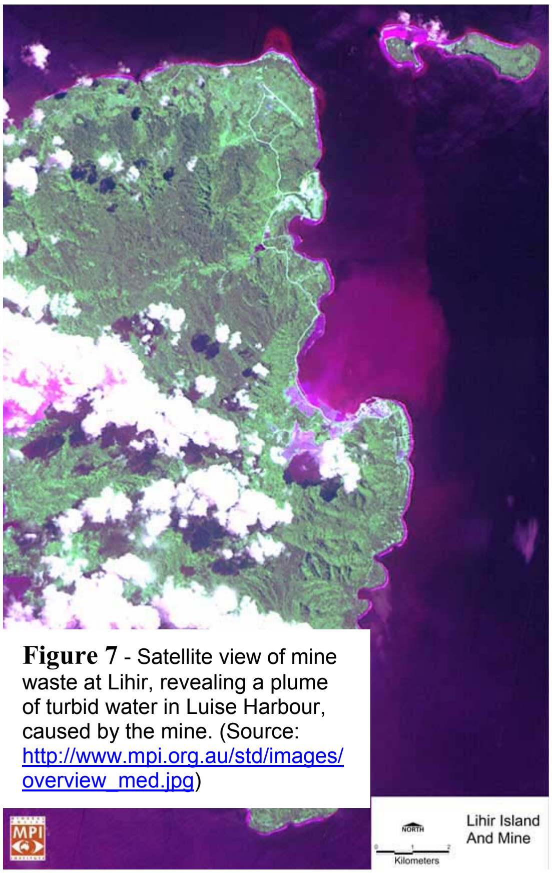

Figure 7 - Satellite view of mine waste at Lihir, revealing a plume of turbid water in Luise Harbour, caused by the mine. (Source: http://www.mpi.org.au/std/images/overview_med.jpg)

Delayed processing of low-grade ore which is stockpiled for up to 15 years allowing leaching of minerals and run off into the harbor (Fig.7). In the first 13 years, it is estimated that 62,317 tons of ore will be stockpiled, awaiting processing. This is stored in a pit adjacent to the open mine (Berne Declaration 1999). The long stockpiling period will generate runoff containing iron, copper, arsenic, zinc, aluminum, manganese, cadmium, lead, and possibly mercury and chromium. This runoff and additional wastewater from the normal mining operations will be discharged into the ocean. Runoff temperatures will vary between 30-80 °C. The Kennecott study states that, because of the chemical interaction between input streams, the available data does not permit estimation of the actual filterable metal concentrations at the mouths of the drainage channels. Still, the channels are expected to be significant contributors of metals to the surface waters of Luise Harbour (Mining Technology undated). According to the share-offering prospectus, runoff from construction and operations will result in sedimentation effects to coral reefs along the island's east coast, and will reduce the diversity of coral species and fish. The document agrees with Kennecott, that it is not possible to predict the expected water quality with great certainty (Mining Technology undated).

Recommendations and suggestions for the future

It is a philosophical question how much social costs and environmental destruction the production of gold, which is mainly used for luxury consumption, is worth. One can argue that in principle, the Lihir goldmine is justified by its economic benefits for Papua New Guinea, but this does not justify the adoption of insufficient environmental standards. This paper demonstrates that Lihir Gold Ltd. in several instances avoided more stringent environmental measures in order to reduce costs

It is clear from the discussions above that the management issues of disposal of mining waste at Lihir Gold mine are controversial. It is senseless to being opposed to mining per se. For PNG, mining is critical to the whole economy, providing 25 % of the country's foreign exchange. The issue is on what terms and at what cost. Are the benefits of mining spread equitably, or do they mainly benefit the urban elite rather than subsistence farmers whose livelihoods are disrupted, and whose local environs are poisoned by tailings deposits (Hobbs 1996)?

Two issues of concern and recommendations to correct them will be discussed.

1. International mining operators operate under different environmental standards in developing countries where their host government has extreme economic pressures upon it.

Ultimately it makes more sense to prevent or lessen the impact of companies who behave irresponsibly or illegally than to patch up the damage afterwards with project assistance. There is a need for an effective and comprehensive code of practice for Australian mining companies operating offshore, setting basic standards for the way they interact with affected communities and manage social and economic as well as environmental impacts. Underwriters, creditors and the mining company themselves have a responsibility to ensure that the projects they are financing and insuring are environmentally sound and abide by this code of practice. The Multilateral Investment Guarantee Agency MIGA should develop criteria for measuring the development impact of projects that go beyond the contribution to economic growth and efficiency. All MIGA projects should be required to make a positive contribution to environmental sustainability. Assessment of environmental impacts needs to be completely independent of the participating parties proposing the mining operation. Creditors need to base their financing of projects on an environmentally sound proposal. National and multilateral guarantee institutions must respect and defend the public interest, including environmental concerns. National authorities, private investors and creditor banks should uphold the same standards for their domestic and international business, and should allow public reviews of their environmental record.

