UNEP

A PRACTICAL GUIDE

REDUCING MERCURY USE IN ARTISANAL AND SMALL-SCALE GOLD MINING

A UNEP Global Mercury Partnership document produced in conjunction with the Artisanal Gold Council and with assistance from UNIDO, University of Victoria, and the International Union of Geosciences Commission on geosciences for Environmental Management (IUGS-GEM); 2012.

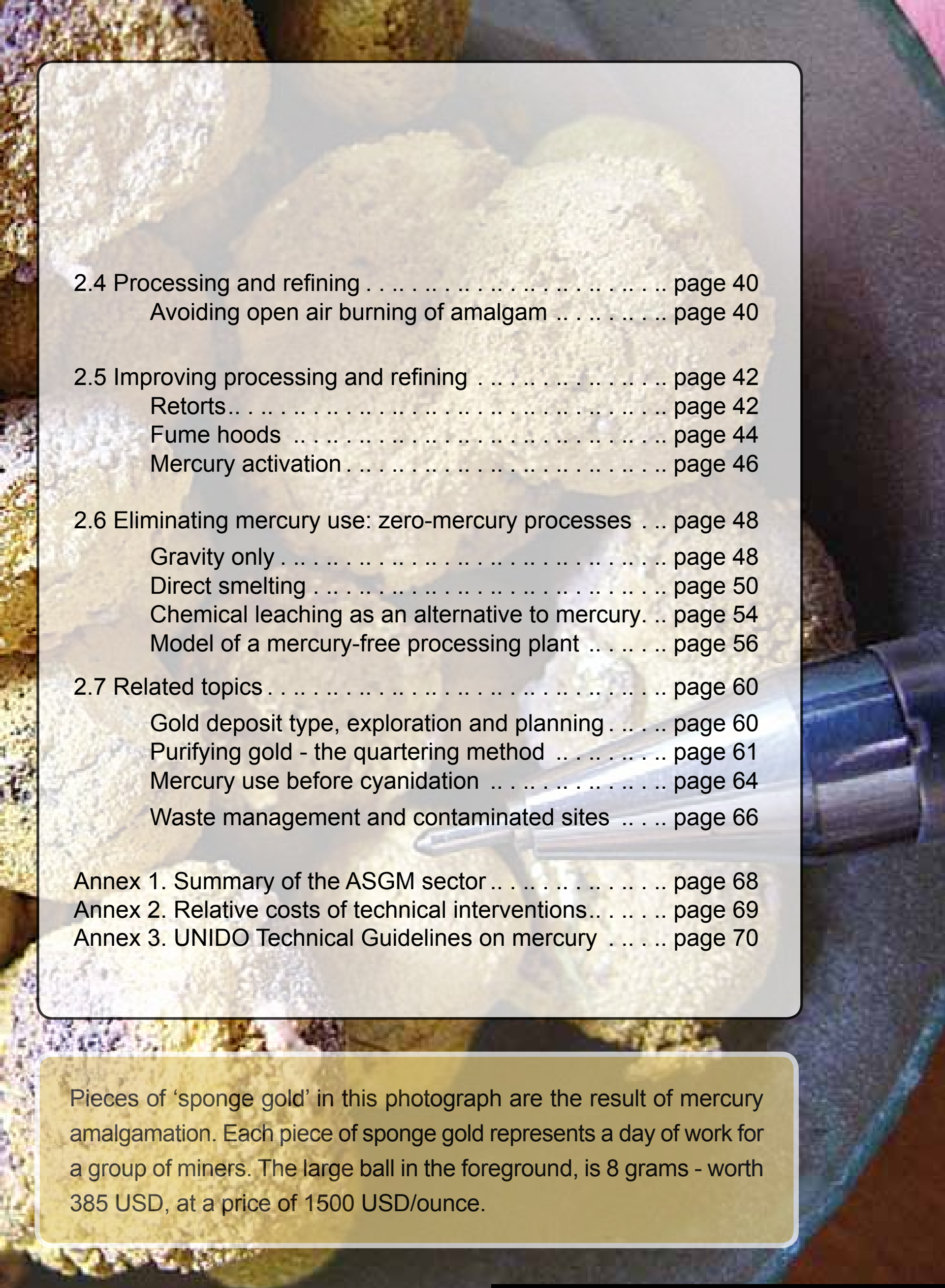
The primary authors of this document are Kevin Telmer and Daniel Stapper of the Artisanal Gold Council (AGC). All of the photographs and images in the document with the exception of those specifically indicated are property of the Artisanal Gold Council and can not be used without permission.

Reducing Mercury Use in Artisanal and Small-scale Gold Mining

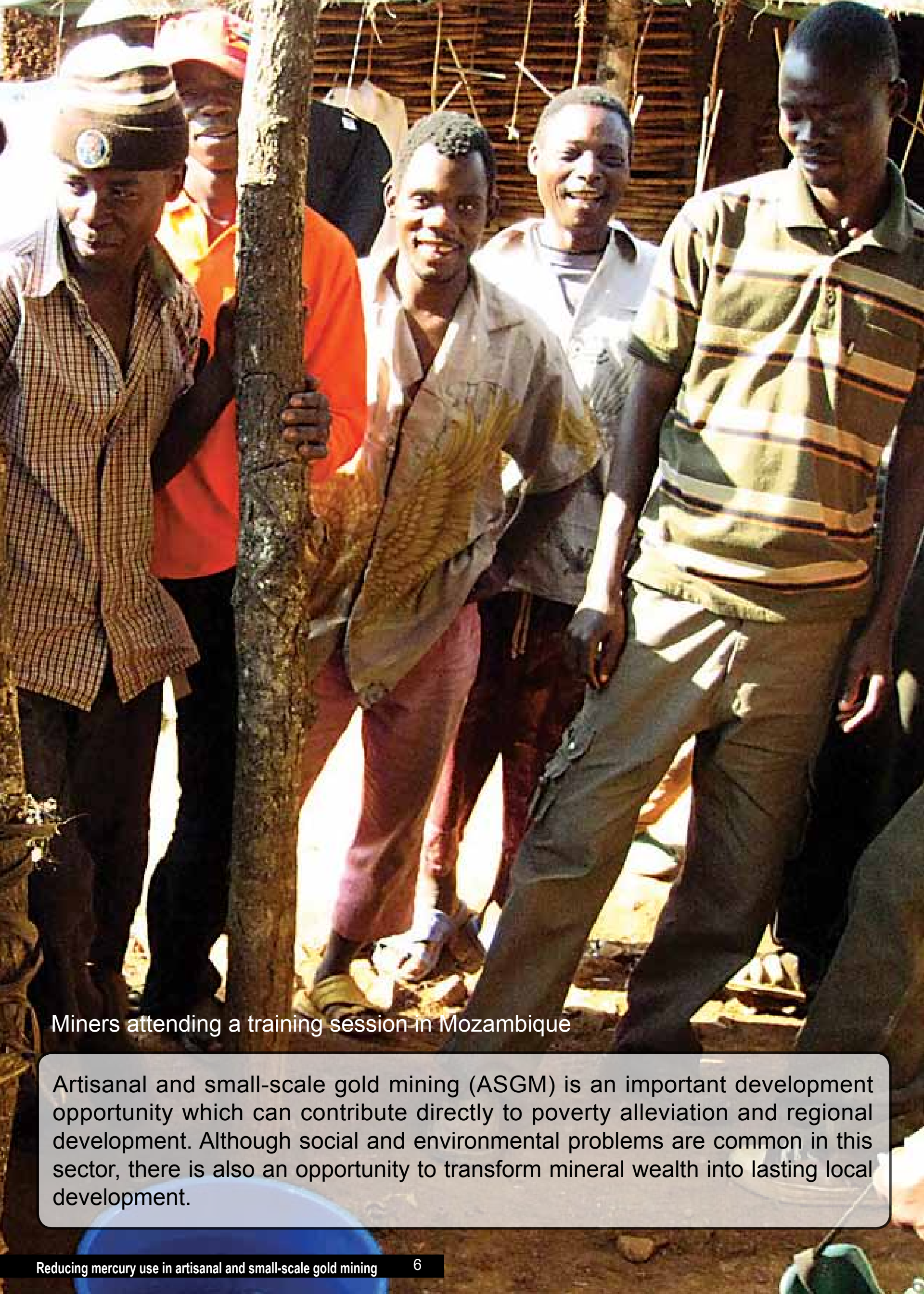
A Practical Guide

A UNEP Global Mercury Partnership document
produced in conjunction with Artisanal Gold Council.
www.artisanalgoldcouncil.org

Table of Contents



Pieces of ‘sponge gold’ in this photograph are the result of mercury amalgamation. Each piece of sponge gold represents a day of work for a group of miners. The large ball in the foreground, is 8 grams - worth 385 USD, at a price of 1500 USD/ounce.



Miners attending a training session in Mozambique

Artisanal and small-scale gold mining (ASGM) is an important development opportunity which can contribute directly to poverty alleviation and regional development. Although social and environmental problems are common in this sector, there is also an opportunity to transform mineral wealth into lasting local development.

Perspective

1. Gold can represent an excellent method of transferring wealth to rural communities: small-scale producers often get 70% or more of international prices, even in remote areas. This is much higher than other products such as coffee, bananas, etc.
2. Artisanal and small-scale gold mining (ASGM) needs to be brought into the formal economy to maximize benefits and enable improvements
3. In order to comply with modern environmental standards, reducing mercury use is a key step in realizing ASGM development opportunities

Who can use this document?

Policy makers, miners and civil society can use this document to learn about technologies and approaches for reducing and eliminating mercury use in artisanal and small-scale gold mining (ASGM).

Governments:

- A simple educational and planning tool for technical aspects of intervention programs and policy considerations
- A decision tool to understand best practice options
- An explanation of the technical fundamentals that underpin and encourage formalization of the ASGM sector

Miners:

- A graphic introduction of best practices
- A guide on how local conditions influence possible improvements in mining practices
- An explanation of barriers to be overcome to improve practices and reduce mercury use

Civil society:

- An educational tool to better understand ASGM
- An explanation of barriers that mining communities face when trying to improve mining practices and reduce mercury use

Why worry about mercury?

