Executive Summary

This report, *Development of Minamata Convention on Mercury Initial Assessment: Mercury Emissions and Releases Inventoryby artisanal and small scale gold mining (ASGM) in Brazil,* describes the emissions and releases of mercury based on the mercury metallurgic balance considering the multiple mineral processes and the available environmental controls of artisanal and small-scale gold mining in Brazil, associated with reasonable scenarios on national gold production. This research was conducted by the Centre for Mineral Technology (CETEM) with the collaboration of the several national institutions, under the general coordination of the Brazilian Minister of the Environment (MMA) and United Nations Environment Program (UN Environment). The main results are vital to attend the Minamata Convention (MC) commitments, in special to subsidize the National Plan of Action for ASGM (MC article 7). It should be highlighted that this work is the initial effort to compile primary information on the quantity of mercury lost to the environment by ASGM and improvements might be expected. The ASGM Mercury Inventory (MI) is a compilation of existing legal ASGM spatial data; data from distinct stakeholders; protocols used to evaluate data; various field data reports, and analyses produced to present the findings, conclusions and recommendations for actions. ASGM is considered an anthropogenic source that loses Hg to the environment through the productive process. According to The Arctic Monitoring and Assessment Program (AMAP/UNEP, 2013), Hg lost to the environment can be understood as being emitted to the atmosphere or released to soils, waters and / or tailings, and from there, can be re-emitted into the atmosphere. Contaminated environmental compartments are considered as sources of Hg re-emission and can remain for the long term in this situation. Therefore, decreasing the source of Hg re-emission requires the reduction of anthropogenic sources of Hg and by actions that may prevent the environmental conditions that promote the re-emissions.

CETEM produced this report to MMA in three volumes:

Volume 1: This volume aims to perform the Brazilian ASGM qualitative and quantitative characterization, to present a perspective of this economic activity in the country and it is the base of the subsequent steps of this research.

The Volume 1 presents ASGM general aspects, as shown below:

(i) Summary of Brazilian ASGM history;
(ii) Hg environmental biogeochemical cycle and ecological and human health risks;
(iii) Mercury occupational and/or environmental exposure and human health risks;
(iv) Compilation of current mercury import data (for use in the activity to describe its origin and characteristics);
(v) Spatialization of the occurrence of ASGM in Brazil;

(vi) Estimated amount of gold produced by ASGM and current national and international gold marketing data;
(vii) Description of the different production processes and techniques used;
(viii) Quantification of mercury used in production processes;
(ix) Description of the environmental control equipment used in the production processes;
(x) Literature data review on the proportion "mercury used vs. quantity of gold produced "based on the different raw materials, production processes and environmental control equipment used / employees;
(xi) Description of requirements for environmental licensing and management of mercury-contaminated wastes and effluents

Volume 2: This volume presents the main results obtained from field work along technical visits to ASGM areas, which are located in distinct biomas (semi-arid, “cerrado”, transition zone between “cerrado” and rain forest, and Amazonian rainforest), in the Brazilian states of Mato Grosso, Pará, Amapá and Bahia. The study focused on the mercury metallurgic balance in the ASGM mineral processing and Hg potential loss to the environment. Mercury levels in the atmosphere were also measured.

The volume 2 presents:

i. Key institutions visited / contacted at Federal, State and Municipal level;

ii. Data obtained during the technical visits to the MAPEO areas in the states of Mato Grosso, Pará (first stage), Amapá, Bahia and Pará (second stage), covering:

- The different techniques used in the mineral production processes;
- The amount of mercury used in the production processes;
- The environmental control equipment used in the production processes and their efficiency in mercury reduction emission and/or release; and
- Management of mercury-contaminated wastes and effluents.

iii. Studies / estimates of the efficiency of environmental control equipment used in ASGM to ultimately;

iv. Estimation of mercury losses to the atmosphere from the knowledge acquired in the areas visited, as a basis for the proposal of a mercury emission factor by ASGM in Brazil,

v. Concentrations of mercury in the atmosphere during the mineral processing, amalgamation and thermal decomposition of the amalgam in the ASGM areas.

