Mercury Contamination in Prey Meas Goldmine
Ratanakirri, Cambodia, 2006 Sampling
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Abstract
Mercury is used to extract gold in simple artisanal gold mines in Ratanakirri province, NE Cambodia. Before this project, the gold amalgam was heated with an open flame to volatilize mercury and recover gold. The process resulted in release of mercury and associated contamination. In this set of analyses from 2006 the miners hair contained up to 42000 ng/g of mercury. Fifty kilometers downstream large predator fish contained as much as 400 ng/g of mercury. Retorts were introduced to recycle mercury. Water in the miner's well was contaminated with bacteria. Ceramic water filters were introduced to treat the well water and alleviate their diarrhea.

Introduction
Artisanal gold mining results in 12-23% of anthropogenic mercury emissions (Eisler 2003). Thus, the need to improve the extraction of gold is at least a regional if not a global concern. Once mine sites are contaminated, restoration is difficult if not impossible in the third world. Moreover in Cambodia, the rivers receiving mercury wastes are targeted to have hydroelectric dams (Figure 1). Typically reservoir construction results in enhanced methylation of mercury, increased several fold bioaccumulation of mercury.

In Cambodia, most goldmines are in the east and north. The goldmine studied in this report is Prey Meas in Ratanakirri province in NE Cambodia. Sotham (2004) states that in his survey in 2003, there are six active mining sites in Prey Meas gold deposit: Bay mot; Bay Hai; Bay Ba; Bay bon; Prey Meas; and Prey Thmei. Specific GPS coordinates are not available for all the mine sites and miners also refer to other mines in the area. Miners informed us that the Prey Meas shafts (within the Prey Meas complex) are now abandoned. Prey Thmei is the only mine site that was sampled in this study. The common practice is to still call the Prey Thmei mine "Prey Meas" and to avoid confusion we will continue to use this term. Sotham (2004) estimates that in the dry season the number of miners increases by several hundred. A census was not done, would be difficult, and the important variable is the number of flumes, not workers.

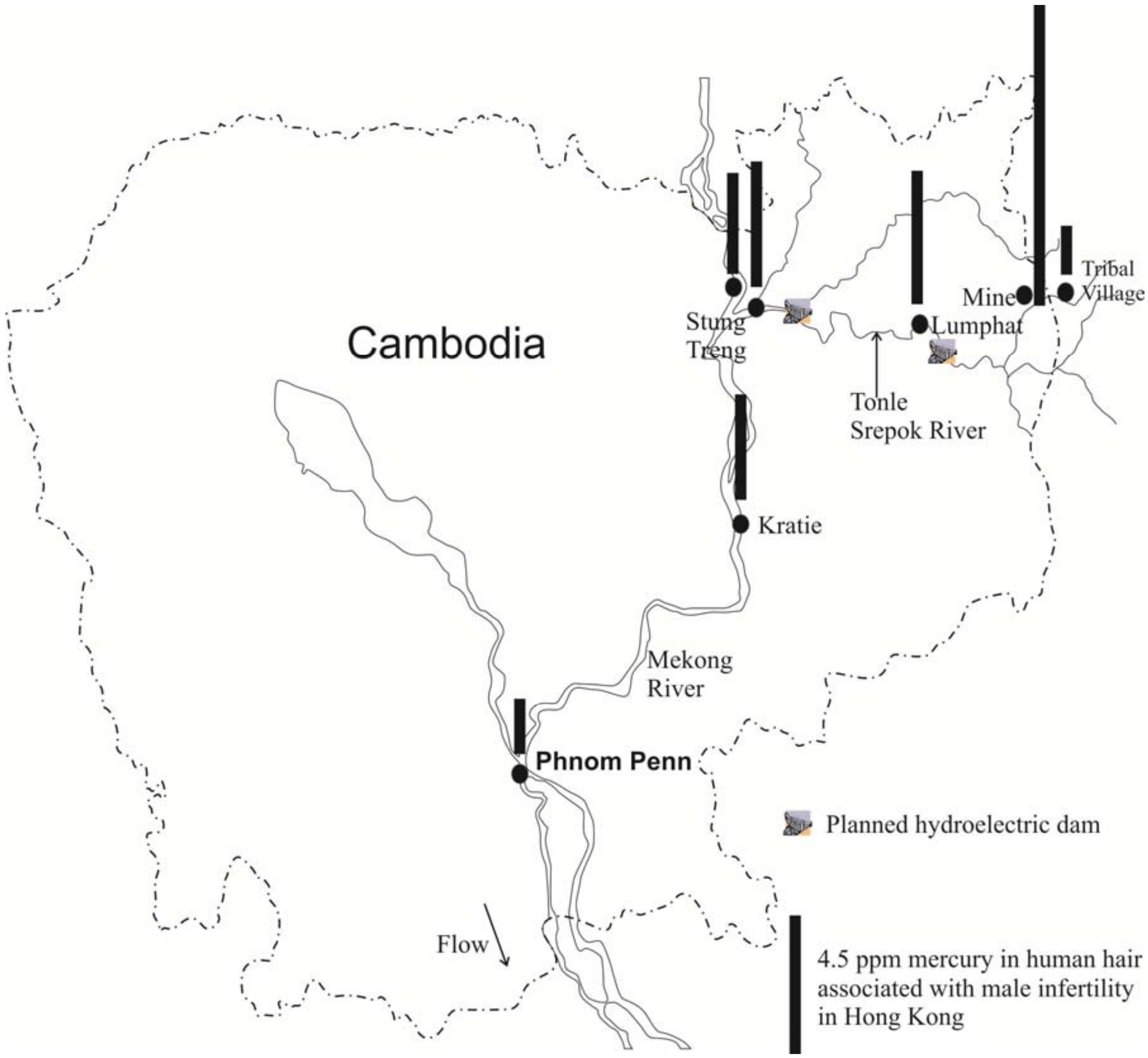

Figure 1. Map of Sampling Sites

Methods

The goldmine site (13°31'22.9" N, 107°22'46.6" E) is in a dry forest about 48 km SE from Banlung. Miners use motorcycles to access the mine. Even when dry, the road access is extremely bad requiring a four wheel drive vehicle with high clearance and a skilled driver. Either off duty policemen or military men were used for drivers. Security was mentioned as a concern in Sotham (2004). Some miners might present risks and some danger could be associated with illegal logging. Trees in various state of being processed were seen but no loggers were visible. We had talked to many drivers and likely everyone with good vehicles knew of our presence.

