Mercury Management in ASM Gold Mining

Proceedings of Pre-Conference Technical, Consultative and Collaborative Session

8th Annual Communities and Artisanal & Small Scale Mining (CASM) Conference

Date: October 7, 2008
Location: Brasilia, Brazil

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Context

This workshop on mercury management in artisanal and small scale gold mining (ASGM) was an initiative of the UNEP Global Mercury Partnership and was organized as a pre-conference event of the 8th Annual Communities and Artisanal & Small Scale Mining (CASM) Conference. The UNEP Global Mercury Partnership, which includes representatives of governments, regional economic integration organizations, and major groups and sectors (including NGOs, science and industry), aims to reduce global mercury pollution through a variety of voluntary initiatives. The purpose of this workshop was to promote awareness and adoption of cleaner production techniques for ASGM operations in order to reduce the amount of associated mercury pollution. All of the techniques presented in this workshop are grounded in field work – all represent mercury reduction strategies based on actual examples used in the field by artisanal and small scale gold miners from various countries. The information presented in the workshop can form the basis of guidance for those planning mercury reduction interventions, to help them select the effective reduction strategies that consider the technical and social realities within ASGM communities.

The workshop was organized into four main sections:

- Overview: how and why mercury is used, and a review of techniques available to reduce or eliminate its use;
- Non-mercury gold extraction techniques;
- Mercury use reduction techniques for miners; and
- Mercury recovery at gold shops.

The pre-conference workshop was chaired by Susan Egan Keane, of the Natural Resources Defense Council, and included eight presenters representing small scale miners and field researchers from Canada, Colombia, Ghana, and Brazil (For a full list of presenters see Appendix A.)

Background

Artisanal and small scale gold mining (ASGM) is estimated to account for about 12 percent of the world's gold production or approximately 330 tons per year.[1] In addition to the 13 to 20 million small-scale miners directly involved in the industry[2], ASGM supports the livelihood of over 100 million people in 70 countries.[3] The number of miners appears to be increasing, driven by record high gold prices: the price of gold has risen from $274.45 oz at the start of 2002[4] to $900 oz in December, 2007.[5]

Mercury amalgamation is commonly used in ASGM as a means to extract gold from ore. Unfortunately, the use of mercury in ASGM can be devastating on a local, regional and global level. When the mercury-gold amalgam is burned to recover the gold, the resulting mercury vapors are directly inhaled by miners and others in the community, posing direct health risks to these individuals. Further, mercury is often released into streams and rivers adjacent to mining sites, severely contaminating these water bodies. Because mercury is a persistent pollutant, the mercury released to air and water from ASGM sites becomes part of the total load of mercury circulating in the global environment. In all, ASGM is estimated to release up to 1350 metric tons of mercury to the global environment annually.[6]

In recent years, the widespread use of mercury in ASGM has drawn the attention of the international community, and addressing this problem is a key component of a broader strategy to combat global mercury pollution. In 2002, GEF, UNDP and UNIDO launched the Global Mercury Project to reduce the amount of mercury used and emitted in ASGM. More recently, the UNEP Governing Council declared that "promoting awareness of alternative livelihood options and promoting transfer of appropriate technology for the small-scale artisanal mining sector which uses mercury" should be a top priority.[7] In response to this decision, UNEP has created the Mercury Partnership for Artisanal and Small Scale Gold Mining, directed at promoting low-mercury and mercury-free ASGM techniques, among other objectives. Finally, both the EU and the US recently passed legislation restricting the export of mercury, which will reduce its availability on the global market, and likely cause its price to rise. These

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[1] Telmer, K.H. and M.M. Veiga, 2008. World emissions of mercury from artisanal and small scale gold mining. In: Mercury Fate and Transport in the Global Atmosphere: Measurements, Models and Policy Implications. Interim Report of the UNEP Global Mercury Partnership, Mercury Transport and Fate Research Partnership Area. July 14. http://www.cs.iia.cnr.it/UNEP-MFTP/index.htm.
[2] Stablum, A. 2008. Big increase in illegal gold mining as price rockets. Thomson Reuters, London.
[3] Telmer and Veiga, 2008.