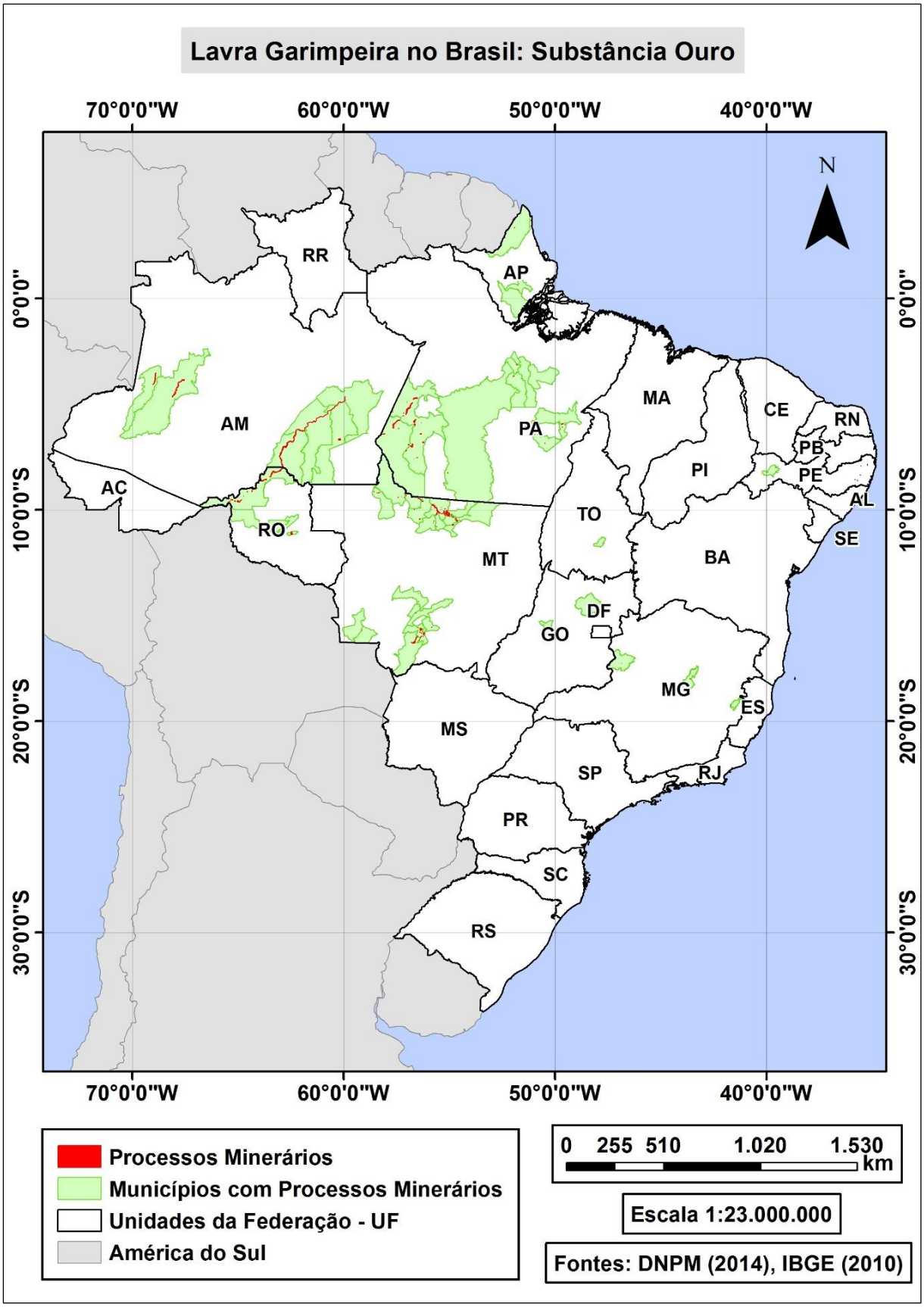
Volume 3: This final report integrates data from previous volumes and presents the estimated mercury emissions and releases from ASGM in Brazil based on distinct scenarios. Additionally, the “Toolkit” (PNUMA) was used, trying to estimate the mercury loss; critical analysis was done and recommendations were proposed.