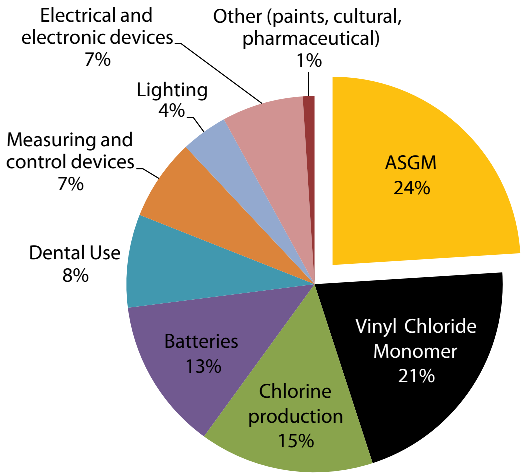
Mercury is a powerful neurotoxin that is harmful to people, but especially to developing fetuses, and young children. Once emitted, mercury can travel great distances through the atmosphere, causing global contamination of ecosystems, fish, birds, mammals, and the human food chain. Worldwide, consumption of mercury contaminated seafood puts billions of people at risk of mercury poisoning, which affects brain and nervous system development and function. Local exposures in mining communities that use mercury can be even more acute.

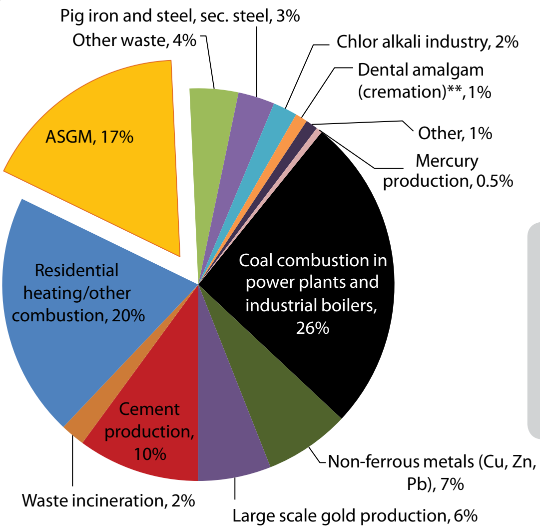
Worldwide mercury consumption and emissions[1]

Mercury Demand (Annual Consumption)

Total = 4,167 tonnes

ASGM is the single largest demand for mercury in the world. An estimated 1400 tonnes of mercury were used by ASGM miners globally in 2011 (www.mercurywatch.org).





Mercury emissions to atmosphere

Total = 1,921 tonnes

ASGM is the largest source of mercury pollution to air and water combined. It is second only to coal combustion as a source of worldwide mercury emission to the atmosphere (illustrated in pie graph, left).

[1] United Nation Environment Programme, Summary of Supply, Trade and demand information on mercury.

How is mercury used to capture gold?

When mercury is brought into contact with gold particles in sediments or crushed ore, it forms "amalgam" - a soft mixture of roughly 50% mercury and 50% gold. To recover gold from the amalgam, it is heated to evaporate the mercury, leaving the gold behind. Mercury is released into air, water, and soil in several of the steps of this process.

1. Rocks or sediment containing gold ("ore") are mined.

2. If necessary, the ore is crushed to liberate gold particles.

4. Mercury is added to extract the gold by forming an amalgam (mixture of mercury + gold).

5. Amalgam is collected and heated, evaporating the mercury, and leaving a porous "sponge gold" product.

Note: Unlike many pollutants, mercury is an element- it cannot be broken down in the environment. The element symbol for mercury is Hg. The diamond symbol at right, is used here to designate mercury vapor emission and human exposure.

3. Frequently, the gold bearing material is concentrated to reduce mass.

Why is mercury used?

- Quick and easy
- Independent - it can be used by one person independently
- Extracts gold in most field conditions
- Cheaper than most alternative techniques
- Facilitates precise transactions and divides profits – between labourers and owners for example
- Miners are not aware of the risks, and those that are aware often do not have access to the capacity or capital required for alternatives
- No choice (boss's instructions)
- It is one method that permits custom processing of small individual ore batches - often an important socio-economic structure.

6. 'Sponge gold' is melted to produce solid gold dore.

7. The dore is refined in gold shops to 24K and traded internationally.

Health risk to miners and families

Millions of miners, infants, children, women of child bearing age (potentially pregnant), and breast-feeding women, work or live in ASGM communities and are at risk of mercury exposure. Pictured above is a man burning amalgam in front of children and in a residential area. Many are unaware of the dangers. Simple cost effective protocols are available, such as those of UNIDO (see annex 3), and can greatly lower risk when followed.

Mercury vapors in the air around amalgam burning sites can be alarmingly high and almost always exceed the WHO limit for public exposure of 1,000 nanogram/cubic meter[1]. This risks the health of workers but also those in the communities surrounding the processing centers. Exposure to levels of mercury vapors above 1,200,000 nanogram/cubic meter can be fatal.

[1] Information on the Human Health effects of Mercury:
http://www.who.int/ipcs/features/mercury.pdf
http://www.who.int/ipcs/assessment/public_health/mercury/en/index.html

Gold shops or processing centres where amalgam burning occurs are the sites of some of the highest levels and most continuous exposures. Like a hotel room used by smokers, mercury vapors absorb and condense on surfaces and are continuously emitted later causing exposure even months after amalgam burning has ceased. Ultimately these vapors also enter the global mercury cycle contaminating the food chain.

Chapter 1 - Mercury use in detail

There are two main ways that mercury is used in ASGM:

1.1 Whole ore amalgamation (WOA)

Whole ore amalgamation is considered a poor practice because it is inefficient and releases large quantities of mercury.

1.2 Concentrate amalgamation

Below, an Indonesian miner pours mercury to prepare a WOA process. The images at right, show concentrate amalgamation: mercury is used on a concentrate to produce amalgam which is later heated to remove the mercury and produce sponge gold.

1.1 Whole ore amalgamation (WOA)

In WOA, mercury is brought into contact with 100% of the ore ('whole ore'). This is done in several ways (see examples presented in the photo sets).

WOA is a poor practice because:

- Mercury use ranges from high (4 parts mercury for each part gold recovered) to very high (20 parts mercury for every part gold or higher). In extreme cases, for example where ore is rich in silver, the ratio can be 50:1.
- WOA is inefficient - it rarely captures more than 30% of the gold and results in major losses of mercury to tailings (waste material).
- Large amounts of mercury are lost to the tailings because the mechanical process produces tiny mercury droplets ("floured mercury") that are too dispersed to capture. The result is mercury contaminated sites that are very difficult to clean up.

example *Whole ore amalgamation in trammels. Mercury is poured into steel drums with ore and grinding media inside. Mercury amalgamates gold as the ore is crushed (Indonesia).*

POOR PRACTICE


example *"Quimbelete" WOA: mercury is mixed with ore in rock basins, and amalgamated by crushing with round boulders (Peru).*

Whole ore amalgamation can be eliminated in most cases by moving to a system that first produces a concentrate that can recover equal or higher amounts of gold, using far less or zero mercury.


example *Copper plates: Mercury is coated onto copper plates and crushed ore is washed over the plates in a slurry. Gold particles stick to the mercury and are scraped up as amalgam (Colombia).*

1.2 Concentrate amalgamation

BETTER

In concentrate amalgamation, gold is first concentrated into a smaller mass before amalgamation - typically using gravity. Mercury is used only on the concentrate which contains the heaviest minerals and gold. In concentrate amalgamation, the ratio of mercury used to gold produced is much lower than WOA (generally 1:1 to 1.3:1), and little or no mercury goes into the tailings. Despite releasing less mercury to the environment than WOA concentrate amalgamation can still result in significant human exposure through inhalation of mercury vapor when safety equipment like retorts or fume hoods are not used.

example *This example begins with sluicing, but numerous different methods can be used for the concentration stage.*

1 *Processing to create a concentrate: in this case a sluice box is used. Heavy gold particles are trapped in sluice carpets as the slurry (ore and water) passes over the inclined surface.*

2 *The concentrate is collected by washing the carpets into a basin. Detergent soap is often used.*

3 *Mercury is added to the concentrate.*

4 *Mercury is mixed into the concentrate often by hand where it draws gold particles into a heavy liquid pool at the bottom of the basin.*

5 *The mercury now contains gold and is carefully separated from the concentrate by panning.*

6 *The mercury gold mixture is filtered through a cloth to separate residual liquid mercury (for re-use), and a soft silver colored "amalgam" which is typically around 50% gold and 50% mercury.*

7 *The ball of amalgam is heated to evaporate the mercury, leaving 'sponge gold' behind. This name refers to its porous texture.*

Chapter 2 - Solutions

This chapter presents technical solutions for reducing mercury use in ASGM. Opportunities exist to improve practices and reduce mercury use and exposure at each step of the mining process, often by reducing costs through improved technology and increased efficiency.

The booklet reviews:

Identifying appropriate solutions - which ones will work

How to reduce mercury use through improving concentration

How to reduce mercury use through other better practices

How to eliminate mercury use with mercury free technologies

The children in this photo are from an ASGM community in Mozambique that is in transition towards a more formal and legal status that includes better practices, reduced mercury use and improved standard of living.

2.1 Identifying appropriate solutions

Reductions in mercury use are more likely to be accepted by miners and become permanent if they increase or at least maintain income. This can be achieved in numerous ways, including:

1. Conserving or eliminating the need for mercury and other reagents, saving costs
2. Saving time by more efficient processing
3. Recovering more gold by improving extraction techniques, which might include using better technology or using existing technology better
4. Getting a better price for gold by following standards that get a better market price. An example of this is the Fairtrade-Fairmined Standard developed by the Alliance for Responsible Mining (ARM) and the Fair Trade Labelling Organisation (FLO). This approach gets miners a premium for good practices through a fair-trade mechanism.

Two-step approach

Technical Interventions for mercury reduction can follow a two-step incremental approach or leap straight to step two where feasible:

Step 1: Reduce mercury use and emissions through improved practices, which use less mercury. This increases (or at least maintains) income for miners, increases awareness, improves health through lower exposures, and can build positive relationships needed to go to step 2.

Step 2: Eliminate mercury use by using alternative mercury-free technologies that increase (or at least maintain) income for miners, and are better for health and the environment.

Solutions chart - which solutions work?

Use this diagram to assess the status of an ASGM operation an
It serves as a general guide. Solutions may vary from situation t

Chapter two outlines many of these solutions in greater detail.

Annex II includes a list of selected technical interventions, comparing the requirements for the intervention, in order of increasing cost.

Mining and Concentration

- Unsafe excavation
- Poor crushing and grinding
- Poor manual sluicing
- Poor & untargeted power sluicing
- Poor planning

- Excavation planning
- Safe ore extraction
- Efficient crushing and grinding
- Improved and targeted sluicing
- Improved panning
- Established operational protocols

EXPLORATION AND PLANNING

Engaging with small-scale miners at the exploration stage can support efforts to reduce and eliminate mercury use. See section 2.7 for more information.

- Excavation planning
- Safe ore extraction
- Advanced crushing and grinding
- Efficient sluicing
- Enhanced concentration
- Standardize operational protocols

d evaluate what solutions to apply.
to situation.

