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Mercury in Artisanal Gold Mining in Latin America: Facts, Fantasies and Solutions

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ABSTRACT

The modern gold rush in the Latin America which started in the 1980s, has involved millions of people who became artisanal miners to escape complete social marginalization. Over 1 million people are involved directly with artisanal gold mining activities, producing somewhere between 115 and 190 tonnes of gold emitting over 200 tonnes of mercury annually to the environment. Most developing countries face enormous social and environmental problems derived from poor mining practices taken together with lack of economic alternatives. The reaction of the dominant society about artisanal mining is biased. Mercury pollution is one of the most serious environmental problems, but this is just the tip of the iceberg of the environmental, social and economic problems associated with artisanal gold mining activities. The general population is ignorant about mercury and its capricious nature. Fantasies, panic and taboos are results of the poor role played by different sectors of the society which have hidden economic interests in not bringing correct information to the public. Affected communities (miners and fish-eating people) have been ignored. Exaggeration of the facts hinders a trustworthy approach. Because of this, all solutions to reduce mercury emissions are regarded with suspicion by miners. More illegality has been generated and artisanal miners are becoming skeptical about the interest of Governments and NGO institutions in solving problems. This paper describes the use of mercury in artisanal Latin American mining pointing out the facts and fantasies about mercury pollution. Solutions for the problem are also indicated. Education is highlighted as the main durable measure to reduce mercury emissions and identify dangerous situations. Processing Centers are described as a concrete and viable solution to reduce mercury use or even eliminate it.

ARTISANAL MINERS AND MERCURY USE IN LATIN AMERICA

A wide range of mining and mineral processing activities are classified as artisanal mining. This ranges from individual panning to large dredging operations. Quite often the terms artisanal and peasant miners are applied to make reference to low-tech manual panners. However, even in a large-scale production, most of those miners do not follow conventional technical approach adopted by organized mining companies. The way of working makes a difference. An artisanal miner works based on instinct, need for feeding his family and paying bills. There is no previous “classical” geological exploration, no drilling, no proven reserves, no ore tonnage establishment and engineering studies. The concept of survival is constantly the driving force for those miners.

Sometimes the artisanal miners are classified as informal miners, which is a broad term that usually indicates illegal activities. Miners are not examples of taxpayers. When gold is sold locally to banks or gold shops, more control is exerted than when it is sold to individuals who use the metal for money laundering. Often, contracts are not signed and production is not shown. Informal is an appropriate denomination for those miners who are indeed part of a hidden, but regionally important, economy.

In many countries the official definition of these miners is based on the production scale. In Chile, an operation processing less than 20 tonnes daily is characterized as small mining (Davidson, 1995). The term small mining does not imply informal or rudimentary operations. There are many small miners in North and South America using adequate technologies to extract gold from small primary gold deposits respecting legal and environmental regulations.

In many countries, the definition of artisanal miners is attached to the type of ore allowed to be exploited. This is a vague concept. The geological characteristic supposes to delimit the type of mining and mineral processing technique allowed to be employed by artisanal miners. These miners discovered the alluvial deposits and currently primary ores are illegally mined. In South America there are some operations with capacity to process over 5 million m^3 of primary ore annually using rudimentary methods. The lack of control in mining and processing confers an artisanal characteristic to those operations. It is clear that the definition of a mining activity should start by identifying who is involved in this activity, how technically and economically skilled is the individual (or company), which grade of mechanization is employed, which mining plan is established rather than define the activity by the size or type of ore. The technical approach to extract minerals can clearly distinguish between an artisanal and a conventional miner.

The term artisanal miners is preferred to be used as a simple way to encompass all small, medium, large, informal, legal and illegal miners who use rudimentary processes to extract gold from secondary and primary ore bodies. The History has shown that without technical support and investment, primary ores are the worst nightmare for artisanal miners. So, artisanal activity is "naturally" controlled by the type of ore deposit. Governments need to provide assistance to guarantee that artisanal miners shall have access to legal titles and work safety concepts when working with primary ores.

In some countries in the South and Central America, the artisanal miners have different local denominations, sometimes with negative connotations. In many cases, the names are derived from native's words or regional terms that do not have a clear meaning about their origins.

- "barequeros" - in Colombia, usually are the very small panners,
- "chichiqueros" - in Southeastern Peru,
- "coligalleros" - in Costa Rica,
- "gambusinos" - in Mexico,
- "garimpeiros" - in Brazil, an old Portuguese term to designate "gold robbers",
- "güiriseros" - in Nicaragua,
- "lavaderos de oro" - in Dominican Republic, are gold washers,
- "pirquineros" - in Chile and Argentina,
- "porknockers" - in Guyana and Suriname.

The terms "mineros artesanales" (artisanal miners) and "pequeños mineros" (small miners) are widely used in the Spanish-speaking countries in Latin America.

Establishment of population of artisanal gold miners in Latin America and their production is a difficult task since these numbers fluctuate considerably. Furthermore, it is also recognized that significant amount of gold is shipped illegally out of Latin American countries basically due to the following:

- government control of foreign currency entering the country,
- existence of foreign currency black market,
- better price of non-refined gold in other countries,
- tax avoidance,
- money laundering.

Virtually all countries in Latin America have artisanal mining activities in which gold is the most mined mineral. Table 1 lists the main gold producing countries in Latin America. For simplification purpose, Guyana was also considered in the list. These countries must encompass over 90% of the artisanal gold mining activities occurring in Latin America. It is observed that there is a certain correlation between gold production and number of miners (Fig. 1). The number of miners per kg of gold produced annually ranges from 2 to 8. For countries producing less than 10,000 kg of gold annually this ratio lies between 2 and 3 and for those regions with gold output from artisans above 10,000 kg, this ratio usually ranges between 4 and 6. This is a typical situation of artisanal activities in which there is no production scale effect on the number of laborers (low mechanization level). Another possible reason for higher ratio in regions with larger gold production can be the higher number of unsuccessful miners lured by gold rushes than in other small producing areas (Veiga 1997).

Based on this investigation, it is estimated that as many as 1 million artisanal miners are currently mining for gold in Latin America and their production can be as high as 200 tonnes (6.4 Moz) of gold annually. Considering that one out of six miners is a woman, as observed in Brazil, there are likely around 170,000 women participating in the labor force of the artisanal mining in all Latin America. However this number is definitely higher in those countries with less mechanized operations. As individual panners, employed as cook or as owner of a mining operation at least 200,000 women are involved with this economy.

Amalgamation is the preferred method used by artisanal gold miners in Latin America. Despite some miners are using cyanidation in Andean operations, mercury is an effective, simple and very inexpensive reagent to extract gold (1kg of Hg costs 1g of Au) when it is used correctly. In most countries the use of mercury is illegal. In Brazil, for example, mercury imports are allowed only for registered industrial uses, however the declared uses (electronic industries, chlorine plants, paints, dental, etc.) are declining. In 1989 this represented about 22% of the total 340 t of mercury. The remainder was imported for re-sale to industries, but it is estimated that over 170 t were illegally diverted to mining activities (Ferreira and Appel, 1991). Even sold in Brazilian “garimpos” (artisanal mining sites) at 5 times the international price, mercury has a cost equivalent to 0.012 g of gold per tonne of ore processed (Veiga & Fernandes 1990). A variety of mining and amalgamation methods are used in artisanal mining operations. Taken together with the fate of contaminated tailings and Au-Hg separation procedures, these methods will define the extent of mercury losses from a specific site.

Table 1 - Estimated gold production and number of miners in Latin America

Country	Gold (tonnes)	Number of Miners
Brazil	30 - 50	200,000 - 400,000
Colombia	20 - 30	100,000 - 200,000
Peru	20 - 30	100,000 - 200,000
Ecuador	10 - 20	50,000 - 80,000
Venezuela	10 - 15	30,000 - 40,000
Suriname	5 - 10	15,000 - 30,000
Bolivia	5 - 7	10,000 - 20,000
Mexico	4 - 5	10,000 - 15,000
Chile	3 - 5	6,000 - 10,000
French Guyana	2 - 4	5,000 - 10,000
Guyana	3 - 4	6,000 - 10,000
Nicaragua	1 - 2	3,000 - 6,000
Dominican Republic	0.5 - 1	2,000 - 3,000
Others	2 - 5	6,000 - 15,000
Total	115.5 - 188	543,000 - 1,039,000