Mercury Analysis

For most mercury analysis, a DMA80 Direct Mercury Analyzer from Milestone was used. The process is detailed in EPA Method 7473: Mercury in Solids and Solution by Thermal Decomposition Amalgamation and Atomic Absorption Spectrophotometry. This process is designated for the determination of total mercury in solids, aqueous samples and digested solutions. Solid and aqueous samples are dried and then thermally and chemically decomposed by controlled heating in an oxygenated decomposition furnace to liberate mercury. The decomposition products are carried by flowing oxygen to the catalytic section of the furnace where oxidation is completed and halogens and nitrogen/sulfur oxides are trapped. The remaining decomposition products are then carried to an amalgamator that selectively traps mercury. After the system is purged with oxygen to remove any remaining residual by-products, the amalgamator is rapidly heated to release mercury vapor. The vapor flows through an atomic absorption spectrophotometer set at 253.7 nm to measure the concentration of mercury. Certified reference materials (CRM) were used for each set of analysis. Results were always within the standard deviation of the CRM. Relative standard deviations were typically around 3%. Blanks were run for each set of analyses and blank values were always much less than 1% of samples.

Drinking Water Analysis

One well with a depth of about 30 m serves the mining community with drinking water. Cyanide in the well water, before and after filtration, was measured using a colorimetric procedure (1NW6) in the Wastewater Technology Centre, an accredited laboratory within Environment Canada. Environment Canada's accredited National Laboratory for Environmental Testing (NLET) analyzed metals and major ions in the well water.

Coliscan kits were used to evaluate bacterial contamination (www.microbiologylabs.com). One ml of water was added to the culture media, swirled, then poured into the culture plates and incubated for 36 hours prior to counting. This procedure is simple but is approved by various American agencies such as the Virginia Department of Environmental Quality for screening purposes. Confirmation analysis was not possible in this study.

A ceramic water filter was donated by Resource Development International (RDI, www.rdic.org) and evaluated at the Prey Meas Mine.

Hair samples

Hair samples were collected from miners February 18 and April 20, 2006 (Figure 2). Also hair samples were collected from a village on the Ou Tran River, approximately 6.1 km from the mine (13°31’51.0” N, 107°26’27.0” E). Figure one includes data from earlier sampling (Murphy et al. 2006). In general, hair was washed prior to analysis.

Figure 2. Collecting Hair Samples

Fish sampling

Samples were collected either by visiting sites by car, motorcycle or boat. Dirt paths allowed access to the river from the goldmine by motorcycles. We got to within a few kilometers of the drainage of the mine to the river. On April 20, two men with a simple net (2 m by 10 m) were not able to collect fish (13°31’51.0” N, 107°26’27.0” E). On April 22-23, a small boat was later used to go 48 km up the Srepok River to collect fish 1 km up the Ou Tran River (13°19’35.1” N, 107°20’51.6” E). Five species of fish were collected from the Ou Tran and another 15 species were collected from the Tonle Srepok but no large predator fish such as snakeheads (Channa sp) were sampled. April 24, snakeheads were collected from the Tonle Srepok River by fisherman and bought at the market in Banlung. Identification was done using the FAO Fishes of the Cambodian Mekong (Rainboth 1996).

Results

Physical Site

The goldmine had enough mature trees that aerial photography might not be useful to measure the extent of mine tailings. The bedrock was overlaid with about 2 m of soil. The gold bearing rock was found in veins that were removed with explosives. The shafts were not supported with timber. The rock was ground and fed into hydraulic flumes (Figure 3). The wastes from the flumes were not treated in any way. There was no attempt to contain the mine tailings (Figure 4). The mercury content of two mine tailings samples was 7734 and 7697 ng/g. Likely this mercury eroded from the flume but it could have reflected mercury volatilized when the amalgam was heated.

Figure 3. Flumes for Gold Recovery (hose at right was used to reveal mercury)

Figure 4. Mine Tailings –left Prey Meas right Ou Tron mines, Cambodia

The active components of the flume were metal sheets that were covered with a layer of mercury to trap the gold. At the end of the day, the gold amalgam was scrapped off the metal sheet (Figure 5). The first next purification step was the squeezing of the unreacted mercury through a cloth. The gold amalgam did not pass through the cloth. Next the miners heated the gold amalgam with an open torch on a piece of clay pottery until the mercury vaporized (Figure 6). At this point, the gold still had obvious black specs and was impure. Next the miner added about 10 times the mass of silver to the gold with nitric acid. The acid was then heated until it boils (Figure 7). The resulting solution was then dumped onto the ground. The acid was flushed with water. The resulting gold looked pure.

Figure 5. Scraping Mercury off Metal Flume

Figure 6. Heating Amalgam to Volatilize Mercury and Recover Gold

Mercury recovered in retorts

First, one retort was made in Canada as a model for local craftsman in Cambodia (Figure 8). The "Canadian" model was constructed from kitchenware utensils that originated from China. As expected, similar products were available in Cambodia. The stainless steel in these products is thin but welders in Canada and Banlung, Cambodia had no difficulty making the required modifications. Heating with a small stove was not effective (Figure 9). A hand-held torch directed the heat to the gold better and not to the overlying water trap (Figures 10, 11). The cost of the retort in Banlung, including labour was $10.50. Mercury was effectively trapped in the retorts (Figure 12). The miners preferred the glass top retort that was only intended for demonstration. Two retort designs were used successfully. A glass jar was also evaluated but the flat top condensed too much water which dropped into the recess with the mercury. The shape for the top must be curved.

Figure 6 shows the process that was used before the introduction of retorts. The heating of mercury in the open contaminated the workers, their families and to a lesser degree everything downstream. As well as the training at the mine site, demonstrations were given to the local Ministry of Environment and craftsmen in Banlung. Presentations were given in Phnom Penh to the Ministry of Environment, Ministry of Fisheries, Plan International, and Rotary Club.


Figure 7. Heating Nitric acid and Silver to Purify Gold


Figure 8. Retort

Figure 9. Retort with Cooking Heater

Figure 10. Retort Demonstration

Figure 11. Heating Retort

Figure 12. Retort After Separation of Mercury and Gold

Mercury in Human Hair

The differences in the mercury content of miner's hair in 2006 on two sampling trips was huge. In February the mean and standard deviation of the mercury in hair was 2327±1498 ng/g. In April the mean and standard deviation of the mercury in hair was 28,788±12200 ng/g. In April three of the miners that used open torches to remove mercury from gold-ore amalgams had more than 40,000 ng/g of mercury in their hair. These are extreme levels well beyond the 10,000 ng/g associated with Minamata disease. Although our note taking changed and on the second trip we recorded more workers that used torches to volatilize mercury from gold amalgam we do not believe that we focused more on these burners during the second sampling. It seemed that something had changed in the gold processing but it was not resolved in 2006. The mean mercury content of both sampling trips (n=20) of miner's hair was 9988 ng/g (Figure 13, (Appendices 2-3). The USA EPA alert level for mercury in human hair is 1000 ng/g (National Research Council: 2000). When the 176 hair samples summarized in figure 1 were collected (prior to 2007) there was not a laboratory in Cambodia that could measure mercury in blood or urine. These are difficult to ship overseas and hair analysis was chosen. In 2006 we evaluated a distilled water wash with sonication that had no effect on the mercury content of hair (Appendix 4). For our purposes it is enough to say that the mercury in the miners' hair reflects exposure to high levels of mercury.

