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Antioquia, Colombia: the world's most polluted place by mercury: impressions from two field trips

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Table of Contents

1. Executive Summary

Worldwide, artisanal gold miners are the main consumers of mercury, using and losing almost 1000 tonnes of metallic mercury per annum or more than 30% of all mercury annually used by different industrial applications[1]. Mercury emitted to the atmosphere and released to the environment has serious environmental and health implications. As the price of gold has been increasing, more artisanal miners are mining and processing gold using rudimentary procedures. About 10 to 15 million artisanal and small gold miners worldwide are working in more than 70 countries to produce around 350 tonnes of gold annually. The number of artisanal gold miners in Colombia is also increasing and the mercury pollution can be as high as 150 tonnes/a giving to the country the shameful first position as the largest world's mercury polluter per capita from artisanal gold mining.

The amalgamation of the whole ore using "cocos" as well as the burning of amalgams without any recovery (condensation) or even filters, are likely causing serious environmental and health problems to the population of the mining towns in the Department of Antioquia. This Department has between 15000 and 30000 artisanal gold miners producing something between 10 and 20 tonnes of gold per annum. Officially the total gold production of the Department of Antioquia in 2008, from companies and artisanal miners, was around 26 tonnes or 63% of the Colombian gold production (41.5 tonnes/a).

This report brings personal observations based on two field trips to the goldfields of Antioquia: one in September 2007 another in December 2009 In these two trips, it was visited the 5 municipalities in Antioquia (Remedios, Segovia, Zaragoza, El Bagre and Niche) selected by UNIDO to implement the Mercury Project in Colombia, and one municipality at the South of the Department of Bolivar, San Martin de la Loba. In the 5 municipalities in Antioquia there are around 13000 workers directly involved in gold mining and jewellery. Indirect data on mercury releases and emissions from the 5 Antioquian municipalities selected by UNIDO indicate that **around 50 tonnes/a are lost** in which 33 tonnes are likely lost with tailings to the terrestrial and aquatic environment and 17 tonnes are emitted to the air. These data need to be confirmed by a accurate mass balance in the processing centers (known as "entables"). The use of mercury in the "cocos" is an inefficient process that loses gold and as much as 50% of the mercury entering the process. The gravity of the mercury pollution was confirmed by air analyses using two spectrometers, LUMEX and Jerome. The pollution is caused by the fact that the "entables" amalgamate the whole ore in the urban environment and gold shops purchase and burn amalgams with 40 to 50% mercury also in towns. The usual levels of mercury downtown Remedios, Segovia and Zaragoza, in front of the "entables" or gold shops range from 2000 to 10000 ng of Hg/m^3 of air, when the World Health Organization established as 1000 ng/m^3 the guideline for public exposure. Levels of 10000 ng/m^3 were measured in front of a school in the location known as La Cruzada. The levels of mercury in air in these towns were usually 10 to 20 times higher than the normal levels analyzed outside the towns (10 to 20 ng/m^3). Inside the "entables", when the "cocos" are operating grinding gold ore with mercury, the air can reach levels near 1 million ng/m^3. Inside the gold shops, when amalgams are not being burned, the levels in air can reach 200000 ng/m^3. Neurological effects of mercury vapour were studied by academics in Antioquia and threatening results revealed that children are being impacted.

[1] Swain,E.B.; Jakus,P.M.; Rice,G.; Lupi,F.; Maxson,P.A.; Pacyna,J.M.; Penn,A.; Spiegel,S.J.; Veiga,M.M. (2007). Socioeconomic Consequences of Mercury Use and Pollution. *Ambio*, v. 36, n. 1, p.46-61.

The main suggestion for immediate action of the Colombian authorities is the creation of a regulation to prohibit the use of mercury in towns, either in "entables" or burning mercury in gold shops. All activities handling metallic mercury must be done outside the towns. The main recommendations for the UNIDO Mercury Project include evaluation of mercury emissions/releases (mercury balance), assessment of transportation and mobility of the atmospheric mercury in the towns and an immediate awareness campaign for miners and population. Other activities related to demonstration of cleaner techniques such as the use of individual retorts, condensers/filters and gravity concentration processes followed by controlled cyanidation are also suggested.

On October 23rd, 2009, United Nations Environmental Programme (UNEP) organized a meeting in Bangkok to discuss a way to stop mercury exports through a Legally Binding Treaty involving the UNEP member countries. The target will be the banning of mercury trade by 2013. The Government of Colombia has been actively participating in the discussion of this treaty attending regularly the international meetings. In this case, the Colombia authorities should also work hard to provide technical assistance to artisanal gold miners in order to change their technology from amalgamation to cyanidation or other process and keep this important economic activity in the rural areas of Antioquia and other Departments alive.

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2. Introduction

The mercury contamination in Colombia by artisanal gold mining (AGM) has been recognized by a number of researchers and local authorities for more than one decade (Hartnagel et al., 1994[2]; Ingeominas, 1995[3], Veiga, 1997[4]). In 2006, representatives from the Government of Antioquia Department requested technical assistance to UNIDO in order to apply the same methodology that UNIDO was using in 6 other countries within the GEF/UNDP/UNIDO Global Mercury Project. With seed funds provided by the Antioquia Government, UNIDO Mercury Project started in September 2009, selecting 5 municipalities in Antioquia (Remedios, Segovia, Zaragoza, El Bagre and Niche, Fig. 1) to evaluate the levels of mercury being released by the AGM and to implement simple interventions for an emergency reduction of the mercury emissions. These are the main gold producing municipalities in Antioquia. My first field trip to the gold region in the Northeast of Antioquia occurred in September 2007 when the 5 municipalities were visited. These 5 municipalities concentrate the main artisanal gold activities of the Antioquia Department and there are 151,000 inhabitants. According to a recent Census conducted by the UNIDO Project, there are about 13000 people directly involved in the gold business in which 7000 are hard rock miners, 2550 work in processing plants and equipment production, 1200 alluvial miners, 2000 panners ("barequeros") and 250 workers in gold shops and jewelries.

In a second trip in December 2009, Remedios, Segovia, Zaragoza, Caucasia and San Martin de la Loba (Department of Bolivar) were visited. It is estimated that there 17 municipalities in Antioquia where artisanal gold mining or gold processing or gold/amalgam smelting are practiced.