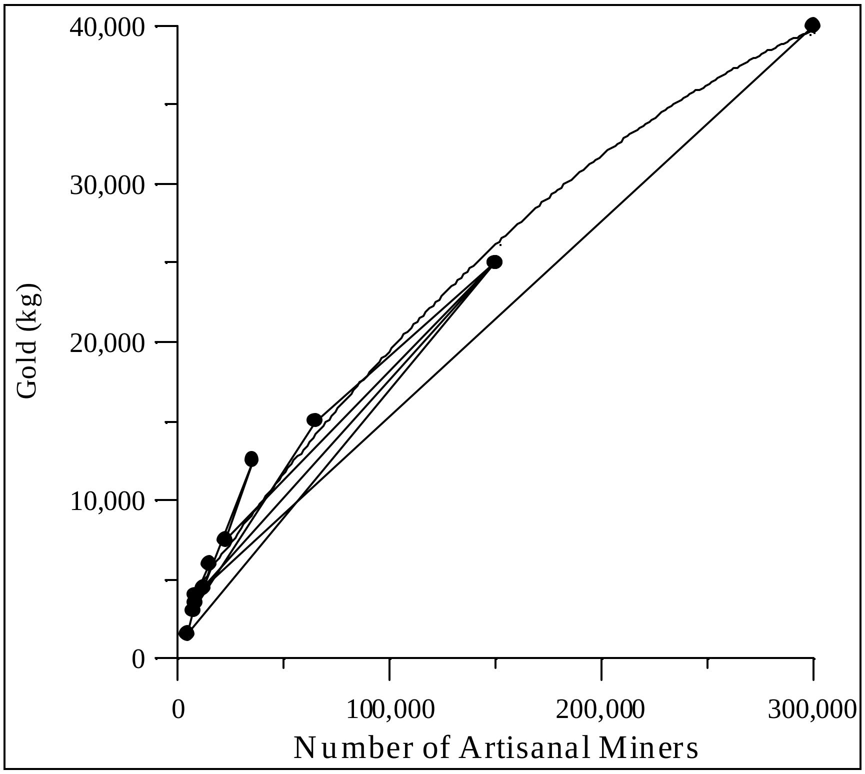

Fig. 1 - Correlation between gold production and number of miners in Latin America

When mercury is placed on sluice boxes to amalgamate the whole ore or is spread on the ground the mercury losses can be as high as 3 times the amount of gold produced. When gravity concentrates are amalgamated, the mineral portion is separated from amalgam by panning, forming an amalgamation tailing which is usually dumped into a water stream creating a “hot spot”. Panning takes place either in waterboxes or in pools excavated in the ground or at creek margins.

Mercury is an efficient reagent to extract more than 90% of gold from gravity concentrates. Excess mercury from the amalgamation step is removed by squeezing the material through a piece of fabric. The amalgam usually contains about 40% mercury. When excess mercury is extracted by centrifuging, as observed in few operations in Venezuela, the resulting amalgam has 20% of Hg. Amalgam decomposition is done by nitric acid 30%, retorting or by burning in open pans. Unfortunately, this latter is the preferred method used by artisanal miners. Mercury released to the atmosphere represents as much as 50% of that introduced into the amalgamation process when retorts are not used. However, when amalgamation is conducted properly and retorts are used, very little mercury is lost to the environment (as low as 0.05%) (Farid et al. 1991). This recycling practice suggests one of the first attack points for providing relief for the environment. The process produces a gold sponge containing about 20 g of mercury per kg of gold which is released when this gold is melted at gold shops. Studies have shown that the majority of Hg emitted by gold smelters is deposited near the emission source (i.e. within 1 km), contaminating the urban areas (CETEM, 1991, 1993, 1995).

Many factors are contributing for the reduction of mercury emission in Latin America from the high levels observed at the end of the 1980s:

1. Reduction of the informal mining activities in Brazil and consequently the gold production, due to scarcity of easily exploitable ores.
2. Introduction of retorts and cyanidation in more-organized artisanal mining regions. More information about mercury poisoning is reaching those artisanal miners involved with Associations and Cooperatives and they are adopting some precautions. The NGOs have played an important role in suggesting technical improvements.
3. High costs are driving miners to recycle mercury. Many miners are amalgamating just the gravity concentrates, instead of the whole ore.

These facts lead one to believe that a ratio of 1:1 for gold produced and mercury lost can be used for a rough estimate of the mercury levels still being emitted in Latin American countries. So, approximately 200 tonnes of mercury are still being released annually by artisanal gold miners. Since the beginning of the new gold boom in Latin America, at the end of 1970s to the present, around 5,000 tonnes of mercury might have been discharged into the forests and urban environment. Part of this mercury is being transformed into methylmercury to be bioaccumulated.

FACTS AND FANTASIES ABOUT MERCURY

Mining and the Environment - the Phantom of the Opera

Protests from international environmental groups have led governments to enforce laws about artisanal miners. For most environmentalists the only acceptable solution for artisanal mining and mercury pollution is the end of all mining activities. However, neither the environmentalists nor Governments know how to enforce laws or to provide social services and economic stimulation to replace the positive benefits generated by this informal economy. For developing countries, the presence of artisanal miners represents an embarrassing situation in strong contrast to the concept of modernity and efficiency pursued by the dominant society. It represents a very labor-intensive activity, which accommodates unskilled workers. Furthermore, the activity is less susceptible to the impoverishing ravages of economic cycles (Brooks 1993). It is only after about a decade of these “rushes” that the true effect of the world environment has become apparent. The progress of artisanal mining is now being impeded by groups who wish to protect their environment. Without strong support from governments, artisanal mining is now becoming a marginal activity. But, despite this negative placement in society (or perhaps because of its placement), informal miners are still predominant and environmental destruction continues.

In the Amazon region, where in 1983 almost 1 million artisanal miners were working, concern for the environment became the focus of harsh criticisms of the miners in the 1990s. For many people, Amazon is regarded as “the lungs of the world” an untouchable sanctuary of nature. Deep ecologists believe that living organisms have rights and humanity must adjust to this (Merchant 1992). In spite of being a habitat for five million species, few people realize that over 25 million people live in poorly organized communities in the Amazon, using inadequate farming methods and coping without technical assistance in agriculture projects that attracted thousands of peasants to such a harsh environment. A strong centralization of the economic and political power into hands of small elite groups occurs in these regions. As a result of the inequities in rural-land ownership, mining is an important escape valve for the predictable outcomes of an agrarian crisis (Hecht and Cockburn, 1990). The fact is that the conflict related to artisanal mining activities is not between humanity and Nature but between humans at the bottom of society’s hierarchy versus those on higher levels.

The Walt Disney cartoon, Pocahontas highlighted the negative aspects of mining. In the movie, miners are villains who destroy trees, lands and native cultures. Unfortunately, as the colonization of the Americas was based on natural resources, confrontation with natives had tragic consequences. This happened 150 years ago. The basic infrastructure of developed countries is now fully developed and consumption of metals per capita is declining. However, mining represents a significant way to supply basic raw materials and is also still a real economic option for developing countries. Western North America was colonized and developed by artisanal miners and it took four generations for them to become industrially organized. Nowadays, they know how to conciliate mining with the environment.

In terms of development, South American artisanal miners are like the North American pioneers. Miners occupied remote areas, established villages, discovered ore bodies and currently they represent a way to defend the frontier areas. But, not infrequently, without support and organization, there are conflicts of cultures (with natives and farmers) and the gypsy characteristics of gold seekers sometimes leaves behind promiscuous communities, poverty and devastation.

There are examples in which organized mining operations are defending the tropical rainforest. Carajás mine, the world's largest iron ore producer (40 million tonnes/year), is located in the middle of the Brazilian Amazon, State of Para. The mine area comprises of 1.2 million hectares of virgin forest and less than 6,600 ha is taken up by the mine, plant and residential townsite. All rainforest outside of the mining area has been destroyed by cattle farmers.

Mercury in the Media - Fantasies Do Not Help

The reaction of the dominant society about artisanal miners is naturally biased and the environmental speech of the ecological groups has used mercury as a form of attacking miners. On January 16, 1997, the TV series “Tarzan” presented in North America an episode in which an artisanal miner using a small sluice box killed more than 100 animals, including fish, panthers, monkeys, birds by discharging mercury into the river. In fact, Tarzan stopped this ecocide and saved rain forest from further perils. The exaggeration of the problem does not contribute to bring solutions but just more confusion.

In Ciudad Guayana, Venezuela, a reporter from a local newspaper published stories about metallic mercury dripping out of water taps in the villages. Discussing the concept with this reporter, he argued that he is not an expert and so, he cannot evaluate this “phenomenon”. In fact, this is a clear indication that he thinks that mercury is a taboo that cannot be discussed by ordinary people. So, actually he transmits this incorrect image to the public creating more mystification and hysteria and, of course, selling more newspapers.

Many environmentalists do not have clear knowledge about mercury toxicity and its transformations in the environment, and so not infrequently they are surprised by theatrical performances of miners with the intent to embarrass ecologists. A classical episode that exemplifies this fact happened in 1987, in Brasília. In a TV show, José Altino Machado, a miner leader, was attacked by the components of a round table about artisanal miners. When an ecologist was doing his stunning speech holding a vial of the “deadly” metallic mercury to impress the public, José Altino took it from his hands and ingested all to show how mercury is inoffensive. In a further interview he declared (Barbosa, 1992):

"*... the mercury we employ is inert: it is the same as that in teeth, the same that old people used to cure constipation; it goes in and goes out of the organism. There is no relation with the mercury in Japan* (Minamata)*... It does not contaminate. Even "garimpeiros" who inhale mercury vapors, they are not poisoned... We will measure mercury levels in the waterways. I challenge someone to show me a person, just a person, contaminated by mercury in the Amazon... The point is, as they* (ecologists and government) *cannot do anything against a citizen pursuing a better way of living, they make up this story of river pollution and shut down all "garimpos". These ecologist "boys" do not realize they are being used as political instruments*."