Certainly the mine workers handling mercury had much more mercury in their hair than miners hauling rock. We also sampled nine tribal villagers 6.1 km from the Prey Meas goldmine who had a mean of 1580 ng/g (±0.34) of mercury in their hair (Appendix 4). The latter tribal village was only 1.88 km upstream from the confluence of the creek that drains the mine site and the Ou Tran River. The hair in this tribal village had much less mercury than all villages downstream of the mines. The lower content of mercury in the tribal village hair could reflect the following:

1) Tribal people traditionally lived in the forest and had a different diet from Khmers. They do eat fish but their diet could influence assimilation of mercury.
2) The fish in the river at the village had less mercury or there were fewer large predator fish. Both seem possible but the data is too modest for certainty.
3) Toxins from the mine or some other factor suppressed methylation of mercury and there was less bioaccumulation. Once the tributary joins the Tonle Srepok River, dilution of toxins would be at least tenfold perhaps then enabling methylation of mercury.
4) The mine site is too oxic for methylation of mercury and may have lacked adequate organic matter for microbes.
5) The pattern of mercury contamination downstream of the mine might reflect another source of mercury such as deforestation (Veiga et al 1994).

About 50 km downstream of the goldmine, human hair had on average slightly more mercury than Dickman et al. (1998, 1999) found in Hong Kong to be associated with fertility problems in men. It is also much higher than the average reported (990 ng/g) to be associated with health impairment of gold workers in the Philippines (Akagi et al. 2000). Individuals (not mean) exceed levels associated with lose of peripheral vision (Barbeau et al. 1976), early nervous system dysfunction (Lebel et al. 1998) or child development (Barbosa et al. 1995, McDowell et al. 2004). Further downstream before the junction with the Mekong River the levels decrease slightly but are higher than Kratie and drop much more in Phnom Penh.

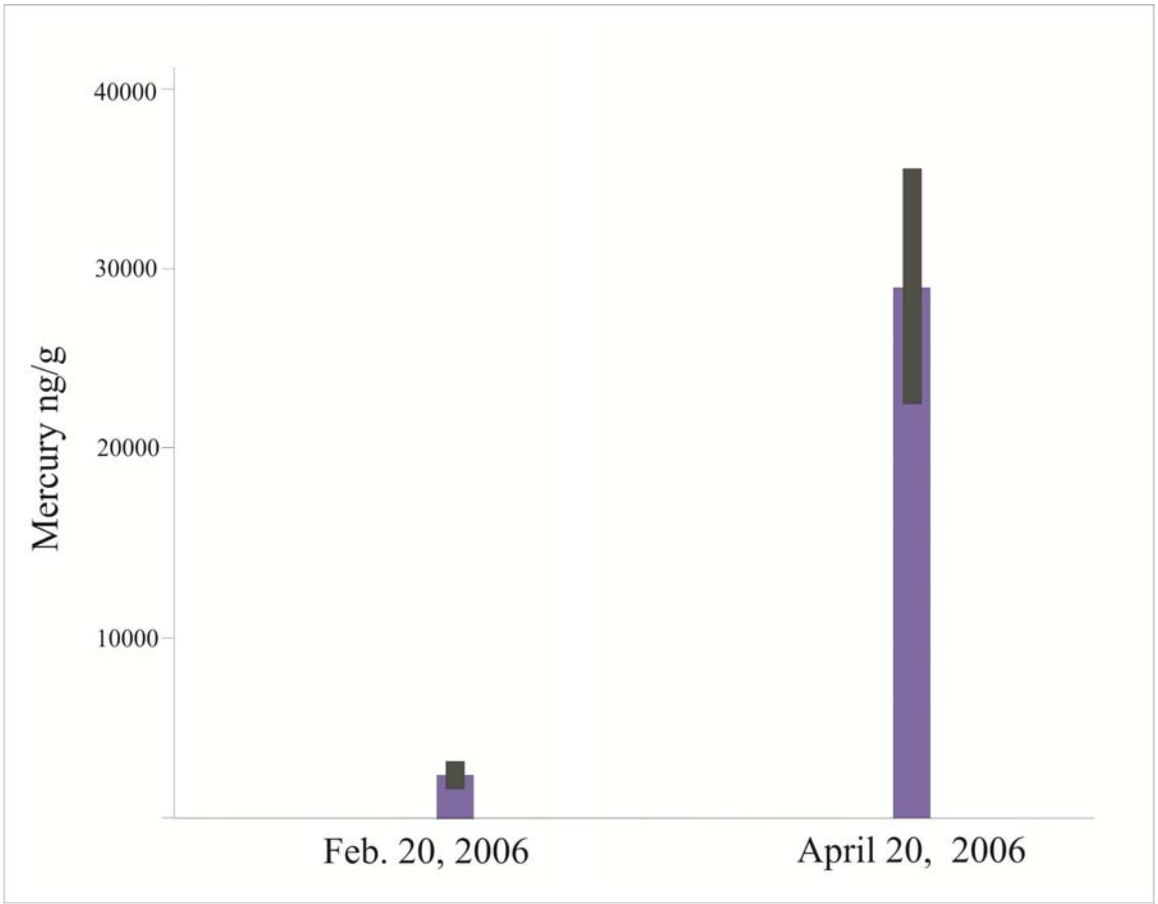

Figure 13 Mercury Content of Miner's Hair 2006

Mercury in Fish

The pattern of mercury contamination in fish is based upon a small sample size but it is suggestive of processes to be evaluated in the future and it may represent what people are eating (Figure 14). Concentrations of mercury were highest in a set of samples from Lumphat collected in February 2006. Lumphat is more than 50 km from the goldmine. Nineteen samples had a mean of 149 ng/g of mercury (Table 1, Appendix). Six of the predator fish had more mercury (200 ng/g) than Health Canada (1978, 1984) has recommended mercury in subsistence settings where people consume a lot of fish. Large predator fish such as snakeheads contained more mercury (400 ng/g) than is generally recommended for pregnant women (Figure 15). The predator fish are more popular. Health Canada's advisories suggest that 1 kg of the average fish in Lumphat could be eaten safely in a week (Health and Welfare 1984). Some people would exceed this amount of fish.

On April 22, eight fish collected from the Ou Tran River had a mean of only 16 ng/g of mercury. In the Srepok River between the Ou Tran River and Lumphat, 20 fish had a mean of 54 ng/g, much less than the fish from Lumphat in February. On one trip in 2006 it was not possible to collect fish from the Ou Tran River near the mine site. It is possible that the mine reduces fish production and if true it would impact predator fish first which would reduce biomagnification and bias the spatial analysis of mercury in fish. To avoid this problem, other animals like clams might be collected for analysis of mercury bioaccumulation.