Colombia has been witnessing vibrant changes of its economy but the rural communities are still struggling to survive. According to the UN Human Development Report[5] published by the United Nations Development Programme (UNDP) in 2009, there are 16% of Colombians still living with less than US$ 1.25 per day and 27.9% with less than US$ 2/ day. The social tensions and presence

[2] Hartnagel, B.; Cramer, S; Bermudez, R. (1994). Reduction of Environmental Contamination from Small MIners in Bucaramanga. Division Regional de Minas de Bucaramanga. Conv. Germany-Colombia (in Spanish).
[3] INGEOMINAS-Inst. Investigaciones en Geociéncias, Mineria y Química, Min. Mines and Energy (1995). Colombia, a Gold Mine. 25 p. (in Spanish).
[4] Veiga,M.M. (1997). Introducing New Technologies for Abatement of Global Mercury Pollution in Latin America. Published by UNIDO/UBC/CETEM. Rio de Janeiro, 94p. ISBN: 85-7227-100-7. (book)
[5] UNDP-United Nations Development Programme (2009). Human Development Report. Overcoming Barriers: Human Mobility and Development. 229p. http://hdr.undp.org/en/reports/global/hdr2009/

of armed groups have pushed the terrorized population to live agglomerated in towns. The rural areas have also witnessed an increasing number of illegal plantations of coca with less or virtually no cattle farms. Nowadays, only 26% of the 45.6 million Colombians live in the rural areas. This is more evident in the Northeast of Antioquia Department. In spite of a gradual reduction of poverty over the recent years, the Colombian statistics department DANE estimates that in 2006, at least 62% of the rural population live in poverty (Perfetti, 2009) [6].

Fig. 1a – Map of Colombia indicating the Department of Antioquia
Source: wikimedia.org

Fig 1b – Map of Antioquia indicating the gold districts selected by UNIDO

In this scenario of poverty and terror, gold mining became a natural option for the rural communities in many Departments in Colombia. Without technical assistance, gold mining started in a very artisanal fashion, using rudimentary techniques and has been generating huge environmental and health impacts. In Antioquia alone it is estimated that there are between 15000 to 30000 artisanal gold miners producing something between 10 and 20 tonnes of gold per annum. The

[6] Perfetti, J.J. (2009). Crisis y Pobreza Rural en América Latina: el Caso de Colombia .Documento de Trabajo N° 43 Programa Dinámicas Territoriales Rurales Rimisp – Centro Latinoamericano para el Desarrollo Rural. Available at: http://www.rimisp.org/FCKeditor/UserFiles/File/documentos/docs/pdf/DTR/N43_2009_Perfetti_crisis-pobreza-rural-caso-Colombia.pdf

gold production from artisanal miners in Antioquia is not quite well established but it is estimated by local experts that around 10 tonnes/a of gold (or 50% of the official gold production) are smuggled and not officially considered. The majority of the gold production comes from the 5 municipalities included in the UNIDO Project. Local authorities[7] revealed that the total gold production of the Department of Antioquia in 2008 was around 26 tonnes from companies and artisanal miners. The official gold production in Colombia in 2008 was 41.5 tonnes[8]. Numbers are still very fuzzy in Antioquia since a Mining Census has not been implemented yet.

It was mentioned by the mayor of Zaragoza that more than 97% of the mining activities in the region are illegal as they lack permits either from the mining or from environmental authorities. As a result of the presence of guerrilla groups in the rural area, most gold ore is processed in the urban environment in Remedios, Segovia and Zaragoza. These processing centers known as "entables" are located beside schools, residences, grocery stores, pharmacies, etc. A common characteristic of the "entables" is the lack of gold concentration process, i.e. the material mined outside the towns are added to small ball mills that can take about 65 kg of ore with mercury. The amalgamation of the whole ore is the worst process in terms of gold recovery and mercury losses are substantial. After amalgamation the Hg-contaminated material is subjected to vat-leaching (percolation) with cyanide solution which produces a more bioavailable and toxic form of mercury, mercury cyanide that has been discharged into the local creeks.

The amount of mercury being used and lost in Colombia is not well known. A study conducted by Telmer and Veiga (2008)[9] estimated that the annual mercury emissions/releases from AGM in Colombia can be between 50 and 100 tonnes, but it seems that this can reach as much as 150 tonnes/a, according to local sources. In this case Colombia occupies the 3rd place in mercury emissions from AGM just after China (240 to 650 tonnes of Hg/a) and Indonesia (130 to 160 tonnes

[7] Lopez Correa N. (2009). Potencial Minero Antioqueño. Secretary of Mines of the Dept of Antioquia. http://www.birdantioquia.org.co/uploads/Presentaci%C3%B3n%20Secretario%20de%20Minas%2016%20abril.pdf

[8] Bronstein, H. (2009). Gold Production in Colombia. http://poorbuthappy.com/colombia/post/colombia-gold-production-1463-million-ounces/

[9] Telmer,K. & Veiga,M.M. (2008). World emissions of mercury from small scale artisanal gold mining and the knowledge gaps about them. In: Mercury Fate and Transport in the Global Atmosphere: Measurements, Models and Policy Implications. Pirrone, N. and Mason, R. (Eds). Chapter 6. p. 96-129. UNEP-United Nations Environment Programme

of Hg/a). In terms of mercury emissions per capita from AGM, Colombia is likely the world's main polluter.

Mercury has been legally imported to Colombia but local miners in Antioquia also reported buying mercury from illegal suppliers who bring the metal from Peru. The amount of mercury consumed by the only alkali-chlorine plant in the country is not available and must be investigated. Very likely a large portion of the mercury legally imported into Colombia is for use in artisanal gold mining. According to the UN COMTRADE (United Nations Commodity Trade Statistics Database), (2009) Colombia imported 71.44 tonnes of metallic mercury in 2007 and 79.04 tonnes in 2008. The main countries exporting metallic mercury to Colombia are listed in Table 1.

Table 1 – Countries exporting metallic mercury to Colombia in 2008

Source: UN COMTRADE (2009)

Country	**Tonnes/a Hg**
Netherlands	25.36
Spain	19.04
Mexico	13.33
Germany	8.63
USA	6.91
Russia	3.11
UK	1.38
Kyrgyzstan	1.28

3. Gold processing Procedures

3.1. Mercury Losses by the "Entables"

Miners accumulate as little as 2 tonnes of ore to take to the "entables" (processing plants) to be processed. The mining process can take 20 days. The "entable" owners charge the miners a nominal fee of US$ 0.5 to 1 per "coco" with the condition that the miners leave their tailings in the "entable" facility to be further leached with cyanide. Some "entables" have 5 to 10 "cocos" (small ball mills) and others have as many as 80. An average "entable" has 40 "cocos". UNIDO has estimated that there are between 2500 and 2700 "cocos" in the 5 municipalities studied in Antioquia.