[4] 2008. Gold price news: 2005 gold price. http://goldprice.org
[5] 2008. Draft business plan of the artisanal and small scale gold mining partnership area. UNEP Global Mercury Partnership.
[6] Telmer, K.H. and M.M. Veiga, 2008.
[7] Decision 22/4, Mercury Program. Mandate given by the Governing Council of UNEP at its 22nd session/Global Ministerial Environment Forum in February 2003.

circumstances may induce more artisanal and small scale miners to consider low-mercury and mercury-free methods for extracting gold.

Section 1: Overview: Why is Mercury Used? What Methods Are Available to Reduce or Eliminate Its Use?

How and Why Mercury is Used in ASGM and Reduction Scenarios; Dr. Kevin Telmer, University of Victoria, Victoria, Canada

Because of the wide range of practices within the ASGM sector worldwide, there is no single solution for reducing mercury use. Understanding the reasons why miners use mercury is critical for the planning and implementation of reduction strategies. Mercury is used in ASGM because: it is easy to use and generates more gold in less time than other technologies; miners can operate independently using mercury; it is effective under the present field and socio-economic conditions; it is accessible and cheap; it facilitates financial transactions through standardization of gold purity; it enables the production of quick capital; miners are generally unaware of the risks; and cost-competitive alternatives are often unknown or unavailable.

Relatively simple, low-tech interventions to reduce mercury use could theoretically result in dramatic reduction of emissions of mercury worldwide from this sector. For example, if 90% emission control is attained from amalgam burning, and the captured mercury is reused, global consumption of mercury could drop by 25%. If mercury reactivation is widely adopted, and reactivated mercury is reused rather than discarded, global consumption could drop by another 25%. If elimination of whole ore amalgamation was widely adopted, global consumption could drop by an estimated 45%, although this change is likely to present a more difficult challenge, because it represents a fundamental change in practices.

In addition to direct benefits for mercury emission reductions, programs to reduce mercury use in ASGM can be a good “point of entry” for working with mining communities on a wider range of social and economic issues, and can be a strong indicator of success in gaining trust and access to the communities.

However, the record of success of ASGM intervention programs to reduce mercury use is mixed at best. While education and health benefits are important and appreciated in ASGM communities, the most important factor in successfully promoting better practices and mercury reduction initiatives is to focus on increasing profits to mining communities.

Given the host of technical and social reasons that drive the choice of gold extraction methods by small scale gold miners, any intervention program to discourage or reduce mercury use will have to address these issues. These include:

Technical:

- Suitability of technology for the type of ore mined
- Building and operational requirements of alternative technologies
- Education levels required of operator
- Time and cost of operations
- Effective grade yielded by different technologies

Social/financial:

- Legal status of miners
- Access to capital
- Risks to health and environment of alternatives compared to mercury
- Transportation/access to markets
- Access to alternative technology
- Established owner/worker/mercury trader hierarchy and division of profits
- Time frame for return in investment
- Ease with which the technology can propagate to other communities