This episode mirrors a situation in which an artisanal miner reacts (in a wrong way) against exaggerated and demagogic positions. However, his opinion about mercury is also biased and incorrect.

Mercury in the Air - Facts

The fact behind this episode is that metallic mercury is very poorly absorbed by the gastrointestinal tract, i.e. the majority is flushed out of the organism. (Rowland et al.,1977). The miner knew this, but the environmentalists did not, let alone the general public. In opposite, inhalation of Hg vapor is the most significant contamination way for miners and gold shop workers. Once in the lungs, Hg is oxidized forming Hg (II) complexes which are soluble in many body fluids. The ultimate effect of Hg and related compounds is the inhibition of enzyme action (Jones,1971). The impairment of the blood-brain barrier, together with the possible inhibition by Hg of certain associated enzymes will certainly affect the metabolism of the nervous system (Chang, 1979).

The kidneys are the affected organs in exposures of moderate duration to considerable levels while the brain is the dominant receptor in long-term exposure to moderate levels (Suzuki, 1979). Total mercury elimination can take several years. In Japan, workers with a peak urinary Hg concentration of 600 µg/l showed neurobehavioral disturbances 20 to 35 years after the mercury vapor exposure (Satoh, 1994). The half-life of mercury in the brain is longer than in the kidney, thus urine levels would not be expected to correlate with neurological findings once exposure has stopped. A short-term exposure to high levels causes clinical symptoms which 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 (Suzuki, 1979; Stopford, 1979). The symptoms usually associated with undue Hg vapor exposure are erethism (exaggerated emotional response), gingivitis and muscular tremors. This latter is a symptom associated with long-term exposure to high levels of Hg vapor. The common manifestation of chronic exposure to excessive levels of Hg vapor is metallic taste and gum diseases, such as gingivitis, ulcers and formation of a blue line at gum margins (Stopford, 1979). 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.

Typical symptoms of long-term Hg-vapor poisoning were patterned by the Mad Hatter in Lewis Carroll's *Alice's Adventures in Wonderland*. Back in the 19th century, workers in the felt-hat industry dipped furs into vats of mercury nitrate solution to make them pliable for shaping. In the process they absorbed the compound through their skin and inhaled mercury vapor. The result was tremors, loss of teeth, difficulty in walking, and mental disability (Putman, 1972).

A level of 60,000 µg/m^3 was measured by Malm (1991) in the air when amalgam is burnt in pans. This number reduces to as low as 10 mg Hg/m^3 when retorts are used. This is still high, but lower than the limit of 50 µg Hg/m^3 for industrial exposure - TWA[1] (BC-MEMPR, 1992). Inside the gold shops, Malm (1991) measured 83 µg Hg/m^3 as a mean concentration for 2 hours of sampling when gold was not being melted.

Symptoms of mercury poisoning have been detected in miners, gold dealers and citizens living near emission sources (Malm et al. 1990; GEDEBAM 1992, Schulz-Garban 1995). Samples of urine have shown high[2] Hg levels (as high as 400 µg/l) for workers burning amalgam daily. Some of these individuals should show signs of mercurialism, however the diagnosis is not easy as symptoms are often confused with fever, alcoholism, malaria or other tropical diseases.

[1] TWA = Time Weighed Average means the 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.
[2] Limits based on European Community assessments for total Hg in urine samples of workers (OECD, 1974):

Hg (µg.l^{-1} or ppb)	SITUATION
< 10	unexposed
10-50	quarterly exam needed
> 50	removal from Hg source
100-500	clinical symptoms likely
> 500	clinical symptoms visible

Mercury in the Water - More Taboos, Less Solutions

Mercury has been an interesting weapon to attack informal miners although little knowledge about its effect is understood by the accusers. Another example is an interview of a renowned ecologist and anthropologist to an important Brazilian scientific journal[3] in 1990. The anthropologist declared:

"... all preserved areas in the Amazon belong to natives. I have seen satellite images and it is possible to distinguish between native areas and mining areas. In the Yanomami land occupied by "garimpeiros", the color of the creeks calls attention; this is caused by mercury contamination of the water..."

Despite her obvious “limited” knowledge on how to interpret satellite images, this anthropologist did state one useful and important fact in her interview: based on rumors about mercury, people in Boa Vista city, State of Roraima, Brazil were no longer drinking tap water and were afraid to eat fish.

The frightening term “methylation”[4] changed the image about mercury. How methylation happens and how it is measured was another mystery and a taboo to be addressed and discussed only by a select elite.

Part of the mercury emitted by gold miners transforms into methylmercury (Me-Hg) which is rapidly taken up by species in the aquatic environment. Riparian communities who have fish as the main diet have shown high levels of mercury in blood (Martinelli et al. 1988; Pfeiffer et al. 1991; Malm et al. 1995; Barbosa et al. 1995; Boischio and Henshel 1996). Women and children, are the main victims because of the lack of information about the danger of this insidious pollutant. Methylation is a complicate issue as many of the key steps to transform metallic mercury into Me-Hg are not understood by many researchers, let alone the riparian communities. However, the effects of the Me-Hg and its incoporation into the food web is well known and can easily be taught to affected communities. As the correct information is not brought to the riparians, more fantasies are created and no solution is derived.

In 1995, through UNIDO, a series of talks about mercury was given to Venezuelan miners and local people (Veiga, 1996). The participation of the public was amazing because the information was delivered in a friendly way. All sort of questions were asked when the audience became less suspicious about the purpose of the seminars. A lady asked if mercury could be sexually transmitted. A scared kid made a speech why he stopped drinking tap water. Despite no evidence, stories about birth of brainless children were also told, all blaming mercury as the main cause. All these questions mirror the huge gap between the knowledge and the fantasy. Likewise it is observed in AIDS-combat campaigns, the only effective way to obtain long-term results is with clear, sincere and direct information about the hazards of mercury compounds and ways to avoid contamination.

In 1989, the Centre of Mineral Technology - CETEM, a federal research center located in Rio de Janeiro began a series of studies in different “garimpos” in the Western part of Brazil to investigate whether mercury was contaminating the Argentine fish (2,000 km South) as purported by some Argentine environmentalists. When the CETEM team arrived in the municipality of Poconé, State of Mato Grosso, the fish consumption was declined and mineral water started to be a good business. An important conclusion reached in this work was that lateritic soils, rich in hydrous ferric oxides, can adsorb all possible oxidizing Hg species. This natural process controls, in part, mercury bioavailability (Veiga and Fernandes, 1990). Neither the media nor environmentalists understood these results and attacked CETEM. However, the conclusions were welcomed and brought tranquillity to citizens in some affected areas.

Mercury in the Water - Facts

The idea that mercury is transferred to the population through the drinking water is one of the most typical myths. Metallic mercury is chemically stable with low solubility (64 µg/l) but the presence of organic acids and oxygen can derive soluble substances. When river sediments are rich in humic substances (humic and fulvic acids), these acids can dissolve metallic mercury dumped by miners or condensed from atmosphere, forming Hg-organic soluble complexes (Veiga and Meech, 1994, Tromans et al. 1996). When dissolved organic matter (say fulvic acid) is present at concentrations higher than 1 mg/l (ppm), the complex formed (fulvate: Hg-FA) is more stable and predominant than any of the inorganic species (Duinker, 1980; Xu and Allard, 1991). How these organic complexes transform into methylmercury (Me-Hg) is unclear. Biotic and abiotic methylation are

[3] Ciência Hoje, v.11, n.64, p. 68-72 (1990)

[4] Methylation is the transformation of inorganic mercury species into the most toxic form of mercury, methylmercury CH_3Hg^+. This process is usually mediated by bacteria, but abiotic reactions can also form methylmercury.

possible processes to generate methylmercury. Particles of organic matter in suspension are substrates of bacteria that favor methylation (Marcus Meili from Univ. Upsala, 1995 - personal communication). In fact, fish caught in darkwaters of the Amazon region almost always show more Hg than those living in white water rivers (CETEM, 1991; GEDEBAM, 1992).

Even in darkwaters, the concentration of mercury complexes in solution is extremely low and unlikely this can be transferred to the humans through drinking water. When Me-Hg is produced in the water column or in sediments, organisms accumulate it so fast that the concentration of Me-Hg analyzed in water is very low (D'Itri, 1990). Because Me-Hg is assimilated rapidly and is eliminated slowly, its synthesis in sediments does not have to be rapid to promote bioaccumulation. The mechanisms and rates of accumulation and elimination are unclear, but appear to depend on the specific biological characteristics of each species of fish as well as the properties of the aquatic systems. A comparison of animals differing in species, size and feeding habits confirms that the food intake of Hg is far more important than direct uptake from water. So the Hg levels in the top predators are always higher than in their food (D'Itri, 1990; D'Itri, 1972; Lindqvist et al., 1991; Connel, 1990). In spite of the better taste of the carnivorous species, riparians must understand that herbivorous fish must be preferred.