About 60 to 70 kg of ore is added to each “coco” together with about 100 to 120g of mercury brought by the miners to the “entable”. Other ingredients (Fig. 2) such as lime, molasse, lime juice, sodium bicarbonate, etc. are also added to the “cocos” to reduce the mercury surface tension in order to trap more gold. The change of pH from 11 ($Ca(OH)_2$) to 5 (lime juice) between amalgamation steps definitely provides some coalescence to mercury droplets but, it is visible when the material is panned, that a large portion of mercury is pulverized and lost during the grinding process.The “cocos” run for 1 to 4 hours depending on the “entable” and type of ore being processed (rich or poor in gold). The grinding rotational speed of the “cocos” was measured. The “cocos” run at a speed 35% faster than the critical grinding speed. In other words, for efficient grinding the speed must be reduced. The minerals from the ‘cocos” are separated from the amalgam with an improvised elutriator. Mercury is trapped at the bottom of the elutriator and the minerals are rejected by overflow. This tailing is then collected in a concrete pool, dried under the sun, to be leached with cyanide. It seems that the mercury losses in the “coco” process are between 25 and 35% but this must be further investigated.

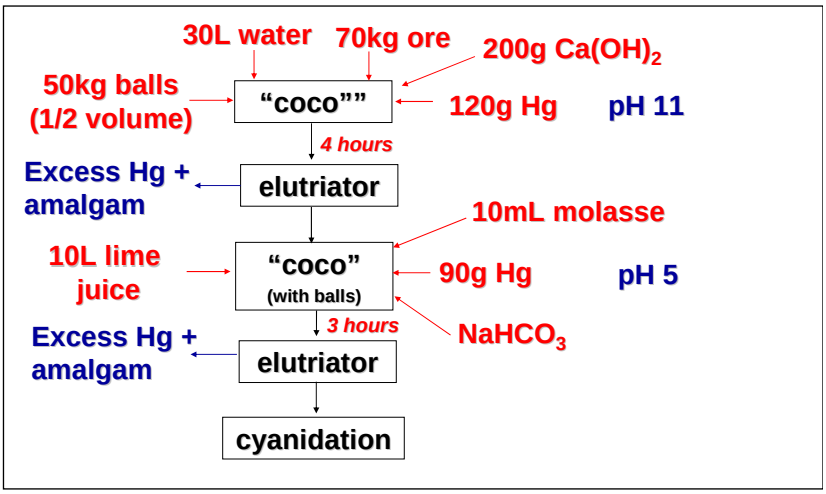


Fig. 2 – Flowsheet of a typical whole ore amalgamation in a “coco”

A flowsheet of the unit operations involved in an “entable” is shown in Appendix 1. The amount of “entables” in the 5 towns selected by the project has being investigated by the UNIDO team but roughly there are 323 “entables” (Table 2). In Remedios, Segovia and Zaragoza, the “entables” operate in the urban environment using “cocos” but in El Bagre and Nechi most “entables” are located outside the town but they also amalgamate the whole ore either using “cocos” or using

copper-amalgamating plates. It was also described and observed in Zaragoza, a large contingent of miners processing alluvial material using backhoe excavators to feed a two-deck sluice box. It was mentioned that miners fill the lower deck of the sluice boxes with mercury. This definitely results in high mercury losses to the environment by attrition of the ore pulp with the mercury drops trapped in the riffles.

Table 2 – Number of "entables" in the 5 municipalities of the UNIDO Mercury Project

Municipality	**Number of Entables**
Remedios/La Cruzada	24
Segovia	94
Zaragoza	47
El Bagre	123
Niche	35
Total	323

An important variable to be investigated is the ratio Hg_{lost}:$Au_{produced}$. This ratio has been used as a parameter to quantify Hg releases from artisanal gold mining operations. One of the common and confusing issues in reporting this ratio is that some authors report the amount of mercury used, which does not necessarily reflect the amount of Hg lost. The main amount of Hg recovered in the process is when excess Hg is squeezed off with a piece of cloth. This Hg is recycled. The ratio of Hg_{lost}:$Au_{produced}$ varies from one operation to another and, when very little gold is produced, the ratio provides a false idea that a high amount of Hg is lost. It is clear that this ratio must be used regionally as a result of (monthly) production of several operations. Those processing plants that recover no or little gold should not be considered. The Hg_{used}:$Au_{produced}$ ratio is a variable that depends on the amalgamation process (Table 3). When only gravity concentrates are amalgamated and retorts are used to condense mercury from amalgams, the mercury losses can be minimized.

Table 3 - Mercury losses according to amalgamation method

Amalgamation Method	**Hg lost : Au produced**
Whole ore	>1
Concentrates, no retort	1
Concentrates, with retort	0.001

Interviewing some miners working in the "entables" in Remedios and Segovia, the Hg_{lost}:$Au_{produced}$ ratio obtained was between 10 and 15 which is compatible with similar operations of whole ore amalgamation in ball mills observed in Talawaan, N. Sulawesi, Indonesia[10]. If in the 5 municipalities in Antioquia there are 323 "entables" and the amount of mercury lost by each "entable" ranges from 5 to 20 kg/month (60 to 240 kg/a), then likely these 5 municipalities are releasing to the aquatic environment and emitting to the atmosphere something between 19 and 76 tonnes of Hg per annum. **In average, 48 tonnes of Hg/a have been likely the amount of mercury released to the environment (air and water)**. In another inventory, UNIDO Mercury Project in Colombia (Mr. Oseas Garcia, personal communication) evaluated the amount of mercury used per "coco". It was observed that each "coco" uses in average 100 g/day of mercury and, according to some entable's owners, 50% of this is lost, then in 2600 "cocos" in the 5 municipalities studied, about **47 tonnes/a of mercury is lost**. In Portovelo, Ecuador, in similar operations of whole ore amalgamation in ball mills (known as "chanchas"), it was quantified that 42% of the mercury is lost in which 2/3 is lost with tailings and 1/3 is lost by evaporation when amalgam is burned[11].

Considering that 10 tonnes/a of gold is produced by artisanal miners in the 5 municpalities in which 50 to 70% of the gold is extracted by amalgamation and 30 to 40% is extracted by cyanidation of the tailings. The reported gold recovery by amalgamation seems very high for such a rudimentary process. Again, these numbers are not very reliable and must be further investigated. If we assume that amalgamation is recovering 50% of 10 tonnes the gold and the Hg_{lost}:$Au_{produced}$ ratio is 10, then the amount of **mercury lost is around 50 tonnes/a**. An accurate mercury and gold balance in some typical "entables" can provide better numbers about the mercury emissions and gold production in the region. How much of this mercury is released to the aquatic environment and how much is emitted to the air, just a mass balance can answer. If the same split of mercury losses found in Ecuador is applied to Antioquia, then, around 33 tonnes/a of mercury is lost with tailings to the terrestrial and aquatic environment and 17 tonnes/a is lost when amalgams are burned. As there is a

[10] Veiga, M.M. (2003). Information about the Project Sites in Indonesia. Report of the Glpobal Mercury Project. GEF/UNDP/UNIDO. 11 p. http://www.globalmercuryproject.org/countries/indonesia/indonesia.htm

[11] Velasquez,P.C.; Veiga,M.M.; Hall,K. (2010). Mercury Balance in Amalgamation in Artisanal and Small-scale Gold Mining: Finding Ways to Reduce Environmental Pollution in Portovelo-Zaruma, Ecuador. *J. Cleaner Production*, v. 18. n.3 p.226–232

large variation on the amount of Hg purchased by each “entable”, it is difficult to establish an accurate estimate of mercury losses.