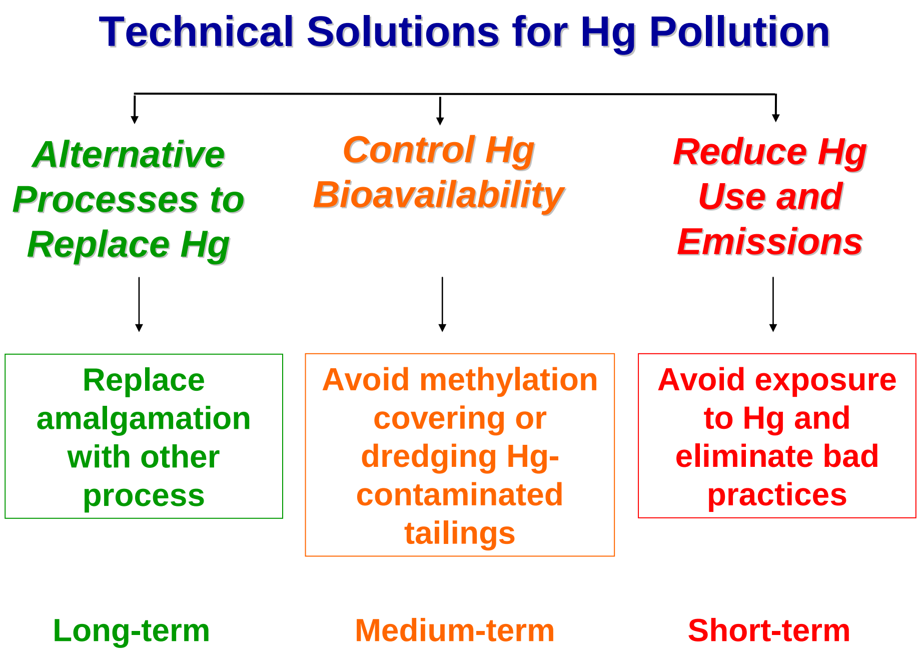
As an example of one social dimension to consider, it is important to understand the role that mercury plays in the financial system within the communities. In some cases, the use of mercury by miners allows for a division of profits that is advantageous to gold-buyers. For example, in North Sulawesi, Indonesia, mercury use for amalgamation reduces financial risk for operation owners of ball mills because the workers responsible for amalgamation keep only the amalgam as pay. If there is little or no gold in the ore, the operation owner loses no money. If there is gold in the ore, the operator allows the miner to keep the amalgam and sends the tailings to a cyanide operation to recover additional gold. In this way, the mercury becomes a signal of whether ore contains profitable quantities of gold.

As another example, in the processing of alluvial gold from Galangan, Kalimantan, Indonesia, landowners use 'mercury men' to provide mercury to the miners. These men ensure that the miners use large quantities of mercury so that the gold is diluted and some is left behind in the residual mercury after amalgamation, which they collect. The landowners then recover the excess gold and in this way, tax the workers on their land.

Because of these types of practices, intervention strategies to reduce mercury use may be met with resistance by those profiting from its use. Cutting stakeholders out of profits is likely to cause unease and aggression within the ASGM community.

Reducing / Replacing Mercury in ASGM; Dr. Marcello Veiga, University of British Columbia, Vancouver, Canada

Approaches to reducing mercury emissions and exposures from ASGM can be divided into three main categories: (1) alternative processes to replace mercury use altogether; (2) methods to reduce mercury use and emissions; (3) methods that control mercury mobility and bioavailability. The presentation focused on the first two approaches.



To reduce mercury use during amalgamation, and thus reduce loss of mercury through the tailings, miners can:

- concentrate gold using gravity or other methods before mercury amalgamation;
- promote good contact between Hg and gold;
- avoid severe grinding that causes 'flouring' of mercury;
- use additives to reduce Hg surface tension;
- "activate" Hg to increase its effectiveness in the gold amalgamation; and
- remove excess mercury from amalgam using a centrifuge to reduce the amount of Hg in the amalgam to 20%.

Among these, the grinding and concentration steps are the areas that hold the most promise to reduce mercury use during amalgamation. Some miners use mercury to amalgamate the whole ore, which requires large quantities of mercury. If miners instead amalgamate gravity concentrates, rather than whole ore, mercury losses can be significantly reduced. Further, the use of copper-amalgamating plates or addition of mercury into grinding circuits (e.g. ball mills or Chilean mills) causes mercury flouring, resulting in between 20 to 30% of the added mercury being lost to the tailings. Modifying these practices has a high potential for reducing mercury use.

Capturing mercury when the amalgam is burned is a critical step to reduce emissions and to reduce direct exposure of miners and gold shop operators to mercury vapor. Simple home-made retorts and fume hood designs were discussed by other speakers.

Techniques exist that can replace mercury altogether in gold extraction.   In some cases, depending on the type of ore, gravity concentration alone, particularly in specially designed sluice boxes, centrifuges or using flotation, may be sufficient to separate out gold. Other mercury-free methods potentially suitable for small scale miners include direct smelting and cyanidation. Direct smelting was discussed by another speaker. Using cyanide to extract gold from ore is a common approach that is familiar to many small scale miners. Cyanide is used to leach gold from the ore or, preferentially, from concentrates. Gold is then precipitated from the cyanide solution using zinc, activated carbon or other methods. Cyanide tailings should always be neutralized using hypochlorate or chlorine – which destroys cyanide complexes.

