UNEP

Toolkit for Identification and Quantification of Mercury Releases

Reference Report and Guideline for Inventory Level 2

Version 1.7
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Reference Report
and
Guideline for Inventory Level 2

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This report is a part of the seventh version of the Toolkit. The Toolkit will be further developed and updated as appropriate.

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The Toolkit can be found on UNEP Chemicals and Health Branch's web-site:

https://www.unep.org/explore-topics/chemicals-waste/what-we-do/mercury/mercury-inventory-toolkit

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Foreword

The UN Environment Governing Council has concluded that there is sufficient evidence of significant global adverse impacts from mercury to warrant further international action to protect human health and the environment from mercury and its compounds. The Governing Council decided that national, regional and global actions should be initiated and urged all countries to adopt goals and take actions, as appropriate, to identify populations at risk and to reduce human-generated releases.

In response to the Governing Council's request, UN Environment has established a Mercury Programme to encourage all countries to adopt goals and take actions, as appropriate, to identify exposed populations, minimize exposures through outreach efforts, and reduce anthropogenic mercury releases. An important part of the UN Environment Mercury Programme is to develop training materials, guidance documents and toolkits on a number of relevant topics that may be of use to Governments and others in their efforts to evaluate and address mercury pollution.

Before taking actions to address mercury, governments will want to consider developing a knowledge-base for evaluating the risks posed by mercury and for taking appropriate action to reduce those risks. This "Toolkit for identification and quantification of mercury releases" (Toolkit) is intended to assist countries to build part of that knowledge base through the development of a mercury inventory that identifies sources of mercury releases in their country and estimates or quantifies these releases.

Executive summary

1. The “Toolkit for identification and quantification of mercury releases” (Toolkit) is intended to assist countries to build a knowledge base on mercury through the development of a mercury inventory that identifies sources of mercury releases in their country and estimates or quantifies the releases.

2. Using the inventory and other additional knowledge, the most cost-effective reduction measures can be identified for decision making. Often, such inventories are also vital in the communication with stakeholders such as industry, trade and the public.

3. Baseline inventories, and subsequent up-dates, can also be used to monitor progress towards pre-set goals, and thereby identify successful approaches which could serve as examples in other areas, as well as areas where the applied measures do not prove adequate and further attention and initiative is needed.

4. This Toolkit aims to assist countries that are developing their mercury inventory to estimate releases of mercury, and also leads them through the process of how to enhance and refine these inventories. The Toolkit’s goal is to guide the inventory makers within a country through the different techniques and stages of developing the inventory, by providing a methodology, illustrative examples and extensive information on mercury release sources. The Toolkit aims to reduce the workload in the creation of national or regional mercury inventories.

5. The Toolkit is designed to produce a simple and standardized methodology and accompanying database to enable assembly of consistent national and regional mercury inventories. It comprises a UN Environment-recommended procedure for the effective compilation of source and release inventories of mercury. Comparable sets of mercury source release data will enhance international co-operation, discussion, goal-definition and assistance. Comparable datasets also help to establish a global picture of the scale of releases, as a step in prioritizing actions to control or reduce releases, and improves possibilities for enlarging the international knowledge base on mercury uses and releases.

6. In this updated version, the Toolkit describes two levels of detail and simplification, called Inventory level 1 and Inventory Level 2. This document describes the methodology of Inventory Level 2 of the Toolkit, and at the same time serves as a reference document providing background information for the further simplified Inventory Level 1. The separate Toolkit Guideline to Inventory Level 1 describes the methodology and procedures of Inventory Level 1.

7. The methodology of Inventory Level 2 consists of a four-step procedure that will facilitate development of consistent and comparable source inventories.

8. In the first step, a coarse screening matrix is used to identify the main mercury source categories present in a country. Also, any existing partial mercury inventories or descriptions of mercury sources in the country (or region) should be identified and collected.

9. In the second step, these main source categories are further classified into sub-categories in order to identify the individual activities that potentially release mercury. If only a qualitative identification of source types present in the country or region in question is desired, step three (quantification) can be omitted, and the qualitative findings can be reported as a commented list of main source categories and sub-categories identified in the country.

10. In the third step, a quantitative inventory is developed. At this step, it may be considered if a full quantitative inventory should be created from the start, or as an initial step, an interim inventory is desired to support of the prioritization of the further work and initiate communication with inventory participants/reviewers. It can be recommended to use the Inventory level 1 tools for interim inventory

development. For a detailed quantitative inventory, activity volume data ("activity rates") and process-specific information is gathered to be used to calculate estimated mercury releases from the identified mercury release sources in the country (or region) in question. Releases are calculated *via* the equation and procedures and source type data described in the Toolkit. However, given the uncertainties and complexities involved, it is anticipated that many inventories may have only qualitative emission or quantitative use information for some sources. This information may in some cases be sufficient for identifying and initiating mercury reduction activities in a given country or region.

11. The fourth and final step is the compilation of the standardized mercury inventory using the results generated in steps 1 through 3. A standardized presentation format is provided to ensure that all known sources are considered (even if they cannot be quantified), data gaps are apparent and inventories are comparable and transparent.

12. The final mercury inventory will show that all potential sources have been considered, even if the activity does not exist or is insignificant in that country. For each source within a country there will be an estimate of releases to all media where data are sufficient and an indication of likely magnitude if full data are unavailable. Major data gaps will be listed. Taken together, this process will help in the interpretation of results and the prioritization of future actions.

1 Background

Mercury

13. Mercury is highly toxic, especially to the developing nervous system. Some populations are especially susceptible, most notably the fetus and young children. Yet mercury continues to be used in many products and processes all over the world, including in small-scale gold mining; manometers and thermometers; electrical switches; fluorescent lamps; dental amalgams, batteries and VCM (vinyl-chloride-monomer) production and some pharmaceuticals. The most significant mercury releases to the environment are emissions to air, but mercury is also released from sources directly to water and land. Important emissions sources include: coal-fired power generation, waste incineration, cement, steel and chlor-alkali production, gold and other metals mining, cremation, landfills and other sources such as secondary smelting operations and industrial inorganic chemical production.

14. Once released, mercury persists in the environment where it circulates between air, water, soils and biota in various forms. Once deposited, the form can change (by microbes) to methyl mercury, a particularly hazardous form that concentrates up food chains, especially the aquatic food chain. Most people are primarily exposed to methyl mercury through the diet, especially fish, and to elemental mercury due to dental amalgams and occupations (such as small-scale mining). Other sources of exposure include skin-lightening creams, mercury used for ritualistic purposes and in traditional medicines, and mercury spills in the home.

15. For more detailed information on chemistry, toxicology, exposures and risk evaluations for humans, impacts on the environment, cycling in the global environment and possible prevention and control technologies for controlling releases and limiting use and exposure to mercury, see the Global Mercury Assessment report (UNEP, 2000).

Context of this Toolkit

16. This Toolkit was published for the first time as a pilot draft in November 2005. This revised Version 1.2 (January 2013) is the result of pilot testing and comments undertaken since the previous release. It will be further developed and revised versions published as appropriate. The most current version of the Toolkit will at any time be available on the UN Environment Chemicals mercury web page at https://www.unenvironment.org/explore-topics/chemicals-waste/what-we-do/mercury/mercury-inventory-toolkit.

17. The revised Toolkit includes a revised Inventory Level 1, a simplified and more standardized inventory methodology. The total Toolkit now consists of a Guideline to Inventory Level 1, accompanying MS Excel spreadsheets for calculation of estimates of mercury inputs and releases on Inventory Level 1 and Inventory Level 2, an inventory reporting template for each level, templates for data collection for Inventory Level 1, and this Reference Report which gives more detailed description of mercury source categories and additional guidance on inventory development, and describes the Inventory Level 2 methodology.

18. The Inventory Level 1 Guideline describes a simplified step by step procedure. It also describes limitations of the Inventory Level 1 methodology and gives advice for situations where you may want to refine your inventory on Inventory Level 2. Finally the guideline provides advice for the reporting of your inventory on Inventory Level 1.

19. This revision of the Toolkit includes revisions of default factors for a number of potentially important mercury release sources. The revisions made here have been coordinated to the extent possible with UN Environment's work of updating the Global Mercury Assessment.

20. The original 2005 pilot draft Toolkit, and Inventory Level 2 of the revised version follows closely the approach and methodology developed and applied in the second edition (February 2005) of the document “Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases”, published by UN Environment Chemicals. Where relevant, text passages from the dioxins and furans toolkit have been applied in this mercury Toolkit. The dioxins and furans toolkit, whose approach and methodology has been pilot-tested in a number of countries, has already been subject to several rounds of comment and review by those experienced in inventory development.

Further development of this Toolkit

21. As with any methodology, the Toolkit needs live testing, validation and updating. The Toolkit is considered an evolving set of tools, which will be updated and revised, as appropriate and feasible, to take account of emerging information and experience. Also, as the Toolkit is predominantly based on experience and information available from industrialized countries, it might not, for some release sources, fully reflect conditions in the developing countries. Input and data from other regions of the world is therefore very important, in order to provide a broader knowledge base for the different sources of mercury releases and improve the Toolkit’s applicability.

22. UN Environment Chemicals invites all users of the Toolkit to provide feedback on all aspects of this product. Users of the pilot draft Toolkit may consult with UN Environment Chemicals where problems with application, interpretation and implementation occur or where the system does not seem to apply to the situation found in the country.

23. Countries are encouraged to use the Toolkit to submit their inventories to UN Environment Chemicals, who will make them publicly available on the mercury programme webpage at http://www.unep.org/hazardoussubstances/Mercury/tabid/434/Default.aspx. Over time, it is hoped to be able to provide, in addition to national inventories from various regions, a forum for exchange of information on countries’ experience with inventory development, case studies, relevant new publications, etc.

2 Introduction to mercury inventories and this Toolkit

2.1 Purpose of mercury inventories

24. Inventories for releases of priority hazardous substances constitute an important decision making tool in the process of mitigating environmental impacts from the pollutants in question. Once a country has decided that mercury pollution is a potential priority problem that needs to be evaluated further, it will typically need to estimate both the relative and the absolute contributions to mercury releases from the different sources present in the country. This information can be used to determine which release source types are significant and which sources should be addressed through release reduction initiatives.

25. Mercury inventories combined with additional knowledge play a role in identifying the most cost-effective reduction measures for decision making. Often, such inventories are also vital in the communication with stakeholders such as industry, trade and the public.

26. Furthermore, baseline inventories, and subsequent up-dates, can be used to set goals, priorities and monitor progress.

2.2 What is this Toolkit

27. This Toolkit aims to help countries that wish to develop a mercury inventory to estimate releases of mercury, and also leads them through the process of how to enhance and refine these inventories. The Toolkit's goal is to guide the inventory makers within a country through the different techniques and stages of developing the inventory, by providing a methodology, illustrative examples and extensive information on mercury release sources. The Toolkit thus facilitates and reduces the workload in the creation of national or regional mercury inventories.

28. The Toolkit is designed to produce a simple methodology and accompanying database to enable assembly of consistent national and regional mercury inventories. It comprises a UN Environment-recommended procedure for the effective compilation of source and release inventories of mercury. Comparable sets of mercury source release data enhance international co-operation, discussion, goal-definition and assistance.

29. The Toolkit's Inventory Level 2 is designed to be adaptable. It is a screen, not an exhaustive registry, and is designed to ensure the positive identification of the bulk of significant sources. Speed and ease of use have been deemed more relevant for the users of this Toolkit than the unattainable goal of 100 percent accuracy.

30. A separate Excel spreadsheet is available electronically, intended to facilitate the calculation of inputs and outputs of the different source categories. Further information on the Inventory Level 2 spreadsheet is provided in section 9.2. The spreadsheet is available on-line at the UN Environment Chemicals website http://www.unep.org/hazardoussubstances/Mercury/tabid/434/Default.aspx or can be obtained by contacting UN Environment Chemicals at the address given on the inside cover of this document.

31. The Toolkit provides links to sources of more information on mercury releases, both general links to other international and national databases, and a multitude of references to individual reports and other documents presenting data and more details on individual mercury release source types.

32. The Toolkit highlights the pathways of mercury within society, and into the environment and other receiving media. The Toolkit aims at providing a methodology and associated input factors and output distribution factors that can be used to estimate mercury releases into all media (air, water, land, products and wastes).