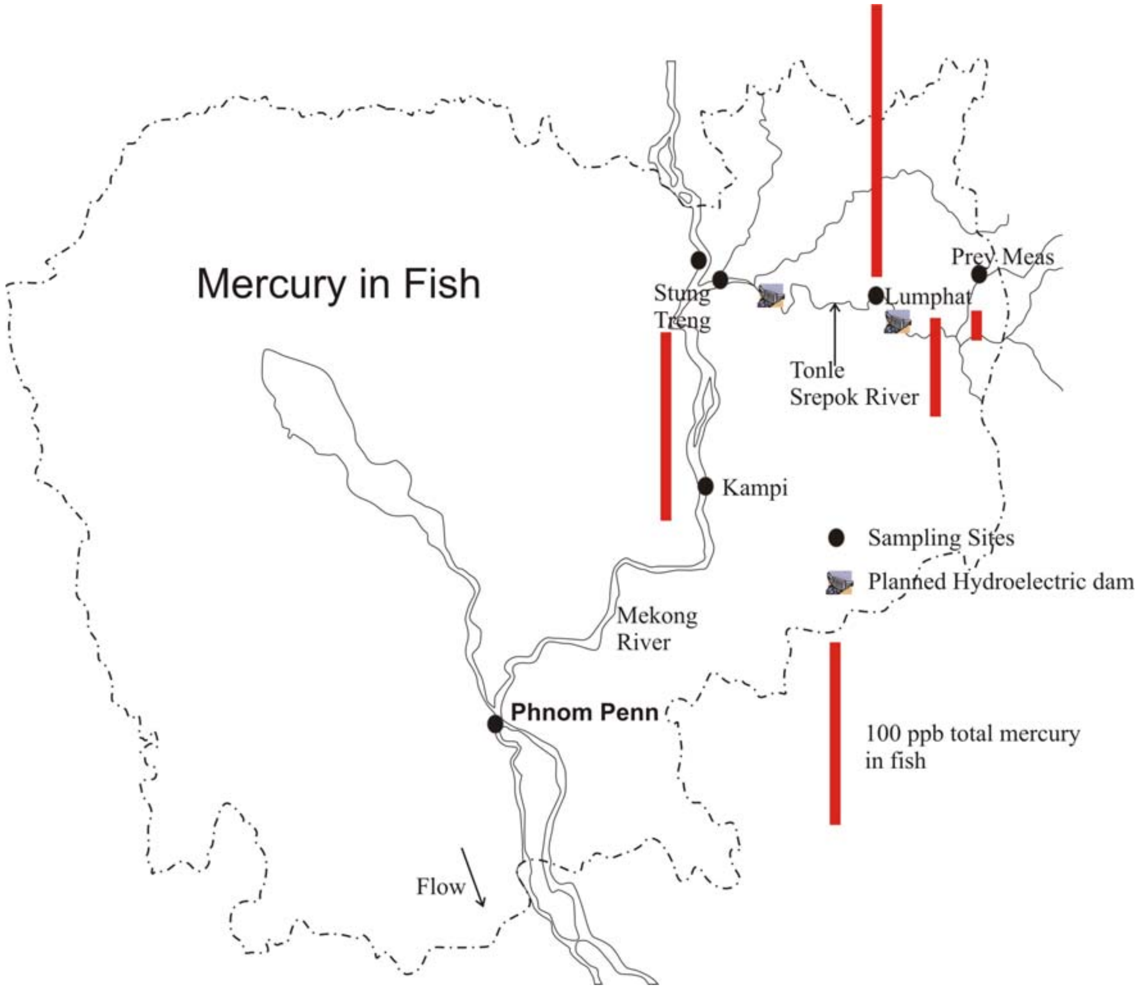

Figure 14. Mercury in Fish

Figure 15. Predator Fish like these Snakeheads are Richest in Mercury

Sanitation

The mine site had no toilets. Furthermore dogs, chickens and pigs roamed freely. Diarrhea and malaria were common. No assessment of parasites or disease has been conducted. The Coliscan analysis indicted that the drinking water well was contaminated. The miners did not always boil water. The RDI filter effectively removed virtually all the bacteria and likely other parasites (Figure 16, Table 1). The free roaming pigs could be a source of Giardia, Blastocystis, liver flukes and other parasites. The filtered water smelled, looked and tasted good. Cyanide in the well water was detected at 0.002 mg/L. The maximum acceptable concentration for cyanide in drinking water is 0.2 mg/L (Ontario 2003). In our analysis, cyanide was not leaking from the cyanide leaching tanks (for gold extraction) into the well water and cyanide did not appear to be a problem in their well water. Further analysis indicates that other aspects of the water quality of the well water, including mercury are acceptable (Table 2, 3).

Table 1 Well water bacteria [per ml]

Colony Type	F-1	F-2	Raw-1	Raw-2
E. coli	0	0	6	4
Unidentified	1	0	12	80
General coliforms	0	0	41	75

F-1 and F-2 and samples that were processed in the RDI ceramic filter.
Raw-1 and Raw 2 are samples that were not filtered by the RDI ceramic filter.