Mercury in Fish - Mercury in Blood

Whatever the route of bioaccumulation, uptake of methylmercury is much more efficient than inorganic Hg. From 70 to more than 90% of the Hg in fish is in the form of Me-Hg (Huckabee et al., 1979). The other forms of Hg found in fish are predominantly inorganic compounds. As Me-Hg is more slowly metabolized and eliminated than inorganic compounds, the overall result is a net bioaccumulation in the organism over time (D'Itri, 1990; Armstrong, 1979).

The natural background in fish has been estimated to be between 0.05 to 0.3 ppm Hg and may be less than 0.01 ppm in short-lived herbivorous species (Suckcharoen et al., 1978). However, the tolerance[5] limit level of Hg in fish is a variable value adopted by many countries to control Hg content in edible parts: 0.5 ppm (mg/kg wet weight) is used by USA, Canada, and Brazil; 0.7 ppm by Italy; 1 ppm by Finland, Sweden and Japan (Johansson et al, 1991).

The guideline of 0.5 ppm Hg is a simplification for legal purposes. The amount of methylmercury ingested daily is the main point to be observed. Based on a maximum ingestion of 15 µg Me-Hg daily (Canadian guideline), Pommen (1991) brought up a table (Table 2) to inform how many grams of fish with different Hg concentration can be ingested weekly. Based on the Table 2, even those fish species with Hg levels below 0.5 should be consumed moderately. The World Health Organization has adopted an ADI (Allowable Daily Intake) level of 30 µg Me-Hg as a safe condition.

Measurements of blood levels of mercury and levels of intake of fish containing Me-Hg suggest that a direct relationship exists in man. Clarkson (1973) compiling results from other authors showed that, for a 70 kg individual, Hg in blood (ppb) = 0.95 x Hg (mg) daily intake from fish.

Table 2 - Relationship of Hg level in fish and quantity consumed
(Pommen, 1991)

Concentration of Total Mercury in Edible portion of fish and seashell (ppm or mg/kg of wet weight)	Safe Quantity for Weekly Consumption (grams of wet weight)
0.5	210
0.4	260
0.3	350
0.2	525
0.1	1050

Mercury in hair from the scalp is a good indicator of Me-Hg exposure. Hair grows about 1 cm per month and accumulates Me-Hg during its formation showing correlation with Hg blood levels. Hair values are about 300 times higher than blood (Nelson et al., 1971). In this case a correlation between Hg in the hair in ppm (H), mass of fish consumed daily in grams (W_f) and Hg concentration in fish in ppm (F) is approximately obtained: $H = 0.285 \times W_f \times F$

[5] This level is established for an average ingestion of 400 g fish weekly.

So, a person consuming 200 g of fish containing 0.5 ppm Hg daily, would be expected to show around 30 ppm of Hg in hair samples. This is clearly an approximation since many site specific variables must be taken into account. The time following fish consumption also plays an important role in Hg blood levels.

Although hair analysis is affected by external factors, such as use of dyes and exposure of Hg vapor, the simplicity of the sampling procedure and analysis indicate hair for toxicological assessment. The normal Hg level in hair is less than 6 ppm and signs of Me-Hg intoxication can be observed with 50 ppm (mg Hg/kg of hair). Levels of 10 ppm must be considered as the upper limit guideline for pregnant women (Skerfving, 1973). Although Me-Hg concentrates in the hair and epidermis, these tissues have small excretory roles in relation to the body burden. Data on excretion of Me-Hg compiled by Nelson et al. (1971) show fecal excretion of about 4% in the first few days and then 1% per day thereafter. Only about 0.1% per day is lost in urine. In contrast, inorganic comp ounds are very poorly absorbed by the gastrointestinal tract.

Me-Hg is easily transferred to man since its intestinal absorption is extremely high. Once inside the cell, Me-Hg has a strong affinity for proteins. It binds to, and affects the configuration of nucleic acids, inhibiting a large number of enzymes by blocking sulphydryl groups. The combination of the lipophilic properties and affinity for the sulphydryl groups of amino acid compounds results in rapid accumulation in the muscles and fat tissues until Me-Hg is metabolized and excreted. When contaminated fish are consumed, kidney accumulation is lower than with inorganic Hg compounds, but the brain is affected significantly. A person with Me-Hg poisoning, or “Minamata disease” has five classical symptoms:

1. visual constriction
2. numbness of the extremities
3. impairment of hearing
4. impairment of speech
5. impairment of gait

The first two symptoms are strongly indicative of the beginning of the illness. Muscular atrophy and mental disturbance are prominent in acute intoxication. Some cases of long-term effects of mercury are reported. Forty-nine cases of people who lived in the Minamata area around 1956, but departed afterward, are reported by Harada (1978). They had eaten contaminated fish for limited periods and the symptoms appeared many years after ingestion had been suspended. Studies on Iraqi and Japanese patients revealed the delayed appearance of neurological symptoms after a lapse of one year in persons who had elevated Hg levels in hair but not confirmed neurological symptoms at the first examination (Suzuki, 1979).

The effect of Me-Hg on the human body in terms of the degree of contamination is thought to be as follows: when Me-Hg enters the body in large doses[6], there are symptoms of acute brain damage such as aberrations of consciousness, convulsions, and paralysis, followed by death. When the Me-Hg intake is lower, mild, atypical or incomplete symptoms may appear or another disease may be manifested. Previously, it was thought that the harmful effects of Me-Hg were confined to the nervous system, however it has become apparent that effects on other organs must also be considered (Harada, op.cit.).

Me-Hg can penetrate into the placental barrier transferring mercury to the fetus. It has been observed that when a female's intake of the poison is large and she becomes ill, sterility occurs. When the dosage is smaller, pregnancy can take place but the fetus may be aborted spontaneously or is stillborn. An even smaller dose permits conception and live birth, but the baby will have severe neurological symptoms. A dosage too small to cause noticeable neurological symptoms in the child may cause congenital mental deficiency. But in any of these cases, the mother's symptoms are relatively mild. It was observed in Iraq that maternal milk contained 5 to 6% of the organic mercury concentration analyzed in the mother's blood (Harada, 1978; Bakir et al., 1973).

Mercury in the Offices - the Gurus

Concern for the environment began to enter into the speech of the artisanal miners in the 90s as a way to address the harsh criticisms. In 1991, Ivo Lubrina, president of the Amazonian Union of “Garimpeiros” - USAGAL declared in an interview (Lobato and Barbosa, 1992):

[6] Accumulation of 30 mg of Me-Hg in a 70 kg adult (0.43 μg/g of body) causes sensory disturbance and 100 mg (1.4 μg/g of body) causes all typical poisoning symptoms. Laboratory studies in cat and mice have shown that 30 μg of Me-Hg per gram of brain is likely the threshold level to manifest neurological symptoms followed by death (Nelson et al., 1971)

"Thanks to radio and TV, "garimpeiros" are concerned now about mercury, but they don't know exactly why. As there is no orientation from government or technical people, everything continues as before. I would say that the transfer of news among "garimpeiros" is happening like a rotten onion: it is going from one hand to another".

In fact, most developing countries have Mining and Environmental Agencies, usually with low budgets and unmotivated personnel. This further increases the distance between technical solutions and artisanal miners.

When artisanal miners start working with primary ores they do not realize that high investment is needed. When they learn that they can not achieve the same production level, as when secondary ore is processed they look for technical assistance. Unfortunately this is not available. Engineering companies usually refuse to help artisanal miners and the consulting price is also very high. Local governments are not prepared to provide specialized personnel or appropriate technology. Research Institutions and Universities have only inaccessible high-tech methods to offer. In the artisanal mining fields, there are lots of “technical people” selling magic processes, usually related to processing methods, but the main problem is associated with lack of geological information and knowledge about mining methods.

Few programs, usually conducted by NGOs, have focused on bringing solution to stop mercury emissions and providing safe technology for miners. On the other hand, a large amount of resources has been used by Universities, Research Institutes and International Agencies into monitoring programs to establish levels of mercury in sediments, air, water and biota. The Amazon region has been used as a living laboratory for academic researchers. Recently, a group of researchers spent three weeks in the Amazon region eating the same fish as the local riparian people. Back to their labs, they published a paper about the amount of mercury accumulated in their hair. No advice for affected communities derived from these experiments. In most monitoring programs, human beings are merely hair, blood, or urine sample donors. In many cases, affected people never learn the results of the monitoring program, unless, of course, they read the scientific literature. The number of academic research is far higher than the number of solutions suggested or effectively implemented in the field.