3.2. Cyanidation of Hg-contaminated Tailings

The tailings from the “cocos” with up to 5000 ppm of mercury are subjected to cyanidation in vat leaching with subsequent gold precipitation with zinc shavings. This usually happens in the “entables” where owners excavate tanks on the ground and line them with permeable cotton rags to allow filtration of the cyanide solution. The filtrated solution passes through a wooden box filled with zinc shavings where gold is precipitated. The operators in Antioquia do not pay attention to the re-dissolution of gold when the zinc precipitation is not conducted under vacuum and usually the gold is lost with the effluents. After gold precipitation on the zinc shavings, the solution is pumped back to the percolation tank. This leaching cycle occurs from 8 to 30 days, depending on the ore grade of the tailings. This is far too long and indicates a lack of aeration in the vat. The amount of mercury retained by the zinc shavings must be evaluated in a mass balance. At the end of the leaching process when miners visually notice that there is no more gold being precipitated on the zinc shavings, they discharges the pulp with gold-barren cyanide solution, but rich in zinc, into local creeks. The zinc shavings, rich in gold, are burned in open-gas furnaces spreading zinc vapour to a wider area. Mercury, lead and other heavy metals in the tailings are leached by cyanide and also precipitated with zinc to be released into the urban air when the zinc is evapourated. This process could be done safely using acid (e.g. hydrochloric) to dissolve and recycle zinc as well as mercury. After burning, gold is melted and sold to the gold shops.

Another important polluting factor in leaching mercury-contaminated tailings with cyanide is that not all mercury is dissolved. In recent investigations in laboratory and in the goldfields in Portovelo, Ecuador, we observed that only 35 to 40% of the mercury from contaminated tailings is dissolved in agitated tanks. In vat leaching, as used in Colombia, it is expected that less than 30% of mercury from the tailings is dissolved. A mass balance of mercury in the cyanidation process is badly needed. The environmental implications of the lower dissolution rate of mercury are dramatic since mercury keeps reacting with residual cyanide retained in the tailings until it is dumped into the

creeks. It was already observed in Indonesia, Brazil and Zimbabwe that mercury in cyanidation tailings is much more bioavailable than metallic mercury and ready to be accumulated in fish[12,13].

3.3. Amalgam burning

The most amazing observation in Antioquia is that amalgams with 40 to 50% of mercury are burned without any condensing system in the urban environment of many municipalities. Miners also take amalgams to be burned in towns with no gold production. In the 5 municipalities selected by UNIDO Mercury Project, there are about 98 gold shops (Remedios = 14, Segovia = 57, Zaragoza = 12, El Bagre = 10, Nechi = 5), i.e. places that buy amalgams, burn off the mercury and melt the gold in front of the miners. The number of gold shops keeps changing since some shops have been closing. There is another type of businessman ("fundición") that charge miners to simply burn the amalgam and melt the gold before selling it to gold shops. An inventory of the gold shops and "fundiciónes" has been conducted by the UNIDO Mercury Project.

In the world, it is not very common to have gold shops buying amalgams. Usually, in other countries, gold shops buy only retorted gold, i.e. amalgam previously burned outside the town either with retorts or in open pans. The retorted gold, known as *doré*, still has 2 to 5% of residual mercury. Even with less mercury than amalgam, the gold shops melting *doré*, must have condensers and filters to avoid emission of mercury vapour to the urban atmosphere.

In Antioquia, miners do not use retorts to recover mercury because they believe that gold is lost in the process and because the price of mercury is low in the region. In September 2007 the price of mercury in Antioquia was US$ 35/kg and in December 2009, US$ 50/kg. In spite of the international price of mercury being US$ 18 to 20/kg, in most mining sites in other countries, the price of mercury is more expensive than in Antioquia. For example in the artisanal gold mining region in the Tapajos region, Brazil, the mercury price fluctuates between US$ 150 and 200/kg. In Tanzania and Zimbabwe the price is around US$ 100 and 150/kg. In Chile the price is between US$

[12] Castilhos, Z.C.; Rodrigues-Filho,S.; Rodrigues,A.P.; Villas-Bôas,R.C., Siegel, S.; Veiga,M.M.; Beinhoff,C. (2006). Mercury Contamination in Fish from Gold Mining Areas in Indonesia and Human Health Risk Assessment. *Science of the Total Environment.* v. 368, p.320–325

[13] Sousa,R.N. and Veiga,M.M. (2009). Using Performance Indicators to Evaluate an Environmental Education Program in an Artisanal Gold Mining in the Brazilian Amazon. *Ambio*, v.38, n.1, p.40-46.

80 and 100/kg. If the price was higher and the accessibility to purchase mercury was more difficult, miners would pay more attention to condense mercury from amalgams and recycle it.

4. Atmospheric Pollution

Using the LUMEX RA 915+ (from University of British Columbia, CERM3) and the Jerome 431X (from CORANTIOQUIA) spectrometers, the atmospheric mercury in the towns visited in the second field trip to Colombia was analyzed. LUMEX RA 915+ is a portable cold vapour atomic absorption analyzer, capable to detect 2 ng/m³ of mercury in air. The Jerome Hg analyzer has detection limit around 3000 ng/m³. The LUMEX uses a Zeeman process (Zeeman Atomic Absorption Spectrometry with high frequency modulation of light polarisation ZAAS-HFM) that eliminates interferences and do not use of a gold trap. The Jerome analyzer uses a thin gold film that, in the presence of mercury vapour, increases the electrical resistance which is proportional to the mass of mercury vapour in the sample.