This scenario would require every mining company, or the industry as a whole to have a comprehensive and specific code of practice, covering all the potential social, economic and environmental impacts of mining, with internal monitoring and feedback systems to ensure proper implementation. There should also be external monitoring, independent of the company, by which compliance or otherwise with the code will be checked and if necessary made public in the company's home country and the host country. Some companies already have their own codes, but these tend to limited in coverage, vague and general in content, and lacking any reference to monitoring: that is, they are relatively easy for a company to comply with, without having to make many changes in its actual operations at the mine site.

The Code

- Must be specific where compliance is easy to measure.
- Must have principles that are based on an Internationally recognized human rights standard such as those set down in United Nations Conventions
- Should be compulsory
- Must include defined penalties or sanctions for signatory companies that fail to meet its standards.
- Must address the social or economic impacts of mining operations particularly for those among poor or marginalized communities.

The Minerals Council of Australia has put together a Code for Environment Management, but it is voluntary, vague and does not impose penalties for non-compliance. Having a Code of Practice is not enough by itself. It is too easy for codes to be used by companies as a public relations exercise, as a way of persuading the public and shareholders that the company is doing the 'right' thing. Therefore mechanisms must be put in place to ensure that independent outside monitoring organizations are used to monitor performance and activities. A Mining Ombudsman can play that role and perform periodic audits of the performance of which are impartial and are willing to make the results publicly available. It is no good to leave this social conscience activity to NGO's because all they can realistically do is provide occasional spot checks when local communities complain.

Another useful form of independent monitoring and of bringing serious breaches to public attention is to have an independent and accessible complaints mechanism. The Australian Government and mining industry need to handle substantial complaints brought by communities against a particular project. Complaints mechanisms are important but they are not the final answer. In the long term, the Australian government must legislate to ensure proper standards.

2. The use of cyanide and its disposal following ore processing by the submarine disposal pipe.

Cyanide leach mining permits are increasingly difficult to obtain in the western US (Haber Inc. 1998) due to its known adverse environmental effects. Companies using cyanide and producing cyanide-containing tailings have good reason to manage these tailings with care. Mining companies should use the minimum effective amounts of cyanide required to recover metals, and dispose of cyanide in a way that eliminates or minimizes environmental impacts.

Policy needs to be aimed at improving the effectiveness of tailings management by:

- Minimising the production of tailings and maximising their safe use.
- Ensuring all tailings structures are operationally safe.
- Contributing to focused and relevant research into strategic issues aimed at improving tailings management.
- Recognizing that effective stakeholder involvement is essential for successful planning, and management of tailings.

The United Nations Environment Program (UNEP), working in partnership with the International Council of Metals and the Environment (ICME) convened an international meeting on cyanide n gold mining in Paris in 2001. The clear consensus was that the cyanide initiative is important and that the process of developing a voluntary global industry Code of practice and management systems should proceed as soon as possible. A Steering Committee has been formed (Almond 2000; Brehaut 2000). Ideally cyanide waste should be stored in lined and covered ponds to prevent contact with local animals, fish and birds. Some companies process the ore in vats that allow the cyanide to be recycled.

The mining operation needs to

- Use the minimum effective amounts of cyanide required to recover metals.
- Dispose of cyanide in a way that eliminates or minimizes environmental impacts. A contained tailings dam, or enclosed vats allowing recycling can bring this about.
- Monitor all operations, discharges and the environment to detect and deal with any escape of cyanide and subsequent impacts of that release.
- Stay abreast of the latest recycling techniques. For example there are two new technologies available: the acidification-volatilization absorption (AVA) method for recycling of cyanide, and a process called the Degussa peroxide process for detoxification of cyanide (Ameef 2001).
- Identify and implement appropriate options for reusing, recycling and disposing of residual cyanide from plant operations.

Finally the paper will introduce a new technology for extracting gold that does not involve cyanide, and is said to be nontoxic. The Haber Gold Process (HGP) is a technology for extracting gold. The process operates by extracting the gold from ores by dissolving the gold into water, and subsequently recovering it. The process is said to be non-toxic, and avoids the release of heavy toxic metals from the ores. Although said to be very powerful, it is not a universal lixiviate, and must be adjusted for different gold ores, according to its properties. Norman Haber developed the technical process in the mid 1980's. Following pilot testing, independent assessment was that the process offers advantages over other processing methods. The Haber Gold Process was found to be time effective and is a non-toxic process. Acute Toxicity Testing done by the California Department of Health Services on aquatic life showed the process to have an 85-100 % survival rate. Comparisons of metals content also showed no leach out of toxic heavy metals with the technology (Brehaut 2000).

Lihir Management Company needs to keep abreast of such developments and be prepared to invest time and money into implementing strategies that utilize less toxic chemicals and reduce the adverse environmental impacts their operation leaves.

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