A typical episode that exemplifies the usual elitist posture of the academic researchers is described as follows. A scientist from a renowned Institute of Venezuela has visited a Center of Amalgamation together with other local authorities and politicians. To impress the locals, he started a scary narration about mercury poisoning. Catching a small frog on the floor, he said *this poor frog died by the deadly fumes of mercury*. At this moment, under indignation of all, the small frog jumped and ran away. This sort of behavior in fact enlarges the distance between science and ordinary people. The scientist attack the use of mercury but he did not realize that Amalgamation Centers are indeed a solution to reduce emissions.

As mercury is an invisible pollutant, it is frequently used as a convenient instrument by highly-positioned people to establish competence and hierarchy of the decision levels. This approach actually does not contribute to find a solution for the problem. Researchers are interested in more research, economic groups are interested in properties discovered by artisanal miners, politicians seek for votes from environmentalists, Press wants sensationalism and miners do not care for pollution. As the mining activity is transitory, no concern with the environment is created by the miners. The general public does not understand the different facets of this issue (Fig. 2). It is difficult to find the equilibrium point.

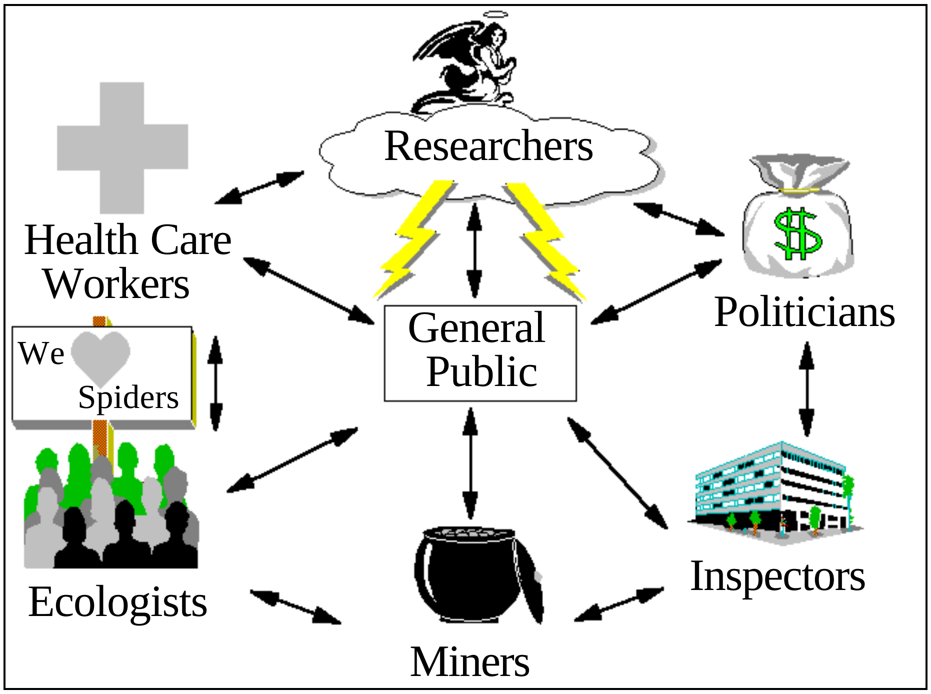

Fig. 2 - Mercury pollution has different understanding by different segments.

Other Villains in the Air

Mining activities are not the only source of mercury emissions. Other sources of mercury are usually underestimated in the tropical environments. Natural and man-made processes have contributed to the levels of Hg emission to air and water systems. As mercury is extremely volatile compared to other metals, the atmosphere is a key area to be investigated. Some natural sources of Hg emission are listed below:

- volcanism
- geologic weathering
- evaporation from waters
- plant transpiration and decomposition

In the past several authors overestimated the natural Hg sources (Kaiser and Tölg, 1980; Salomons and Förstner, 1984). According to some of these studies, more Hg was emitted to the environment from natural sources than from anthropogenic sources. However, more accurate investigations have established that only 40% of total Hg emissions come from natural sources, which means an average of 2,500 tonnes/year of Hg (range: 100 to 4900) (Nriagu, 1989).

Forest fires can be expected to mobilize Hg contained in biomass and redistribute it into the atmosphere either as vapor or attached to particulates. Today, with the very high rate of deforestation by fire in South America, Hg emissions derived from wood combustion must be significant (Veiga et al., 1994). The amount of Hg emitted by deforestation has been calculated from estimates of biomass distribution in the Amazon. If we assume that the majority of Hg compounds is released from above-ground biomass even without complete combustion, using an estimate of Hg levels in plants and organic matter ranging from 0.03 and 0.1 mg/kg, something between 40 and 90 tonnes of Hg are likely released annually only in the Amazon environment. Kaufman et al. (1992) analyzed ~ 1,000 mg/kg Hg in smoke particles smaller than 2.5 µm in a forest fire in the Amazon.

There are several "sinks" that control Hg availability for uptake by biota: the largest being the atmosphere followed by rivers, lakes and oceans. The forest, sediments and soils contribute significantly to Hg transformation and mass transfer. Deforestation may have an important role in transferring Hg from the forest into other sinks (Meech et al., 1995) (Fig. 3 and 4).

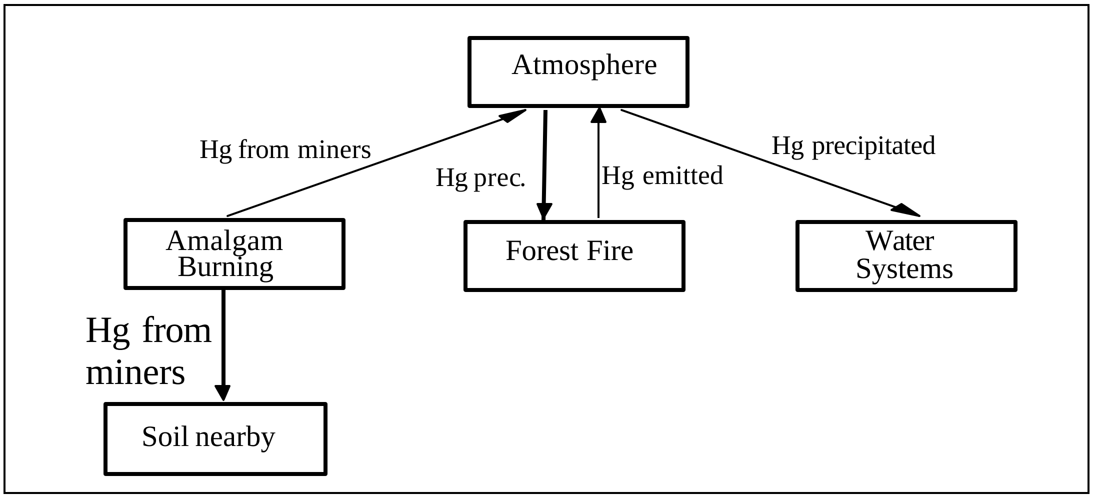

Fig. 3 - Forest fires redistributes Hg emitted by amalgam-burning

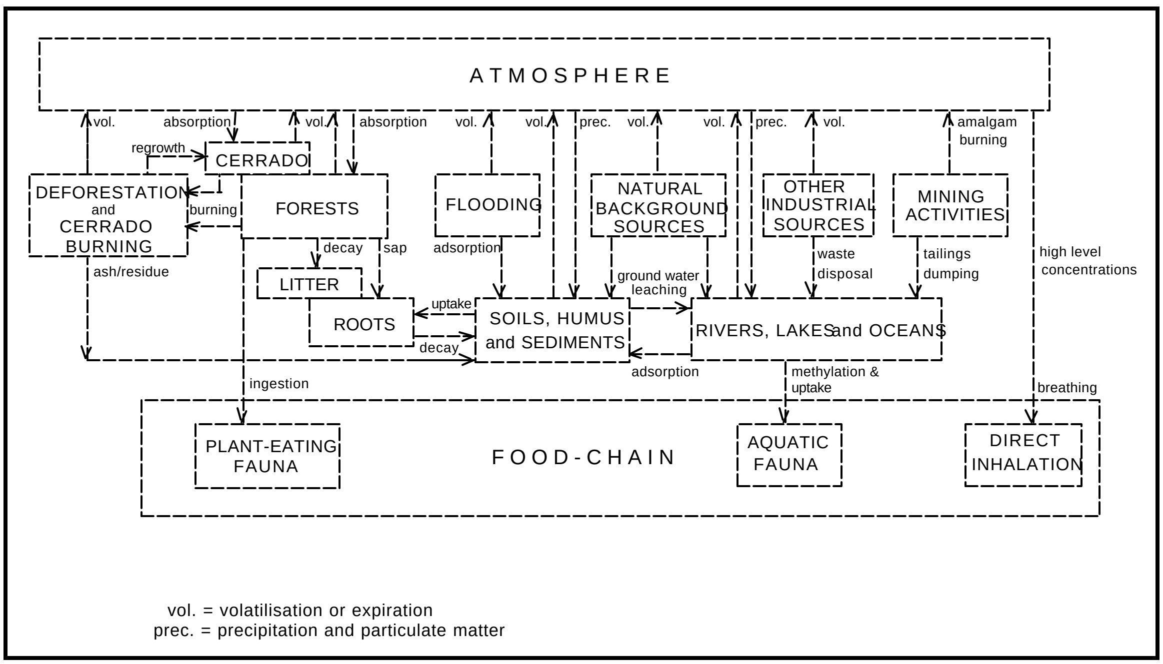

Fig. 4 – Sources of Mercury in a Tropical Forest

Mercury in Impoundments - A Silent Villain

The mercury bioaccumulation process in man-made reservoirs is a phenomenon recently recognized in several countries such as USA, Canada, Sweden, Finland and Brazil. In many cases, no specific pollution source is identified and it is attributed to a global effect.