A guideline for inorganic mercury vapour of 1000 ng (10^{-9} g) of Hg per m³ of air has been established by the World Health Organization (WHO, 2000)[14]. In industrial environments where workers are subjected to long-term exposure to Hg vapour, WHO (2000) has mentioned that the LOAEL (lowest-observed-adverse-effect-level) might be around 15000 to 30000 ng/m³. The recommended health-based exposure limit for metallic Hg is 25000 ng/m³ for long-term exposure (TWA - time weighed average concentration for a normal 8 hour day and 40 hour workweek, to which nearly all workers can be repeatedly exposed without adverse effect). The normal atmospheric levels of Hg in rural areas are about 2–4 ng/m³, and in urban areas about 10 to 20 ng/m³ (Veiga and Baker, 2004)[15].

The mercury levels analyzed in the ambient air of the Colombia municipalities are shown in Table 4. It is clear that the levels of mercury are far above the WHO guidelines. The simple use of mercury in the ball mills emits significant amounts of mercury vapour to contaminate streets and

[14] WHO – World Health Organization (2000). Air Quality Guidelines for Europe. 2nd Edition. WHO Regional Publications, European Series, N. 91. http://www.who.dk/document/e71922.pdf

[15] Veiga,M.M. and Baker, R. (2004). Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-scale Gold Miners. Published by GEF/UNDP/UNIDO Global Mercury Project. Vienna, ISBN 92-1-106429-5, 289p.

neighboring houses in the visited municipalities. The employees of the gold shops, working in extremely contaminated sites are likely the most intoxicated individuals, but toxicological and neuropsychological exams were not performed. The University of Antioquia conducted a toxicological investigation of kids from Segovia and concluded that more than 70% of the children show signs of psychological alteration likely caused by long-term exposure to mercury vapours. Specific neuropsychological tests to characterize mercury intoxication must be applied by the UNIDO Mercury Project.

Table 4 – Measurements of atmospheric mercury in selected parts of the described towns

Location	Hg (ng/m³)	Remark
REMEDIOS		
Remedios-Segovia road	10-20	In the field, inhabited area
Main plaza	100-400	In a holiday, few gold shops working
Inside the City Hall	100-200	In a holiday
Calle Real (on the street)	500-5000	In a holiday; at least 6 gold shops in this street but not burning amalgam.
In front of a gold shop (on the street)	3000-5000	In a holiday
Inside a gold shop	5000-60000	Gold shop not operating
Inside a bakery	200-300	In a holiday; bakery neighbour a gold shop
La Cruzada (on the street)	5000-10000	Near a school
La Cruzada (on the street)	500-900	In front of an “entable” operating
La Cruzada (on the street)	1000-3000	In front a concentration of 6 “entables”
SEGOVIA		
Main plaza	100-200	In a holiday
Calle Real (on the street)	150-300	In a holiday
Calle 48 (on the street)	1000-1500	In a holiday
Entable Guamo	15000-20000	At the door of the “entable”; “cocos” working
Entable Guamo	Up to 80000	Near “cocos”
Inside another “entable”	Up to 943000	Near “cocos”; probably somebody had burned amalgam inside the “entable”
Calle Castillos	Up to 40000	Near a school
In front of gold shop (on the streets)	3000-5000	Gold shops not burning amalgams
“Fundicion” Calle 47A (on the street)	3000-5000	Amalgam being burned with a mercury condensing system
At the door of this “fundición”	20000-30000	
Inside this “fundición”	40000	
At the nose of the operator (in the same “fundición”)	60000	A child was near this worker
At the exit of the condensing system	100000	
When Zinc precipitate is melted	616000	
ZARAGOZA		

Main plaza	40-50	
Main Street with 4 gold shops	1000-3000	Measurements on the street; no amalgam was burned
Street with no gold shop	800-1000	Parallel to main street
Inside a gold shop	Up to 80000	No amalgam was being burned
Expired air (“entable” worker)	Up to 2500	Miner exhaled air into the LUMEX
Clothes of this worker	5000	
Hands of this worker	6000	
Expired are (no workers)	50-500	Kids showed higher levels
CAUCASIA		
Streets (no gold shop)	30-40	
Calle 21 (5 gold shops)	4000-5000	Measurements on the street
Inside the gold shops	100000-200000	No amalgam was being burned
Inside a pharmacy	5000	Other side of the street from a gold shop
SAN MARTIN de la LOBA		
Inside of an “entable”	7000-8000	Far from “cocos”
Near “cocos”	Up to 80000	“Cocos” were located in open environment with plenty of ventilation
Inside the City Meeting House	5000	Somebody contaminated with mercury brought dust to the building

It is possible to observe in Segovia (Table 4), that when a 200 g amalgam with 100 g of mercury, is burned in a fume hood with an efficient condensing system, the exhausted gas still contains 100000 ng/m³ which is 100 times higher that the WHO (World Health Organization) guidelines for public exposure. In other words, even if the mercury abatement system had efficiency of 99.99%, the gases would still leave the facilities with large amounts of mercury. Palliative solutions can be implemented but a definitive solution is needed. Filters and condenser can bring to the public and operators the false idea of safety, but there is no way to resolve this problem with condenser and filters since the amount of mercury burned is very high.

Fig. 2 – Tupperware Hg condenser implemented in 35 gold shops in Galagan, Kalimantan, Indonesia.

The 35 home-made fume hoods installed by the GEF\UNDP\UNIDO Global Mercury Project team in Kalimantan, Indonesia, were made with a 150W exhaustor connected to a water box which was a transparent Tupperware (Fig.

2). With positive pressure on the water tank, this condensing system was useful for abatement of 95% of the mercury. This procedure was implemented to condense Hg vapour from amalgams once the Indonesian miners and gold shop owners refused to use retorts in the field. The condensers reduced substantially the mercury pollution in the town of Galagan but the air is still contaminated with mercury. It is important to highlight that those Indonesian gold shops use to burn less than 30 g of amalgam per batch. In Antioquia, the problem is worse than in Indonesia as gold shops burn more than 200 g of amalgam per batch. The use of condensers can reduce the levels of mercury in the urban atmosphere but they will not solve the problem, since the mercury levels in air will still be above the WHO guidelines. The only solution is NOT burning amalgams in towns.

There is no "entable" in the town of Caucasia, but the fact that miners are bringing amalgams from other municipalities to this town, causes not only loss of royalties by the municipality where the gold was mined but also a huge pollution in a very populated city (second of Antioquia).In Table 4, it is possible to observe high levels of mercury in the air of Calle 21, in Caucasia. Due to the poor ventilation of the street, the levels of mercury are very high everywhere, including inside a pharmacy at the same side of the street as the gold shops.

In Caucasia, it was demonstrated to a gold shop owner using the two mercury spectrometers that the levels of mercury inside the shop were around 200000 ng/m^3, and nobody was burning any amalgam (Appendix 2). The owner did not believe in the measurements and said that he had recently analyzed his urine and the levels of mercury were "normal". It was explained to him that mercury in urine can decrease to a background level (for example 5 µg/L) in less than 15 days, but this does not mean that there is no mercury already in his brain. What he did not know is that the total mercury levels in urine would not be expected to correlate with neurological findings once exposure has stopped[16].