Cyanide use is often considered an unattractive option for small scale miners because gold recovery typically takes longer with cyanide than with mercury. However, some recent field tests have demonstrated the advantages of using cyanide leaching in small ball mills, like the ones used now in Colombia, Ecuador and Indonesia for mercury amalgamation. To demonstrate this simple technique, cyanide was added, at pH 10.5, to leach a pre-concentrate from Indonesia. In this test, more than 93% of gold dissolved in 6 hours. In a field test in Ecuador, an ore sample was ground in Chilean mill and then pre-concentrated in a sluice box. The pre-concentrate, containing 17.3 g Au/t, was split: 160 kg was given to the miners to be amalgamated as usual; 695 kg was leached with cyanide in an agitated tank, and 80 kg was leached with cyanide in a ball mill. The results were quite illuminating to the Ecuadoran miners: only 26% of the gold from the pre-concentrate was recovered with amalgamation, while 94% of the gold was recovered from after 31 hours of agitated leaching with cyanide. But even better results were found using the ball mill-leaching process, where miners extracted 95% of the gold in 8 hours.

The test above convinced the Ecuadorian miners that they can replace mercury with cyanide in the ball mills. In this trial, miners were also shown how to extract the gold adsorbed on the activated carbon using a simple process conducted in a Thermo-box (soda cooler).

In addition to efforts to educate miners to reduce the use of mercury, efforts should also be made to prevent the use of mercury and cyanide together. Mercury-rich tailings are often leached with cyanide to recover additional gold. Leached mercury forms complexes with cyanide, and these complexes compete with gold during the zinc precipitation process (Merrill-Crowe Process) or during adsorption by activated carbon. As a result, the effluents from these processes are rich in soluble mercury cyanide. In addition, some mercury remains in tailings after leaching, and these tailings, which now contain both residual mercury and cyanide, are dumped into rivers. Mercury-cyanide complexes are very mobile and are also very bio-available, as evidenced by high levels of mercury in fish that have been observed in the areas where artisanal miners are using both mercury and cyanide. This practice of using cyanide after mercury amalgamation has led to major environmental problems in Brazil, Ecuador, Indonesia, and Zimbabwe. Miners should be warned against this practice.

Section 2: Non-mercury Processes

Direct Smelting of Gold Concentrates as an Alternative to Amalgamation in Small-scale Gold Mining Operations; Dr. Sulemana Al-Hassan, School of Mines, University of Tarkwa, Ghana

Several ASGM processing methods are common in Ghana, including washing and panning, shallow pitting, and shaft mining underground. While mercury use has traditionally been widespread, direct smelting is being introduced as a viable alternative. It is effective and easy, suitable for processing small batches of concentrate and allows miners to track their products throughout the process.

Once a gravity concentrate has been made using panning methods, fluxes are added to the concentrate to assist melting and to react with other metals and impurities so that these separate out. Cheap, non-toxic fluxes are used; these include borax, sodium carbonate and silica sand. Clay crucibles are used to smelt the concentrate in small furnaces which must get very hot (> 1000 degrees). The heavy gold sinks to the bottom of the graduated crucible and a glassy slag containing the unwanted components lies above it. Once the crucible and its contents are adequately cooled it is smashed and the gold bead is knocked off the base of the glass slag.

When developing this approach, the methods were adjusted to address high sulphur content in concentrates; high metal content in addition to gold; crucibles failing at high temperatures; and the need for fuels other than wood. Gas fuel furnaces are showing strong potential as an alternative fuel source. Another concern is that there is some gold left in the slag – to deal with this, the shattered slag is kept, crushed and smelted again.

The kits used for direct smelting are easily assembled by local artisans, and there has been good demand for these kits among the miners in Ghana since their introduction.