33. The Toolkit is designed to be applicable to all countries, but is intended especially to assist countries who have not yet developed comprehensive mercury inventories to get started or further enhance their preliminary inventories. Different countries will investigate sectors differently depending on the resources available and the priority given to each sector.

34. The Toolkit's Inventory Level 1 provides a procedure which allows a stepwise approach to 1) identify main source categories present in the country or region, 2) further identify individual source sub-categories (source types), and ultimately - if desired - 3) develop quantitative estimates of releases from the identified sources, or a prioritized selection of sources. Also, it may be appropriate to carry out additional work on particular sources at some future date as further information or resources become available. The use of default release factors side-by-side with local measured data will help to refine and improve the Toolkit for use in other countries.

35. The separate Toolkit Guideline to Inventory Level 1 describes the further simplified methodology and procedures of Inventory Level 1.

2.3 Limitations of this Toolkit

36. The Toolkit was designed to include all known mercury release source types, yet sources may exist that are not accounted for in the Toolkit. If a country identifies any new sources, these sources should be included in the national inventory, and countries should submit the information on their existence, their characteristics and potential significance to UN Environment Chemicals for addition to the data base on mercury.

37. The data presented in this Toolkit are primarily extracted from easily accessible data sources. Additional data may exist that would add to - or possibly modify - the characterization of the individual release source types. Data from developing countries may add significantly to a global understanding of mercury releases, because the prevailing conditions may be quite different from the situation in developed countries, where most of the presented data were collected.

38. Although the use of source specific data is always the preferred approach and will lead to the best estimates of releases, an attempt has been made when developing this Toolkit, to develop default input and distribution factors that might be of use to those users who have difficulties obtaining source specific data. It should be noted that the default factors suggested in this Toolkit are based on a limited data base and as such, they should be considered subject to revisions as the data base grows. Therefore, it may be appropriate to review, and confirm to the extent feasible, main source specific data for local/national conditions, before major decisions are taken on implementation of mitigation initiatives.

39. As described in section 2.1 of the UN Environment Global Mercury Assessment report, the form (or species) of mercury releases is an important factor for environmental fate and transport, toxicity, and controllability. We appreciate the value of gathering and reporting releases for the different forms of mercury (especially elemental mercury and oxidized mercury), and we realize that some countries (and other organizations) have attempted to do this. At this time we have determined that providing guidance for the calculation and reporting of the releases of the different species of mercury is beyond the scope of this draft document. Therefore, this draft document presents no guidance for calculating or reporting the different forms of mercury releases. Nonetheless, future versions of this Toolkit might include such information.

3 Anthropogenic mercury release sources

40. The releases of mercury to the biosphere can be grouped in four categories (UNEP, 2002):

- Natural sources - releases due to natural mobilization of naturally occurring mercury from the Earth's crust, such as volcanic activity and weathering of rocks;
- Current anthropogenic (associated with human activity) releases from the mobilization of mercury impurities in raw materials such as fossil fuels – particularly coal, and to a lesser extent gas and oil – and other extracted, treated and recycled minerals;
- Current anthropogenic releases resulting from mercury used intentionally in products and processes, due to releases during manufacturing, leaks, disposal or incineration of spent products or other releases;
- Re-mobilization of historic anthropogenic mercury releases previously deposited in soils, sediments, water bodies, landfills and waste/tailings piles.

41. Figure 3.1 shows these release categories with main types of possible control mechanisms.

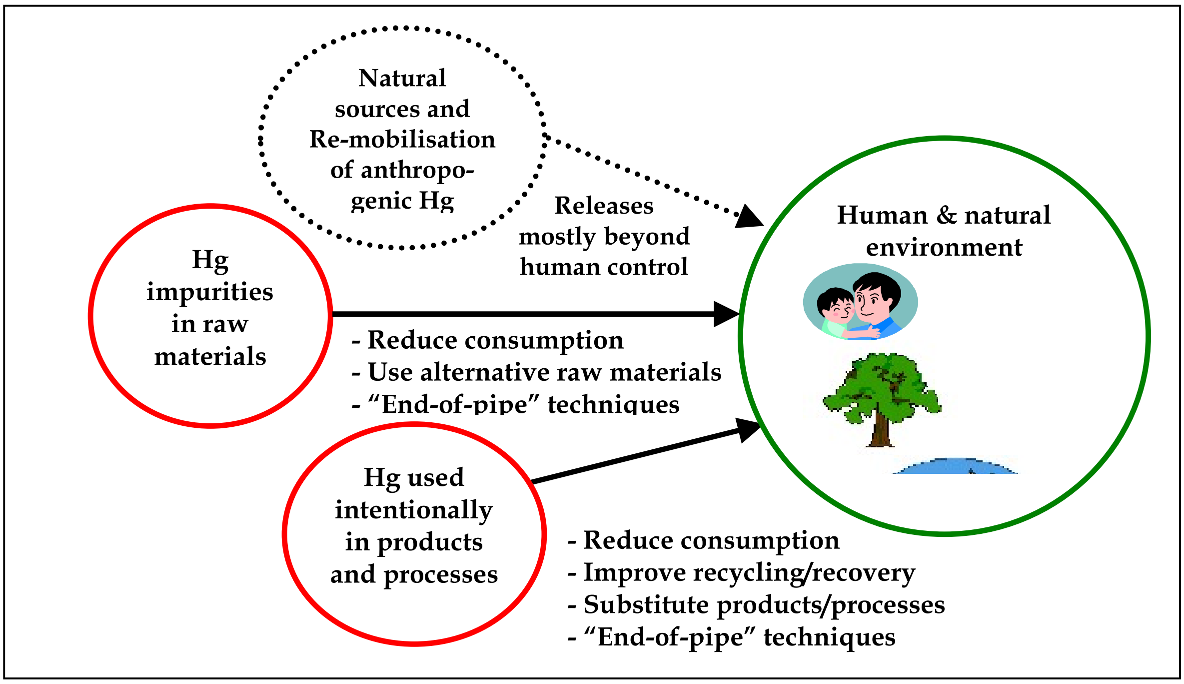


Figure 3-1 Main sources of mercury (Hg) releases to the environment and main control options

42. This Toolkit aims at guiding users in the identification and quantification of human-generated mercury releases that can potentially be reduced through various regulatory actions or other approaches. Therefore, the Toolkit concentrates on current anthropogenic releases from mobilization of mercury impurities, from intentional use of mercury in products and processes and from human-generated deposits such as landfills, contaminated sites and mine tailing piles. These overall modes of anthropogenic releases form the backbone of the categorization of release sources in the Toolkit.

43. Natural mercury sources and remobilization of previous atmospheric deposition are not covered in this Toolkit, as release reduction initiatives are not relevant for these sources. These sources do, however, contribute to the adverse impacts of mercury on human health and the environment, and may in some areas warrant particular attention for these reasons. For more reading on natural mercury sources and remobilization, see the Global Mercury Assessment (UNEP, 2002).

3.1 Pathways of releases to the environment

Mercury is persistent in the environment

44. A fact that is basic to the understanding of mercury's pathways in society and the environment is that mercury is an element and, although it may change between different forms in its cycle, it cannot be broken down or degraded into harmless substances. This means that once mercury has been brought into circulation in the society/biosphere by human activity it does not "disappear" again in time spans comparable to human lifetime and will need to be managed (stored or disposed of) for the longer term.

Releases throughout the "life-cycle" of a product or process

45. To illustrate the nature of mercury flows in society and mercury releases to the environment, the life-cycle concept can be of use. The life-cycle concept is a "cradle to grave" approach that recognizes that all stages in the "life" of a product or process (extracting and processing raw materials, manufacturing, transportation and distribution, use/reuse, recycling and waste disposal) may have potential environmental impacts. The life-cycle approach can be used during data gathering and development of an inventory and for ranking the environmental burdens of products, processes and services.

46. The diagram below breaks down a product or process life-cycle inventory into inputs containing mercury and outputs of mercury in material and environmental releases.

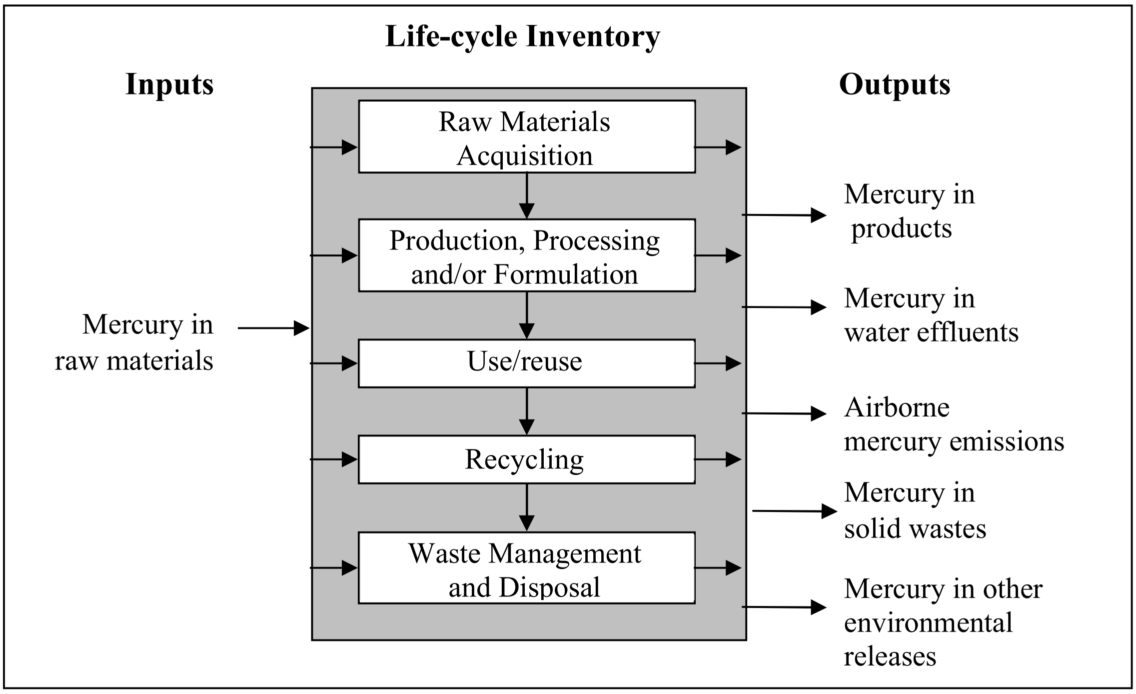
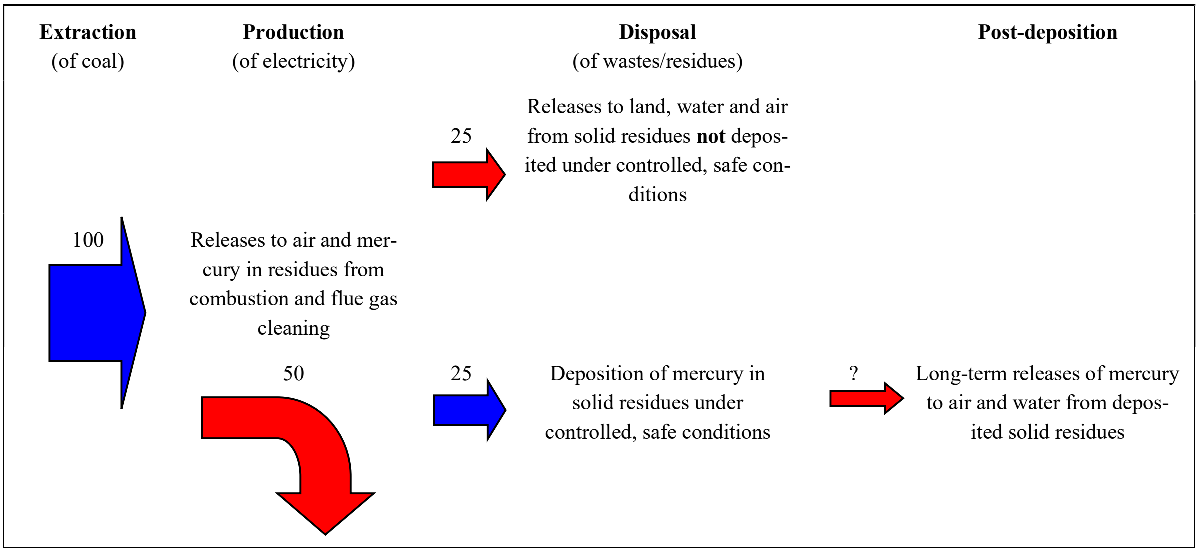