Several studies are in agreement that mild subclinical signs of central nervous system toxicity can be observed among people who have been exposed occupationally to elemental mercury vapour at a concentration of 20000 ng/m^3 or above for several years. Extrapolating this to continuous exposure and applying an overall uncertainty factor of 30 (10 for interindividual variation and 3 for

[16] Veiga and Baker (2004). Op.cit.

extrapolation from a lowest-observed-adverse-effect level, or LOAEL, with slight effects to a no-observed-adverse-effect level, or NOAEL), a tolerable concentration of 200 ng/m³ was derived. (WHO, 2003)[17]

A short-term exposure to high Hg levels causes clinical symptoms that mainly involve the respiratory tract. Mercury levels in the urine of new workers should be lower than those of workers with a longer duration of exposure (Stopford, 1979)[18]. Symptoms typically associated with high, short-term exposure to Hg vapour such as those miners are subjected to when they burn amalgams in gold shops, are chest pains, dyspnoea, cough, haemoptysis, impairment of pulmonary function and interstitial pneumonitis (Stopford, 1979). Acute Hg poisoning, which can be fatal or can cause permanent damage to the nervous system, has resulted from inhalation of 1,200,000 to 8,500,000 ng/m³ of Hg (Jones, 1971)[19]. A few hours of exposure to high Hg levels may cause acute chemical bronchitis and pneumonitis. Two hours after exposure, lung injury appears as hyaline membrane formation, and finally, extensive pulmonary fibrosis occurs. Clinical findings correlate with the duration of exposure, the concentration of Hg and the survival time after exposure. In Japan, autopsies performed on 3 individuals who died due to acute high level Hg vapour exposure (2 weeks) revealed diffuse organized pneumonia, renal cortical necrosis, disseminated intravascular coagulopathy, and infarctions in the brain and kidneys. Drugs such as chelating agents and corticosteroids appear to effectively decrease the inflammation and delay pulmonary fibrosis (Asano et al, 2000)[20]. Experiments with animals indicate that continuous exposure to Hg above 300 ng/m³ of air may present a health hazard. Long-term, low-level Hg vapour exposure has been characterized by less pronounced symptoms of fatigue, irritability, loss of memory, vivid dreams and depression (WHO, 1991a)[21]. Occupational exposure of Hg has resulted in effects on the central nervous system. Acute exposure has caused delirium, hallucinations and suicidal tendency as well as erethism (exaggerated emotional response), excessive shyness, insomnia and, in some cases, muscular tremors. The latter symptom is associated with long-term exposure to high levels of Hg vapour. In

[17] WHO – World Health Organization, 2003. Elemental Mercury and Inorganic Mercury Compounds: Human Health Aspects. IPCS-INCHEM. Concise International Chemical Assessment Document 50. http://www.inchem.org/documents/cicads/cicads/cicad50.htm#10.4.1

[18] Stopford, W., 1979. Industrial Exposure to Mercury. In: The Biogeochemistry of Mercury in the Environment. p.367-397 J.O. Nriagu (ed.). Elsevier/North-Holland Biomedical Press, Amsterdam.

[19] Jones, H.R., 1971. Mercury Pollution Control. Noyes Data Co., New Jersey, 251 p.

[20] Asano, S.; Eto, K.; Kurisaki, E.; Gunji, H.; Hiraiwa, K.; Sato, M.; Sato, H.; Hasuike, M.; Hagiwara, N.; Wakasa, H., 2000. Acute Inorganic Mercury Vapour Inhalation Poisoning. Pathology International, v.50, p.169-174.

[21] WHO - World Health Organization, 1991a. Environm. Health Criteria. 118. Inorganic Mercury. Geneva, 168 p.

milder cases, erethism and tremors regress slowly over a period of years, following removal from exposure pathways (WHO, 1991b)[22]. A person suffering from a mild case of Hg poisoning can be unaware because the symptoms are psycho-pathological. These ambiguous symptoms may result in an incorrect diagnosis (Cassidy and Furr, 1978)[23].

The seriousness of the situation in Antioquia is evident. Neuropsychological tests will only confirm the high level of intoxication of the population living near the gold shops and "entables".

5. Lectures

In my two trips to Colombia a series of lectures was given to authorities, academics, environmental inspectors, community members and miners. These lectures brought to the attention of the audience the measures to reduce mercury pollution implemented by the GEF/UNDP/UNIDO Global Mercury Project from 2002 to 2008 in Brazil, Indonesia, Laos, Sudan, Tanzania and Zimbabwe. The idea of having a mobile training center such as the TDUs – Transportable Demonstration Units, was very well received. These units do not bring just one type of equipment to process gold using less or no mercury, but a series of machines that can be locally built to concentrate gold and amalgamate or leach only the gravity concentrates. The reduction of the mass to be amalgamated or leached is a fundamental measure to reduce pollution. The amalgamation of the whole ore, as observed in Colombia is unacceptable and must end. The worst case of all is the amalgamation of the whole ore using a grinding media like the "cocos". The mercury losses can be as high as 20 times the amount of gold produced.

The lectures in Colombia showed how to build retorts using simple materials such as salad bowls or water pipes or stainless steel drinking water cups. The lectures were accompanied by demonstrations of retorts and analysis of mercury in the expired air (lungs) of the audience.

[22] WHO – World Health Organization, 1991b. Guidelines for Methylmercury in Fish (CAC GL 7 – 1991) http://www.who.int/fsf/Codex/methylmercury.htm

[23] Cassidy, D.R. and Furr, A., 1978. Toxicity of Inorganic and Organic Mercury Compounds in Animals. In: Toxicity of Heavy Metals in the Environment, part 1. p.303-330. F.W.Oehme (ed.). N.York, Marcel Dekker Inc.

The effectiveness of these lectures in Colombia is very questionable since a permanent technical assistance must be immediately implemented to bring solutions to the miners and affected communities.

6. Remarks

In general, there are two different routes of environmental and health impacts of mercury released and emitted by artisanal gold miners:

1. Hg vapour exposure from amalgam burning or gold melting,
2. Methylmercury (MeHg) from dietary sources, especially fish.