Processing →	Refining	
Whole ore amalgamation Chemical leaching after mercury Open-air amalgam burning No process control Little or no waste management	Lack of fume hoods Poor chemical management Poor purity assaying	POOR PRACTICE
No whole ore amalgamation Closed basin amalgamation Use of retorts / fume hoods Mercury reactivation Basic process control Basic waste management	Use of fume hood Proper chemical management Educated purity assaying	BETTER
Zero mercury methods Washing and sorting concentrates Direct smelting Chemical leaching Advanced process control Advanced waste management	Use of fume hoods Best chemical management Formal purity assaying	BEST

2.2 Mining and concentration

Gold liberation (crushing and milling)

In order for gold to be concentrated it must be "liberated". Many alluvial gold deposits do not require liberation, because gold already occurs as free gold particles. In most other deposit types, however, gold occurs inside other minerals and must be separated from these before it can be concentrated. This is accomplished by crushing and milling rocks into a powder. The technical term for this is "comminution".

Crushing and milling is a multi-step process. Primary crushing can be done manually using hammers, or with machines such as jaw crushers. This produces a gravel that must then be milled into a powder. Good milling produces an even grain size that is fine enough to liberate the gold for the chosen extraction process. There are many types of mills used in ASGM, some which require water (wet milling) and some which do not (dry milling).

Rocks are crushed manually using hammers (not shown), and then milled using ball mills (Tanzania, 2010).

Flour mills traditionally used for corn and millet, are inefficiently used to mill rock requiring miners to re-process material three times (Nigeria, 2011). This dry method produces enourmous amounts of hazardous dust.

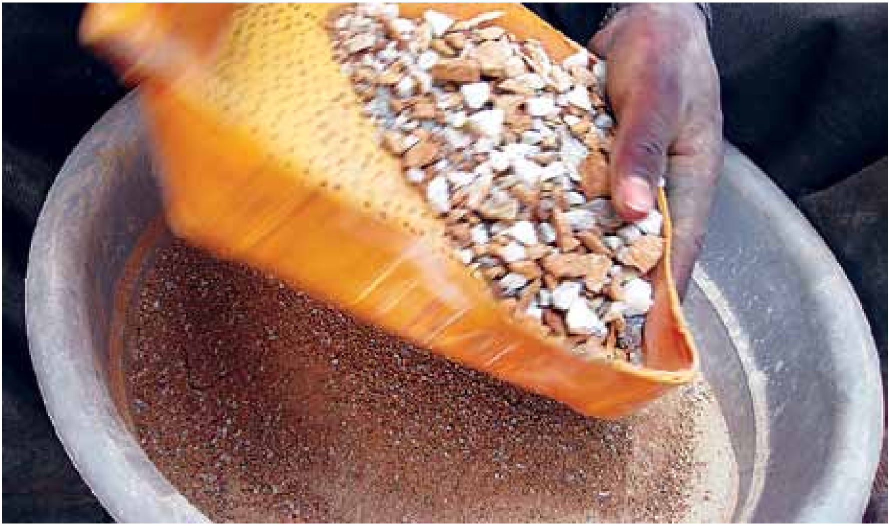
In the Nigerian State of Zamfara, naturally lead rich ores milled in this way have tragically caused a serious lead poisoning epidemic. Children accidentally ingest soils that have been highly contaminated by milling dust rich in bio-available lead. For more information search the US Center for Disease Control for "lead poisoning Zamfara, Nigeria".

Hammer mills have become widespread in ASGM in many countries. These are typically powered by a 20-30 horsepower motor. Rock is manually delivered by the operator, hammers batter the material and it passes through a screen. The material passes directly onto sluice to produce a concentrate which is subsequently amalgamated with merecury, as in the photo above (Mali, 2011). Due to poor grain size control (see next page) this method rarely recovers more than 30% of the gold in the ore.

Stamp mill for reducing rocks to pea-sized particles in preparation for further milling (Sulawesi, Indonesia, 2007).

The importance of grain size

Creating a concentrate typically works best if the particles being concentrated are of similar size. Screens should be used for sieving (sorting) material for this reason. The use of screens is simple and cheap, and can improve gold recovery in many ASGM contexts.



Above and left- miners crush rocks manually with a steel mortar (not shown) and then screen the crushed material to produce batches of fine material which is then passed along to the concentration stage (Mali, 2011).

This photo shows the screen on the underside of a hammer mill. The hole size of this screen is around 2mm, meaning that the material passing through the screen will have a maximum size of 2mm (Burkina Faso, 2011). For most ores, this is too coarse and will leave much of the gold unliberated and unrecoverable.

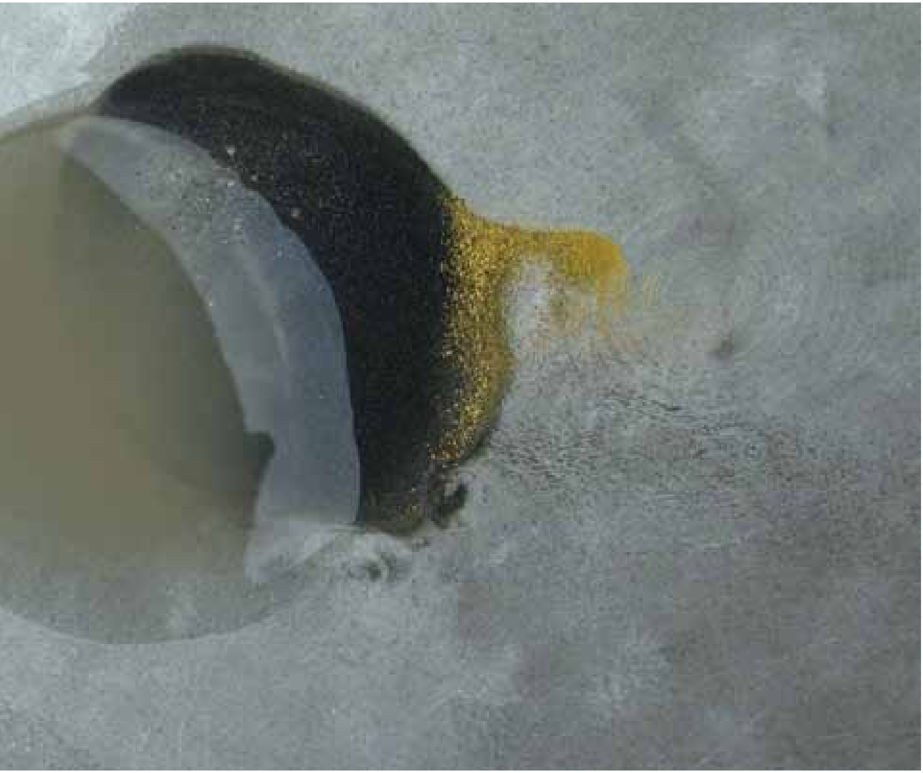
Grain size of the gold particles must be investigated and understood so that adequate and efficient liberation of the gold particles is accomplished during milling. It is generally effective to mill rock to smaller than 0.5mm (0.02 inches; 35 mesh), but in many ASGM operations rock is only milled to 2mm (0.08 inches; 10 mesh), resulting in poor gold liberation. Running tests on gold liberation and recovery is important and will reveal how to improve gold recovery.

In many hard-rock ore deposits, gold is not present as "visible gold", and the rocks must be crushed very finely in order to effectively liberate gold particles (product of ball mill, Mozambique, 2009).

2.3 Improving concentration

Producing concentrates is an essential step in the gold mining process, and if done well, can enable reduction or even elimination of mercury use.

Concentration can be done in several ways and in several steps, nearly all of which use gravity to separate heavy particles including gold, from lighter particles. Concentration greatly reduces the mass of material that must be processed to separate the gold. Concentrating eliminates the need for whole-ore amalgamation, and reduces the amount of mercury required for amalgamation to roughly 1 part mercury per part of gold recovered. If the mercury is recycled, losses can be decreased by 95%. If concentration is done with sufficient sophistication, it can eliminate the need for mercury altogether.



Choosing a technology (or technologies over several stages of concentration) to produce a concentrate depends on the type of ore, grain size and mineralogy of the gold, access to capital and know-how with which to acquire and operate processing equipment. Annex two provides a general list of the requirements and costs of selected technical interventions. Many of the more costly interventions will only be accessible to formalized miners with access to capital.

Because concentrating gold is challenging, ASGM miners can lose 25-75% of gold during concentration due to poor practices. This inefficiency can result in tailings containing a significant amount of gold which can eventually be reprocessed often using other methods such as chemical leaching.

Sluices

BETTER

Sluices work on the principle that heavy particles sink to the bottom of a stream of water while lighter particles tend to be carried downstream and discharged. A rough surface, typically carpets, can trap the gold and other heavy particles. Like a ball rolling down a hill, flow and momentum increase with distance, making the trapping mechanism less effective further down the sluice, particularly for fine gold. For this reason most gold is caught in the first meter of simple sluices like the one shown below. More sophisticated designs can avoid this problem (see opposite page and page 60).

For efficient sluice operation, consistent water supply is important. When buckets are used to deliver sediment and water onto sluices, surges in flow can lift gold particles off the carpets, reducing gold recovery. This can be avoided by filling a small reservoir like an oil barrel that delivers consistent flow to the sluice (see opposite photo).

Large sluice boxes are constructed with wooden timbers and lined with plastic and carpets (Indonesia).

Water availability and delivery are important for efficient sluicing.

Above- a fuel drum filled with water and hoses is used to deliver water to sluices (Tanzania).

At right- water is delivered to sluice through a plastic pipe with holes drilled in it (Liberia).

Zigzag sluice configurations where a top sluice drops material onto a second sluice can be used to break flow velocity and therefore increase gold recovery.

Sluices are usually inclined at 5 to 15 degree angles. A combination of two sluice surfaces can be the optimal set-up. These are called primary and scavenger sluices (see also page 60).

At right, a zigzag sluice is cleaned out at the end of the day (Suriname).

Centrifuges

BETTER

A centrifuge consists of a rotating bowl that has a series of ridges that trap gold as the bowl spins. Force applied to the feed material (milled ore, heavy mineral concentrate, alluvial sands, etc.) can be 50 to 200 times the force of gravity, providing more effective separation of gold from lighter minerals than systems that depend on gravity only. Ore is usually fed into the concentrating bowl in a slurry of 60-75% water (40-25% solids). Inside the bowl, material moves upwards as the bowl spins, and heavy minerals including gold are trapped between the ridges while light minerals flow up and out of the bowl, ejected as tailings.

For small-scale centrifuges an operating cycle typically lasts 0.5 to 2 hours, after which the concentrate must be cleaned out of the bowl from between ridges (see opposite page).