Atmospheric mercury from different emission sources is constantly being deposited on the soil. Mercury biomethylation depends on soil characteristics and usually only a small portion of the total Hg exists as Me-Hg, ranging from 0.1% to 1.4%. The concentration of total Hg in sediments is not a good predictor of Me-Hg and certain environments enhance rates of Me-Hg production relative to total Hg concentration. The rate of biological methylation is determined primarily by the form of available Hg in the aquatic system as well as the methylating capacity of the microbes (Kelly et al., 1994). In environments contaminated with inorganic mercury, equilibrium can be reached, between the methylation and the demethylation activities of the bacteria communities. In other words, the competition between bacteria which demethylate and bacteria which methylate will determine the rate and extent of Me-Hg produced. The conditions created when soils are flooded appear to favor bacteria community which methylates. This increases the methylation rate.

The effect of impoundment in increasing methylmercury in aquatic biota has been a huge problem around the world. This phenomenon is associated mainly with the amount and quality of organic matter in flooded sediments which affect microbial activity and increase methylation rates (Stokes and Wren 1987, Lucotte et al. 1995). This effect was recently identified in the Guri hydroelectric reservoir, Venezuela (Veiga 1996). From 219 fish samples, 93 specimens (or 42.4%) showed levels above 0.5 ppm Hg. About 90% of the most appreciated carnivorous fish in the region (*Raphiodon vulpinus*), showed average Hg levels of 2.7 ppm (0.17 to 8.25 ppm; 31 samples). The government of Bolivar State, UNIDO and La Salle Foundation have distributed leaflets to the affected communities showing how much fish can be consumed safely each week. Children and pregnant women are the main target of the campaign.

As Guri reservoir is located 50 km upstream mining activities in the Caroni river, the natural reaction of population was to blame miners for such pollution. Since 1989, three works conducted by professionals from Venezuela (Briceño, 1989; Bermudez et al., 1994; Leal, 1994) and one from a Canadian Company (Minproc, 1991) have investigated the bioaccumulation in "Bajo" Caroni (mining area). Compiling data from these four works, it is observed that about 40% of the fish samples were carnivorous and less than 6% of fish samples have Hg levels above 0.5 ppm. The relatively dangerous conditions for bioaccumulation are indicated by natural variables such as slightly low Eh, slightly acidic pH, low conductivity, dark water colour, low biomass productivity and low amount of fine ferruginous particles in the sediment. In general, biota samples are showing low to medium bioaccumulation levels. In spite of stopping Hg emissions in "Bajo" Caroni, mercury content in sediments is subjected to complexation and further methylation due to medium levels of organic matter in sediments, as well as in solution. At the moment, this process seems to be occurring slowly and permanent monitoring should be applied.

The Figure 5 compares the bioaccumulation results of Guri and “Bajo” Caroni. About 50% of fish samples from Guri and 40% of samples from “Bajo” Caroni were carnivorous. In spite of this small difference, the impoundment effect on Hg bioaccumulation process in Guri is clear.

We can hypothetically assume that Guri soil before flooding had 0.1 ppm Hg in which 1% was already methylated. Considering that 1 m^2 of soil with thickness of 0.1 m has 100 kg of material, then 1 m^2 of Guri soil had 0.1 mg of methylmercury. The flooded area was 4000 km^2 which leached 400 kg of soluble methylmercury into the Guri water system. The Guri Committee has estimated that 20,000 tonnes of fish is exploitable annually from Guri. So, assuming that the fish biomass is 20 times this number, so this exercise indicates that the leaching action of flooding was enough to elevate the Hg level of all fish to 1 ppm in the first step of inundation. This is an approximation and Hg is accumulated differentially by the position of each fish in the trophic chain. However, this is indicative that Me-Hg washed out by flooding was an important source of Hg contamination in 1986 when the reservoir was filled. The decomposition of submerged vegetation, bacterial activity and quality of organic matter are establishing the methylation rate of natural and industrial (including mining) mercury which is submerged.

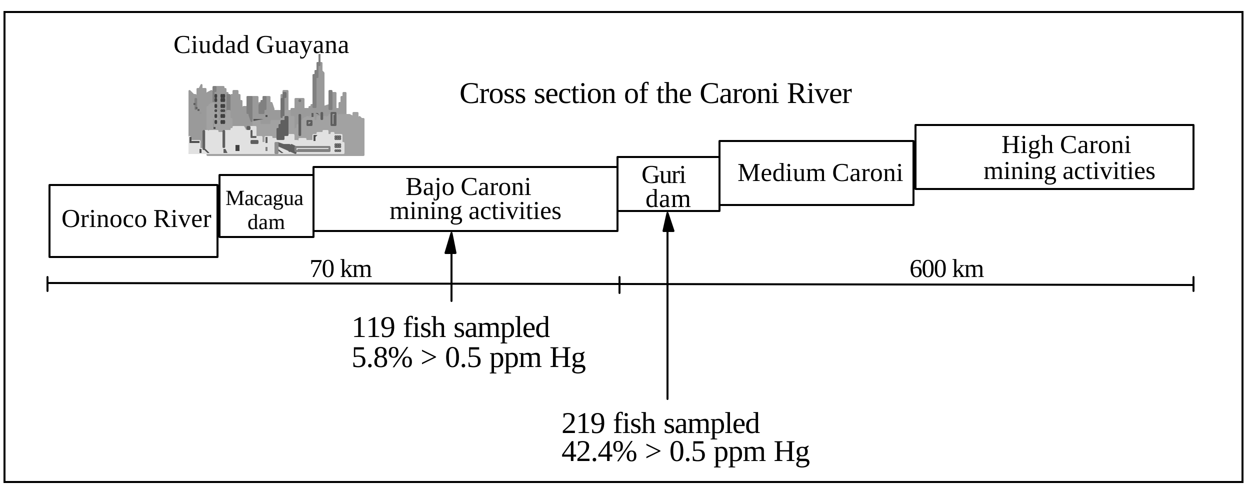

Fig. 5 - Comparison of Hg levels in fish from "Bajo" Caroni and Guri.

APPROACHES TO THE MERCURY PROBLEM

Different approaches have been applied to the Hg pollution problem in Latin America, but with low effectiveness. The following approaches can be identified :

- Armed
- Legal
- Ecological
- Educational

The use of **armed** force has been applied in many episodes in Brazil and in Venezuela, when miners threatened indian cultures, or ecological parks or companies' leases. These measures have shown temporary effects because miners are dispersed. So, they have always returned to their illegal activities.

The **legal** approach to artisanal mining has been tried by administrators and legislators. In most developing countries, mercury is not allowed to be used in mining activities. The legal measures to control the use of mercury have shown temporary effects because. An example of the inefficiency of legal control of mercury emissions can be observed in the Venezuelan Environmental Law, Decree 2225 of April 23, 1992 which says that an alkali plant is allowed to emit to the atmosphere 2.3 kg of mercury daily. This is almost 800 kg of Hg per year. So, can a miner emit this level of Hg as well? The legal approach is usually fraught with ambiguity. Enforcement is a fragile measure to stop the impact from informal mining activities in inaccessible regions. The lack of trained inspectors and ethical law enforcement personnel is the main difficulty in implementing effective legal control of miners.

The **ecological** approach comprises warnings and denunciations made by environmentalists and research groups. They investigate the level of Hg pollution in the environment to sound alarms. It is an important measure, but few suggestions to stop emissions and to mitigate highly polluted areas have actually been generated. In addition, the decision-making people do not have access to or understanding of the technical results of academic researchers.

Only a few **educational** measures have been applied to the mercury problem in Venezuela. Few attempts by technical people to alert the miners and provide options for handling mercury have been done. The amount of budget and effort spent in this method were certainly lower than those of other approaches.

Education is a prerequisite for long-term reduction of Hg-emissions and to move this squad of unprivileged workers into an organized society. Educational measures can be viewed as an assembly of recommendations addressed at people involved with mining to convince them to adopt safe methods for the environment and themselves. As Mr. Ivo Lubrina - a miner leader said: *it's a hard job to teach ecology for an illiterate and poor miner.* These measures may not necessarily reach informal miners directly, but through skilled people who may be in frequently contact with them. Miners must be convinced they are being affected by Hg-vapors and causing irreversible health problems for their neighbors, friends and family members. Brochures explaining the danger of mercury distributed by international institutions and association of miners in Latin America and Africa may provide some help.