Findings

The ASGM in Brazil is an extremely heterogeneous sector, even belonging to the same denomination. It presents multiple and unparalleled not allowing simplifications. It varies from the aspect of legality (by the mining permission and / or receipt of areas with mining concessions), the size of the areas, kind of applicants or permission holders (individuals or legal entities), the existence or not of cooperatives, the number of associated members and the degree of their maturity, in work relationship, in the way of managers performance of areas of cooperatives or holders of mining permits, production scale, type of ore, type of equipment, in its efficiency and quality, level of maintenance of these equipment, etc. Moreover, the distinct degree of clarity in the guidance provided by government institutions and their carrying out of inspections, increase the features of the sector. A general aspect, however, is the use of mercury in the amalgamation of gold.

It is difficult to know the number of gold artisanal miners in Brazil due to the lack of a demographic census for this purpose. However, some numbers have been indicated, varying by an order of magnitude, from approximately 80,000 to 800,000, depending on the source of information.

The ASGM areas selection for the technical visits was made from the organization of data and interpretation of the information then available. Therefore, first, the most important gold producing units of the federation both in legalized areas and / or potential areas were identified. The strategy was to integrate the records of the National Department of Mineral Production (DNPM) with the bases of Brazilian Institute of Geography and Statistics (IBGE), in Geographic Information Systems (GIS) database, specially developed by our staff for this analysis. The results showed that there are currently (up to July / 2017) 1,515 gold process requiring small-scale mining license ("permissão de lavra garimpeira") in Brazil. They reach an area of approximately 500,000ha distributed in 10 states: Amazonas / AM; Amapá / AP; Bahia / BA; Goiás / GO; Minas Gerais / MG; Mato Grosso / MT; Pará / PA; Pernambuco / PE; Rondônia / RO and Tocantins / TO. These areas were requested by 235 applicants, of whom 191 are Individuals and 44 are Legal Entities. Of these, 28 are cooperatives. Legal Entities hold an area equivalent to 88% of all PLG areas. The 10 largest areas are cooperatives and their areas represent 95% of the areas required by Individuals. They are located in four states: AM, PA, RO and MT. A single cooperative is responsible for almost 30% of the entire Brazilian PLG area; their areas are located in the states of PA, AM and RO. The top 10 Individuals applicants hold 6% of the PLG area in the national territory and are located in 2 states: MT and PA. A single Individuals applicant with 162 PLG areas, all located in the State of the PA, holds 2% of the PLG area in Brazil. This description shows the concentration of large areas of MAPEO linked to a small number of applicants, either Individuals or Legal Entities (cooperatives).



Map1. Location of gold PLG processes in Brazil (base year 2014)

At second, the conditions of support of the local institutions and of logistics were considered and, finally, the receptivity by the productive sector were considered. For these reasons, the pre-selected states were: AP, BA, MT, PA and RO. However, the

technical visit in RO was canceled due to the occurrence of violent conflicts between government institutions and ASGM and logging companies.

The main focus of the technical visits was to obtain site specific information and carry out the mass balance of mercury during mineral processing in order to quantify mercury loss to the environment. Information about gold production and the use of mercury are sensitive issues and just asking directly about it could not produce reliable results. Then, indirect questions were also asked to confirm the answers obtained for such questions. Indirect questions include salaries of workers, number of workers, daily or weekly income obtained, operating costs, etc. A semi-structured questionnaire was developed and applied to area managers and gold artisanal miners in the areas visited. The triangulation of the information was obtained with the qualitative analysis of the similarity or agreement between the results of the experiment and the answers obtained to the direct and indirect questions of the questionnaire.