The Icon™ machine shown at left, made by Falcon Concentrators is designed to process up to 2 tonnes ore per hour. Models of this type range from 5-10 thousand $US. Below-this small-scale centrifuge contructed in Zimbabwe uses turbulence bars which act to keep the concentrate bed active. This is not an efficient centrifuge but is realtively cheap at an approximate cost of 1-2 thousand $US.

Centrifuges come in a variety of designs and cost ranges, with more expensive designs having better engineering and therefore higher efficiencies and throughput capacities.

Generally, centrifugal concentrating requires:

- slurry feed with relatively uniform grain size (good milling and screening is important)
- access to process water
- access to a power supply
- capital investment (beginning at several thousand dollars).

Centrifuges must be tuned to the ore being processed, and they must be operated with diligence. This is accomplished by adjusting feed grain size (milling control), rate of feed, rotation velocity, and cycle duration. One of the main challenges is to keep the concentrate bed active (avoid compaction between the ridges) - this ensures that heavy gold particles will replace lighter ones, which flow over the ridges and out of the bowl.

Spiral concentrators

BETTER

Spiral concentrates can help to enhance concentration. They are specialized pans with spiral grooves on their surface, mounted on a tilted axis. They can be useful to work concentrates from many kilograms down to a few hundred grams. The concentrate produced by a spiral concentrator may be suitable for zero-mercury treatments such as direct smelting (see page 52).

Typically, a small motor run by a battery turns the pan, and water showers the spirals. Concentrates are added to the bottom of the pan using a small scoop. Heavy minerals are carried upwards in the spirals as water washes lighter minerals back down. Heavy particles like gold remain in the spirals and are lifted up to drop through a hole in the center of the pan into to a cup.

A miner using a large spiral concentrator as a final concentration step (North America).

Vortex

BETTER

Vortexes can help to enhance concentration. During the final step of producing a high grade concentrate, vortexes are particularly good at capturing fine gold.

Water enters a 30-50cm bowl at a laterally angle from a hose causing the water to rotate creating a whirl-pool which drains out through an elevated hole in the center.

Concentrate is placed into the bowl and the spinning water suspends light particles, while heavier particles (e.g. gold) is left behind. The suspended particles flow through the elevated drain into a bucket below.

Flow can be supplied by a small pump or a raised water vessel. For best results use clean water. Vortexes are very cheap and simple to operate.

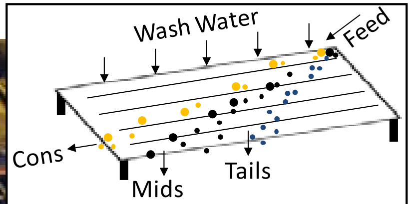
Blue Bowl Vortex

Fine gold produced from a vortex

Shaking tables

Shaking tables are slightly inclined with a trough along the lower edge, and slightly raised ridges along their length. The mineral feed and water are added along the high edge of the table, and a motor is used to shake the table. Inclination, water flow and shaking result in particle movement along the table towards the lowest corner. Light particles are more easily washed over the ridges than heavy particles separating them along the table and creating a heavy gold rich concentrate (see schematic).

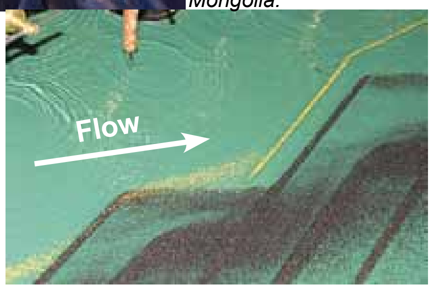
Shaking tables can provide excellent separation of liberated gold from other minerals and produce high grade concentrates greater than 50%. The gold must still be extracted from the concentrate using another process (gravity, chemical, or direct smelting for example).Tables can be expensive, however, and require careful attention and training to operate effectively. As a result, they will likely only be accessible to organized small-scale miners with access to capital.



schematic of a shaking table

A large shaking table is used at a small-scale mercury free processing plant in Mongolia.

A photograph showing the separation mechanism of a table - yellow gold is separated from less heavy black sands. The particles are directed by grooves in the table's surface.



Flotation

BETTER

Flotation separates different materials by taking advantage of differences in their surface properties. Chemical agents are used to float minerals and form a mineral rich foam which is then separated from the surface of the bath to produce a concentrate. Flotation is one of the main processes used by large scale mines to concentrate sulfides and gold, but can easily be done at the small scale too.

The principle behind flotation is the ability to attach bubbles or other buoyant materials to a mineral's surface - a function of the minerals "wetability". A hydrophilic mineral is one that is easily wetted, while a hydrophobic mineral is one that is water repellent. Many minerals such as silicates, sulfides, oxides, and carbonates can be separated by flotation- even minerals that have similar density and are difficult to separate by gravity. For this reason, flotation can enable the processing of complex ore types, including ores that are difficult to process using gravity methods.

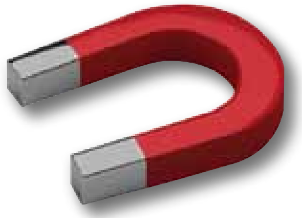
At right, this flotation system begins with a crusher, then mill, then proceeds to a sluice to capture coarse gold, and then proceeds to this flotation cell. A sulfide concentrate rich in gold is skimmed from the system using paddleboat skimmers. The gold in the concentrate is extracted with cyanide (Ecuador).

3 Main steps for flotation:

1. Add chemical reagent to slurry (crushed ore and water) to make minerals hydrophobic
2. Bubble the slurry to transport desired minerals upwards and create a surface froth (a mineral rich foam)
3. Skim (separate) the floating mineral foam from the flotation cell to produce concentrate

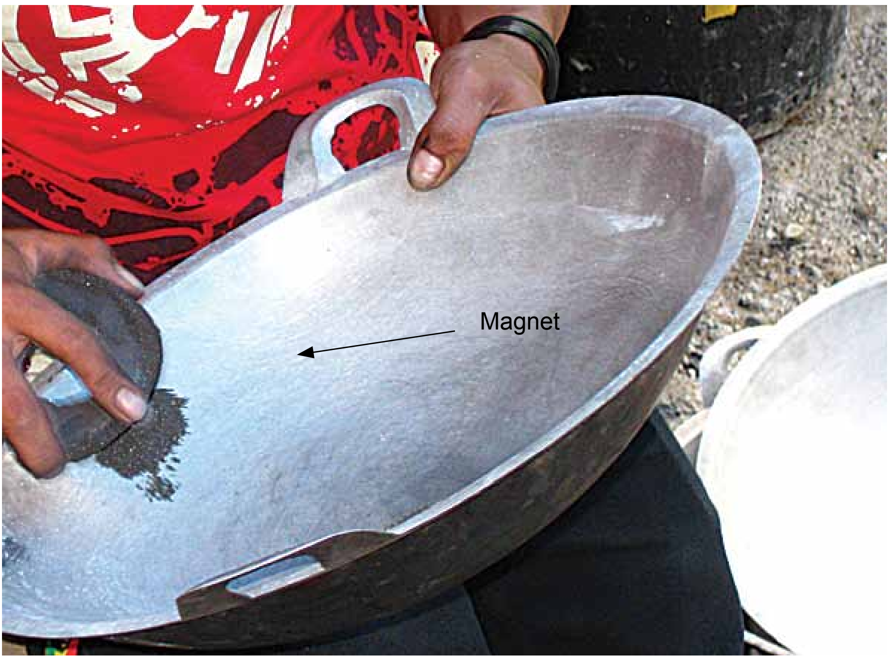
Magnets

BETTER



Magnets are often used as a tool to enhance concentration and to remove magnetic minerals - mostly magnetite. Magnetic minerals are typically dark in colour but some such as pyrrhotite (a sulfide) can be bronze colored and have a metallic lustre.

A handheld magnet is used to remove unwanted minerals, with care to avoid losing gold. To do this, the magnet is used below the pan to separate magnetic from non-magnetic minerals. Frequently wet mineral concentrate is heated to dry the minerals before using magnets for this purpose. This also increases the strength of magnetism in some minerals. A piece of paper or plastic is often used to cover the magnet so that the minerals can be easily removed from it.



Dark magnetic minerals are picked up by using a magnet, leaving non-magnetic minerals (including gold) behind.

Magnets have also been used to form sluice beds by making a “carpet of magnetite”. In certain cases, these magnetic sluices can improve the efficiency of recovering fine gold from concentrates. A thin magnetic sheet is placed on a small sluice. Magnetic mineral particles collect on the surface, forming a bed into which fine gold particles can settle. The sluice liner is comprised of polarized magnetic strips along its length.

2.4 Processing and refining

Avoid open air burning of amalgam

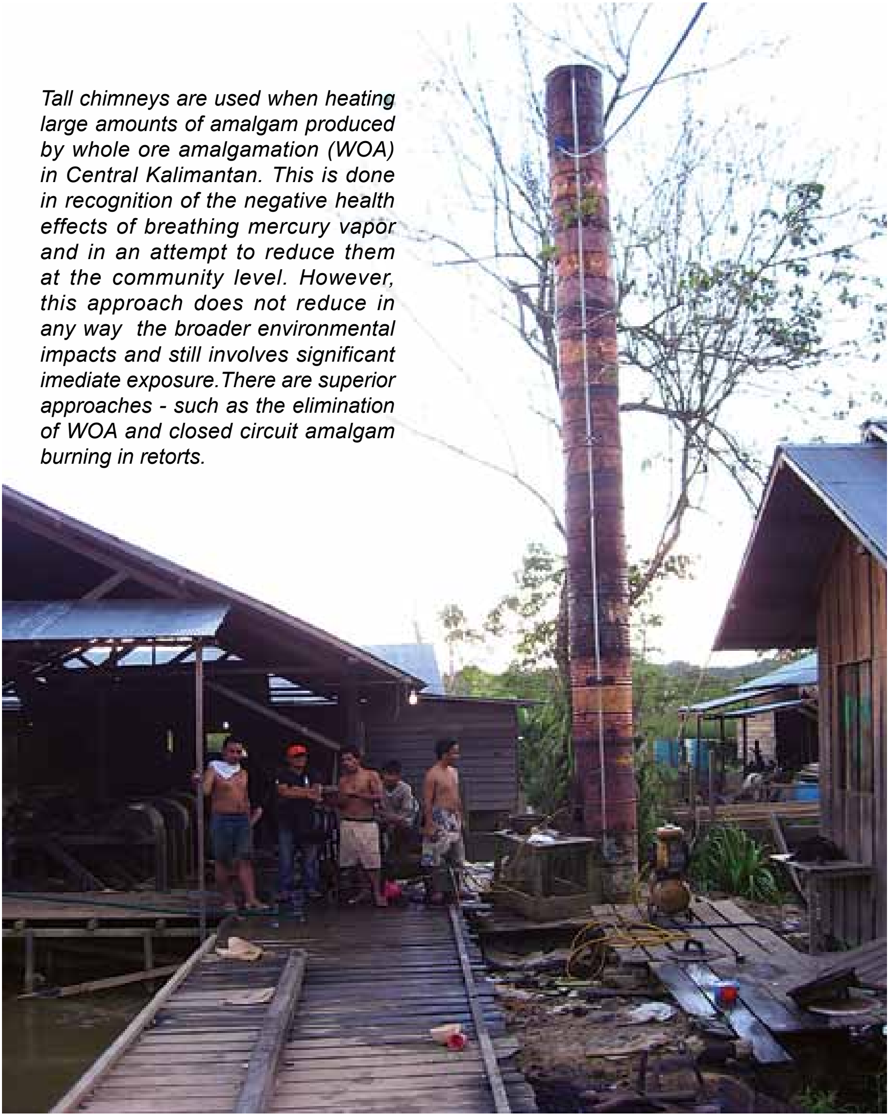
POOR PRACTICE

Once an amalgam has been formed, it is heated to evaporate the mercury from the gold. This is often done by heating the amalgam in the open, releasing mercury vapor into open air ("open air burning"), or alternatively by heating the amalgam inside of a mercury capturing device such as a retort or fume hood ("closed-circuit burning").