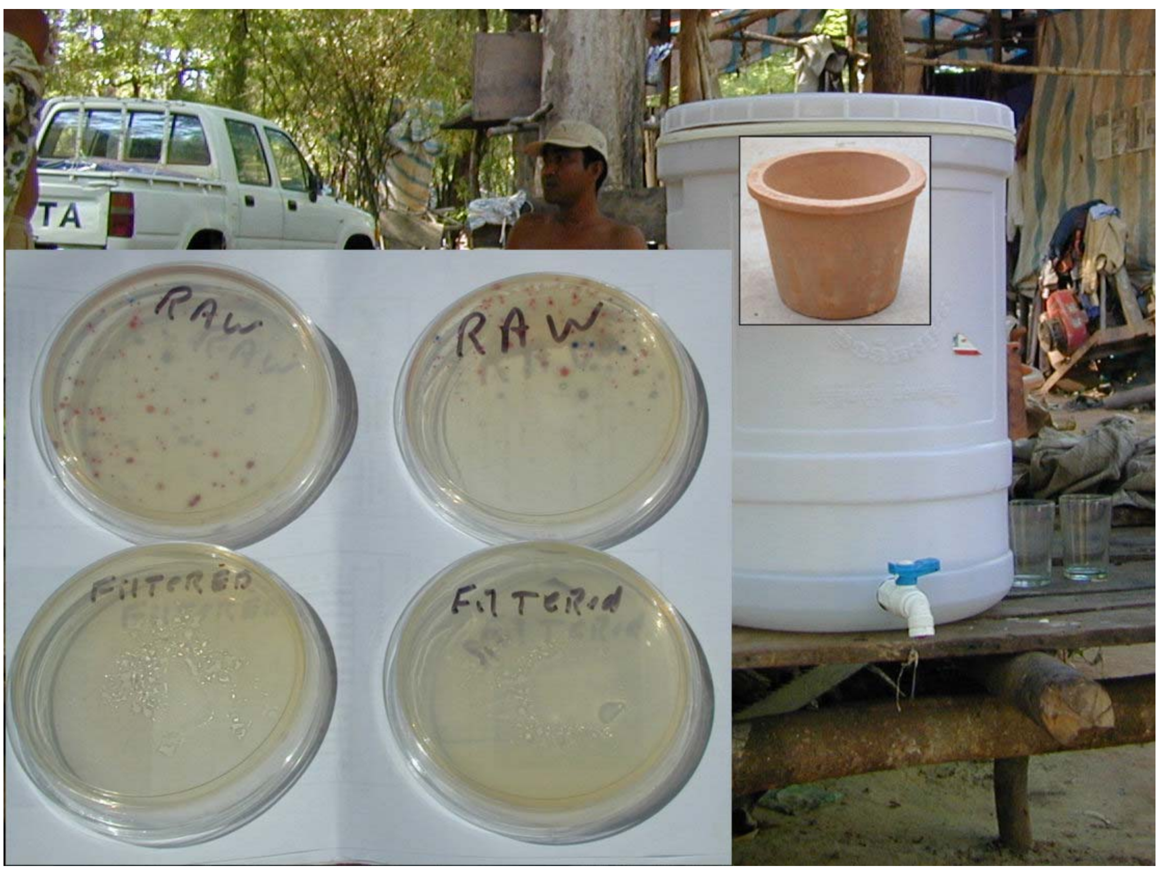

Figure 16. Ceramic Water Filter Removed Bacteria from Well Water

Table 2 Major Ions in Prey Meas Mine Wellwater (ppm)

Cl	2.07
SO_4	32.6
Ca	56.6
Mg	11.4
Na	10.8
K	9.53
$SiIO_2$	57.4

Table 3 Metals in Prey Meas Mine Wellwater (ppb – except for Hg)

Metal	Concentration
Ag	0.034
Al	193.
As	2.51
B	0.7
Ba	216.
Be	0.017
Bi	0.018
Cd	0.473
Co	2.47
Cr	0.084
Cu	1.56
Fe	1850
Ga	0.034
Hg ng/L	10.88
La	0.226
Li	4.9
Mn	492.
Mo	0.138
Ni	0.90
Pb	5.35
Rb	2.39
Sb	0.030
Se	0.21
Sr	51.1
Tl	0.008
U	0.0030
V	0.707
Zn	31.8

Turbidity Downstream

Figure 17 illustrates the extremely high turbidity in the river receiving drainage from the goldmine and perhaps deforestation. The rocks in the stream were covered with a layer of ground rock. Although no measurements were made, it is highly likely that this turbidity suppressed periphyton (attached algae), invertebrates and in turn fisheries (especially spawning, Mol and Ouboter 2004).

Figure 17. High Turbidity in Ou Tron River Downstream of Goldmine

Suggestions for Further Analysis

Estimate of Mercury Flux from Goldmines

It is important to estimate the flux of mercury from the goldmines. Several aspects need to be resolved before a good calculation is possible. The number of flumes being used, pumping rate of flume pumps, and the number of mines is not well documented. GPS readings are not available for most mines. Veiga (2005) says that 50% of mercury applied to a flume escapes. Lacerda and Solomons (1998) report mines with higher and lower rates of mercury loss.

Silver Used to Purify Gold

The miners use silver to purify gold and then dump the silver rich solution. Silver is very toxic to fish and other aquatic animals (Silver 2003). In the USA, water with more than 3 ppm of silver cannot be flushed down a drain. Silver costs about $494/kg and recovery methods are available. As with the retort for mercury recovery, it is critical to provide miners with a simple system they can use for profit. Unlike with mercury, recycling silver will not likely protect the health of the gold miners but still it should be evaluated.

The following process is used in Ecuador to recover silver (Veiga, personal communication)

1. melt gold and pour it in water - the higher the height the better to obtain fine grains of gold
2. leach with HNO_3 (this will dissolve Ag and Cu)
3. filter and have gold in a brown powder
4. add NaCl in the solution (a fine white powder will precipitate - $AgCl_2$)
5. filter this powder
6. mix this powder with steel wool and use HNO_3 and water (50%)
7. a dark silver power will be precipitated - filter it
8. melt silver and pour into water to make beads (easier to sell)

Alternative Methods of Gold Extraction

Cyanide leaching tanks were observed but the process of cyanide extraction of gold was not part of this study (Figure 17). The miners that we worked with did not use cyanide. Not all miners were cooperative and to study the details of cyanide management would require time to find miners willing to consult. Furthermore other gold extraction methods could be evaluated as a replacement to minimize loss of mercury or replace mercury extraction. The miners believe that mercury extraction is the easiest method.

Figure 17. Cyanide Extraction of Gold

The next step in mine engineering in Cambodia could be the use of a gold concentration procedure prior to amalgamation (Spiegel and Veiga 2005). By processing a smaller mass of ore, mercury amalgamation can be confined to a barrel, more of the mercury can be recovered and a much smaller mass of contaminated tailings is produced (Wotruba 2003)

Mine Tailings

The volume of the tailings is uncertain and so is the erosion and downstream transport of mercury from the tailings. The retort is effective but it is still uncertain and it is highly likely that more mercury escapes from the flume. This initial evaluation should be followed by more analysis, especially measurement of a mercury budget. Studying the site does not detract from ongoing efforts to change mining practices and reduce the release of mercury. It is important to understand the problems and prepare for the future. Sediment analysis downstream of a goldmine in Canada indicated that 50 years after the mine closed the flux of toxic metals continued at the same rate (Wong et al. 1999). Lacerda and Salomons (1998) review sites where mercury contamination from gold mines lingers for centuries.

Toxins in the ore could suppress methylation of mercury. Silver that is dumped from the gold purification is very toxic to bacteria (S. Silver 2003) and may well suppress methylation of mercury. The sulfide concentration of the mine tailings is also important. As sulfides oxidize, sulfuric acid is formed. The acid is toxic and it dissolves metals converting innocuous minerals into toxic wastes. Sulfide is known to suppression methylation of mercury (Steffan et al. 1988) and sulfides may be present in the volcanic rock. Tailings management should be designed to manage sulfide toxicity. Neutralization of sulfuric acid with base is highly unlikely at this remote site. Prevention of oxidation by placement of the tailings back in the mine or covering is technically possible but also unlikely. Construction of a tailings pond might enhance mosquitoes and malaria. Management of tailings would be much easier if the mine was managed by one operator not 30 independent families. There are many small tailings deposits.