Twenty-six (26) ASGM areas were studied: seven (7) in the Pará state (six in the first phase and one in the second phase), ten (10) in Mato Grosso state, five (5) in Amapá state, (3) three in Bahia state and one (1) in Rondônia state. From this total, seventeen (17) areas were visited, and in fourteen (14) areas were also performed the metallurgical balance experiments: in twelve (12) areas it was possible to carry out the complete metallurgical balance experiments of use and loss of Hg (or mass balance of mercury in productive processes of the ASGM) and in two (2) areas partial experiments were carried out. Of the fourteen (14) areas where the experiments were carried out, six (6) exploit the secondary ore, one (1) exploits the secondary ore tailings, and seven (7) exploit the primary ore.

In relation to the origin of Hg used in ASGM, the great majority reported the purchase of Hg without invoice. According to them, the acquisition of legalized Hg is very difficult because there is no formal market of the product while the illegal is quite easy. According to information received, the price of Hg varies in the Brazilian states, from R$ 600,00 to R$ 1,200.00 Brazilian Reais / kg. Additionally, t was known how easy is to buy Hg on internet sites.

The total mass of Hg lost to the environment by MAPEO covers: 1) the mass lost to soils, waters, sediments or wastes (contained or not in retention basins) and 2) the mass lost directly to the atmosphere.

The main factors influencing the atmospheric emissions of Hg by ASGM are: the amount of Hg present in the amalgam, the production of gold and the application of abatement systems for these direct emissions (retorts, fumehood,etc.). The main factors influencing releases (losses to soils, waters and / or tailings) of Hg by ASGM are: the amount of mercury used for gold produced, the amount of gold produced and the existence of environmental control systems (filtration, waste retention, waste management, etc.). It is known that released Hg for tailings, soils and rivers can be re-emitted, but the estimated emission to the atmosphere from tailings, soils and rivers is not the subject of this research project.

By taking in account the results obtained from the mercury mass balance experiment, we calculated: (i) the proportion of mercury used per gram of gold produced according to the different raw materials and production processes; (iii) the proportion of recovered mercury and mercury lost to the environment, based on the environmental control equipment available and / or used. Subsequently, such processes were associated with the measurement of mercury contents in the atmosphere, when available.

The average ratio of Hg_{used}:$Au_{produced}$ was similar in general sampling and in the experiments, and resulted in around 5:1. In the experiments, the difference in this ratio according to the type of ore was clearer and more pronounced: the primary ore consumed 8:1, about four times more Hg than the secondary ore (2:1). Most of the gold production by ASGM in Brazil comes from secondary gold ore.

The filtering technique is routine in Brazilian ASGM. In general terms, 70% of the initial Hg mass is recovered by filtration and by the use of controls to decrease the emission of mercury into the atmosphere (such as fume hood and retorts).

The mercury losses, on average, are 30% of the initial Hg mass, with 15% being released to soils, waters, sediments and tailings and 15% emitted directly into the atmosphere. While the average loss of mercury from processes with secondary ore is around 10%, for primary ore it attains almost 45%.

Therefore, for the hypothetical scenarios, it was assumed that 80% of the gold production is of concentrated secondary ore, with Hg_{used}:$Au_{produced}$ ratio of 2: 1 and 10% of mercury lost; the remaining 20% is of primary ore, concentrated or whole with Hg_{used}:$Au_{produced}$ ratio of 8:1 and 45% of mercury lost.

The observed variations in the Hg_{used}:$Au_{produced}$ relationship and the percentages of mercury losses among the different ASGM visited indicate that the loss of Hg varies according to the type of ore, but also, on the scale of production and possibly also as a consequence of the orientations received and / or the intensity of government inspection, which by its turn is impacted, among other factors, by the accessibility to ASGM.