Open air burning of amalgam is a poor practice that occurs in processing and refining. When amalgam is burned the mercury evaporates as highly toxic vapor, which is invisible and odorless. This poisons miners, gold shop operators, families and communities. The problem is worstened when gold shops are located in urban areas where many people can be unknowingly exposed. In addition to the acute inhalation concern, this mercury is emitted to the atmosphere and circulates around the world causing global pollution of ecosystems and the food chain - particularly fish.

Acute mercury vapor exposure through inhalation: Above- amalgam is heated by placing it on a hot wooden ember, and blowing on the ember to increase the temperature (Mozambique). Left- a young miner heats amalgam using a candle and a steel spoon (Indonesia).

Gold shops that do not use fume hoods often have air-mercury concentrations exceedingly high – even when they are not burning amalgam.



Tall chimneys are used when heating large amounts of amalgam produced by whole ore amalgamation (WOA) in Central Kalimantan. This is done in recognition of the negative health effects of breathing mercury vapor and in an attempt to reduce them at the community level. However, this approach does not reduce in any way the broader environmental impacts and still involves significant imediate exposure.There are superior approaches - such as the elimination of WOA and closed circuit amalgam burning in retorts.

While it is ideal to move to non-mercury processing and refining, it is often a realistic initial step to reduce mercury use first. This can help set the stage to move to mercury free practices over time.

2.5 Improving processing and refining

Retorts BETTER

To avoid open burning, the mercury in the amalgam can be captured and recycled using a retort or fume hood. Simple and affordable models can reduce mercury emissions by 75 to 95%. Recycling mercury prevents the need for fresh mercury imports. This can lower costs for miners and gold shops by reducing mercury consumption.

Capturing and recycling mercury can be an effective first step in moving towards mercury free processing.

Retorts heat amalgam in one part and cool and condense the mercury vapor back into a liquid in another part of the device. The mercury can then be re-used.

(1) Amalgam is placed in a stainless steel retort; (2) The retort is clamped tight, and placed on a gas burner; (3) Mercury vapor leaves the amalgam, condenses in the steel tube, and drips into the vessel containing cool water. Once the retort has fully cooled after use, it is opened to recover the gold.

Important precautions

- Once a retort or fume hood is used, it becomes contaminated with mercury and must be treated with care - they should be kept in a secure space and precautions must be taken if they are transported inside cars or in backpacks to prevent exposure.
- Retorts should never be operated by children or by women of child bearing age.
- Retorts should only be used in very well-ventilated areas, preferably outdoors or inside of a fume hood.
- Retorts should not be opened until cool or else mercury gas can escape and cause exposure.


Numerous types of retorts are used in ASGM. An appropriate type can be chosen by users who understand their specific needs. Above right- the three pieces, glass bowl, metal pan and enamel cup, required for a `kitched bowl' retort', a low cost and simple design (Colombia).

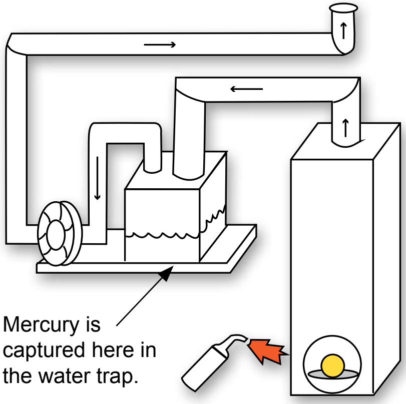
Below right- the 'kitchen bowl' retort uses wet sand as a seal around the edges of the overturned glass bowl (CASM, Mozambique meeting).

Below left- large retorts fabricated for use with large amounts of amalgam (Indonesia). There are many other retort designs.


Fume hoods

BETTER

Like retorts, fume hoods designed with mercury capture systems can reduce mercury emissions and exposure to mercury fumes. A well designed but affordable system can capture 80% of emissions. Highly sophisticated systems can capture more but are more expensive and complicated to operate. Two different fume hood designs are presented here.



example *The waterbox mercury condenser is a cheap and easy-to-manufacture add-on to small fume hoods like chimneys used in many gold shops. Mercury vapor is pushed through the system by a fan. The vapor is bubbled through water in the plastic vessel, and cools. This causes the mercury to condense as liquid mercury and sink below the water where it is isolated from the atmosphere. The mercury can be collected for re-use.*

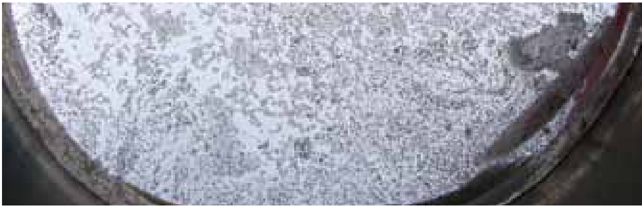
Above right- basic schematic of water trap setup; right and below- fume hood installations in gold shops showing 100 watt blower fan, and plumbing fixtures (Indonesia).

example *This fume hood design by the USEPA uses common fuel drums, impaction plates and a fan to trap mercury aerosols. The drum is typically attached to the fume hood exhaust system of a gold shop. Mercury collects inside the drum.*

Recycled mercury must be treated with care to prevent contamination and exposure. Captured mercury needs to be collected and stored safely. A good way to store mercury is to tightly seal it in durable glass, steel, or plastic vessels under a layer of water which prevents the mercury from evaporating.

Mercury activation

Mercury is less effective for amalgamation when it has become contaminated with other substances through use or has become oxidized- see the photo below. An effective method for cleaning and activating mercury was developed by Dr. Freddy Pantoja (Colombia). The method uses a solution of table salt and a simple battery to clean and 'activate' the mercury. The resulting 'mirror clean' mercury amalgamates gold more effectively, lowering mercury use, and prevents miners from discarding used mercury into the environment.



The surface of used mercury that has developed a layer of oxides. These inhibit amalgamation causing greater mercury losses and poor gold recovery

Steps

1. Pour the mercury into a plastic, glass, or ceramic cup. Do not use a metallic cup because the metal will conduct electrical current.

2. Mix a large spoon of table salt into a glass of water. Once the salt is dissolved, pour salt solution over the mercury. Sodium hydroxide (commonly called lye or caustic soda) also works very well- it produces less toxic by-products such as chlorides and is less corrosive to copper wires.

3. Connect copper cables. The negative pole of a 9V or 12V battery is connected to the mercury and the positive pole to the solution - a motorbike or car battery works well. The surface of the mercury will become clean in 5 to 10 minutes. Mercury activation can be done immediately before amalgamation to ensure minimum mercury use and maximum gold recovery.

Copper wires are used to connect the battery to the mercury and the salt-water solution.

Left- 9 volt battery being used for mercury activation. Six common 1.5v batteries connected in series also work well.

Right- after activation the mercury surface is a clean reflective mirror; water is kept on top so that mercury vapor does not escape.

4. For best results, the activated mercury can be filtered through a pinhole filter. To do this, make a tiny hole (<1mm) in the center of a piece of paper and carefully pour the mercury through the hole - dirt and oxides will be trapped on the paper. Filtering is helpful to clean mercury even when it has not been activated.

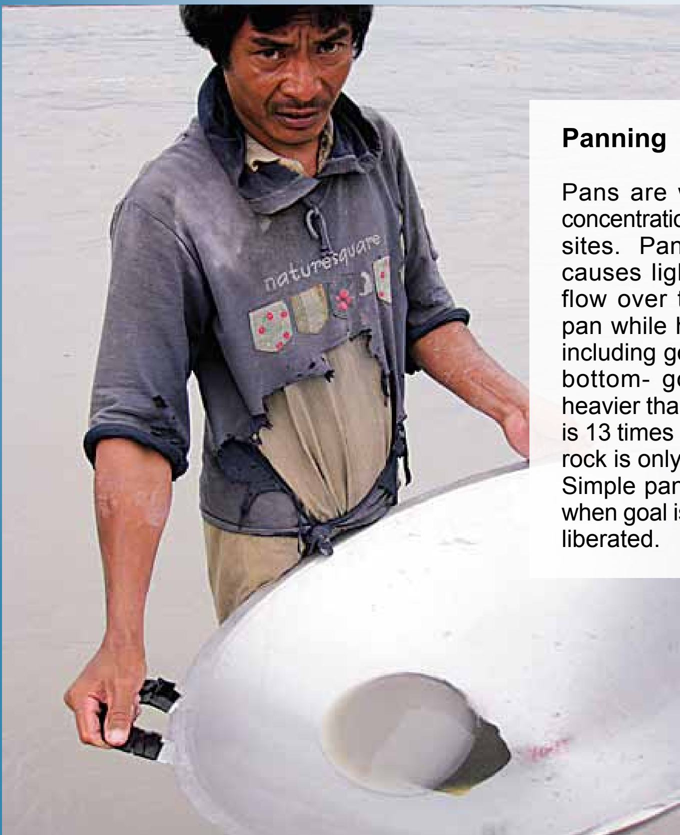
Activated mercury stored securely in a durable glass bottle with water on top, tape around the tightened cap, and properly labelled as mercury and as toxic.