Inhalation of Hg vapour is the primary exposure pathway for miners, gold shop workers and people living near areas where mercury and amalgams are handled. Usually more attention is given by authorities and researchers to the effects of ingestion of fish contaminated with methylmercury. This is understandable since methylmercury is much more toxic than metallic mercury and the worldwide events related to consumption of contaminated fish left a legacy of thousands of people dead or impaired (e.g. Minamata, Iraqi, etc.). In addition, fish is not only consumed by rural population but also by people living in large cities who usually have more political clout to pressure authorities to find solutions for fish pollution. In many cases, mercury vapour pollution is perceived as a restricted occupational exposure, i.e. to workers like miners and gold shop employees. Information about mercury contamination of neighbours living near processing centers or gold shops has been limited to a few cases. Information about long-way travel of mercury vapour emitted by gold miners is also limited. Rural communities living in towns that depend on artisanal gold mining activities have also little interest in ending the sole economic activity of the region, even if this activity is polluting their families. The main advocates for the changes must be the women. They understand the health effects on their children as they are daily following the development of their offspring and they can detect earlier the physical and intellectual abnormalities.

Any action to change behaviours of the gold miners[24] must be based on Presence, Persistence and Patience of trainers. The health and environmental effects caused by misuse of mercury and cyanide

[24] The term “miners” in this context, includes not only those excavating gold ore, but also those processing as well as the “entable” and gold shop owners.

do not have the same repercussion as the economic effect of low gold recovery. In this case, it is advised to start any intervention in Antioquia showing how "new" cleaner techniques can increase the gold production. This is the first step to gain confidence from miners. Then, the Mercury Project must select right leaders who can be future trainers of the miners. These must be people from the polluted communities who can have long presence in the field with miners and know the idiosyncrasies of their own communities. In a practical way, when they demonstrate to miners that they can recover more gold from tailings using cleaner techniques, this is the first step to establish a durable (and persistent) relationship between these trainers and miners. It is also critical to remember that many artisanal miners may have had no experience of being a "successful learner" then patience is critical in this process.

After my two trips to Colombia and confirmation of the threatening levels of mercury vapour in the urban environment in the municipalities of Antioquia, a priority must be given to stop the insane practice of bringing mercury to the urban environment, either to amalgamate the whole ore in "cocos" or to burn amalgams with 40-50% of mercury in gold shops. NO MERCURY CONDENSING SYSTEM OR FILTER in the world will be capable of reducing the levels of mercury in the Colombian towns if tonnes of mercury continue being burned and spread in the atmosphere. The condensing systems must be installed to trap residual mercury (around 3%) in a retorted gold *doré*. Individual retorts must be promoted and a site OUTSIDE the towns must be implemented for miners to burn their amalgams using retorts. In 1995, the Government of Bolivar State, Venezuela, implemented in the field centers to amalgamate concentrates that miners brought from their dredges. These centers had trained operators that charged the miners a nominal fee to safely extract gold from their gravity concentrates (amalgamation) and retort amalgams using retorts under the miners' supervision. These centers had also well-guarded gold buyers that melted and purchased the gold[25.] This is badly needed in Antioquia.

Miners in Antioquia must be trained to understand the advantages of gravity concentration and/or flotation of gold. The amalgamation or cyanidation of these concentrates will reduce substantially the use and losses of mercury and increase the gold recovery. In Segovia, the UNIDO Mercury

[25] Veiga,M.M. and Beinhoff,C. (1997). "UNECA Centers, a Way to Reduce Mercury Emissions from Artisanal Gold Mining and Provide Badly Needed Training". UNEP (United Nations Environment Programme) - Industry and Environment, Oct-Dec. 1997, v. 20, n.4, p.49-51.

Project demonstrated the use of an Icon-Falcon centrifuge. This concentrator applies a centrifugal force of 150G to the gold particles allowing recovery of fine gold grains and better separation of gold from the silicate gangue. The operating parameters of a centrifuge are not trivial and must be exhaustively investigated before promoting this piece of equipment to the local miners. The Icon, developed in Langley, BC, Canada, processes a maximum of 2 tonnes/h and the discharge time depends of many parameters such as the pulp density, amount of solids processed, counter flow water, rotational speed, grade of the ore and concentrate, etc.

The environmental problems caused by this immense release of mercury and cyanide with tailings to the local aquatic systems have not been evaluated yet. All creeks in the Antioquia municipalities visited are silted with tailings and likely they have no aquatic life. The mobility of mercury with tailings must be investigated.

On October 23rd, 2009, United Nations Environmental Programme (UNEP) organized a meeting in Bangkok to discuss a way to stop mercury exports through a Legally Binding Treaty involving the UNEP member countries[26]. The target will be the banning of mercury trade by 2013. The Government of Colombia is actively participating in the discussion of this treaty attending regularly the international meetings. In this case it is imperative that the Colombian authorities find ways to provide technical assistance to artisanal gold miners in order to organize them and improve their mining and processing techniques to replace completely amalgamation with other cleaner process.

Authorities wishing to reduce mercury emissions may have to adopt a similar approach to that most successfully used to combat drug trafficking: reduce consumption with awareness campaigns, and simultaneously hinder traffic and easy access. Better control of Hg use (e.g. use in closed circuits, recycling Hg with retorts) should also be accompanied by an increase in the price of Hg[27].

[26] Mercury Policy (2009). http://mercurypolicy.org/?m=200910

[27] Veiga,M.M.; Maxson,P.; Hylander,L. (2006). Origin of Mercury in Artisanal Gold Mining. *J. Cleaner Production*, v.14, p. 436-447.

7. Recommendations

7.1. General Recommendations

The following general recommendations are listed in order of priority. These are based on my personal judgment and my experience of working for almost 30 years with issues related to mercury in artisanal gold mining. These are recommendations for the authorities of Antioquia and Colombia to implement:

1. Amalgams cannot be burned in the urban environment (even using condensing systems)
2. Amalgams MUST be burned outside the urban environment using individual retorts
3. “Entables” cannot be located in the urban environment either
4. Amalgamation of the whole ore (in “cocos” or with copper plates or spreaqding mercury on the sluice boxes) must not be allowed in any circumstance.
5. A long-term presence of trainers (technical assistance) in the field is needed
6. Organization of miners in cooperatives or small companies is a first step to the formalization process.