Figure 3-2 Illustration of a life-cycle inventory broken down into inputs and outputs for material as well as environmental releases

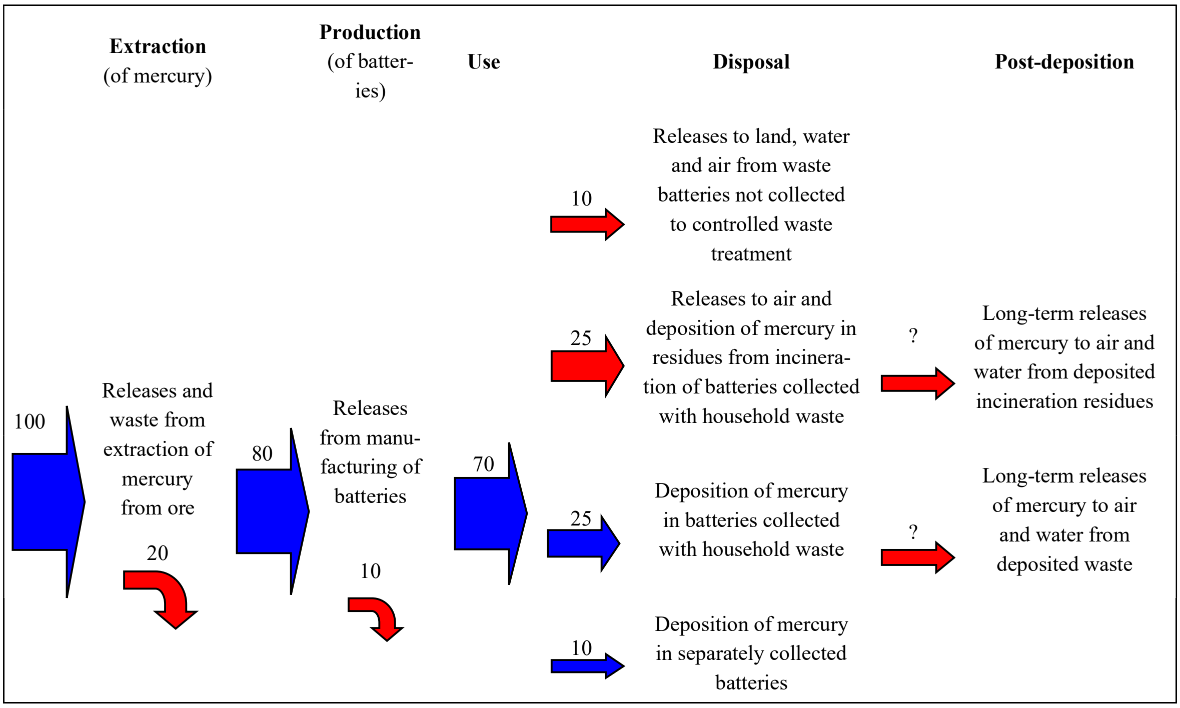
47. Mercury releases may occur at all stages of the life-cycle of a mercury-added product or process. As mercury is an element and therefore neither formed nor degraded during this life-cycle (though it may change form), the total inputs of mercury will equal the total outputs. This means that the mercury releases from a particular human activity can be viewed as the consecutive distribution of the original mercury input to various media or release pathways during various stages of the life cycle of the product or process in question.

48. Examples of the life-cycle of mercury in a process and a product, and the mercury releases occurring throughout the life-cycle are given in Figure 3-3. Only those phases in the life-cycle that are relevant to releases of mercury are shown in the figure.

a) The life-cycle of mercury in production of electricity from coal combustion.



b) The life-cycle of mercury in mercury oxide batteries.



Notes: Numbers indicate relative percent of the original mercury input (content in coal and ore, respectively) following the different release pathways, in a fictive, but realistic example.
A red arrow indicates where direct releases occur and a blue arrow indicates other flows.

Figure 3-3 Illustration of the life-cycle of mercury in a) a process (production of electricity from coal combustion) and b) a product (mercury oxide battery) (hypothetical - for illustration purposes)

49. For the sake of convenience, releases from primary extraction of mercury, as well as releases from treatment of general (household) waste and waste water, are described and assessed separately in this Toolkit, but the important links between these phases and the production and use phases in between, are noted in the description of the mercury release sources.

3.2 Examples of mercury releases to different pathways

Releases to environmental media

50. Figure 3-4 below gives examples of anthropogenic mercury releases to the different environmental media (here termed as pathways, but often also called compartments or routes).

Examples of anthropogenic mercury releases to the environmental media

Destinations of releases to the environment and types of releases to each receiving environmental medium:

- **Air - the atmosphere:** Point sources and diffuse sources from which release may be spread locally, regionally and hemispherically/globally with air masses.
    - Emissions from major point sources such as coal fired power plants, metal extraction, waste incineration, chlor-alkali facilities, secondary scrap recycling/smelting, cement production, industrial inorganic chemicals production and diffuse sources such as housing (fossil fuel combustion);
    - Emissions from artisanal gold mining;
    - Emissions from cremation, primarily due to dental fillings containing mercury;
    - Emissions from mercury-containing paints;
    - Diffuse releases from uncollected waste products (fluorescent lamps, batteries, thermometers, mercury switches, lost teeth with amalgam fillings etc.);
    - Evaporation of previous discharges to soil and water;
    - Evaporation of mercury disposed of on landfills.
- **Water – aquatic environment:** Point sources and diffuse sources from which mercury will be spread to marine environments (oceans), and freshwaters (rivers, lakes etc.).
    - Direct discharges from industry and households to aquatic environments;
    - Emissions from artisanal gold mining;
    - Indirect discharges via waste water treatment systems;
    - Surface run-off and leachate from mercury contaminated soil and landfills without leachate collecting membrane and leachate water cleaning system;
    - Wash-out of mercury previously applied or deposited on land.
- **Land/soil – terrestrial environment:** General soil surfaces and ground water.
    - Diffuse releases from uncollected waste products (batteries, thermometers, mercury switches, lost teeth with amalgam fillings etc.);
    - Local releases from industry: On site materials and waste storage, broken/unused pipes, and equipment and building material contaminated with mercury;
    - Spreading of sewage sludge with mercury content on agricultural land (used as fertilizer);
    - Application on land, seeds or seedlings of pesticides with mercury compounds;
    - Use of solid residues from waste incineration and coal combustion for construction purposes (slag/bottom ash and fly ash);
    - Burial of persons with dental amalgam fillings.

Figure 3-4 Examples of anthropogenic mercury releases to the different environmental media

Mercury flows/releases to other pathways

51. In addition to the release pathways (air, water, land) mentioned above, this Toolkit works with the output pathways "products", "general waste" and "sectors specific waste treatment". This is done for practical reasons in the inventory work, yet the final receiving media may in the long term

ultimately be land, air and water. Some examples of mercury flows/releases to "products", "general waste" and "sectors specific waste" are given in Figure 3-5 below.

Examples of mercury flows/releases to the intermediate pathways "products", "general waste" and "sector specific waste treatment"

- **Products (as output pathway): By-products that contain mercury, which are sent back into the market and cannot directly be allocated to environmental releases;**
  By-products with mercury content, either in trace concentrations where mercury is an impurity in recovered materials, or as by-product mercury or raw by-product mercury compounds from primary metal extraction (mining)
  - Gypsum wallboard produced from solid residues from flue gas cleaning on coal fired power plants (with mercury trace concentrations);
  - Sulphuric acid produced from desulphurization of flue gas (flue gas cleaning) in non-ferrous metal plants (with mercury trace concentrations);
  - Chlorine and sodium hydroxide produced with mercury-based chlor-alkali technology (with mercury trace concentrations).
  - Metal mercury or calomel as by-product from non-ferrous metal mining (high mercury concentrations

- **General waste:** Also called municipal waste in some countries. Typically household and institution waste - the large bulk of general waste from the population - where the waste undergoes a general treatment, such as incineration or deposition under controlled circumstances.
  - Consumer products with intentional mercury content, such as batteries, thermometers, human teeth with mercury amalgam fillings, electronic devises with mercury switches, fluorescent tubes, etc. that is not collected/treated in separate systems;
  - Normal high volume product waste like paper, plastic, etc., with very small trace concentrations of mercury.

- **Sector specific waste treatment:** Waste from industry and consumers that is collected and treated in separate systems, and in some cases recycled.
  - Hazardous industrial waste with high mercury content, usually from intentional mercury use – that may be stored in sealed containers on specially protected deposits, or in some cases incinerated (due to content of other substances which are combustible);
  - Hazardous waste from secondary smelting/scrap recycling operations;
  - Hazardous consumer waste with mercury content, mainly separately collected batteries, thermometers, mercury switches, lost teeth with amalgam fillings etc.;
  - High volume rock/waste from extraction of metals or minerals;
  - Solid residues from waste incineration (slag/bottom ash and fly ash).

Figure 3-5 Examples of mercury flows/releases to the intermediate pathways "products", "general waste" and "sector specific waste treatment" of anthropogenic mercury releases to the different environmental media.

52. As illustrated in Figure 3-3, waste disposal is a major output/release route in the life-cycle of mercury-containing products and materials. Waste treatment and wastewater treatment are examples of mercury release sources, for which the origin of the mercury has to be assessed, in order to consider properly possibilities for cost effective release reductions. While these systems are implemented for the reduction of environmental impacts from various pollutants, they do not generally provide terminal elimination of all the mercury present in the wastes. This is due to mercury's special characteristics in combination with the applied technologies and procedures (as described in sections 5.8 - 5.10 on the different waste treatment systems). For mercury, reduction or elimination of mercury before it becomes a waste (in products and processes) is considered widely as a cost effective release reduction option.

53. For more information on output pathways, see the description of the Toolkit inventory approach in section 4.4.4. For examples of the relative importance of mercury releases from different sources from a number of countries, and also between impurity mobilization and intentional mercury use, see chapter 6 of the Global Mercury Assessment report (UNEP, 2002).

3.3 Overall estimated global mercury emissions to air

54. The Global Mercury Assessment: Sources, Emissions, Releases and Environmental Transport (UNEP, 2013) states that total global atmospheric emissions of mercury from human activity in 2010 were estimated to be approximately 1960 (1010 – 4070) tonnes/year. Based on a less exhaustive database, quantified anthropogenic releases to water from point sources are estimated at 185 (42.6 – 582) tonnes/year, and releases from contaminated sites to water are estimated at 8.3 – 33.5 tonnes/year. Recent inventories for mercury releases to other environmental media, land and waste are not available.

55. A brief overview of the global emissions, extracted from (UNEP, 2013), is provided in this section order to assist those developing national inventories to put their results into an overall global perspective. The estimated anthropogenic releases of mercury to the atmosphere by sector are shown in Table 3-1.

56. As shown, artisanal and small-scale gold mining emissions are, in the 2010 inventory, the major source of emissions to air, at 727 tonnes per year.