It is not necessary to assume toxicity is suppressing methylation of mercury. The large concentration of mine tailings discharged has no nutrient value to microbes. In other mine sites, the lack of organic matter near the mine was associated with little methylation (Betancourt et al. 2005). The impact of the mine tailings could likely be best resolved with biological analysis of streams receiving mine wastes and compared to neighboring non impacted streams. Likely mercury suppresses the biological diversity and potentially the productivity of streams.

Impacts of River Turbidity

There are many concerns associated with the high discharge of mine tailings and soil erosion. The most obvious might be the rapid infilling of planned hydroelectric dams and irrigation reservoirs. More closely related to the theme of this study is the potential for downstream methylation of mercury from either mine tailings (Boudou et al. 2005) or from soil erosion (Roulet et al. 2001, Mainville et al. 2006).

Discriminating soil erosion from mine tailings would be useful for managers. Modern particle counters can quickly assess the size and shape of particles. Samples that were collected from the Mekong River were preserved and analyzed in Environment Canada laboratories; the preservative method worked well. This approach could distinguish turbidity associated with mine tailings from soil erosion. The alternative of taking turbidity readings with sensors exists but access to the rivers is difficult; it would be necessary to track each tributary. Satellite images might provide insight.

Furthermore, particle analysis should provide some insight into the fate of such materials in reservoirs that are planned downstream of the goldmines. Ideally, an assessment would estimate how quickly these reservoirs would be filled by mine wastes. The need for hydroelectricity is substantial and hydroelectric reservoirs are being developed quickly in neighboring Laos and Vietnam (Oxfam 2006). The establishment of dams in an area with goldmines using mercury increases mercury toxicity synergistically (Boudou et al. 2005). Boudou et al. did their study in tropical French Guinea. In the north of Canada where this has happened far more often the increased methylation and bioaccumulation of mercury in reservoirs can last 20-30 years (Rosenberg et al.1997). A recent review of mercury management in reservoirs provides a few options but likely only two are relevant to Cambodia; removal of trees prior to reservoir construction and prevention of mercury contamination (Mailman et al. 2006).

Human Health

Any attempt to resolve if mercury is impairing human health is difficult. Logistics and poor health conditions of the mining population may mask evidence of mercury poisoning. Large-scale epidemiological evidence of the association of mercury in artisanal gold mines does not exist (Eisler 2003). Extrapolating from other sites with mercury contamination like Hong Kong or Brazil is uncertain. The toxicity of mercury reflects other issues like the concentration of selenium which is known to assist in mercury detoxification (Koeman et al. 1973, Chen et al. 2001). Brazil is known to have naturally high concentrations of selenium which provides some protection from mercury (De Campos et al. 2002). Animal experiments and epidemiological analysis suggests that mercury can impair the immune system and enhance malaria (Crompton et al. 2002, Silverberg et al. 2005). However, recent work by Alves et al. (2006) indicates that for methylmercury from fish, malaria is not enhanced.

Further work on malaria in Cambodia would likely have a difficult time generating enough data to test this hypothesis. To collect samples from 100 to 200 people would be challenging. The optimal time for malaria is the rainy season when access to the mines is very difficult. The miners who own equipment stay at the mines throughout the year. Doing clinical evaluations of malaria with a kit like Malacheck™ would be a good humanitarian activity and perhaps provide basic scientific data. If such an effort were made, it would likely be more effective if other diseases like TB, diarrhea or parasites were also included in the sampling. Lebel et al. (1996) developed a battery of simple tests including measurement of loss of peripheral vision, and color discrimination that might be useful to measure early nervous system toxicity. If it were possible to do any clinical analysis of disease and the relationship with mercury, it would be wise to include other measurements of mercury. Mercury in hair is accurate, sensitive and provides a good integration of exposure to mercury. But further insights could be obtained by doing mercury analysis of urine (Adimado and Baah 2002) or blood. Any health analysis would be challenged by the lack of local medical resources and more serious issues than mercury. For example in this province, one in four children die before the age of five (National Institute of Statistics 2001).

The isolation of the miners likely contributes to malnutrition. Training and support to establish gardens could be effective. Parasites should be evaluated. Sanitation could likely be improved with donation of latrines. Safety in the mine shafts is a concern.

Impact on Wildlife

Although there was considerable concern associated dolphin mortality in the Mekong River all studied dolphin samples had normal concentrations of mercury (Murphy et al 2005). Assessment of rare animals like dolphins is difficult but some monitoring of endangered species is warranted. Several aquatic birds in Cambodia are vulnerable. For example, the rare Pallas's fish eagle (Haliaeetus leucoryphus) can be found at Stung Treng, downstream of the goldmines. Low concentrations of mercury are known to impair development of fish eating birds (Nacci et al. 2005). Fish eating mammals can also be impacted (Aulerich et al. 1974). Monitoring of non-motile animals like the freshwater mussel (Pelecypoda Corbicula Balnddiana or Pelecypoda Corbicula Moreletiana) might be more useful for mapping sources of mercury sources (Callil and Junk. 2001). Monitoring of fish is also important in that they are the major pathway for bioaccumulation of mercury to people and endangered animals. Monitoring of fish is much more difficult in that they move, and their mercury concentration reflects size, and species. There are more than 1000 species of fish.

Landmine and Unexploded Ordinance (UXO) Contamination

War records released from the Vietnam War shows areas a few km north of the Prey Meas mine were bombed "exceptionally heavily with munition types more likely to be possibly still dangerous (i.e. Cluster bombs and air-dropped land mines" (Map 6436 Andong Meas). The map indicates a few UXOs were dropped very close to the goldmine. None of miners hesitated to enter the woods and locally deer snares are another concern. NGOs are developing ecotourism along parts of the old Ho Chi Minh trail. Demining is likely required.

Social concerns

The migrant workers are paid $70 a month which is about twice the wage for other unskilled workers in Cambodia. However, mine equipment owners have difficulty getting laborers because of the mine has a repudiation for being harsh. The migrant workers spend their money at a local karaoke pub and there are potential impacts on the tribal women in the adjoining village.

The equipment owners are primarily families with many children. There is no school or teacher available at the mine. We did not visit the closest tribal village but a tribal village on the Ou Tran river (Dol, (13°31'51.0" N, 107°26'27.0" E, about 6.1 km east by north) had a school building but no teacher.

 

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Going up the Tonle Srepok River to Collect Fish Samples

Junction of Ou Tran River and Tonle Srepok River

Potential Hydroelectric Dam Site on Tonle Srepok River, Downstream of Goldmine

References

Adimado AA., Baah DA. Mercury in human blood, urine, hair, nail, and fish from the Ankobra and Tano River Basins in southwestern Ghana. Bull Environ Contain Toxicol 2002;68:339-46.