The “democratization” of the knowledge is a key step towards emission reduction and remedial procedures.

TECHNICAL SOLUTIONS

All approaches to the problem are important, but technical solutions must be introduced. Solutions for the problem have received little attention from researchers and governments. An integrated approach to mercury problem is necessary. Three main actions are delineated:

1. Search for alternative processes to avoid mercury
2. Implement remedial procedures to highly polluted sites
3. Apply measures to reduce mercury emissions

Attempts to introduce **alternative processes** for amalgamation, have not succeeded either. When tried, use of mercury was reduced, but never eliminated. Alternative methods need too much skill and investment than does the simple process of amalgamation. The only possibility to eliminate widespread use of amalgamation is to promote Processing Centers, i.e. miners take their gravity concentrates to a central establishment for processing by specialized people using amalgamation or leaching methods in a controlled laboratory environment. Such an approach, successfully applied in Venezuela, is hard to adopt by miners spread throughout the jungle. Implementation demands a very organized measure combining efforts from governments and miners together.

Remedial procedures are necessary when mercury bioaccumulation is evidenced by monitoring programs. In this case, the only indicator or evidence of bioaccumulation is biota, in particular fish, specifically carnivorous fish, preferably those with low mobility (e.g. black piranha). Predictions about risk of bioaccumulation can also be made based on natural variables (sediment type, Hg levels in sediments, water conductivity, Eh, pH, humosity, etc.) but these are not evidence of Hg pollution but rather evidence of environmental conditions that can lead to bioaccumulation.

Based on the nature of emissions, mercury can be concentrated in "hot spots", when amalgamation tailings are dumped into the waterstreams or dispersed in the sediments, when atmospheric Hg is deposited. There are different procedures to amend these situations. Whether "hot spots" should be dredged or covered is decided by the level of Hg in biota and an evaluation of costs involved with the dredging operation and spoil treatment. Covering is recommended for "hot spots" in enclosed systems. In a river, this technique would be less satisfactory, because erosion during high flows would simply re-expose the contaminated river bottom. Covering "hot spots" is a technique based on the fact that any possible oxidation of metallic mercury is controlled by adsorption so that the action of methylation agents is hindered. The remedial actions must focus on reducing oxygen access to the water-sediment interface and/or adsorbing all oxidized mercury that might form. This process was used in Minamata Bay to control methylmercury production in sediments. A series of covering procedures for polluted sediments is suggested for testing. Some of the covering materials that can be tested are shown below (Veiga and Meech, 1995a):

- Laterite crusts: iron oxides adsorb oxidized mercury.
- Pyrite: oxidized mercury can be precipitated as sulfide.
- Fibers: adsorb oxidized mercury released from sediments.
- Rubber scraps (e.g. old tires): adsorb oxidized mercury.
- Scrap Iron (cementation process): precipitates Hg(II) soluble compounds.

Dredging procedures to remove "hot spots" from the water system are expensive measures and are recommended only when the gold content in the spoil can return part of the costs or when mercury bioaccumulation cannot be controlled by covering processes. Usually, "hot spots" have high gold content. A separate processing plant must be implemented to extract gold and mercury from dredged material.

Procedures to minimize mercury bioaccumulation when mercury is dispersed in sediments have been applied in Canada and Sweden where fish from natural and man-made reservoirs show increasing mercury levels over time (Rudd et al., 1984; Lindqvist et al. 1991). Procedures such as selenium, liming or intensive fishing or re-suspension of sediments are applicable for enclosed environments such as lakes and reservoirs but no short term result has been observed. Some of these techniques could be tested in Hg-polluted mining areas, but the cost is a major impediment for these methods.

For affected communities in which fish is the main diet, unfortunately the most practical and immediately applicable solution is change of food habit. As carnivorous species accumulate more methylmercury than other species, a massive educational campaign is needed to suggest ingestion of herbivorous fish and other sources of protein.

Reduction of mercury emission is a practical way to cope with the problem. There are two approaches to be followed :

1. Systemic Solutions are those which consist of measures dependent on institutions, agencies and even private companies for implementation.
2. Individual Solutions are brought to miners by various sources but their use depends on each individual to adopt the suggested measures.

In both approaches, education is a pre-requisite for long-term solution to reduce mercury emission.

Systemic Solutions

A very creative solution has been implemented in Venezuela: Amalgamation Centers. This solution can be easily reproduced in other developing countries. Miners take their gravity concentrates to these Centers to be safely amalgamated by technical operators. In the government-owned Amalgamation Centers in Venezuela, the service is free. In private Centers, miners pay US$ 0.7 per kg of concentrate to be amalgamated. Based on the Carhuachi Center, a remarkable Amalgamation Center in Caroni River, UNIDO and a Venezuelan Non-Governmental Organization, PARECA have designed a new Processing Center - UNECA - **UN**it of gold **E**xtraction and **C**ontrolled **A**malgamation (Veiga 1997). Gold is extracted by amalgamation using special plates or leaching using the NaCl electrolytic process (Sobral and Santos, 1995). The first method reduces the use of mercury. The electrolytic process actually eliminates amalgamation. Special retorts and melting furnaces working under fume hoods with charcoal filters impregnated with iodine are used (Fig. 6).

Miners must be committed to take their concentrates to the Center. A strong educational campaign must precede the Center installation. This consists of a series of meetings with miner leaders to convince them about the risk of the poor amalgamation practices and the benefits brought by UNECA Centers. As well, governments must be assisted to find ways to legalize this Centers and enforce the law in mining regions where the Center will be set up to guarantee that miners will stop their own amalgamation. Changes in the legal and economic organization of the miners are not necessary to introduce the Centers in mining regions. Mining Departments and Small-Miner Associations can also have their own Processing Centers.

The UNECA-type Processing Center is suitable for installation in mining villages or in any central area to facilitate transportation of gravity concentrates. Gold recovery is actually improved and mercury exposure to the operators is insignificant. For a miner who takes his concentrate to a Processing Center, there is the additional benefit of reducing costs in his own processing plant. These Centers play an important role in bringing information about mercurialism caused by Hg vapor and contaminated fish ingestion. Miners can be given brochures and additional instructions while they wait for the processing of their concentrates. The Centers can provide advice for miners on how to improve their production and can provide a meeting place for other purposes of education and organization.

The total investment of almost US$ 250,000 to install a UNECA in a mining region can be drastically reduced after the installation of the first Center as many local manufacturers can be trained. The variable costs such as engineering and consulting fees can also be reduced as the technology is transferred to local technical people who can be in charge of building other Centers.

The operating costs for a UNECA Processing Center might be around US$ 15,000/month but this depends on local costs. The Center works with 5 people (or less): 2 technicians + 3 helpers in just one shift (8 hours, for 5 days/week). One technician is also in charge of administration. Three armed people in charge of security must be considered.

As in Venezuela, the UNECA Center can charge US$ 1/kg of concentrate processed. Assuming the concentrates weigh between 30 and 60 kg with grades ranging from 2,000 to 5,000 g/tonne, the cost of US$ 30 to 60 charged by the Center represents 2 to 5% of the gold content in the concentrates. Processing 500 kg of concentrates daily, which is approximately the amount treated by a Venezuelan Center, the income of US$ 10,000/month will be derived. This almost covers the operating cost.

The UNECA Centers are also decontamination centers. Using the electrolytic process or special-amalgamation plates, residual mercury and gold can be extracted from dredged “hot spots”. Tailings produced by individual miners who insist on amalgamating their concentrates can also be treated in the Center. As gold content in amalgamation tailings is high, the decontamination step, as observed in Venezuela, is a profitable operation conducted by private companies. The Center gives a safe end (landfill) to the decontaminated residues.