The total production of gold by ASGM should be considered to be related to the sum of legalized and declared production plus the illegal production, which may be the undeclared production from legalized areas and the gold production from non-legalized areas (protected areas, areas without environmental license, without PLG or mining concession, in indigenous lands, in environmental protection areas, etc.). The legal gold production by ASGM is tracked by the payment of Tax on Financial Transactions (Imposto sobre Operações Financeiras - IOF). In 2016, it was approximately 25 tons of gold. The quantification of illegal production is not a trivial task.

Table 1 shows the estimates of total gold production by Brazilian ASGM in 2016, based on the relationships suggested in the literature and the information obtained during the field work.

Table 1. Production of gold (tons) by Brazilian MAPEO in 2016 and estimates of total production (declared and illegal).

Oficial	Oficial +10%	Oficial +30%	Oficial +50%	Oficial +80%*	Oficial +100%**	Oficial + 3x	Oficial + 8x
DNPM	GIATOC, 2016	De Acevedo (2014)	***Personal Communication	***Personal Communication	***Personal Communication	Seccatore et al, 2014	Seccatore et al, 2014
25	27.5	32.5	37.5	45	50	75	200

* 60% undeclared and 30% illegal production; ** based on comments that a small part is declared and that most of the gold produced is not declared and is smuggled to neighboring countries; ***Personal Communication

Thus, the annual production estimate can vary by one order of magnitude.

There is information that more than 80% of the declared gold production in 2016 was made in the states of PA and MT. Therefore, the data from ASGM visited in PA and MT can represent more than 80% of the annual national gold production by ASGM. For this reason, we assume that the production of gold by ASGM in Brazil is significantly represented by the reality of ASGM located in PA and MT. These two states (along with RR and RO) were also cited as the largest producers of illegal gold.

As mentioned, several assumptions have been made in this document. Part of them is based on a bibliographical review, the experience of the technical team and the meetings results with the different institutions that are related to the ASGM sector and another part is based on the results obtained from the Hg mass balance experiments and the experience of the during fieldwork.

The hypothetical scenarios took into account the uncertainties and variations in the parameters of the calculations, especially with regard to gold production information and the percentage of release and mercury emission resulting from the experimental data observed in the technical visits to ASGM. The uncertainty of gold production data is more shaped to unlawfulness and / or undeclared legal production. And the variations in loss factors are the consequence of different parameters, such as type of ore, technologies used, scale of production, etc.

Based on the scenarios presented in table 2, the emission of Hg directly into the atmosphere by ASGM in Brazil for the year 2016 ranges from 11 tons to 161 tons, considering the legalized and illegal production of gold, the different mineral processes and the percentage of use of emission controls.

Table 2. Hg estimative emissions directly into the atmosphere and potential releases to soils waters and / or tailings (contained or not) and Hg distribution factors lost to the atmosphere and soils. water and / or tailings.

S	Au p	Condition of legality	Ore type	% application	Hgu :Aup	MHgi	MHgi total	Rec 1	ΣHg Rec 1 + Hg amal	**Hg Rel.***	**Hg total Rel.***	Amalgam burning	% application	Hg emitted	**Total Hg emit.****	**Total Hg Emit. legal+ilegal**	Total Hg lost: Σreleased +emitted	Factor atm. (%)	Factor soil (%)
25	25	100% legal	Secondary	90	2:1	45	65	32.5	57.5	7.5	**7.5**	Controlling	80	6	**11**	**11**	18.5	59	41
		0% ilegal	Primary	10	8:1	20						No Controlling	20	5					
27.5	2.5		Secondary	90	2:1	4.5	6.5	3.25	5.75	0.75	**8.25**	Controlling	20	0.15	**2.15**	**13.15**	21.4	61	39
		10% ilegal	Primary	10	8:1	2						No Controlling	80	2					
32.5	7.5		Secondary	90	2:1	13.5	19.5	9.75	17.25	2.25	**9.75**	Controlling	20	0.45	**6.45**	**17.45**	27.2	64	36
		30% ilegal	Primary	10	8:1	6						No Controlling	80	6					
37.5	12.5		Secondary	90	2:1	22.5	32.5	16.25	28.75	3.75	**11.25**	Controlling	20	0.75	**10.75**	**21.75**	33	66	34
		50% ilegal	Primary	10	8:1	10						No Controlling	80	10					
45	20		Secondary	90	2:1	36	52	26	46	6	**13.5**	Controlling	20	1.2	**17.2**	**28.2**	41.7	68	32
		80% ilegal	Primary	10	8:1	16						No Controlling	80	16					
50	25		Secondary	90	2:1	45	65	32.5	57.5	7.5	**15**	Controlling	20	1.5	**21.5**	**32.5**	47.5	68	32
		1x more ilegal	Primary	10	8:1	20						No Controlling	80	20					
75	50		Secondary	90	2:1	90	130	65	115	15	**22.5**	Controlling	20	3	**43**	**54**	76.5	71	29
		2x more ilegal	Primary	10	8:1	40						No Controlling	80	40					
200	175		Secondary	90	2:1	315	455	227.5	402.5	52.5	**60**	Controlling	20	10.5	**150.5**	**161.5**	221.5	73	27
		8x more ilegal	Primary	10	8:1	140						No Controlling	80	140					