Akagi H, Castillo ES, Cortes-Maramba N, Francisco-Rivera AT, Timbang TD. Health assessment for mercury exposure among schoolchildren residing near a gold processing and refining plant in Apokon, Tagum, Davao del Norte, Philippines. Sci Total Environ 2000;259:31-43.

Alves, M.F., N. Fraiji, A. Barbosa, D. De Lima, J. Souza, J. Dórea, and G. Cordeiro. 2006. Fish consumption, mercury exposure and serum antinuclear antibody in Amazonians. Internat. J. Environ. Health Res. 16(4):255-262.

Aulerich RJ, Ringer RK, Iwamoto S. Effects of dietary mercury on mink. Arch Environ Contam Toxicol 1974;2: 43-51.

Barbeau A, Nantel A, Dorlot F. Etude sur les effets medicaux et toxicologigues du mercure organique dans le Nord-Ouest quebecois. Comite d'intervention sur le mercure au Quebec, Ministere des affaires socials du Quebec, Editeru official du Quebec, 1976 ; pp 278. 1.

Barbosa AC, Boischio AAP, East GA, Ferrari I, Goncalves A, Silva PRM. 1995. Mercury contamination in the Brazilian Amazon. Water Air Soil Pollut.80:109-121.

Betancourt, O. A. Narva´ez, and M. Roulet. 2005. Small-scale Gold Mining in the Puyango River Basin, Southern Ecuador: A Study of Environmental Impacts and Human Exposures. EcoHealth 2:323–332.

Boudou, A., R. Maury-Brachet, M. Coquery, G. Durrieu, and D. Cossa. 2005. Synergic Effect of Gold Mining and Damming on Mercury Contamination in Fish, Environ. Sci. Technol. 39: 2448-2454.

Callil, C.T. andW.J. Junk. 2001. Aquatic gastropods as mercury indicators in the Pantanal of Pocene Region (Mato Grosso, Brazil).Water Air Soil Pollut. 319: 319–330.

Chen, Y-W, Belzile N, Gunn JM. Antagonistic effect of selenium on mercury assimilation by fish populations near Sudbury metal smelters? Limnol Oceanogr, 2001;46(7):1814-1818.

Crompton P, Ventura AM, de Souza JM, Santos E, Strickland GT, and Silbergeld E. Assessment of Mercury Exposure and Malaria in a Brazilian Amazon Riverine Community. Environ. Res. Sect. A 2002;90:69-75.

De Campos MS, Sarkis JES, Muller RCS, Brabos ES, Santos EO. Correlation between mercury and selenium concentrations in Indian hair from Rondonia State, Amazon region, Brazil. Sci Total Environ 2002; 287:155-161.

Dickman MD., Leung CKM, Leong MKH. Hong Kong male subfertility links to mercury in human hair and fish, Sci Total Environ 1998;214:165-174.

Dickman MD, Leung CKM, Koo LCL. Mercury in Human Hair and Fish: is there a Hong Kong Male Subfertility Connection? Marine Pollut Bull 1999;39:352-356.

Eisler, R. 2003. Health risks of gold miners: a synoptic review. Environ. Geochem. Health 25:325-345.

Health Welfare Canada. Methylmercury in Canada. Exposure of Indian and Inuit Residents to Methylmercury in the Canadian Environment. 200 pg. Health and Welfare Canada, Medical Services Branch. 1978.

Health Welfare Canada. Methylmercury in Canada. Exposure of Indian and Inuit Residents to Methylmercury in the Canadian Environment. 164 pg. Health and Welfare Canada, Medical Services Branch. 1984.

Koeman JH, Peeters WHM, Koudstaa-HoL CHM. Mercury-selenium correlations in marine mammals. 1973. Nature 245:385-386.

Lacerda, L.D. and W. Salomons. 1998. Mercury from gold and silver mining: a chemical time bomb. Springer, Berlin, 146p.

Lebel J, Mergler D, Lucotte M, Amorim M, Dolbec J, Miranda D, Arantes G, Rheault I, Pichet P. 1998. Evidence of early nervous system dysfunction in Amazonian populations exposed to low-levels of methylmercury. NeuroToxicology 17(1):157-168.

Mainville, N. J. Webb, M. Lucotte, R. Davidson, O. Betancourt, E. Cueva, and D. Mergler. 2006. Decrease of soil fertility and release of mercury following deforestation in the Andean Amazon, Napo River Valley, Ecuador. Sci. Total Environ.368:88– 98.

Mailman, M., L. Stepnuk b, N.Cicek, R.A. Bodaly. 2006. Strategies to lower methyl mercury concentrations in hydroelectric reservoirs and lakes: A review. Sci. Total Environ. 368:224– 235.

Map 6436 Andong Meas, 2004, National Atlas of landmine and UXO Contamination, Cambodian Mine Action Authority, Phnom Penh.

McDowell MA, Dillon C, SE, Osterloh J, Bolger PM, Pellizzari E, Fernando R, Montes de Oca R, Schober, T. Sinks T., Jones RL, Mahaffey KR.. Hair Mercury Levels in U.S. Children and Women of Childbearing Age: Reference Range Data from NHANES 1999-2000. Environmental Health Perspectives Volume 2004;112:1165-1171.

Mol, J.H. and P.E. Ouboter 2004. Downstream effects of erosion from small-scale gold mining on the instream habitat and fish community of a small neotropical rainforest stream. Conservation Biology 18:201-214.

Murphy TP,Sampson M, Guo J, Parr T, Gilbert M, Irvine K. Mercury Contamination Along the Mekong River, Cambodia. 2006. NWRI Report, Environment Canada.

Nacci, D, Pelletier M, Lake J, Bennett R, Nichols J, Haebler R, Grear J, Kuhn A, Copeland J, Nicholson M, Walters S, Munns WR. An Approach to Predict Risks to Wildlife Populations from Mercury and Other Stressors. Ecotoxicology, 2005.14, 283-293.

National Institute of Statistics, Directorate General for Health [Cambodia], and ORC Macro. 2001. *Cambodia Demographic and Health Survey 2000*. Phnom Penh, Cambodia, and Calverton, Maryland USA: National Institute of Statistics, Directorate General for Health, and ORC Macro. http://www.measuredhs.com/pubs/pdf/FR124/00FrontMatter.pdf

National Research Council: 2000. Toxicological effects of methylmercury. Washington, DC: National Academy Press.

Ontario Ministry of Environment. Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines. June 2003. http://www.ene.gov.on.ca/envision/techdocs/4449e.htm

Oxfam. 2006. Inventory & GIS Resource of River Based Developments in the Sekong, Sesan and Srepok River Basins**,** eastasia@oxfamamerica.org, Phnom Penh, Cambodia.

Rainboth WJ. FAO Species Identification Field Guide for Fishery Purpose, Fishes of the Cambodian Mekong. 1996. 265 p.