2.6 - Eliminating mercury use: zero mercury processes

BEST

Gravity only

Gravity methods are the most widely used method of concentrating gold in ASGM. Using gravity is effective because gold is heavy: approximately 7 times heavier than an average rock of the same size. There are a wide variety of approaches to gravity concentration from basic such as panning and sluicing, to more complex such as centrifuges and shaker tables.



Panning

Pans are widely used for concentration in many ASGM sites. Panning with water causes lighter particles to flow over the edge of the pan while heavier particles including gold remain in the bottom- gold is 19 times heavier than water; mercury is 13 times heavier; average rock is only 3 times heavier. Simple panning works best when goal is coarse and well liberated.

Naturally occuring alluvial gold grains are not pure 24K gold. They contain other metals and typically range from 85 to 95% gold.

The sequence of images above shows miners panning up a sluice box concentrate (1,2), and then drying and heating it (3) to allow magnetic minerals to be removed (4) to produce a high grade gold product (5).
This process requires about 1.5 hours.

Direct smelting

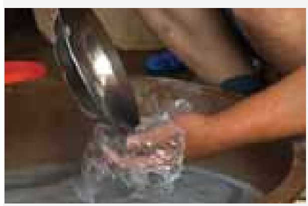
- A small mass of high grade concentrate is first produced (by panning or by using a shaking table for example), then it is melted to separate the gold from other minerals.
- This method is sometimes referred to as the 'borax method', because sodium tetraborate (borax) is often used as a flux at the end of the process to facilitate melting. However, this is a misleading name because 'better concentration' (milling, sluicing and concentrating) is where the main knowledge needs to be applied, not in the smelting at the end, which can be done with other fluxes other than borax as well. A more appropriate name is 'direct smelting'.
- A similar approach is employed by many gold shops to produce gold dore from gold dust or from sponge gold.
- Efficient concentration is a key requirement for direct smelting.

Direct smelting is an alternative processing pathway that does not use mercury. However it is important to understand that it is not a direct replacement for mercury because it is not applied at the same stage of processing. Mercury is commonly applied to large masses of concentrate - for example, 20 kg coming from the carpets of a sluice - whereas direct smelting is performed on small masses of high grade concentrate usually no larger than 100g. If working with sluice carpet concentrate, additional concentration beyond the stage at which mercury is applied is required before direct smelting can be applied.

Below and on the following page, two examples of direct smelting are given.

Example #1: Direct smelting as practiced in the Philippines

1 *Concentrate is carefully reduced by panning until it is more than 25% gold. Care is taken so that gold is not lost in the process; this is done using multiple pans (below).*



2 *The concentrate is collected, and mixed with equal parts borax. Roughly 50 grams of the mixture is poured into a small plastic bag.*

Information about direct smelting

Heating requires both energy and time and there are always some energy losses. This means that melting double the mass of concentrate will require more than double the time if the same energy is applied. For this reason direct smelting is difficult to scale up to larger masses.

Direct smelting works best and will be most appealing for situations where small masses of high grade concentrates can be produced without substantial losses of gold during the concentration stage. Concentrates masses of 50 to 100 grams are manageable.

In some cases, when concentrates contain unliberated gold and little gold is lost in the additional concentration step, direct smelting can produce more gold than the mercury process.

In other cases, for example where the gold is well liberated and is fine grained, the losses of gold that occur during the additional concentration step can discourage adoption of direct smelting.

3 *A clay crucible is pre-heated using the blow torch and melting a small amount (5g) of borax in it.*

4 *The plastic bag is placed in the crucible and heated by burning charcoal and a fan blows to increase the heat for 5-15 minutes. The result is solid gold dore.*

Direct smelting (cont.)

Example #2: Direct smelting as developed in Ghana[1]

The Ghanaian direct smelting kit is designed to smelt around 50g of concentrate in 20 minutes. It is a well engineered system that produces consistent and high quality results. Heating a larger mass requires more time and more fuel, different equipment, or multiple kits.

1 *Produce 25-100 grams of concentrate containing at least 5% gold.*

2 *Place the concentrate in a high temperature clay crucible. If the concentrate contains sulfide minerals it may help to first oxidize it with a torch.*

3 *Mix in appropriate fluxes and reagents to lower the melting temperature and viscosity of the non-gold minerals. The most effective recipe will depend on the ore and must be learned experimentally. Two common recipes are provided below:*

#1

- 1 part concentrate
- 1/2 parts borax
- 1/2 part lime (CaO)

#2

- 1 part concentrate
- 1/2 part borax
- 1/2 part potassium nitrate
- 1/2 part silica

[1] system designed by Prof. Sulemana Al-Hassan at University of Mining and Technology (UMAT) , Tarkwa, Ghana.

4 *Place crucible in furnace and heat until the concentrate is above the melting point of gold (1064°C) for at least 5 minutes. This will produce two separate liquids or 'melts' – a silicate melt that is typically thick but light (low density), and a metallic melt of the gold and other metals such as silver lead and copper that is heavy, viscous (thin), and sinks.*

5 *Remove the molten concentrate (the melt) from the furnace and pour into a cuppel (triangular shaped vessel). The gold will sink into the bottom of the cuppel.*

6 *Cool the cuppel, remove the hardened slag, and break the gold bead from the bottom of the slag with a small hammer.*

Chemical leaching as an alternative to mercury

Chemical leaching of various types can be a viable alternative to using mercury in small scale mining if done properly and well managed. This requires capital, training, monitoring, and also innovation.

The industrial gold industry which once used mercury, moved away from it by adopting chemical leaching methods. The dominant method used by large scale mines is chemical leaching using cyanide[1]. While cyanide and mercury are both hazardous substances, cyanide is a degradable compound that can be destroyed and is not persistent in the environment.

Cyanide can obtain very high recovery rates - often 90% of the gold in the ore - and it is cheap. Innovations in cyanide leaching allowed large deposits of low gold grade to be processed, allowing formerly uneconomical ore deposits to be exploited[1].

For the same set of reasons, the use of cyanide has become increasingly adopted by small-scale miners. Unfortunately, misuse and poor management of cyanide in small-scale mining is common and has led to disastrous local pollution and safety hazards. In these cases better practices or alternative methods need to be developed.

left - small-scale cyanide processing plant, cement lined tanks are used for vat leaching;

below left -
cyanide solution is drained from vats;

below center -
activated carbon is used to absorb gold - cyanide complexes from solution;

below right - chemistry lab and critical safety equipment is present on site and miners are trained to use it (Tanzania).

[1] Müller J., and Frimmel H.E. (2010), Numerical Analysis of Historic Gold Production Cycles and Implications for Future Sub-Cycles, The Open Geology Journal, 4, 29-34.

Reprocessing tailings that were initially processed inefficiently is increasingly common in ASGM because it can be economically viable due to recovery of gold that remains in the tailings. A poor practice occurs when mercury contaminated tailings are reprocessed using cyanide. This is a poor practice because the resulting mercury/cyanide compounds are more easily dispersed in waters and make mercury more bio-available. It is explored further in page 64.

POOR PRACTICE

One of the biggest problems with cyanide use in small-scale gold mining is a lack of waste management. In some cases tailings impoundments have been built and waste management efforts have been made, but there remains great need for improvement.

Reprocessing tailings for gold while moving them into a proper waste management system is a feasible way to remediate some contaminated sites.

An innovation that can help with waste management is pre-concentration and in mill leaching[2]. Pre-concentration produces a concentrate that minimizes the amount of cyanide (or other leachate) required. This is followed by "in-mill leaching", during which the gold is simultaneously liberated and leached, reducing the time required for processing. Benefits of this process include (i) reduced and less toxic waste stream that is simpler and cheaper to manage; (ii) processing times that can compete with mercury (1 day) leading to reduced or zero mercury use; (iii) high gold recoveries. In the system shown below, a porous capsule contains a bag with activated carbon that is inserted into the mill[2].

[2] Sousa R.N., Veiga M.M, Klein B., Telmer K., Gunson A.J., Bernaudat L. (2010), Strategies for reducing the environmental impact of reprocessing mercury-contaminated tailings in the artisanal and small-scale gold mining sector: insights from Tapajos River Basin, Brazil . Journal of Cleaner Production, vol. 18, 1757-1766.

Model of a mercury-free processing plant

With the right equipment and a suitable ore, high gold recoveries can be possible with only gravity methods. The system illustrated on the following pages was installed in Mongolia[1] and recovers around 70% of the total gold - a relatively high percentage for an ASGM operation.

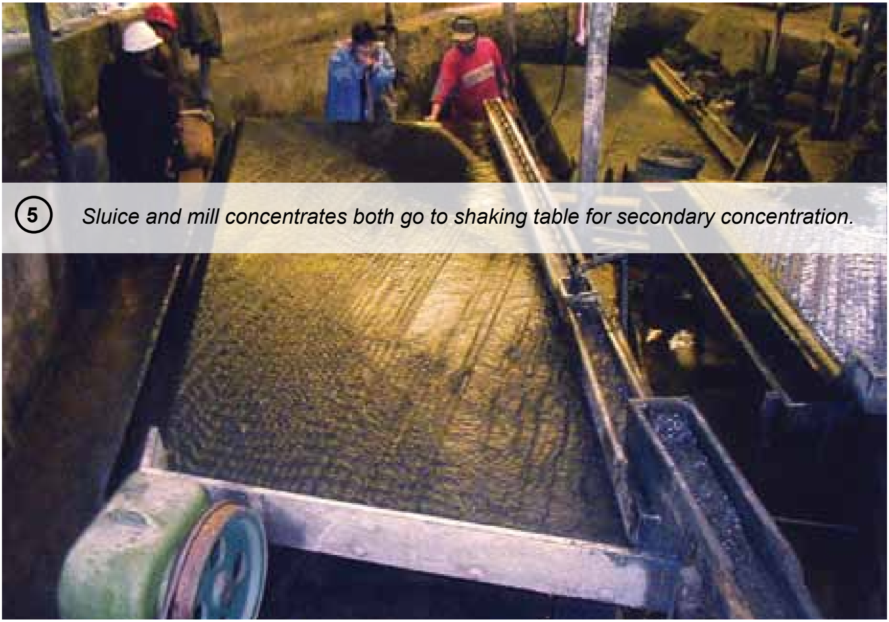
1 *Gold bearing rocks are extracted from a properly timbered mine shaft*

2 *Rocks are crushed down to 1-2 cm size using a jaw crusher*

[1] The project and plant design was developed by the Sustainable Artisanal Mining Project, (SAM), a collaboration between the Mongolian Government and the Swiss Development Cooperation (SDC), Mongolia.

3 *Chilean mills are used to mill the rock- a large portion of the gold stays in the mill; rock powder flows with water from the mill onto a primary sluice, and then a secondary scavenger sluice which captures fine gold.*

4 *Concentrate is washed from sluice carpets.*



5 *Sluice and mill concentrates both go to shaking table for secondary concentration.*

Gold concentrate from shaking table.