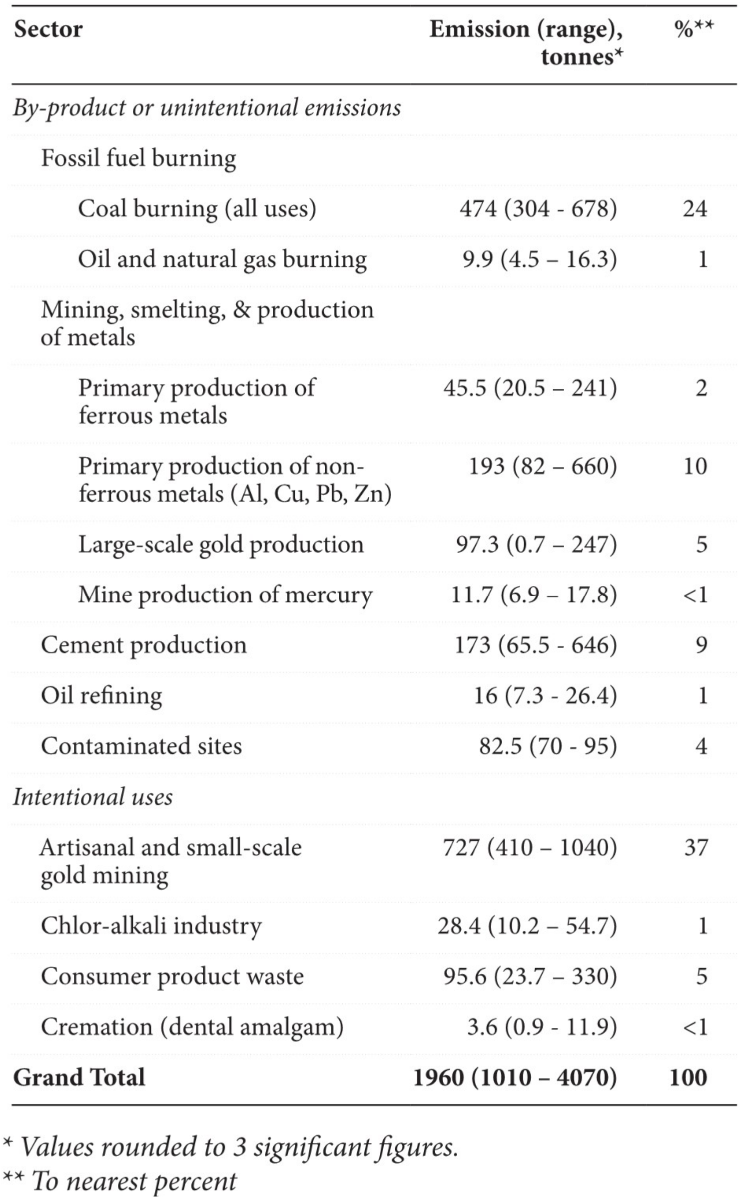
57. Coal burning is still a major source of emissions, responsible for some 475 tonnes of mercury emissions to air annually, compared with around 10 tonnes from combustion of other fossil fuels. According to the inventory, more than 85% of these emissions are from coal burning in power generation and industrial uses.

58. Other major mercury sources to the air are the (large-scale) production of non-ferrous metals (such as gold, zink, copper and lead), cement production, waste handling of mercury-added products and contaminated sites.

59. Geographically, about 40 percent of global anthropogenic releases of mercury to the atmosphere are emitted in East and Southeast Asia. Other major contributors are Sub-Saharan Africa (16 percent) and South America (13 percent); the latter two primarily due to artisanal and small-scale gold mining.

60. As regards releases from point sources to water, the major quantified contributions were from the non-ferrous metal production sector and from waste handling of mercury-added products. Releases to water from artisanal and small-scale gold mining are not quantified individually, but are likely a major source.

Table 3-1 Summary of Global anthropogenic emissions to the atmosphere in 2010 by sector (UNEP, 2013).



Sector	Emission (range), tonnes*	%**
By-product or unintentional emissions		
Fossil fuel burning		
Coal burning (all uses)	474 (304 - 678)	24
Oil and natural gas burning	9.9 (4.5 – 16.3)	1
Mining, smelting, & production of metals		
Primary production of ferrous metals	45.5 (20.5 – 241)	2
Primary production of non-ferrous metals (Al, Cu, Pb, Zn)	193 (82 – 660)	10
Large-scale gold production	97.3 (0.7 – 247)	5
Mine production of mercury	11.7 (6.9 – 17.8)	<1
Cement production	173 (65.5 - 646)	9
Oil refining	16 (7.3 - 26.4)	1
Contaminated sites	82.5 (70 - 95)	4
Intentional uses		
Artisanal and small-scale gold mining	727 (410 – 1040)	37
Chlor-alkali industry	28.4 (10.2 – 54.7)	1
Consumer product waste	95.6 (23.7 – 330)	5
Cremation (dental amalgam)	3.6 (0.9 - 11.9)	<1
Grand Total	**1960 (1010 – 4070)**	**100**

* *Values rounded to 3 significant figures.*
** *To nearest percent*

4 Steps in the creation of a mercury inventory on Inventory Level 2

4.1 Introduction to the Inventory Level 2 concept

61. This section describes the procedures of the Toolkits Inventory Level 2. If you are performing the first inventory using this Toolkit, we recommend developing the inventory on the simpler and more standardised Inventory Level 1 first, unless you have decided that you want to perform a detailed inventory from the start. The Toolkit's "Guideline to Inventory Level 1" describes the recommended initial steps in your first inventory development with this Toolkit, and also gives advice on when it can be beneficial to refine selected parts of your inventory on Inventory Level 2.

62. The Toolkit's Inventory Level 2 consists of a four-step standardized procedure to develop consistent and comparable source inventories, as set out in Figure 4-1 below.

ESTABLISHING A NATIONAL MERCURY RELEASE INVENTORY USING THIS TOOLKIT

STEP 1 - Apply screening matrix to identify main source categories present in the country or region investigated and identify existing descriptions of mercury sources in the country;

STEP 2 - Classify main source categories further into sub-categories and gather additional qualitative information to identify existing activities and sources of mercury releases in the country; and if feasible, the relative importance of each;

STEP 3 - Gather detailed quantitative information on the identified sources, and quantify releases with source specific data or default mercury input and output distribution factors from this Toolkit;

STEP 4 - Apply nation-wide to establish full inventory and report results using guidance given in the standard format.

Figure 4-1 The recommended four-step approach used to establish a national mercury release inventory using the Toolkit

63. In the first step, a coarse screening matrix is used to identify the main mercury source categories present in a country. Also, any existing partial mercury inventories or descriptions of mercury sources in the country (or region) should be identified and collected. If you have completed Inventory Level 1, this step in Inventory Level 2 need not be done again.

64. In the second step, these main source categories are further classified into sub-categories in order to identify the individual activities that potentially release mercury. If only a qualitative identification of source types present in the country or region in question is desired, step three (quantification) can be omitted, and the qualitative findings can be reported as a commented list of main source categories and sub-categories identified in the country. However, to give a better basis for preliminary evaluation and prioritization of further actions to address mercury releases, it is highly recommended to include, as a minimum, information that indicates the relative magnitude of the sub-category as a source of mercury releases, as described in step 3 below. If you have completed Inventory Level 1, step 2 in this Inventory Level 2 need not be done.

65. In the third step, a quantitative inventory is developed. At this step, it may be considered if a full quantitative inventory should be created from the start, or as an initial step, an interim inventory is desired to support the prioritization of the further work and initiate communication with inventory participants/reviewers. An interim inventory may present the identified source sub-categories along with indication of their relative importance. A preliminary impression of the relative importance - magnitude of mercury releases - of the identified source sub-categories can be formed by gathering and applying activity volume data (see below) and/or other relevant information such as the approximate number and size of facilities in a particular industry, approximate number of people engaged in a

particular activity, such as gold mining, or similar. Obtaining some information on the principal intentional uses of mercury within the country will be particularly helpful as an important input to the interim inventory. An interim report can be developed with outline as described in section 4.5.3.

66. For a full quantitative inventory, activity volume data ("activity rates") and process-specific information is gathered to be used to calculate estimated mercury releases from the identified mercury release sources in the country (or region) in question. Releases are calculated *via* the equation and procedures given in section 4.4, and source type data described in chapter 5.

67. The fourth and final step is the compilation of the standardized mercury inventory using the results generated in steps 1 through 3. A standardized presentation format is presented in section 4.5.2, in order to ensure that all known sources are considered (even if they cannot be quantified), data gaps are identified and inventories are comparable and transparent.

68. A flowchart, further illustrating the details of the process described above, is given in Figure 4-2 below.

4.1.1 Life-cycle approach

69. As illustrated in Figure 3-2 earlier, mercury releases may occur at all stages of the life-cycle of a mercury-added product or process. As mercury is an element and therefore neither formed nor degraded during this life-cycle (though it may change form), the mercury releases from a particular human activity can be viewed as the consecutive distribution of an original mercury input to various media or release pathways during various stages of the life cycle of the product or process in question. Therefore, this Toolkit works with the parameters "**mercury input**" and "**output distribution**" for each of the activities in the life-cycle chain.

70. The inventory approach in this Toolkit is organized according to the relevant products and processes. For each such product or service, the releases are described and assessed for the phases of the life-cycle where mercury releases can potentially occur (even if the phases in the life cycle can be considered individual release sources in terms of space and time). This approach is followed in most of the more advanced existing national inventories of mercury fluxes and releases, often in the form of so-called substance flow assessments (or analyses).

71. Examples of the life-cycle of a process and a product containing mercury and the mercury releases occurring throughout its life cycle are given in Figure 3-3 above. Only those phases in the life-cycle that are relevant to releases of mercury are shown in the figure.

72. As can be seen from the examples in this figure, not all phases in the life-cycle have equal potential for mercury releases. At what stage of the life-cycle significant releases may take place depends very much on the character of the materials, processes and products involved. This Toolkit focuses on the major releases that may take place throughout the life-cycles (see sections 4.2 and 4.3), and describes in more detail, in chapter 5, where in the life-cycles of the different release sources significant mercury releases may occur, along with available data of how much of the mercury input is released in each phase.

73. For the sake of convenience, releases from primary extraction of mercury, as well as releases from treatment of general (household) waste and waste water, are described and assessed separately in this Toolkit, but the important links between these phases and the production and use phases in between, are noted in the description of the mercury release sources.

Mercury inputs

74. The life cycle of mercury-added products or processes is often not described fully in the available literature, as quantitative data may be lacking or poor for some of the life-cycle phases. Therefore, mercury inputs are often derived from the most easily available data types (as can be seen in the mercury source descriptions in chapter 5). For battery production, for example, mercury inputs may be derived from relatively well-documented mercury concentrations in the produced batteries in combination with data on the tonnage of batteries produced, and not from the actual inputs to battery manufacturing.

75. Examples of mercury inputs for each release source type are - to the extent data has been obtained in the process of developing this Toolkit - presented in the source description sections in chapter 5.

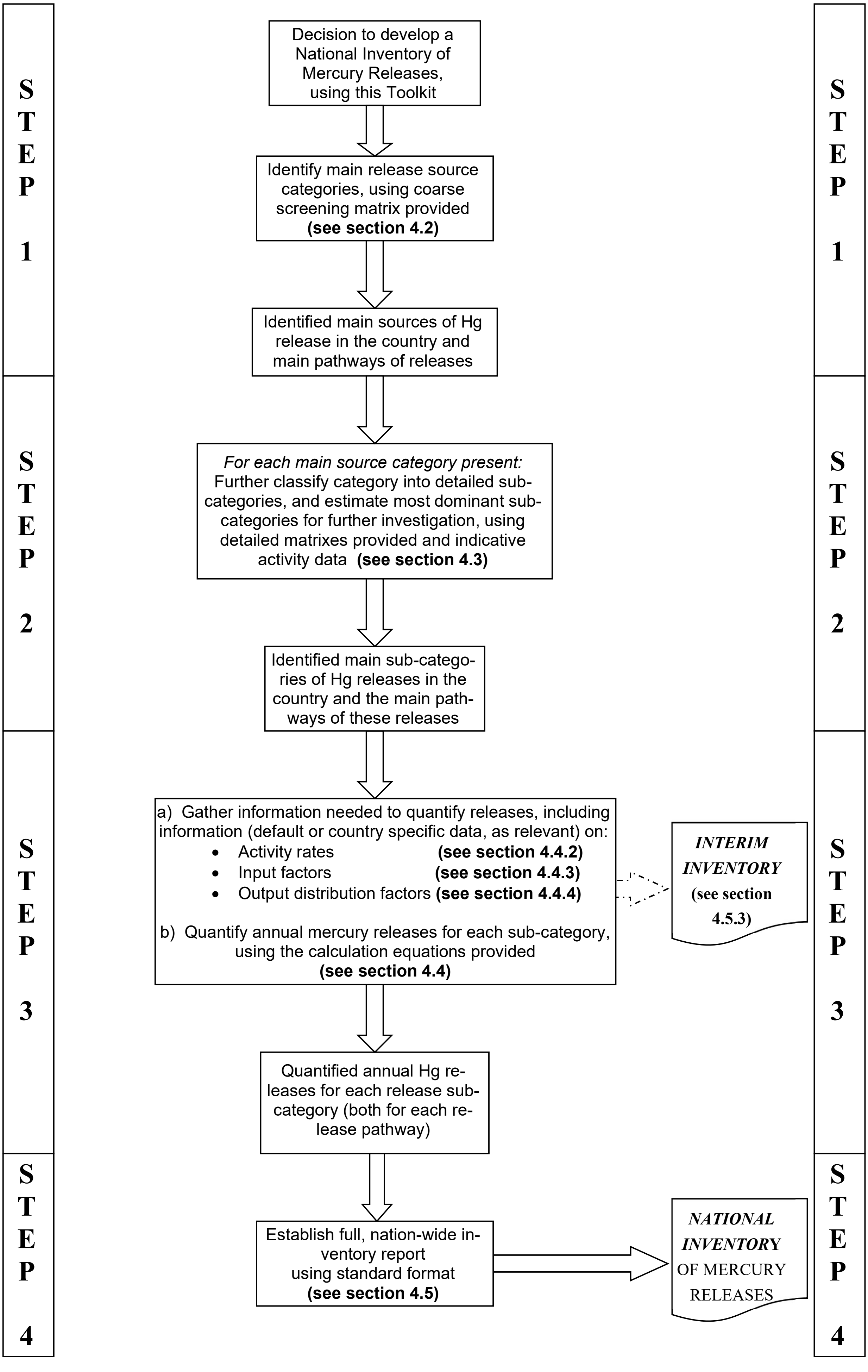


Figure 4-2 Flowchart detailing the four-step approach to establish a national mercury release inventory using the Toolkit

76. For some selected sources, default input factors have been presented in the source description sections in chapter 5 in this Toolkit.