Rodrigues F.S, Z.C. Castilhos, R.L.C. Santos, A.V.Yallouz, F.M.F. Nascimento, S.G. Egler, et al. 2004. Environmental and health assessment in two small scale gold mining areas—Indonesia— Sulawesi and Kalimantan. CETEM's Technical Final Report to UNIDO-Reserved; 211 pp.

Rosenberg, D.M., F. Berkes, R.A. Bodaly, R.E. Hecky, C.A. Kelly, and J.W.M. Rudd. 1997. Large-scale impacts of hydroelectric development. Environ. Rev. 5: 27–54.

Roulet, M., M. Lucotte, R. Canuel, N. Farella, Y. G. De Freitos Goch, J. R. Pacheco Peleja, J.-R. D. Guimara˜es, D. Mergler, and M. Amorim. 2001. Spatio-temporal geochemistry of mercury in waters of the Tapajo´s and Amazon rivers, Brazil. Limnol. Oceanogr., 46(5): 1141–1157.

Silver, S. Bacterial silver resistance: molecular biology and uses and misuses of silver compounds FEMS Microbiology Reviews. June 2003. 27:341-354.

Silbergeld. E.K., I.A. Silva, and J.F. Nyland. 2005. Mercury and autoimmunity: implications for occupational and environmental health. Toxicol. Appl. Phamacol. 207:S282-S292.

Sotham, S. Small-scale gold mining in Cambodia, A Situation Assessment, ed. C. Middleton, Oxfam, America. July2004.http://www.oxfamamerica.org/newsandpublications/publications/research_reports/research_paper.2004-09-20.9108673524.

Spiegel, S.J. and M.M. Veiga. 2005. Building Capacity in Small-Scale Mining Communities: Health, Ecosystem Sustainability, and the Global Mercury Project. EcoHealth 2: 361–369.

Steffan RJ, Korthals ET, Winfrey, MR. Effects of acidification on mercury methylation, demethylation, and volatilization in sediments from an acid-susceptible lake. Appl Environ Microbiol. 1988:8: 2003–2009.

Veiga MM, Meech J, Oriate N. 1994. Mercury Pollution from Deforestation. Nature 368: 816-817.

Veiga, M.M. 2005. Next Steps of the Global Mercury Project, CASM Salvador 2005. www.casmsite.org/Documents/Salvador/37-GMP-Veiga.pdf, page 5.

Wong, H.K.T., Gauthier, A., and Nriagu, J.O. 1999. Dispersion and toxicity of metals from abandoned gold mine tailings at Goldenville, Nova Scotia, Canada, Sci. Total Environ.228: (1)35.

Wotruba, H. 2003. Technologies for Small Scale Mining, Examples of traditional and alternative mining and processing methods. Part 2. CASM Annual Meeting, Elmina, Ghana September 2003. www.**casm**site.org/Documents/Elmina%**2**0-%**2**0Workshop%**2**0-%**2**0Technol%**2**0-%**2**0**Part**%**2**0II.pdf

Appendix 1

Fish collected from Tonle Srepok River Feb.19 and Feb. 20, 2006

Latin name	FAO name	fish type	weight	Mean Hg	Stdev
			fish g	ng/g	
Datnioides quadrifasciatus	barbed tigerfish	fish crustacean predator	150	124	5
Clarias meladerma	blackskin catfish	predator	250	84	4
Laides sinensis		unknown	100	52	4
Mystus nemurus		insect, crustacean, fish predator	200	141	1
Osphroenmus exodon	elephant ear gourami	herbivore	400	13	2
Mystus wykioikes		not given	400	72	4
Pangasius larnaudiei		fish, insects, plants	8000	112	4
Hemisilurus Mekongensis		fish predator	300	**206**[2]	26
Channa marulius	Snakehead	fish predator	1400	**297**[2]	15
Channa melasoma	black snakehead	fish predator	400	28	4
Channa orientalis	walking snakehead	crustacean fish predator	50	25	0
Mystus wykioikes		crustacean fish predator	100	**249**[2]	16
Microneam Micronema		crustacean fish predator	100	**228**[2]	25
Ompok bimaculatus	butter catfish	crustacean fish predator	800	**371**[2]	29
Channa melasoma	black snakehead	fish predator	350	156	3
Channa melasoma	black snakehead	fish predator	1700	**414**[2]	16
Channa melasoma	black snakehead	fish predator	350	60	0
Notopteru notopterus	bronze leatherback	insect fish predator	100	53	2
Mactrognathus taeniagaster		insects worms	100	143	0
Mean Albacore tuna[1]				149 **350**[2]	

[1] http://www.sciencenews.org/articles/20040327/food.asp

[2] Health Canada (1978, 1984) has recommended mercury not exceed 200 ng/g in subsistence settings where people consume a lot of fish

Appendix 2

Hair Mine Workers, Prey Meas, Feb. 18, 2006

13°31'22.9" N, 107°22'46.6" E

Name	Age	Sex	Mean Hg, ppb	St.dev
Say Pirum[1]	21	m	687	16
Min[1]	30	m	807	2
Sat Chek	30	m	3629	163
Cheuon[1]	25	m	581	26
Se Yatra	20	m	1647	31
Thy	45	f	2089	132
Rine	47	m	1719	30
Sokear	40	f	5044	127
Sokha	25	m	2280	41
Yo Volarstar	22	m	3288	85
Seng Nana	46	f	5315	108
Teth Tola	46	m	1260	21
Wen Veoung Knan	39	m	1904	55

[1]These workers only removed rock from the mine shafts.

Appendix 3					
Miners from Prey Ba, sampled April 20 2006					
Sample	Sex	Age	Hg (ng/g)	Hg (ng/g)	Notes
Ked Sambadh	M	24	> 42,000	>42000	Burner for 8 years
Seno Ly	M	51	29523	29326	Burner for 10 years
Sokear	F	>50	14534	13948	Hair strand ca. 40 cm
			7960	8043	old end Sokear's hair
Sim Navy	M	31	34880	35173	Burner
Sene Khunra	M	42	42840	41833	Burner
Sarin	M	54	29882	31196	Burner for 5 years

Both duplicates are shown

Appendix 4 Hair Washing Experiment

Sample	Initial	Washed	Control
#27	2406	2216	2175
#36	1576	1632	1731
#46	3596	3650	3658
CRM	4640±260		4669
Blank	1.3		

CRM = certified reference material

Appendix 5 Dol Tribal Village April 6, 2006,

Miner	Age	Mercury ng/g	Sex
Swam	12	1066	M
Viet	13	1263	M
Thien	15	1769	F
Kheng	25	2500	F
Chamlaiw	26	3571	M
Bibng	30	480	M
So Gneon	35	1870	M
Lalair	40	895	M
Kamnot	18	675	M
CRM		4498 (4640±260)	

CRM is certified reference material (certified value in brackets)

Appendix 6 Fish from Ou Tran River, April 2006