Reducción del Uso de Mercurio en Vetas-California, Departamento de Santander, Colombia; Erwin Wolff, Profesional Especializado CDMB, Santander, Colombia

Project Rio Surata (Reducción de la Contaminación Ambiental Debida a la Pequeña Minería en la Cuenca del Río Suratá) is funded by the BGR and the ministry of mining in the state of Santander. The goal is to reduce the environmental effects of ASGM, including mercury emissions. In the past, waste management has not been considered or used in the region.

The project has replaced mercury with cyanide for many small scale miners. This controlled use of cyanide has reduced the amount of mercury pollution flowing into the rivers. Chemical controls have reduced cyanide concentrations, production costs, and the pollution associated with gold recovery. Gold production has increased while mercury and cyanide consumption have been reduced. One of the main challenges has been overcoming the mistaken belief among miners that using more CN and Hg means getting more gold. Interventions have focused on introducing pH control and improvement in gravimetric concentration through better grinding. Teaching the miners to effectively retrieve the silver present in the ore has also been widely successful.

Section 3: Reduction of Mercury Use and Emissions by Miners

Tecnologias Apropiadas Para Disminuir la Contaminación con Mercurio en la Mineria del Oro a Pequeña Escala; Jose Francisco Meneses, Metallurgical Technician from Nariño, Colombia

In the state of Nariño, Colombia, a program to encourage reduction of mercury use among small scale miners in a cooperative has shown good results. A demonstration unit is used to show miners better practices and encourage them to use similar methods. Pre-treatment of ore using various reagents, including those derived from local plants, is enabling much higher recovery. Ore is processed in a hermetically-closed 'trammel' type mill, 80-100kg at a time, for 1.5 hours, with reagents, after which a smaller amount of activated mercury is used to amalgamate gold from the ore. Activated mercury is most effective when used directly after it has been reactivated and before it becomes oxidized, within approximately 2 hours. Mercury reactivation kits are readily available, which consist of a cell containing a saline solution, two electrodes, and a source of energy (a battery or electrical adapter).

After the amalgam is collected, the remaining ore passes through an elutriator and then over a sluice box with carpets. The process of separating the recovered gold from the mercury is carried out in a closed retort, which prevents air contamination and allows for the recovery of the used mercury.

Mercury Use Reduction and Land Reclamation in the Tapajos Region, Brazil; Rodolfo Neiva de Sousa, University of British Columbia, Vancouver Canada

As part of the Global Mercury Project, a training program was carried out in the Tapajos region of Brazil. The main objectives were (1) protecting forest and water; (2) reducing mercury use; (3) improving health and sanitation; (4) promoting legalization of mines; and (5) improving gold production. The project used a 'training of trainers' approach: a cadre of miners were trained on best practices, and then these miners were then sent out to communities to train other miners. In this way over 4000 miners were trained in a single year. The "best" mercury use practices promoted by this project included reactivation of used mercury, recycling of mercury using retorts, and using pools for amalgamation.

- **Reactivation**: Miners learned how to reactivate mercury by using an electrolytic process with a car or motorbike battery and 10% table salt solution (Pantoja, 2000). This simple process forms sodium-amalgam which is more coalescent and effective in the amalgamation process than pure mercury. Sodium amalgam is easily recovered, and less mercury is lost by "flouring" (droplets formation). This method was promptly assimilated by the miners since more gold is recovered from the gravity concentrates when reactivation is used, thus increasing profits.

- **Retorts**: Retorts reduce miners' exposure to mercury vapors and recover mercury to be reused. Many different types of retorts were demonstrated to miners, such as those made of kitchen-bowls or with salad cups or water pipes. The program also bought retorts from a local manufacturer and donated to miners. The measured mercury recovery was above 95% using this local retort.

- **Pool amalgamation**: Miners were taught to excavate a small pool far away from rivers and line it with canvas or a plastic sheet. Then, miners amalgamate the concentrates in these pools, and any mercury lost is confined to the pool and can be recovered.