77. It should be noted that, in an ideal world, estimating releases of mercury from the various release sources should be based on actual data, specific to the specific product, industrial facility or activity under consideration. However, in reality, one will find that this is rarely the case, and that it is often time-consuming and costly to generate such information. Although the use of source specific data is always the preferred approach and will lead to the best estimates of releases, an attempt has been made when developing this Toolkit, to develop preliminary default input and distribution factors that might be of use to those users who have difficulties obtaining source specific data.

78. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows. Also the presented default factors are expert judgments based on summarized data only, and - at present - no systematic quantitative approach (i.e. consumption-weighted concentration and distribution factors derivation) has been involved in the development of the factors.

79. Because of the uncertainties in using non-specific data, it may be wise to calculate and report intervals for the mercury inputs and outputs when using the default factors. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

Output distribution factors

80. For each mercury release source type, outputs are - to the extent data has been obtained - presented in the source description sections in chapter 5 as the relative share of the **inputs** that follow each specific output pathway (or release pathway) - designated here as output distribution factors. The output pathways include:

- Direct releases to the atmosphere (air);
- Direct releases to aquatic environments (water);
- Direct releases to land (terrestrial environment, including ground water);
- Flows of mercury as an impurity in marketed products (for example gypsum wallboard produced from solid residues from flue gas cleaning on coal fired power plants);
- Flows of mercury to the public waste water treatment system;
- Flows of mercury to the general waste treatment system;
- Flows of mercury to sectors specific waste treatment or disposal systems.

  The principles applied in this "output path" vary between the sectors; it may for example involve special separate collection and recycling, special safe deposition for high concentration mercury waste, or use of low concentration residues in road construction or other similar activities. To distinguish such disposal activities from uncontrolled "direct releases to land", the first mentioned should be characterized by an element of evaluation by risk assessments or informed acceptance from the authorities. Knowledge of the actual treatment or disposal taking place should always be noted in the developed inventory reports.

81. It should be noted that uncontrolled, informal or illegal deposition or incineration of waste on manufacturing sites or other places, with no evaluated mercury retention, is considered in this Toolkit as direct releases to land, atmosphere and water, as relevant. Note also that in the source description sections (Chapter 5), a distinction between direct release to water and releases to the waste water system is not made. This is because the distribution between these two pathways is so variable among

countries and local conditions, that it is difficult to state anything general about it in a global perspective.

82. Marketing products and materials with intentional mercury contents is not considered a release pathway in the Toolkit context. Marketed mercury amounts with such products and materials are however dealt with extensively in the source description sections (Chapter 5), and must also be quantified in the inventory in order to estimate mercury releases to the environment. Examples of such products and materials are mercury thermometers, batteries and metallic mercury.

83. For some selected sources, default output distribution factors are presented in the source description sections in chapter 5 in this Toolkit. See section above on mercury inputs for some comments on the use of these default factors.

4.2 Step 1: Screening matrix; identification of main source categories present

84. The first step in developing a standardized mercury source inventory is identification of main source categories present in the country (or region) investigated, and the main release routes for each category. If you have completed Inventory Level 1, this step in Inventory Level 2 need not be done again. The coarse screening matrix provided in Table 4-1 below facilitates preliminary evaluation of activities (industries, product uses, domestic activities, *etc.*), which potentially release mercury to one or more of the output pathways as defined above. For each main source category, the presence or absence of the activity in the country or region should be confirmed.

85. As an additional element in this initial work - and for further use - any existing partial inventories or descriptions of mercury sources in the country should be identified.

Table 4-1 Screening Matrix – Main source categories and release pathways

Chapter	Main Source Category	Air	Water	Land	Products	Waste/ residue
5.1	Extraction and use of fuels/energy sources	**X**	**X**	x	x	**X**
5.2	Primary (virgin) metal production	**X**	**X**	**X**	**X**	**X**
5.3	Production of other minerals and materials with mercury impurities	**X**	x	x	x	x
5.4	Intentional use of mercury in industrial processes	**X**	**X**	**X**	**X**	**X**
5.5	Consumer products with intentional use of mercury	**X**	**X**	**X**	**X**	**X**
5.6	Other intentional products/process uses	**X**	**X**	**X**	**X**	**X**
5.7	Production of recycled metals ("secondary" metal production)	**X**	**X**	**X**	**X**	**X**
5.8	Waste incineration	**X**	**X**	**X**	x	**X**
5.9	Waste deposition/landfilling and waste water treatment	**X**	**X**	**X**		**X**
5.10	Crematoria and cemeteries	**X**		**X**		x
5.11	Identification of potential hot-spots	Probably registration only, to be followed by site-specific evaluation				

Notes: **X** - Release pathway expected to be predominant for the individual main source category;
x - Additional release pathways to be considered, depending on specific source and national situation.

86. These main mercury source categories are broad enough to capture the wide variety of industries, processes and/or activities known to potentially cause releases of mercury. Each main source

category is structured to have common characteristics and manageable complexity. In the screening matrix, the large "**X**" denotes the release pathway expected to be predominant for the individual main source category, and the small "x" shows additional release pathways that should be considered. While some main source categories may generally contribute more than others to a national mercury release inventory, this distinction is deliberately not made here, as these relations are expected to differ considerably depending on national or regional conditions.

87. It should be noted that, for simplification, releases to water and to waste water treatment systems are treated as one in the table. The same is the case with general waste and sector specific waste treatment.

88. The coarse screening matrix provides guidance on the areas in which information will be required, and may influence the composition of a team to collect initial information about possible sources of mercury present in a country. The screening matrix will be the starting point for a strategy to seek advice and expertise that will be needed during the more detailed information gathering and data evaluation work.

89. Resource persons with thorough knowledge of the sectors, where mercury releases can happen in the country (or region), can be very valuable in the creation of a mercury inventory. Emphasis should be put on the identification of such persons. Such persons may be industry's own experts, from research institutions, from local or national environmental authorities, relevant consultants, among others. Such resource persons may have significant knowledge that has not been reported and published.

4.3 Step 2: Identification of sub-categories of sources present

90. In the second step, processes or sub-categories within each main source category that are present in the country or region under investigation are identified. If you have completed Inventory Level 1, this step in Inventory Level 2 need not be done again. Each of the ten main source categories has been divided into a series of sub-categories that are described in the subsections below. The list of sub-categories constitutes the summary matrix of the mercury inventory, which is to be compiled, as described later in section 4.5).

91. For each sub-category listed, an investigation should establish the presence or absence of the activity in the country or region. Easily accessible data is most valuable at this stage. Centralized statistical information may be most appropriate. Any sub-category, which is reliably known not to be present, can be eliminated from further investigation. However, the fact that the process is absent should be noted in the inventory.

92. In the sub-sections below, the main source category is broken down into a number of sub-categories and details relevant to each sub-category are given. In addition, a table indicating the main release pathways for each sub-category is included. Columns 2-6 of the table identify the pathways into which significant amounts of mercury may potentially be released. The large "**X**" denotes the release pathway expected to be predominant, and the small "x" shows additional release pathways to be considered, depending on specific source and national situation. The right column indicates whether a point source approach (PS) or an overview approach (OW) is deemed most relevant. For more explanation on point source and overview inventory approaches, see section 4.4.1.

93. For simplification, releases to water and to waste water treatment systems are treated as one in these tables, as was done for the main source categories in Table 4-1. The same is here the case with general waste and sector specific waste treatment.

4.3.1 Extraction and use of fuels/energy sources

94. This category covers the following main sub-categories:

- **Coal combustion in large power plants**, with thermal boiler capacity above 300MW;
- **Other coal combustion**, such as smaller combustion plants, domestic heating and other coal uses;
- **Extraction, refining and use of mineral oil**, i.e. all mercury releases in the life-cycle of mineral oil), such as heating, power production, use in transportation, synthesis of chemicals and polymers, carbon black production, etc.;
- **Extraction, refining and use of natural gas**, i.e. all mercury releases in the life-cycle of natural gas), such as heating, power production, use in transportation, synthesis of chemicals and polymers, carbon black production, etc.;
- **Extraction and use of other fossil fuels**, such as oil shale, peat, etc.;
- **Biomass fired power and heat production**, using wood, straw, etc.;
- **Geothermal power production**.

95. The main pathways of releases of mercury and the recommended inventory approach for each of these sub-categories is indicated in the table below.

Table 4-2 Extraction and use of fuels/energy sources: sub-categories with main pathways of releases of mercury and recommended inventory approach

Main category - Extraction and use of fuels/energy sources							
Chapter	**Sub-category**	**Air**	**Water**	**Land**	**Product**	**Waste/ residue**	**Main inventory approach**
5.1.1	Coal combustion in large power plants	**X**	x	x	x	**X**	PS
5.1.2	Other coal combustion	**X**		x	x	x	OW
5.1.3	Extraction, refining and use of mineral oil	**X**	**X**	x	x	x	OW/PS
5.1.4	Extraction, refining and use of natural gas	**X**	**X**	**X**	x	**X**	OW/PS
5.1.5	Extraction and use of other fossil fuels	**X**	x	x		x	OW
5.1.6	Biomass fired power and heat production	**X**	x	x		x	OW
5.1.7	Geothermal power production	**X**					PS

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

4.3.2 Primary (virgin) metal production

96. This category covers the following main sub-categories:

- **Primary extraction and processing of mercury**, i.e. dedicated primary mercury mining;
- **Gold and silver extraction with the mercury-amalgamation process,** i.e. mercury is used intentionally to extract gold and silver, as opposed to other gold and silver extraction processes;

- **Zinc extraction and initial processing**, i.e. primary zinc extraction and processing where mercury impurities are present in the ores;
- **Copper extraction and initial processing**, i.e. primary copper extraction and processing where mercury impurities are present in the ores;
- **Lead extraction and initial processing**, i.e. primary lead extraction and processing where mercury impurities are present in the ores;
- **Gold extraction and initial processing by other processes than mercury amalgamation,** where mercury is present as a natural impurity in gold ore;
- **Aluminium extraction and initial processing**, i.e. primary aluminium extraction and processing where mercury impurities are present in the ores or other feedstock materials;
- **Extraction and processing of other non-ferrous metals,** i.e. primary extraction and processing of other non-ferrous metals, such as nickel and others;
- **Primary ferrous metal production**, such as production of iron, steel, ferromanganese, etc.

97. The main pathways of releases of mercury and the recommended inventory approach for each of these sub-categories is indicated in the table below.

Table 4-3 Primary (virgin) metal production: sub-categories with main pathways of releases of mercury and recommended inventory approach

Main category - Primary (virgin) metal production							
Chapter	**Sub-category**	**Air**	**Water**	**Land**	**Product**	**Waste /residue**	**Main inventory approach**
5.2.1	Primary extraction and processing of mercury	**X**	**X**	**X**	**X**	**X**	PS
5.2.2	Gold and silver extraction with the mercury-amalgamation process	**X**	**X**	**X**			OW
5.2.3	Zinc extraction and initial processing	**X**	**X**	**X**	**X**	**X**	PS
5.2.4	Copper extraction and initial processing	**X**	**X**	**X**	**X**	**X**	PS
5.2.5	Lead extraction and initial processing	**X**	**X**	**X**	**X**	**X**	PS
5.2.6	Gold extraction and initial processing by other processes than mercury amalgamation	**X**	**X**	**X**	**X**	**X**	PS
5.2.7	Aluminium extraction and initial processing	**X**		x		x	PS
5.2.8	Extraction and processing of other non-ferrous metals	**X**	**X**	**X**		**X**	PS
5.2.9	Primary ferrous metal production	**X**				x	PS

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathways expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

4.3.3 Production of other minerals and materials with mercury impurities

98. This category covers the following main sub-categories:

- **Cement production,** including mercury in lime, waste as fuel and other feedstock materials;
- **Pulp and paper production**, including mercury impurities in wood, other fuels and caustic soda, and in some cases mercury-based slimicides;
- **Production and processing of other raw materials**, including production and use of lime, light weight aggregates, mineral fertilisers, and others.