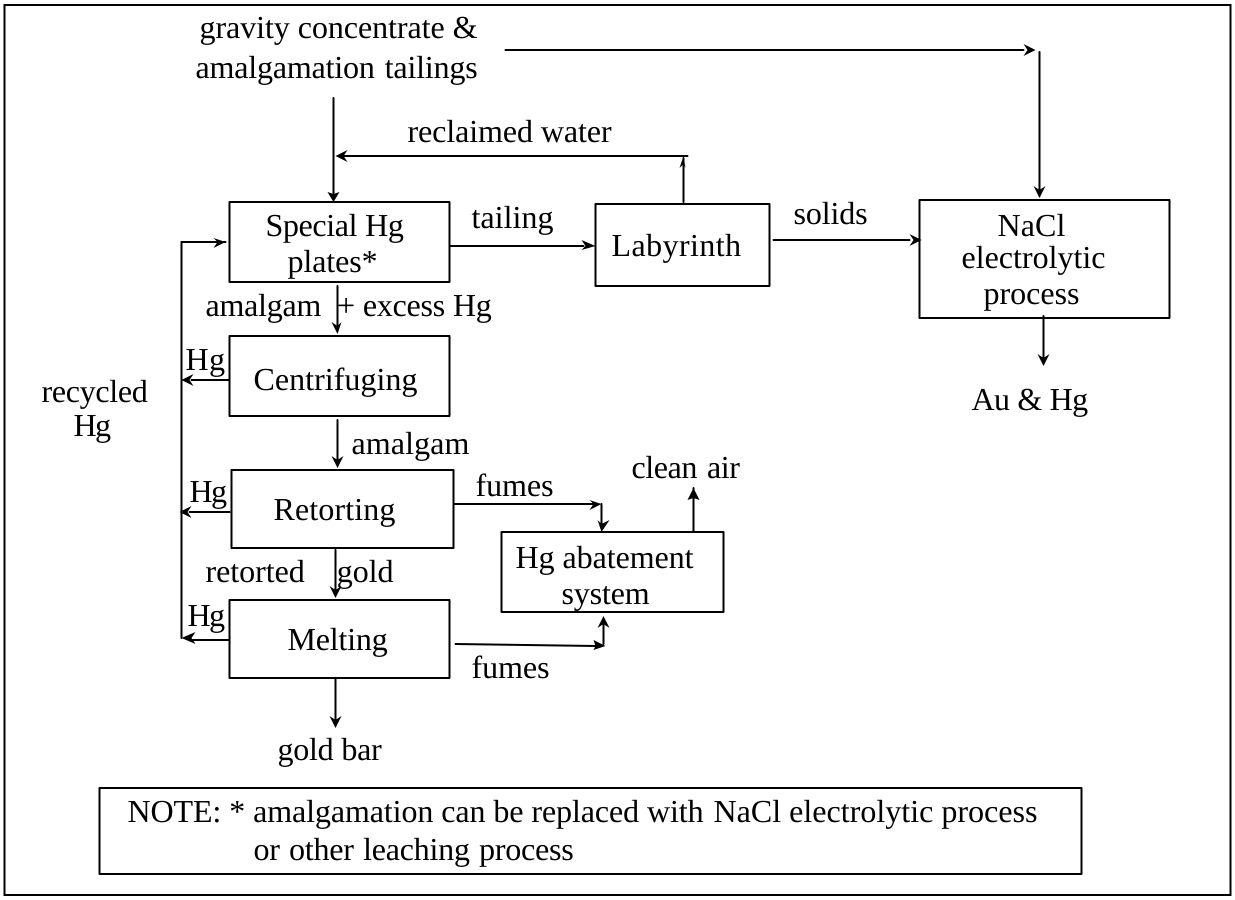

Fig. 6 - Steps in a UNECA Processing Center

Governments must set up a mechanism to guarantee that the Processing Centers will receive gravity concentrates and amalgamation tailings from miners. This can be done by decrees, contracts and agreements. UNIDO is prepared to assist the development and implementation of these Processing Centers in any country.

Another important systemic measure comprises organization of the artisanal mining activities. Creation of Miners' Association has been seen as an important step in organizing mining activities as well as an effective channel for introduction of clean techniques.

In spite of being a difficult measure to be implemented, law enforcement is an important element in controlling mercury sales and misuse. Miners must stop using mercury in their sluices or spreading Hg on the ground in hydraulic monitoring operations. The aim must be to force miners to think about amalgamating only concentrates. This reduces emissions and gives an opportunity to introduce new techniques in the future, such as the Processing Centers. The same police action must be applied to the large majority of gold dealers who melt gold and release mercury into the urban atmosphere. Solutions such as small scrubbers or filters must be enforced. These dealers are usually rich companies which can easily afford to introduce safety equipment. Legal control on miners burning mercury in open pans is more difficult since this operation is rapidly done and miners are often moving about from area to area.

It is also noteworthy to highlight the importance of permanent biological monitoring and technical assistance. Monitoring programs have been the focus of environmental agencies. They are important to follow changes in the bioaccumulation levels in a region to alert fish-eating people. This is usually an expensive task since chemical labs and specialized personnel are needed to analyze mercury levels in biological samples.

Technical assistance, as discussed above, comprises actions to bring practical solutions for miners to improve their productivity and reduce mercury emission. This must also be part of a permanent policy of Mining Departments which need trained people to deal with artisanal miners in a trustworthy manner. Miners are usually suspicious about government representatives, even when they bring profitable solutions. Engineers, technicians or consultants give suggestions but they never stay around to see the outcome of their ideas. An intelligent approach must be devised to train government personnel to guarantee that they will provide continued and durable technical assistance.

One of the greatest difficulties in reducing emissions and recognizing dangerous sites is the scarcity of people who can transfer knowledge about the issues. A multi-disciplinary approach is needed which can handle field observations as a preliminary step for rapid evaluation of the pollution extent.

Since use of personal computers has also become popular in artisanal mining communities, especially in schools, a computer program (HgEx) has been developed to transfer knowledge about mercury pollution to ordinary people. Using Artificial Intelligence techniques, the system can identify dangerous situations even when only imprecise data are available. Non-technical users can interact with HgEx to make reliable predictions about bioaccumulation risk and toxicological problems without sophisticated analyses of biological samples. Individuals subjected to Hg-exposure or those who eat fish predominantly can receive advice based on a questionnaire about diet habits, work behavior, life-style, etc. HgEx also contains an extensive tutorial section (over 1000 hypertext pages) on all aspects of mercury. Inputs are based on field observations. The program can be used in hospitals and environmental agencies. Local people do not need permanent presence of a specialist (Veiga and Meech, 1995b).

Individual Solutions

This group of solutions is focused directly at the individual artisanal miner to reduce his/her emission of mercury. A special-amalgamation plate, devised by a Brazilian company, Rio-Sul, is an effective way to extract gold with negligible mercury loss. Some small operations in Brazil are using successfully the Rio-Sul plates to proceed with amalgamation of gravity concentrates (Veiga et al., 1995b).

Retorts can be used to capture volatilized mercury, condensing it with recovery above 95%, allowing the mercury to be recycled and resulting in substantial reduction in air pollution and occupational exposure (Braga et al. 1995). There are many types of retorts. Some are made with stainless steel while others use inexpensive cast iron. Mercury losses during retorting depend on the type of connections or clamps used. A homemade retort built with standard plumbing water pipes can be easily assembled to reduce mercury emission (Veiga et al. 1995a). Use of this type of retort is easily understood and accepted by miners because it is inexpensive. All materials are familiar and accessible to the miners.

Methods for mercury abatement from fumes released when gold bullion is melted are available and can be easily implemented. In 1989, a Brazilian company developed a special mercury condensing fume-hood. The prototype had a series of condensing plates coupled with activated charcoal filters impregnated with iodine solution. This equipment reduces mercury emission drastically. More than 99.9% of mercury from the fumes is retained by this special fume-hood (Veiga and Fernandes 1990).

CONCLUSION

Artisanal gold mining in developing countries is a temporary activity. This will persist up to the exhaustion of easily extractable gold. Artisanal activities on primary ore deposits are inefficient and expensive. In all regions where miners insist on applying rudimentary methods to extract and process primary ores, the results are not encouraging. The activity is creating social and economic problems in municipalities where mining is the main economic activity, due to the migratory nature of miners. It is clear that gold panners who conduct very-small scale mining for their subsistence will exist for many decades, as long as new discoveries of alluvial gold ore are made in remote regions. Since mechanized operations introduced into artisanal mining tend to evolve into organized activities, technical and legal support to meet mining and environmental regulations should be made available to small-miners. Governments must find a way to transfer legal titles to those who indeed have discovered the majority of gold deposits in developing countries. This is an important way to stop migration of these miners and create concern for the environment.

Mercury pollution has been used by different segments of the society as a useful villain and affected communities have been ignored. Myths and taboos about mercury pollution is creating hysteria and helping hidden interests of economic groups. This is enlarging the gap between artisanal miners and organized society and creating more illegality. The problem can not be ignored or approached with exaggeration. True facts are the only way to create a trustworthy environment to implement, TOGETHER WITH MINERS, effective solutions for mercury pollution. Education is a prerequisite for long-term solutions for the mercury emission problem. The creation of Processing Centers to amalgamate or leach gravity concentrates is perhaps the most concrete systemic solution to reduce emissions or eliminate mercury use. Since miners agree to bring gravity concentrates to these

Centers, as observed in Venezuela, amalgamation can be conducted safely and without emission. Other solutions to reduce mercury emissions are:

- Stop the use of amalgamation for the whole ore.
- Use of special Hg-based plates to amalgamate gold from gravity concentrates.
- Use of retorts to separate mercury from gold.
- Use of filters in shops melting gold.
- Formal education in schools.
- Creation of Miner Associations as a form of union organization.
- Law Enforcement.
- Biological monitoring in sensitive areas and technical assistance.

The efficiency of any measure depends on miners' commitment. Governments and technical people must understand the trait of the Latin American artisanal miners to change their behavior and transform a squad of unprivileged people into citizens.

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