Methods for reducing other environmental impacts of mining were also promoted in the program. As most artisanal miners work with alluvial and colluvial gold along the riverbanks, the most common practice is just to dump the tailings into the river. The miners were trained instead to return sediments to back-fill old pits. The soil is contained in the pits and the reclaimed water is returned to the operations. Sometimes miners work in new areas where no old pits are available to receive tailings. In these cases, miners dispose tailing over land or in the rivers. Miners were taught to build a triple barrier made of palm leaves that retain a large part of the tailings. Miners were also informed of the advantages of rehabilitating degraded areas, and some of them have started a modest plantation of fruit trees (such as mango and cashew trees) for their own consumption.

Section 4: Mercury Emissions Reduction and Recovery at Gold Shops

Reducing Mercury Emissions of Small Scale Gold Buying Shops in Amazonia: Designing and Implementing Low Cost, Easy to Build and Effective Mercury Capture Systems in Gold Shops in Brazil and Peru; Ms. Daniela dos Santos Pinto, Brazilian Agency for Environment and Information Technology/ USEPA

A mercury capture technology developed by Argonne National Laboratory with support from the USEPA has been introduced for use at gold shops where amalgam is burned in fume hoods on a regular basis. The system contains a powerful extractor fan that creates negative air pressure which draws the exhaust from the fume hood into the mercury capture system, which is housed in a 200 liter metal drum. A series of baffle plates act as impaction surfaces for mercury aerosols to strike and coagulate. The extractor fan and the baffle plates are joined in a single unit that is easy to transport and insert into the 200 liter drum.

Installations and trials with the system have already been carried out in Brazil and Peru. Tests have shown the apparatus to be effective for capturing at least 80% of the mercury in the vapor. This will reduce the environmental release of and human exposure to mercury vapors from gold shops which are typically located in urban areas.

The system is affordable for the majority of gold shops in developing countries – estimated cost for materials, labor and installation is $450 (USD). It is easy to construct using locally available materials and local technologies; is low maintenance; relatively lightweight (50 kg) and transportable.

Fume Hoods for Mercury Capture in Gold Shops – Indonesia; Daniel Stapper, University of Victoria, Victoria Canada

A mercury capture and recovery technology has been successfully demonstrated at gold shops in Indonesia. The technology is a simple water trap made using a plastic Tupperware container, a fan and some plastic plumbing fixtures. It is designed to recover the mercury from amalgam burning in gold shops or by miners in the field. The technology is extremely portable – the presenter unpacked it from a mid-sized suitcase and assembled it as part of the demonstration. It is designed as an add-on to pre-existing fume hoods (in Indonesia these are small, made of wood panel and have chimneys). The chimney vapor is redirected to the water trap which sits on a shelf mounted next to the fume hood.

A fan draws mercury vapor through the water trap which consists of a 20 liter Tupperware filled with water to a depth of approximately 10cm. The apparatus forces the water to froth and bubble as the mercury vapor passes through, causing it to cool and the mercury to condense. When this happens, clean elemental mercury settles below the water in the plastic bin where it can be recovered and resold or reused. On the other side of the fan the residual vapor (that may still have some mercury left in it) can be passed through an activated carbon filter (optional) and is then be vented back to the chimney.

The estimated cost of this mercury trap system is $30 (USD) in Indonesia, where Chinese made ‘Blower fans’ can be purchased for approximately $20. A strong fan is required and is a critical element of the design. In tests to date, approximately 80% of the mercury has been recovered; further test results are forthcoming. The system is easy for miners and gold-shop owners to install, understand, and benefit from. Due to interest in the system at the conference, a schematic of the system was photocopied and distributed.

Appendix A: Presenter List

Susan Egan Keane, Natural Resources Defense Council (NRDC)

Dr. Marcello Veiga, University of British Columbia;

Dr. Kevin Telmer, University of Victoria (British Columbia)

Dr. Sulemana Al-Hassan, University of Mines and Technology, Tarkwa, Ghana

Jose Francisco Meneses, Miner, Corponariño region, Colombia

Rodolfo Neiva de Sousa, University of British Columbia

Erwin Wolff, BGR/Colombia

Ms. Daniela dos Santos Pinto, Brazilian Agency for Environment and Information Technology

Daniel Stapper, University of Victoria (British Columbia)