99. The main pathways of releases of mercury and the recommended inventory approach for each of these sub-categories is indicated in the table below.

Table 4-4 Production of other minerals and materials with mercury impurities: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Main category - Production of other minerals and materials with mercury impurities							
Chapter	**Sub-category**	**Air**	**Water**	**Land**	**Product**	**Waste/ residue**	**Main in-ventory approach**
5.3.1	Cement production	**X**		x	x	x	PS
5.3.2	Pulp and paper production	**X**	x	x		x	PS
5.3.3	Lime production and light weight aggregate kilns	**X**			x		PS
5.3.4	Others minerals and materials						PS

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

4.3.4 Intentional use of mercury in industrial processes

100. This category covers the following main sub-categories:

- **Chlor-alkali production with mercury-technology**;
- **VCM (vinyl-chloride-monomer) production with mercury-dichloride ($HgCl_2$) as catalyst**;
- **Acetaldehyde production with mercury-sulphate ($HgSO_4$) as catalyst**;
- **Other production of chemicals and polymers with mercury compounds as catalysts**.

101. The main pathways of releases of mercury and the recommended inventory approach for each of these sub-categories is indicated in the table below.

Table 4-5 Intentional use of mercury as an auxiliary material in industrial processes: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Main category – Intentional use of mercury as an auxiliary material in industrial processes							
Chapter	**Sub-categories**	**Air**	**Water**	**Land**	**Product**	**Waste/ residue**	**Main inventory approach**
5.4.1	Chlor-alkali production with mercury-technology	**X**	**X**	**X**	**X**	**X**	PS
5.4.2	VCM (vinyl-chloride-monomer) production with mercury-dichloride ($HgCl_2$) as catalyst	x	x			**X**	PS
5.4.3	Acetaldehyde production with mercury-sulphate ($HgSO_4$) as catalyst	?	?	?	?	?	PS
5.4.4	Other production of chemicals and polymers with mercury compounds as catalysts	?	?	?	?	?	PS

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

4.3.5 Consumer products with intentional use of mercury

102. This category covers the following main sub-categories given below. The category includes products that may be used by broader groups (and may be subject to public waste handling procedures). It also includes releases from production, use and disposal.

- **Thermometers containing mercury**, including medical thermometers, other glass thermometers (used in laboratories, for educational purposes, etc.) and other mercury thermometers (industrial, marine diesel engines, etc.);
- **Electrical and electronic switches, contacts and relays with mercury**, including:
  - Level switches in sewer pumps, water pumps, car boot lids (lighting), car ABS sensors, car ride-control systems, freezers lids, fall alarms for the elderly, railway signals, lights in children's shoes, etc.,
  - Multiple pole level switches in excavation machines,
  - mercury-wetted contacts (in electronics),
  - Data transmission relays or "reed relays",
  - Thermo-switches, etc.;
- **Light sources with mercury**, including:
  - Linear fluorescent lamps,
  - Compact bulbs (small energy saving fluorescent lamps),
  - Street advertisement with fluorescent tubes,
  - Other mercury-containing lamps (Hg-lamps and Na-lamps for street lighting, UV lamps for skin tanning, light source in LCD flat screens for TV and computers, laboratory atomic absorption spectrometry lamps, head lamps in some car brands, etc.);
- **Batteries containing mercury**, including:
  - Mercury oxide batteries (cylindrical and button),
  - Alkaline cylindrical cells (containing mercury). (Note: in recent years mercury content in cylindrical alkaline cells has been reduced/eliminated in many battery brands.),
  - Button shaped cells of most types (containing mercury);
- **Biocides and pesticides**, including seed dressing, sugar cane seedling dip and other pesticides;

- **Paints**, including some latex paints and possibly other paints containing mercury compounds as biocides for shelf life preservation;
- **Pharmaceuticals for human and veterinary uses**, including vaccines, eye drops, some herbal medicines, disinfectants, etc.;
- **Cosmetics and related products**, including skin lightening creams and soaps, preservation in eye cosmetics, etc.

103. The main pathways of releases of mercury and the recommended inventory approach for each of these sub-categories is indicated in the table below.

Table 4-6 Consumer products with intentional use of mercury: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Main category - Consumer products with intentional use of mercury							
Chapter	**Sub-category**	**Air**	**Water**	**Land**	**Product**	**Waste/ residue**	**Main inventory approach**
5.5.1	Thermometers with mercury	**X**	**X**	**X**	**X**	**X**	OW
5.5.2	Electrical and electronic switches, contacts and relays with mercury	**X**	x	**X**	**X**	**X**	OW
5.5.3	Light sources with mercury	**X**	x	**X**	**X**	**X**	OW
5.5.4	Batteries containing mercury	**X**	x	**X**	**X**	**X**	OW
5.5.6	Biocides and pesticides	**X**	**X**	**X**	**X**	**X**	OW
5.5.7	Paints	**X**	x	x	**X**	x	OW
5.5.8	Pharmaceuticals for human and veterinary uses	**X**	x	x	x	**X**	OW
5.5.8	Cosmetics and related products		**X**		**X**	x	OW

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

4.3.6 Other intentional products/process uses

104. This category covers the following main sub-categories given below. It includes releases from production, use and disposal.

- **Dental amalgam fillings**;
- **Manometers and blood pressure gauges**, including:
  - Blood pressure gauges,
  - Other manometers/pressure controls for industrial uses, for educational purposes, district heating pressure valves (such pressure controls may contain hundreds of kilos of mercury per control valve), etc.;
- **Laboratory chemicals and equipment**, including:
  - Special laboratory apparatus (Coulter Counters etc.),
  - Chemical reactants for COD analysis, Kjeldahl analysis (nitrogen analysis),
  - Electrodes for physio-chemical measurements, such as calomel electrodes and others;
- **Ethnic/cultural/ritualistic uses**, including mercury metal use in religious/ethnic/cultural rituals and practices and folklore medicine;

- **Other mercury metal uses**, including:
  - Educational uses,
  - Gyroscopes with mercury;
  - Vacuum pumps with mercury
  - Marine navigation lights in light houses (in some types the lens/lamp unit floats on mercury),
  - Mercury in large bearings of rotating mechanic part in for example older waste water treatment plants;
- **Miscellaneous products**, including:
  - Infra-red detection semiconductors,
  - Tanning,
  - Pigments,
  - Browning and etching steel,
  - Certain colour photograph paper types,
  - Recoil softeners in rifles,
  - Explosives (mercury-fulminate),
  - Fireworks,
  - Executive toys;

105. The last two sub-categories, other mercury metals and miscellaneous products, covers a large range of uses that have been reported and are 1) either known to be generally small uses (low consumption), or 2) uses with very little data available. These uses can not, however, be ruled out as potentially important release sources locally or nationally

106. The main pathways of releases of mercury and the recommended inventory approach for each of these sub-categories is indicated in the table below.

Table 4-7 Other intentional products/process uses: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Main category - Other intentional products/process uses							
Chapter	**Sub-category**	**Air**	**Water**	**Land**	**Product**	**Waste/ residue**	**Main inventory approach**
5.6.1	Dental mercury-amalgam fillings	x	**X**		**X**	**X**	OW
5.6.2	Manometers and gauges	x	**X**	x	**X**	**X**	OW
5.6.3	Laboratory chemicals and equipment	x	**X**		**X**	**X**	OW
5.6.4	Mercury metal use in religious rituals and folklore medicine	**X**	**X**	**X**	**X**	**X**	OW
5.6.5	Miscellaneous product uses, mercury metal uses and other sources	**X**	**X**	**X**	**X**	**X**	OW

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

4.3.7 Production of recycled metals ("secondary" metal production)

107. This category covers the following main sub-categories:

- **Production of recycled mercury ("secondary" metal production)**, including the collection and processing involved in recycling of mercury;
- **Production of recycled ferrous metals (iron and steel)**, including the collection and processing involved in recycling of iron and steel (such as scrap yard handling, scrap auto smelting, shredder, re-melting furnace).
- **Production of other recycled metals**.

108. The main pathways of releases of mercury and the recommended inventory approach for each of these sub-categories is indicated in the table below.

Table 4-8 Production of recycled metals: sub-categories with main pathways of releases of mercury and recommended inventory approach

Main category - Production of recycled metals							
Chapter	**Sub-category**	**Air**	**Water**	**Land**	**Product**	**Waste/ residue**	**Main inventory approach**
5.7.1	Production of recycled mercury ("secondary production)	**X**	**X**	**X**	**X**	**X**	PS
5.7.2	Production of recycled ferrous metals (iron and steel)	**X**	x	x		x	PS
5.7.3	Production of other recycled metals	**X**	x	x		x	PS

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

4.3.8 Waste incineration

109. This category covers the following main sub-categories:

- **Incineration of municipal/general waste** - mainly domestic (household and institution) waste, which may contain mercury from both intentional uses of all kinds as well as from impurities in various high volume materials);
- **Incineration of hazardous waste** - usually combustible wastes collected separately, which may contain mercury from intentional uses (e.g. pesticides, paints, pharmaceuticals, organic mercury compounds) as well as general mercury impurities;
- **Incineration of medical waste** – usually waste representing hygienic risk from hospitals, etc., which may contain mercury from intentional uses in the medical sector (thermometers, batteries, pharmaceuticals, dental material with fillings etc.) as well as general mercury impurities. Medical waste is sometimes incinerated in separate incinerators, sometimes in selected municipal waste incinerators equipped for the purpose;
- **Sewage sludge incineration** - much of the mercury in wastewater (originating from all sorts of mercury uses, but often dominated by dental amalgam wastes) ends up in the sewage sludge. - If not spread on farmland as fertiliser, sewage sludge may sometimes be incinerated in separate incinerators, sometimes in municipal waste incinerators;
- **Informal waste burning** - private or local informal waste burning in open fire, barrels, domestic heating ovens, etc.

110. It should be kept in mind that the original input of mercury to waste incineration is the mercury present in products with intentional use of mercury and production wastes containing mercury, as well as other products with mercury impurities (virtually "all materials" contain trace amounts of mercury). Mercury contributions to waste from intentional product and process uses, as well as certain other waste types, are sought estimated under the respective product and use sub-categories of this Toolkit. The waste disposal step does, however, for many such products and materials represent a potentially major mercury release activity in their life-cycle.

111. The main pathways of releases of mercury and the recommended inventory approach for each of these sub-categories is indicated in the table below.

Table 4-9 Waste incineration: Sub-categories with primary pathways of releases of mercury and recommended inventory approach

Main category – Waste incineration							
Chapter	**Sub-category**	**Air**	**Water**	**Land**	**Product**	**Waste /residue**	**Main inventory approach**
5.8.1	Incineration of municipal/ general waste	**X**	x	x	x	**X**	PS
5.8.2	Incineration of hazardous waste	**X**	x			**X**	PS
5.8.3	Incineration of medical waste	**X**	x			**X**	PS
5.8.4	Sewage sludge incineration	**X**	**X**			**X**	PS
5.8.5	Informal waste burning	**X**	**X**	**X**			OW

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

4.3.9 Waste deposition/landfilling and waste water treatment

112. This category covers the following main sub-categories:

- **Controlled landfills/deposits**, i.e. deposition of waste under controlled procedures (based on risk assessments), and retention of pollutants in the waste, including:
  - Domestic (household and institutional) waste,
  - Medical/hazardous waste,
  - Solid combustion/incineration residues,
  - Wastewater sludge;
- **Diffuse deposition under some control**, such as deposition of incineration residues and other solid residues under roads, in constructions, etc. under controlled procedures (based on risk assessment) and with some retention of pollutants from wash-out, etc.;
- **Informal local deposition of industrial production waste**, such as chlor-alkali production waste, chemicals production waste, and other waste (on production site or elsewhere);
- **Informal dumping of waste,** i.e. uncontrolled, informal dumping of general waste diffusely or at informal waste dumps;
- **Waste water system/treatment**, - where any mercury in wastewater (originating from all sorts of mercury uses, but often dominated by dental amalgam wastes) ends up in the sewage sludge, and to a lesser degree in the output water.