6 The gold concentrate is smelted (with borax) and poured into iron moulds. The resulting unrefined gold ingots (gold dore) are ~94% pure in this example but purity varies with ore type.

7 Tailings from this process are properly managed. While still containing 30% of the gold, they are accumulated on site for future collection for subsequent processing, perhaps by a flotation and leaching technology.

2.7 - Related topics

Gold deposit type, exploration and planning

Exploration is one of the most difficult aspects of mining. ASGM mainly relies on prospecting by trial and error - walking the ground and testing for gold content. Engaging with small-scale miners at the exploration stage can support efforts to reduce and eliminate mercury use. Planning how best to extract a deposit helps to maximize the resource, minimize land use, and improve gold production, which in turn makes reducing mercury use more affordable and sustainable.

Gold is a very rare element. Its average concentration in the earth's rocks is 3-4 nanograms/gram (parts per billion). However, because it is so precious, ore deposits with gold grades as low as 0.1 grams per tonne are mined by ASGM from shallow alluvial sediments (e.g. the aerial photograph below). On the other end of the scale, mineralized veins (primary ores) can contain 10 to 50 and as high as 200 grams of gold per tonne of ore.

Generalized gold deposit types exploited by ASGM are:

[A] alluvial deposits (particles of gold in river sediment)

[B] weathered rock or soil hosted gold (saprolites)

[C] hard-rock hosted gold (primary or lode gold).

Deposit type dictates the type of extraction possible, which in turn dictates if and how mercury is used (and potentially eliminated). Best practices in one situation cannot necessarily be applied elsewhere. Mercury reduction approaches must fit the ore type and current practices.

Lack of deposit management during mining of a alluvial gold in Kalimantan, Indonesia. Miners are burying the ore deposit in tailings, complicating further access to the ore. Poor deposit management causes rapid areal expansion (excessive and poor landuse) and loss of resources and wealth.

Purifying gold – the quartering method

Gold can be easily purified to 99.5% in a relatively simple process called the quartering method. This is done in some gold shops to produce an internationally tradeable product and receive higher margins. It also increases local know-how, and can provide an unbroken supply chain of local gold for use in local gold craft. By connecting sellers more closely to the markets and earning them more money, purification can bring market influence and finances towards moving to lower or zero mercury use. The method is particularly common in Asia.

The quartering method involves melting 2.5 parts silver together with 1 part gold dore. The silver-gold melt is cooled and digested in nitric acid leaving behind a pure gold residue because gold is not soluble in nitric acid whereas silver and other metals are. Borax is also used in this process and so it is relatively easy purify gold where gold dore is being produced. The Quartering Method is presented and explained on this and the next two pages.

1 *Right: weigh the gold dore and then weigh out 2.5 times that amount of silver and place in a crucible to be melted.*

2 *Left: melt the silver and gold in a crucible with a torch, adding a teaspoon of borax or other fluxes to assist in melting and removing mineral impurities.*

(3) *Left: pour the molten silver-gold alloy from a height of 1 meter into a bucket of water with a steel bowl placed in the bottom. Below: when the molten metal is quenched in the water it forms high surface area pellets - a silver-gold gravel.*

(4) *Acid Digestion: Place the silver-gold gravel into an Erlenmeyer flask. Add 20mL of pure nitric acid per gram of gold and boil for 10 minutes fitted into a condenser. NOTE: Used acid must be collected to recapture dissolved silver, and then be properly disposed.*

NOTE: Nitirc acid fumes are poisonous and must not be inhaled. Water traps, fume hoods, and proper ventilation are needed to eliminate human and environmental exposure.

5 *The gold remaining in the flask looks like a brown mud. Wash it into a steel pan, and rinse with clean water. Drain the water, and dry the gold over low heat.*

6 *Finally, place the dried gold into a high temperature crucible. Melt it with a torch, and pour the molten gold it into a button or bar.*

To recover the silver, place a copper bar into the used acid in a plastic pail. Silver beads will precipitate from solution onto the bottom of the vessel. Silver is also sometimes precipitated as silver-chloride by adding table salt to the used acid - this produces a white precipitate silver chloride; however, this method produces noxious fumes and should be avoided.

Mercury use before cyanidation

POOR PRACTICE

Processing mercury contaminated material with cyanide is a poor practice. Tailings from whole ore amalgamation often contain significant amounts of mercury and gold. For this reason, other miners (often a different group than the mercury users) buy and reprocess these tailings using cyanide.

This greatly exacerbates mercury pollution by delivering mercury to the environment as dissolved mercury-cyanide compounds. These toxic compounds are more easily dispersed in waters and make mercury more bio-available.

The tailings and waste from this process create heavily contaminated sites that are very difficult to clean up. Such sites continue to emit mercury to the atmosphere and contaminate the hydrosphere and food chain over prolonged times.

Small-scale pit leach, heap leach, tank leach, and agitated tank carbon-in-leach (CIL) cyanidation operations are often used to reprocess mercury contaminated slurries and tailings (a poor practice). Increasingly, cyanidation is being used to process ores directly without first using mercury, resulting in vast reductions of mercury pollution - similar to the way the formal large-scale gold mining industry operates. However, management of the waste stream remains a challenge.

Tiny mercury droplets can be seen in the feed material at operations that practice whole ore amalgamation before cyanidation.

Avoiding mercury use before cyanidation

1. Eliminate whole ore amalgamation (WOA). A first step to avoiding WOA is to concentrate ores prior to mercury amalgamation. This greatly reduces amounts of mercury used, eliminates mercury from the cyanide circuit and is also progress towards total elimination of mercury.
2. Remove mercury from feed before applying cyanide - this applies to tailings already contaminated with mercury. However no standard methods exist for this process - those being tested require further development and research.
3. Do not use mercury in the first place – if needed, use only gravity or other methods to recover gold before using cyanide.

Waste management and contaminated sites

One of the main differences between the large scale formal gold mining sector and the ASGM sector is that ASGM generally does not practice waste management or do so using substandard practices. This creates contaminated sites.

Some countries such as Ecuador and Mongolia have begun to address this issue. Generally this involves centralizing waste management (not processing), but retaining the existing individualistic and small scale socio-economic conditions vital to the ASGM community. Waste management systems (tailings disposal systems) that are accessible and affordable for ASGM communities are constructed to meet international standards.

By integrating environmental and social needs, this approach brings the added benefit of further facilitating formalisation, legalisation, and generating more wealth through better mining and processing practices. A general framework is:

(a) centralized waste management

(b) retention of custom milling - non-centralized processing

(c) develop community governance structure

(d) elimination of mercury from the waste stream

(e) elimination of mercury use in processing

(f) improved mining and processing practices - health, safety, and environmental educational programs which serve to increase miners' awareness and serve as further disincentives to mercury use.

(g) clean up of contaminated sites - reprocess and dispose of existing poorly managed tailings

(h) establish environmental monitoring system and measure improvements through environmental assessments.

A stepped approach to implement this strategy is to construct a model processing plant and waste management system and use it as a training centre to demonstrate (i) mercury free processing; (ii) better gold recovery or less costs per unit gold recovered; (iii) appropriate waste treatment; and (iv) approaches to innovation, training, and communications. The model plant is designed to be easily replicated locally.

Poorly managed waste, contaminated sites, and a solution for artisanal and small scale gold mining in Portovelo, Ecuador: (a) substandard tailings ponds; (b) direct discharge to rivers; (c) site contaminated with tailings; (d) an adjacent valley (burned pasture) that is a suitable for a tailings impoundment that meets international standards and that can serve the needs of the ASGM community.

Annex 1. Summary of the ASGM sector

- ASGM is a major gold producer and the world's largest employer in gold mining, representing around 15% of gold supply (around 400 tonnes) and 90% of the gold mining workforce worldwide
- The number of miners is estimated to be around 10-15 million in 70 countries, including approximately 3 million women and children
- At 1600 USD/oz, ASGM gold production has a gross value of around 20.5 billion dollars; this equates to about 2000 USD/miner per year
- The secondary economy of ASGM, using a multiplier of 5, is around 100 billion USD and involves 50 to 100 million people. At a normalized wealth level (purchasing power parity: PPP), this is roughly 40 times poorer than the average US citizen
- There is significant and growing interaction between the formal mining industry and ASGM. Both conflict and cooperation with formal mining operations has been growing in many countries
- The use of mercury is widespread in ASGM. Mercury use in ASGM is estimated to be 1400 tonnes per year in 2011 (www.mercurywatch.org)
- Irresponsible mercury use in ASGM causes health and environmental problems both locally and globally
- Mercury pollution problems are generally caused by socio-economic barriers to the adoption of better practices

Annex 2. Relative cost of technical interventions for a single mine operator, in order of increasing cost [1].

Technical intervention	Approximate cost (USD)	Barriers
Screens for sieving material	5 - 50	requires additional time and knowledge
Retort	5 - 50	requires additional time and knowledge
Reactivation (salt water and 12-volt battery)	5 - 20	requires additional time and knowledge
Improved Sluice	10 - 100	requires water, access to supplies
Mercury vapor capture system	50 - 500	requires additional time and knowledge
Direct smelting kit	depends on system used 100 - 2,000	initial cost; effective only on small batches of high grade concentrate; requires efficient heat source, technical know-how
Improved milling	2,000 - 10,000	high initial cost; requires energy, may require water, technical knowledge
Shaking table	1,000 - 10,000	high initial cost; requires energy, water, technical knowledge

[1] Developed at the Global Forum on Artisanal and Small-scale Gold Mining, 7–9 December, 2010, Manila - hosted by UNEP and its partners in the Global Mercury Partnership.

Annex 3. UNIDO Technical Guidelines on mercury management in artisanal and small-scale gold mining

I. PURPOSE

In the absence of an international management code for mercury management in artisanal and small scale gold mining (ASGM), many governments have been unsure how to address policy in ASGM.

The UNIDO International Guidelines on Mercury Management in Artisanal and Small-Scale Gold Mining are proposed for the purpose of assisting governments in the development of policy, legislation and regulation that will lead to improved practices of artisanal and small-scale gold mining (ASGM).

These guidelines apply to all legal mining areas, gold shops, and mineral processing operations where mercury is used for gold amalgamation. The guidelines provide minimum standards which can lead to the future elimination of mercury use in ASGM operations. In all cases possible, miners should be encouraged to adopt appropriate mercury-free mineral processing methods.

The central aim of these guidelines is to assist governments in the development of legislation and/or regulation to accomplish the following goals: (1) reduce ASGM-related mercury emissions into the environment; (2) reduce occupational and second-hand exposure to mercury; (3) eliminate the major inefficient and unsafe practices of mercury use; and (4) reduce unsafe storage and disposal of mercury.