S= Gold production scenarios; Aup = Gold produced; % application: ASGM percentage working in the indicated condition; MHgi = Hg Initial mass; Total MHgi = Total Hg initial mass; Rec 1 = Hg Mass recovered at the filtration; ΣHg Rec 1+ Hg amal = Recovered Hg mass added to the mass potentially present in the amalgam; Hg rel. * = Hg released or lost to soils. water and tailings: MHg- (ΣHg Rec 1+ Hg amal); Hg emitted. ** = Hg directly emitted into the atmosphere; Hgu: Aup = Hg ratio used: Au produced.

It is known that the quality of the estimates is a consequence of the validity of these various assumed propositions. The greater consensus is obtained on key data for the estimates, the greater their accuracy. The choice of scenario that best represents the reality of Brazilian ASGMis the way to decrease the uncertainties of the estimates.

Although direct losses to the atmosphere have been calculated to be less than 15% of the initial mass, mercury contents above 220 μg m^{-3} in the atmosphere were observed during decomposition of the amalgam, even with the use of retorts or fume hood. Although such levels are intermittent, it is suggested that the monitoring be performed with high temporal frequency. Additionally, in some areas, managers or workers performing thermal decomposition of the amalgam used non-appropriate masks. It is essential to know the pattern of exposure of this population of gold artisanal miners and / or their relatives and provide protective guidelines adequate to the living culture of that population. Technological alternatives for mineral processing and environmental control should be developed and presented to the sector.

The mercury content in the atmosphere observed in the gold shops varied orders of magnitude, indicating the diversity of this potential source of mercury emission. Even if it is to melt the “doré” gold with about (only) 1 to 5% of remaining Hg, the gold shops carries out tens of hundreds of fusions per day and there are cases where the gold artisanal miners directly melt the amalgam in the gold shops, which can lead to in a considerable final charge of Hg emitted. Therefore, it is important that gold purchase stores are also considered as significant in the general estimation of Hg emissions by ASGM and in the potential human and occupational environmental exposure.

In the experiments carried out and the information received in the present research in Brazil, the Hg: Au ratio in the amalgam was shown to be constant and on average 1:1. This seems to be an important divergence from the assumptions made in the Toolkit, which assumes that may be great variation in Hg levels in amalgams. This relationship is essential because it is the basis for the estimation of direct Hg emission into the atmosphere and may be abated by the use of control systems (retorts and / or chapels or others), depending on their efficiency.

This inventory is characterized as a pioneering initiative within the the Minamata Convention on Mercury. Thus, throughout its implementation it will be necessary to employ additional efforts so that the results can be refined and complemented. However, the information is vital to support the discussions regarding the preparation of the National Plan of Action for MAPEO, as recommended by Article 7 of the Convention.