113. It should be kept in mind that the original input of mercury to waste is the mercury present in products with intentional use of mercury, products with mercury impurities ("all products"), and

production wastes containing mercury. The waste disposal step does, however, for many such products and materials represent a major mercury release activity in their life-cycle.

114. The main pathways of releases of mercury and the recommended inventory approach for each of these sub-categories is indicated in the table below.

Table 4-10 Waste deposition/landfilling and waste water treatment: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Main category - Waste deposition/landfilling and waste water treatment							
Chapter	**Sub-category**	**Air**	**Water**	**Land**	**Product**	**Waste/ residue**	**Main inventory approach**
5.9.1	Controlled landfills/deposits	x	x	**X**		**X**	OW
5.9.2	Diffuse deposition under some control	x	**X**	**X**		**X**	OW
5.9.3	Informal local deposition of industrial production waste	**X**	**X**	**X**			PS
5.9.4	Informal dumping of general waste	**X**	**X**	**X**			OW
5.9.5	Waste water system/treatment		**X**	**X**		x	OW/PS

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

4.3.10 Crematoria and cemeteries

115. This category covers the following main sub-categories:

- **Crematoria**;
- **Cemeteries**.

116. The main pathways of releases of mercury and the recommended inventory approach for each of these sub-categories is indicated in the table below.

Table 4-11 Cremation and cemeteries: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Main category - Cremation and cemeteries							
Chapter	**Sub-category**	**Air**	**Water**	**Land**	**Product**	**Waste/ residue**	**Main inventory approach**
5.10.1	Crematoria	**X**				x	OW
5.10.2	Cemeteries			**X**			OW

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

4.3.11 Identification of potential hot-spots

117. This main category has some overlap with some of the waste deposition sub-categories, but focuses on previously deposited mercury that still has a potential for significant releases and risks to humans and the environment.

118. Hot-spots exist as the direct result of disposal practices as described in sections 5.9.3 and 5.9.4 or of inadequate disposal of contaminated materials. Release from these sites may already be ongoing or can be expected to begin if no remedial action is taken. Table 4-12 below describes an indicative list of locations where hot-spots for mercury can potentially be found.

119. Hot-spots may be linked to an existing production process, and releases may be ongoing from processes on-site or from historical activities. Other potential hot-spots are reservoirs where mercury containing materials have been stored, dumped or accumulated over many years. In these cases the release may be ongoing, imminent or only potentially threatening in the future. Identification of such sites can in some case be difficult.

120. Site-specific evaluation of each hot-spot should determine its current status: immediate threat or potential for releases in the future. In either case the site should be registered.

121. The main pathways of releases of mercury and the recommended inventory approach for each of these potential hot-spots is indicated in the table below.

Table 4-12 Potential hot-spots: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Main category - Potential hot-spots							
Chapter	**Sub-category**	**Air**	**Water**	**Land**	**Product**	**Waste/ residue**	**Main inventory approach**
	Closed/abandoned chlor-alkali production sites	x	**X**	**X**		**X**	PS
	Other sites of former chemical production where mercury compounds are/were produced (pesticides, biocides, pigments etc.), or mercury or compounds were used as catalysts (VCM/PVC etc.)	x	**X**	**X**	x	**X**	PS
	Closed production sites for manufacturing of thermometers, switches, batteries and other products	x	**X**	**X**	**X**	x	PS
	Closed pulp and paper manufacturing sites (with internal chlor-alkali production or former use of mercury-based slimicides)	x	**X**	**X**		**X**	PS
	Tailings/residue deposits from mercury mining	x	**X**	**X**	**X**	**X**	PS
	Tailings/residue deposits from artisanal and large scale gold mining	x	**X**	**X**		**X**	PS
	Tailings/residue deposits from other non-ferrous metal extraction	x	**X**	**X**	**X**	**X**	PS
	Sites of relevant accidents	x	**X**	**X**		**X**	PS
	Dredging of sediments	x	**X**	**X**		**X**	PS
	Sites of discarded district heating controls (and other fluid controls) using mercury pressure valves		**X**	**X**			PS

Main category - Potential hot-spots							
Chapter	**Sub-category**	**Air**	**Water**	**Land**	**Product**	**Waste/ residue**	**Main inventory approach**
	Sites of previous recycling of mercury ("secondary" mercury production)	x	X	X	X	X	PS

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

4.4 Step 3: Data gathering and quantification of mercury releases

122. In the third step of the process, a quantitative inventory is developed. Activity volume data ("activity rates") and process-specific information and data are gathered to be used to calculate estimated mercury releases from the identified mercury release sources in the country (or region) in question. In this section, the involved data types are first presented, then general advice on data gathering is given in section 4.4.5. It should be emphasized that data gathering is not limited to this step of the procedure, but may be necessary throughout the process of developing the mercury inventory.

123. As a preliminary step, it may be considered to create an interim inventory to support the prioritization of the further work and initiate communication with inventory participants/reviewers. An interim inventory may present the identified source sub-categories along with indication of their relative importance. A preliminary impression of the relative importance - magnitude of mercury releases - of the identified source sub-categories can be formed by gathering and applying activity volume data (see below) and/or other relevant information such as the approximate number and size of facilities in a particular industry, approximate number of people engaged in a particular activity, such as gold mining, or similar. An interim report can be developed with outline as described in section 4.5.3.

4.4.1 Quantification principles

Basic quantification equation

124. The basic aim of the Toolkit is to enable an estimation of the average annual release to each pathway or vector (air, water, land, products, general waste, sector-specific waste treatment) for each release process identified. The estimate can be calculated using the following basic equation:

EQUATION 1:

Estimated mercury release to pathway X = activity rate * input factor * output distribution factor for pathway X

125. In other words, the annual estimated mercury releases for each pathway is calculated by:

☑ Multiplying the amount of feed material processed or product produced per unit of time (e.g. tons or pieces per year) – referred to as the **activity rate** - with

☑ An "input factor". For sub-categories with only one life-cycle phase (such as coal combustion) the input factor is the mercury content (*e.g,*. in grams of Hg) per unit of feed material processed. For sub-categories with more than one life cycle phase (such as battery production), the input factor is defined for each phase. For example, the input factor for the production phase is amount of mercury released per metric ton of batteries produced or product produced (*e.g.,* metric ton or piece) – referred to as the **input factor** –

☑ and the fraction or part (unit-less) of the mercury input that is released through the particular pathway (air, water, land, product, general waste, or sector specific waste treatment) - referred to as the **output distribution factors**.

126. However, it is important to note that the input factors for many sub-categories are more complicated than defined above. For sub-categories with only one dominant life-cycle phase (such as coal combustion or waste incineration) the input factor is the mercury content (e.g. in grams of mercury) per unit of feed material (e.g. coal, waste, etc.) processed. For sub-categories with more than one life-cycle phase (such as batteries or thermometers containing mercury) the input factors are more complicated and must be defined for each phase.

127. It is also important to make sure that the units for activity rate, input factors and releases are appropriately used in the calculations. If the units are not consistent (and do not result in correct mathematical results), conversion factors must be used to convert the units correctly, to assure that units follow proper mathematical calculations. The mercury releases per year should be calculated and presented in kg (or metric tons) of mercury per year for each relevant pathway (such as kg of mercury emitted to air per year). Note that, in the source description sections in chapter 5, input factors are presented in the most relevant (metric) units to enhance readability. Make sure that these units are converted to the right level of magnitude to result in releases in Kg in the reporting.

128. In this Toolkit, it is suggested to assess and present all mercury releases individually to promote transparency and a uniform procedure. On the summary level of the inventory report, all the releases to a specific pathway are summed up for each source sub-category (and main category). This is done for each of the pathways relevant for the life-cycle of the sub-category in question. See the example given below, and section 4.5 on presentation of the inventory.

National overview or point source approach

129. For some sub-categories, the actual sources may be a limited number of well-defined point sources (with a specific geographical position), often with individual plant-specific characteristics. In such cases, the **point source approach** is applied. The estimate of total national (or regional) releases from this sub-category is calculated as the sum of the mercury releases (calculated with equation (1)) for each individual point source present nationally (or regionally).

130. Sub-categories where a point source approach might be most optimal include, among others, large coal fired power plants, municipal waste incinerators, chlor-alkali production and cement production.

131. For other mercury sources, a point source approach might not be relevant, might be difficult to implement, or just not optimal. Instead, an **overview approach** can be applied. This is the case for sources, where releases are not confined to a specific geographical position (sometimes also called "area sources"), sources where the available data are inadequate to perform an inventory with the point source approach, or sources where the point sources are operated under very similar conditions. In such cases the total national (or regional) releases from the sub-category may be calculated using national (or regional) activity rate numbers combined with general mercury input factors and output distribution factors, or by extrapolating releases from a few well documented point sources to the national or regional scale (using point source and national activity rates to scale up the release estimates).

132. Sub-categories where an overview approach is recommended include, among others, residential coal combustion, disposal of mercury thermometers, cremation and landfills.

133. In order to assist users of the Toolkit to estimate the releases from individual sub-categories, the main, recommended approach for each sub-category is indicated in the sub-category overview tables in section 4.3 and chapter 5. The **point source approach** is abbreviated "PS" and the **overview approach** is abbreviated "OW" in these tables.

Calculation of individual releases throughout the life-cycle

134. Within a specific sub-category, the releases from the relevant phases in the life-cycle are calculated individually, but described in the same section of the inventory report.

135. For each source sub-category described in chapter 5, an indication is given of the main release potentials for each phase throughout its life-cycle (production - use - disposal) and to which environmental media the releases are likely to happen. The information is given both in the text and in a table, as shown below.

Table 4-13 Example of an overview table indicating main releases and receiving media in the life-cycle of a product or service (here for batteries with mercury)

Phase of life cycle	**Air**	**Water**	**Land**	**Products**	**General waste**	**Sector specific treatment/ disposal**
Production	**X**	x	x	**X**		x
Use						
Disposal	**X**		**X**		**X**	**X *1**

Notes: ***1**: Separately collected batteries containing mercury (or categorized under sorting as such) may be disposed of in specially secured landfills;

X - Release pathway expected to be predominant for the sub-category;

x - Additional release pathways to be considered, depending on specific source and national situation.

136. It should be noted that within a specific sub-category, a point source approach may be best for estimating releases from the production phase, while the overview approach may be most suitable for the use and disposal phases. This is, for example, the case for mercury thermometers, where a country may only have one or a few thermometer factories, but where mercury thermometers (including imported thermometers) are used for a variety of purposes spread on the whole geographical area of the country, and are broken or disposed of locally.

Examples of calculation of mercury releases

137. Section 4.4.7 displays three examples of calculations of inputs and outputs for selected source categories. In the examples, the following table is used to sum up the results from the calculations. The table enables the presentation - in summary - of all the data included in the calculations, and the results of the calculations.

Table 4-14 Example of a possible table presenting, in summary, the estimated mercury releases for a specific sub-category

[Sub-category name]	**Unit**	**Production**	**Use**	**Disposal**	**Sum of releases to pathway from assessed part of life-cycle**
Activity rate					-
Input factor for phase***1**					-
Calculated input to phase ***2**					-
Output distribution factors for phase: *3					
- Air					-
- Water					-
- Land					-
- Products					-
- General waste treatment					-
- Sector specific waste treatment					-
Calculated outputs/releases to: *4					

[Sub-category name]	**Unit**	**Production**	**Use**	**Disposal**	**Sum of releases to pathway from assessed part of life-cycle**
- Air - Water - Land - Products - General waste treatment - Sector specific waste treatment					

Notes: *1 [(Cross) reference to where input factors where taken from or how they were developed];
*2 Sub-calculation for use in the reporting with formula "Input = input factor * activity rate" for each phase;
*3 [(Cross) reference to where input factors where taken from];
*4 Calculated with equation (1) for each of the pathways within each phase, for example: Mercury release to air from production = activity rate production * input factor production * output distribution factor to air for production.

4.4.2 Use of activity rates

138. As mentioned above, the activity rate is a parameter describing the volume of the activity in the sub-category in question per unit of time (usually per year).

139. The choice of activity rate basis will vary between sub-categories, because in different sub-categories, different activity rates may best describe what the volume of the activity is, and certain data may be more easily available from public statistics or other sources.