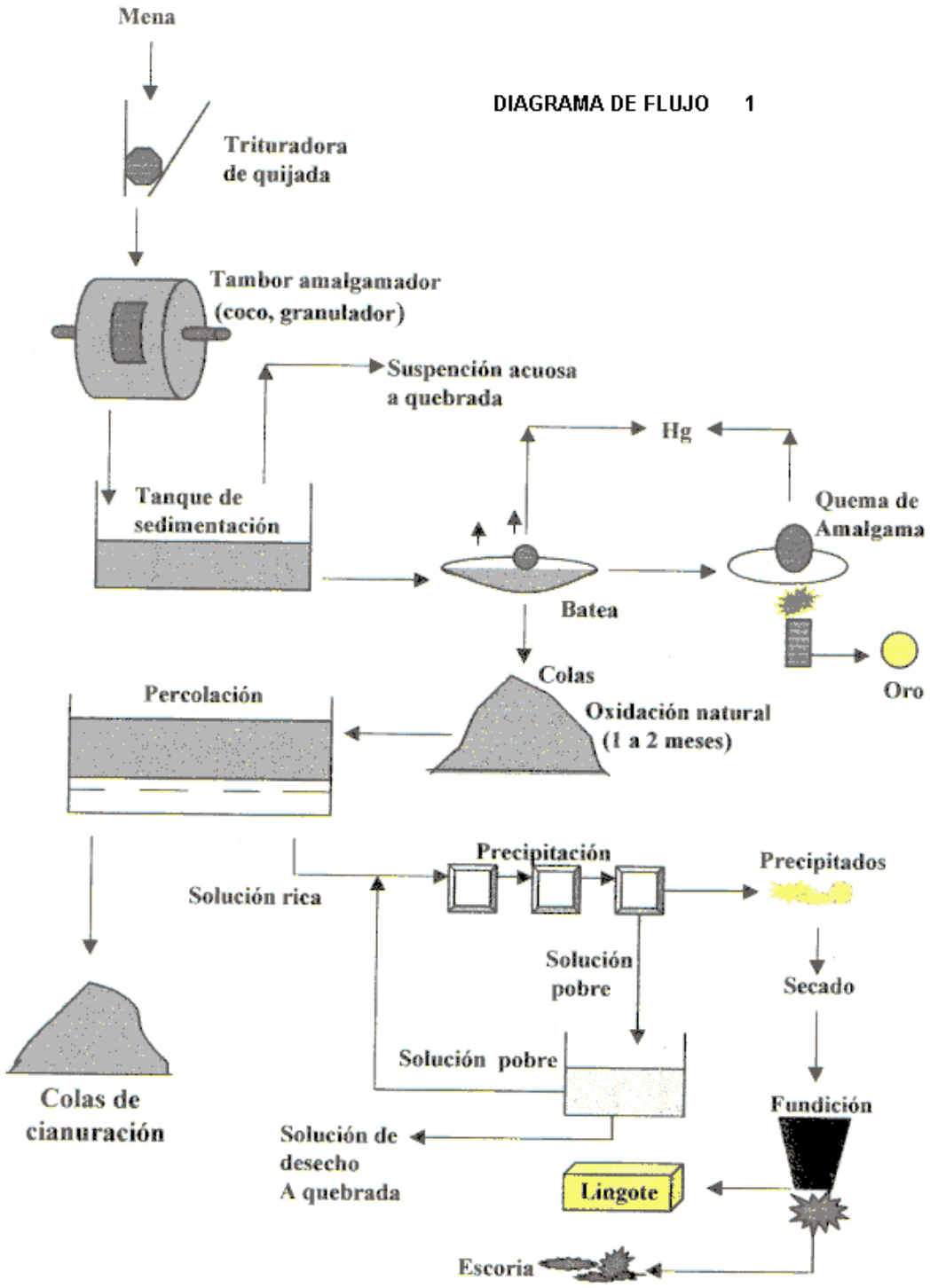
7.2. Recommendations for the UNIDO Mercury Project in Colombia

The following are recommendations for the UNIDO Mercury Project in order of priority:

1. A balance of mercury and gold in the amalgamation and cyanidation processes currently used in Antioquia will provide a picture of the amount of mercury losses as well as the main routes of losses, and the main losses of gold in the processes. The amount of mercury lost per “entable” (or per “coco”) is important information to establish the amount of mercury released to the environment in Antioquia. This will give tools to authorities to prove to miners that their processes are ineffective and pollutant. The quantification of mercury losses is a powerful instrument for policy makers. This will also provide a picture of the species of mercury being emitted/released (e.g. mercury vapourur, metallic with tailings, mercury-cyanide, etc.) and the fate of mercury compounds in the water courses.
2. Obtain a comprehensive evaluation of the behaviour of mercury in the atmosphere in at least one town (e.g. Segovia). This will provide better numbers to prove that mercury is contaminating people in the towns. This evaluation can also provide hints about the possibility of mercury vapour to travel long distances.
3. Help governments implement strong policies to eliminate use of mercury (burning amalgams or use in “entables”) in the urban environment.

4. Create a strong policy guideline to support the actions of the authorities. A policy should be strongly based on education first and enforcement later. The access to mercury and cyanide cannot be so easy. A miner acquiring these chemicals, as well the person selling them, should be trained to understand the hazardous impacts and how to mitigate them.
5. Demonstrate how a local manufacturer can build locally gold shop condensers and air filters (e.g. using activated carbon with potassium iodide solution). It is important to show to gold shops that this is just a palliative solution and they cannot burn amalgams in towns Only retorted gold should be allowed to be melted in towns and even this operation MUST be conducted with good condensers and filters for mercury vapour.
6. Demonstrate and promote use of various types of individual retorts to be used outside of the town. Help authorities establish amalgamation centers to amalgamate concentrates and burn amalgams in retorts OUTSIDE the towns.
7. Establish a quick but yet efficient health assessment of the neuropsychological effects of the mercury vapours to the population of the 5 municipalities of the project.
8. Initiate an immediate awareness campaign to the public in the towns impacted by mercury vapours. Use material (e.g. pamphlets, brochures, posters, feather, etc.) developed TOGETHER with local miners and community members. Use women and kids to disseminate the results of the health assessment showing how they are victims of the insane mercury pollution in Antioquia.
9. Select trainers to be trained by UNIDO team. These trainers must promote cleaner technologies. It is important that ALL TECHNOLOGIES must be previously tested and approved by miners.
10. Demonstrate various types of concentration equipment and individual retorts.
11. Demonstrate a procedure of cyanidation of gravity concentrates in “cocos”. This replaces completely the use of mercury.
12. Conduct a quick environmental assessment of the impacts of mercury on the aquatic life. The environmental assessment must be concentrate in fish analyses since this is more indicative of bioaccumulation. It is important to select good bioindicators.

Appendix 1 – Flowsheet of the gold amalgamation procedure used in Antioquia



Appendix 2 – Selected photos

01– Woman and kid working in a rented "entable" adding ore to a "coco" in Segovia

02 – The "cocos" amalgamate the whole ore

03 – Gold shop in Zaragoza; all mercury is released to the streets; no filters

04 – Levels of Hg in the lungs of kids are 20 times higher than the background

05 – Jerome detecting 189000 ng Hg/m^3 of air inside a gold shop in Caucasia

06 – Demonstrating to miners in Nechi how to make a kitchen bowl retort