II. BACKGROUND

These measures are formulated based on health, environmental, technical, socioeconomic and legal assessments that were undertaken by the Global Mercury Project. This project was initiated with the support of the Governments of Zimbabwe, Tanzania, Sudan, Indonesia, Brazil and Laos, with the United Nations Industrial Development Organization (UNIDO), the Global Environmental Facility (GEF) and the United Nations Development Program (UNDP).

In more than 50 developing countries across Asia, Africa and South America, an estimated 15 million people are involved in artisanal and small scale gold mining (ASGM). This activity usually involves the use of substantial amounts of mercury in mineral processing, often in highly unsafe and environmentally hazardous conditions. As many as 100 million people may be affected, directly and indirectly, by mercury emitted from ASGM. Mercury is a neurotoxin that bioaccumulates through the food chain, and mercury misuse in ASGM is responsible for an estimated 1,000 tonnes of mercury discharged annually into the environment, with negative impacts in diverse ecosystems including international waters. Globally, many of the hazards are similar – extensive emissions in tailings, contamination of water bodies, vapor inhalation, etc. However, environmental regulations are minimally developed for ASGM in most countries or not yet developed, and consequently, mercury is generally unaddressed.

III. IMPLEMENTATION

Governments should identify the appropriate authority responsible for implementation of these guidelines, and make any appropriate modifications to the technical measures to include in developing new mercury laws, policies or regulations. It is recommended that such policies be adopted under the clear jurisdiction of authorities that are responsible for small-scale mining issues, in consultation with other relevant authorities, recognizing that such authorities may be best suited to conduct monitoring.

Strong emphasis should be placed on encouraging local-level governance and community based monitoring systems. Community stakeholder participation in the processes of policy development and field implementation are critically important.

Governments should provide ways to legalize the artisanal and small-scale miners as well as to educate them on environmental management. Technological assistance and capacity/education services should be provided in all areas where there is a high concentration of small-scale miners.

These guidelines apply to all legal operations where mercury is used to amalgamate gold, amalgam is being burned or retorted, and gold is being melted. These guidelines provide minimum threshold standards that significantly reduce mercury emission and exposure where properly implemented. However, in all cases possible, miners should be encouraged to adopt appropriate mercury-free mineral processing methods.

IV. PRINCIPAL TECHNICAL MEASURES

1. RESPONSIBILITY OF EMPLOYERS OF MINING/PROCESSING PLANTS / GOLDSHOPS OPERATION

In all cases, the primary mining/ore processing license holder and gold shop owners should be held legally responsible for safe practices, including those involving mercury. The mining license holder or gold shop owner should institute reasonable safety measures to prevent the exposure of employees or other persons to mercury fumes.

2. LICENSE TO WORK WITH MERCURY

All licensed operations where mercury is used or handled should obtain a special license specifically for mercury at its facility. When miners apply for mining licenses and before beginning operations, miners should demonstrate awareness of how to comply with these guidelines.

3. NO WHOLE ORE MERCURY AMALGAMATION

No person should amalgamate the entire ore, through the use of a mercury-copper plate or using mercury directly into any gravity concentrator, centrifuge, or ball mill, Chilean mill of stamp mill. This causes mercury flouring which reduces recovery and induce that a large portion of mercury is lost to the environment with tailings. Amalgamation must be used ONLY for gravity concentrates.

4. MERCURY AMALGAM BURNING

No person should heat/burn mercury amalgam to recover the gold without using a retort. Retorts contain and condense the mercury vapor releases and should be used to recycle mercury (in the form of a bowl retort, pipe retort, hood, etc). Amalgamation burning must not take place in domestic residences. This must be done distant (say MORE THAN 500m) from any house. No children and pregnant women must be present during the retorting activities.

5. NO MERCURY-CYANIDE INTERACTION

No person should use mercury in conjunction with cyanide, or conduct cyanidation of mercury rich tailings as this practice increases mercury methylation.

6. AMALGAM BARREL

Amalgamation of concentrates must NOT be conducted manually. This must be conducted in small plastic or steel rotating barrels with rubber balls or a chain inside to increase the homogenization of the mixture of concentrate and mercury. Amalgamation time should be kept as short as possible. Amalgamation should be controlled and stopped, if no visible free gold can be seen. The amount of mercury added into the barrels must be gradual, until all free gold is caught. No cyanide or potassium permanganate or any other oxidizing agent must be allowed to be added to the barrel; only a dash of detergent is enough to clean gold particle surfaces. An amalgam separator such as an elutriator must be promoted to separate amalgam from heavy minerals after amalgamation. A carpet sluice placed after the elutriator will ensure that the fine mercury is captured.

7. CENTRALIZED AMALGAMATION SITES

Amalgamation and retorting should only be conducted in designated sites (amalgamation pools and isolated retorting places) distant at least 500 m from any inhabited place. For any mining location where amalgamation occurs, the primary license holder or mine manager shall designate a portion of the mining location as the prescribed structure, facility or locale where amalgamation may take place. Amalgamation may only take place in such structure, facility or locale. The holder of an ASGM license shall ensure that washing or settling ponds are constructed in his or her license area to provide for washing and sluicing, and no such washing and sluicing shall be done along or close to rivers, streams or any other water sources.

8. PROTECTION OF WATER BODIES

No person should conduct amalgamation or separation of amalgam from concentrates or burning amalgam or retorting in any natural water body or within a distance of 100 metres from any natural water body, including rivers, streams, lakes, and other water bodies.

Amalgamation tailings must not be discharged into a water body or in places susceptible to flooding.

9. PROTECTION OF RESIDENTIAL AREAS

No person should use mercury for amalgamation or any other purposes in residential areas or within a distance of 100 metres from any residential areas, including villages, towns, cities, or settlement areas.

10. DISPOSAL OF MERCURY OR MERCURY-CONTAMINATED TAILINGS

Any disposal of mercury-contaminated tailings should be done in a safe and proper way. No person should discharge mercury-contaminated tailings into a water body or in places susceptible to flooding. Disposal of mercury-contaminated tailings must be done by placing it on a clay or laterite soil-lined pit of several metres depth, located 100 metres away from any water body. When the hole is filled with mercury-contaminated tailings, this must be covered with 1 meter of clay or laterite, then compacted, covered with soil, and re-vegetated.

11. EXTRACTING RESIDUAL GOLD FROM MERCURY-CONTAMINATED TAILINGS

Mercury-contaminated tailings must not be recycled to the concentration circuit once this contaminates the primary tailings. If any process is to be applied to recover residual gold from mercury-contaminated tailings such as leaching with cyanide, thiourea, etc., the residual mercury must be removed (e.g. by gravity concentration) prior to leaching. The effluents and tailings from gold extraction must still be treated as mercury-contaminated tailings and must be buried.

12. CONDENSERS FOR GOLD SHOPS

Any shop buying retorted gold, or any shop that is retorting gold, must have a proper fume hood installed to capture, condense and recycle mercury. The design of the fume hood should be such that over 90% of the mercury is captured.

13. STORAGE OF MERCURY

Metallic mercury should be stored safely at all times when not used; in (a) a secure location that is inaccessible to children; and (b) unbreakable air-tight containers that are covered with a thin layer of water (e.g. 1 centimetre) to prevent mercury evaporation. Mercury should NOT be stored in a domestic residence.

14. PROTECTION OF PREGNANT WOMEN AND CHILDREN

People who perform amalgamation, retorting, melting gold or handling mercury must ensure that no pregnant women, or children under the age of sixteen, enter the structure, facility or locale in which mercury is being used.

15. MERCURY-FREE METHODS

The above guidelines demonstrate minimum threshold requirements. These measures significantly reduce mercury emission and exposure where properly implemented. However, in all cases possible, miners should be encouraged to adopt appropriate mercury-free mineral processing methods. For small amounts of concentrate, the blowing-tapping method should be promoted.

www.unep.org/hazardoussubstances/Portals/9/Mercury/Documents/ASGM/UNIDO%20
Guidelines%20on%20Mercury%20Management%20April08.pdf

Acknowledgements and permissions

The primary authors of this document are Kevin Telmer and Daniel Stapper of the Artisanal Gold Council (AGC). All of the photographs and images in the document with the exception of those specifically indicated are property of the Artisanal Gold Council and can not be used without permission.

AGC is thankful for the assistance, feedback and materials provided by:

Brenda Koekkoek, United Nations Environment Programme (UNEP)
Usman Tariq, United Nations Environment Programme (UNEP)
Juan Manuel Barbeito, United Nations Environment Programme (UNEP)
Ludovic Bernaudat, United Nations Industrial Development Organization (UNIDO)
Susan Keane, National Research Defence Council (NRDC)
Marcello Veiga, University of British Columbia
Patience Singo, Sustainable Artisanal Mining Project, SDC
Rickford Viera, Goldmining Pollution Abatement Project Coordinator, WWF
Peter Appel, Geological Survey of Denmark
Sumali Agrawal, Yayasan Tambuhak Sinta
Budi Susulorini, Blacksmith Institute
Marianne Bailey, US Environmental Protection Agency
Mihir Deb, and Sulemana Al-Hassan, IUGS-GEM Working Group on gold and mercury
Zero Mercury Working Group (ZMWG)
International POPs Elimination Network (IPEN)
Human Rights Watch (HRW)
The UNEP Global Mercury Partnership
Communities and Small Scale Mining (CASM)
IUGS and its Commission on Geoscience for Environmental Management for support and assistance in arranging various international presentations on gold and mercury
University of Victoria, School of Earth and Ocean Sciences

And especially the numerous miner groups and others that we work with, many of whom are seen in the photographs in this publication.

Indonesian miners in North Sulawesi are trained by their Philippino colleague, 2011.

www.unep.org
United Nations Environment Programme
P.O.Box 30552 Nairobi, Kenya
Tel.:++254-(0)20-62 1234
Fax: ++254-(0)20-62 3927
E-mail: uneppub@unep.org

UNEP

Helping artisanal and small-scale gold miners to derive the greatest benefit from this development opportunity, while minimizing the environmental and social consequences is absolutely possible. All that is needed is understanding, innovation and will.

For more information, contact:
UNEP DTIE Chemicals Branch
11-13 Chemin des Anémones
CH- 1219 Châtelaine, Geneva
Switzerland
Tel.: +41 (0) 22 917 12 34
Fax.: +41 (0) 22 797 34 60
Email: metals.chemicals@unep.org
Web: http://www.unep.org

1972-2012:
Serving People
and the Planet

DTI/1557/GE
ISBN 978-92-807-3282-5