140. For example, the input of mercury with coal is most directly calculated by multiplying the concentration of mercury in the coal used (gram mercury per metric ton of coal), with the consumption of the same coal (metric ton coal per year). Remember here to observe if the weight basis is "dry matter" or other.

141. On the other hand, for mercury thermometers, the best-known data are mercury content per thermometer (gram mercury per piece) and the number of thermometers consumed or produced per unit of time (such as pieces per year).

142. In order to assist users of the Toolkit to estimate the releases from individual sub-categories, the activity rate data types needed for the quantitative inventory calculations are listed in the individual sub-category descriptions in chapter 5, along with the type of mercury input factors. The information is structured in overview tables like the example given below.

Table 4-15 Example of an overview table indicating activity rate data and mercury input factor types needed to estimate releases from a specific sub-category (here for batteries with mercury)

Life-cycle phase	**Activity rate data needed**	**Mercury input factor**
Production	Metric tons of batteries produced per year (in the country)	Kg of mercury released per metric ton of batteries produced ***2**
Use	Not needed (Releases negligible)	Not needed (Releases negligible)
Disposal	Metric tons of batteries consumed (or disposed) per year ***1**	Kg of mercury disposed or released per metric ton of batteries consumed ***3**

Notes: *1 As a substitute for metric tons disposed of per year. If good estimates of amounts of batteries disposed of exist, these should preferably be used. In times of changing consumption, the two numbers differ from each other;
*2 Kg of mercury released per metric ton of batteries produced = amount of mercury input

(kg mercury) used to produce each metric ton of batteries multiplied by the percent of input mercury that is released during this phase of the life cycle";

*3 This input factor can also be defined as kg of mercury in each metric ton of batteries multiplied by the percent of this mercury that is released from disposal phase of the life cycle. If one assumes that eventually all the mercury in the batteries is eventually released to some media, than the "percent of mercury released" can be assumed to 100%.

143. In some cases, data on the proposed activity rate basis may not be available (or may be difficult to obtain) in a country. In such cases, it may be possible to derive activity rates to the proposed units using alternative input data and conversion data (or conversion factors). In the example with coal, the coal consumption in metric tons per year may not be available, but primary energy production numbers (such as MW primary energy per year) from the power plants may be available. In this case, the activity rate data can be derived using available data on energy content in the coal type(s) being used (such as MW per metric ton). It is crucial to ensure that these conversions are made on the proper basis, preferably primary energy content (total chemical energy content in dry coal). For further description, see US EPA (2002a), and consult energy production experts.

144. In the example with thermometers, if numbers of sold thermometers are not available, perhaps data on the value or the weight of the consumed thermometers is available and can be used as the activity rate. Again, alternative input data and conversion factors/data are needed.

145. For many source sub-categories, examples of such alternative data and conversion factors/data are available in the literature. Otherwise, they may be obtained through direct contact with the sector in question, such as an industry trade association (or possibly other knowledgeable organizations), as part of ones own investigations. Unfortunately, it has not been possible to provide comprehensive information on such conversion data in this Toolkit.

Definition of consumption

146. It is important to note that "consumption" of a product or material per year in a country or region is defined as given in equation (2), where yearly production, imports and exports refer to the same country or region:

EQUATION 2:

Consumption per year = Production + Imports – Exports (per year)

Disposal may reflect consumption from earlier years

147. The calculation of mercury outputs from disposal should ideally be based on total product amounts being disposed of in the year in question, but often such data are not readily available, and consumption numbers are therefore used instead as best estimates. As a default, current consumption can be used. In cases where the consumption pattern is changing rapidly, consumption numbers from previous years (an average product life-time earlier) may be preferred, if available. For a number of products, disposal takes place some (or many) years after it was purchased (consumed).

Use elemental mercury basis for compounds

148. For sub-categories where mercury compounds are applied, calculations should be based on activity rates and input factors converted to elemental mercury content. For this conversion, data on atomic weights for the compound(s) in question versus atomic weight for elemental mercury should be applied, as shown in equation 3:

EQUATION 3:

= * # of Hg atoms in compound molecule * atomic weight of Hg

Content of Hg	**Weight of Hg-compound**	**(atomic weight of compound molecule)**

Notes: "#" means number.

149. As an example, the content of elemental mercury in 1 kg of the compound diphenylmercury (molecular formula $C_{12}H_{10}Hg$) can be calculated as follows:

$$\text{Content of Hg} = \frac{1\ \text{kg}}{C_{12}H_{10}Hg} * \frac{1 * 201\ ^{\text{g Hg}}/\text{mol}}{(12 * 12.0 + 10 * 1.01 + 1 * 201)\ ^{\text{g compound}}/\text{mol})} = {\sim}0.566\ \text{kg Hg}$$

150. Atomic weight can be found in good versions of the Periodic System, and molecular formulas must be sought in chemical handbooks or on relevant Internet sites such as http://www.chemfinder.com and http://www.inchem.org/ , public product registers such as http://www.spin2000.net , or chemical suppliers' sites such as http://www.sigmaaldrich.com .

4.4.3 Choice of mercury input factors

151. As mentioned above, the mercury input factor is simply defined as the mercury content (for example in gram Hg) per unit of feed material processed or product produced (for example metric ton or piece) as relevant for the individual source type. However, as described in sections 4.4.1 and 4.4.2 above, the input factors for sub-categories with more than one life cycle phase are a bit more complicated. Nonetheless, examples of mercury inputs to each release source type are - to the extent data has been available - presented in the source description sections in chapter 5. The examples are derived from easily available literature, and reflect conditions prevailing at the place and the time they were observed. In chapter 5, time and origin of the data is generally described along with the data given.

152. It is important to note that, for certain source sub-categories, the mercury input factors change over time. Significant examples of this are consumer products that over recent years have been subject to a regulatory pressure towards reduction - or elimination - of mercury content, such as batteries and light sources.

153. Similarly, the mercury input factors vary with geography. Changes in mercury content in products have not happened at the same speed in all regions of the world. Also, for natural raw materials - including fuels - mercury concentrations vary considerably with geographical location due to differences in geology and, for some sources, also due to previous anthropogenic mercury deposition loads.

154. Thus, the choice of mercury input factors may have significant effects on the release estimates calculated. Some recommendations with regards to choosing mercury input factors include:

- For quick, rough first estimates of mercury releases for a sub-category, the default input factors as presented in chapter 5 may be used; unless the default input factors clearly do not reflect the prevailing conditions. **It should be noted that, as described in section 4.1.1, the default factors defined in this draft Toolkit are preliminary and subject to future revisions.**

- In cases where a mercury input example factor is given that is judged to reflect the prevailing conditions better than the default input factor(s), this can be used for the release calculations. The same is the case for sub-categories for which no default distribution factors are presented in this Toolkit.

- Where your own well-documented, valid mercury input data are available, or can be obtained given available resources, their use in the inventory calculations is highly recommended instead of the default, or example, factors.

- In all cases, an input factor should be chosen that seems to best represent the sub-category under investigation. Also, the input factors used and their background should be explicitly noted in the inventory report. This will facilitate later updating of the inventory, enable external evaluation of the inventory and enhance comparability between inventories.

155. Whatever input factors (as well as other data) are chosen, it may be appropriate to review and/or confirm these factors/data for local/national conditions before major decisions are taken on implementation of mitigation initiatives.

156. In order to assist users of the Toolkit to estimate the releases from individual source sub-categories, advice on main source specific data is given under a separate sub-heading for each sub-category described in chapter 5.

4.4.4 Choice of output distribution factors

157. As mentioned above, output distribution factors are the relative shares of the **inputs** that follow the output pathways relevant in the individual case. Examples of output distribution factors for each of the mercury release source types are - to the extent data has been available - described in chapter 5. Like for input factors, these examples are derived from easily available literature, and reflect conditions prevailing at the place and the time they were observed. In chapter 5, time and origin of data are generally described along with the data given.

158. Recalling from section 4.1.1 above, the output pathways include:

- Direct releases to the atmosphere (air);
- Direct releases to aquatic environments (water);
- Direct releases to land (terrestrial environment, including ground water);
- Flows of mercury as an impurity in marketed products (for example gypsum wallboard produced from solid residues from flue gas cleaning on coal fired power plants);
- Flows of mercury to the public waste water treatment system;
- Flows of mercury to the general waste treatment system;
- Flows of mercury to sectors specific waste treatment or disposal systems.

  The principles applied in this "output pathway" vary between the sectors; it may for example involve separate collection and recycling, special safe deposition for high concentration mercury waste, or use of low concentration residues in road construction or other similar activities. To distinguish such disposal activities from uncontrolled "direct releases to land", the first mentioned should be characterized by an element of evaluation by risk assessments or informed acceptance from the authorities. Knowledge of the actual treatment or disposal taking place should always be noted in the developed inventory reports.

159. It should be noted that uncontrolled, informal or illegal deposition or incineration of waste on manufacturing sites or other places, with no evaluated mercury retention, is considered as direct releases to land, atmosphere and water, as relevant.

160. Note also that in the source description sections, a distinction between direct release to water and releases to the waste water system is not made. This is because the distribution between these two pathways is so variable among countries and local conditions that it is difficult to state anything general about it in a global perspective. When performing the inventory, it must therefore be noted for each source quantified, if the water releases are discharged directly, or to the waste water system. For some countries it may not be relevant, or it may be complicated to make the distinction between direct

releases to water, and releases to waste water treatment. In such cases they can be treated as one output pathway.

161. Marketing products and materials with intentional mercury contents is not considered a release pathway in the Toolkit context. Marketed mercury amounts with such products and materials are however dealt with extensively in the source description sections (Chapter 5), and must also be quantified in the inventory in order to estimate mercury releases to the environment. Examples of such products and materials are mercury thermometers, batteries and metallic mercury.

General key factors for the distribution of mercury outputs

162. For **point sources** like coal combustion, waste incineration and non-ferrous metal production, key aspects in the distribution of outputs are often the emission reduction systems applied on the point source. The mercury retention efficiency and other factors vary extensively depending upon the emission reduction devices used and how well they are functioning.

163. For manufacturing facilities such as mercury-cell chlor-alkali plants, mercury thermometer factories and battery production facilities, the magnitude of the mercury releases are very dependent on how well a facility incorporates prevention measures, advanced clean-up measures, proper operations, and various other work practices to minimize leaks, spills, and other non-specific mercury releases, or fugitive releases. For this Toolkit this concept will be called the “workplace procedures” for mercury.

164. Good workplace procedures could include, among others, the following: production takes place in closed units (rather than open units); equipment is well maintained to prevent mercury losses; the processes are monitored closely and often for mercury leaks so that leaks are detected early; detected leaks are fixed immediately using proper techniques; mercury spills are carefully collected; careful recycling of mercury wastes and losses is applied; and procedures for safe handling and storage of mercury feedstock and wastes exist, are well-described and followed in practice.

165. These source types may also employ release reduction systems that are somewhat similar to systems used on “point sources”, such as filters for the production room exhaust ventilation system (rather than being vented directly to air without being filtered); and mercury content in process water are carefully precipitated and retained in filters (rather than being directly released to sewer system). These source types also may have process vents that can be controlled with more classic end-of-pipe controls such as scrubbers, carbon filters, and retorts.

166. For **consumer products with intentional use of mercury**, the disposal phase is often important for the distribution of outputs to receiving media. Disposal habits and waste management systems vary greatly between countries and sometimes even localities. Important parameters include: The extent to which waste collecting systems exist, are well functioning, and controlled by environmental authorities; and the extent to which mercury-bearing wastes are collected and treated separately, and which waste treatments techniques are applied for the different waste streams.

167. Thus, output distribution factors may vary extensively between countries and even between localities and individual point sources. Therefore, selection of the most appropriate output distribution factors is crucial for the accurate quantification of mercury releases.

168. For the choice of output distribution factors, the recommendations given in section 4.4.3 for mercury input factors also apply.

4.4.5 Gathering of data

169. In the following sections, some basic guidance is given on the gathering of the different data types needed for the inventory. It should be emphasized, however, that data gathering is not limited to this step of the procedure, but may be necessary throughout the process of developing a mercury inventory.

Existing descriptions of mercury release sources

170. As a first activity in the collection of data, make sure to identify and collect any existing partial inventories or descriptions of mercury sources in the country. This could for example be existing dioxins and furans inventories, inventories of local areas, inventories of certain industry sectors, or selected statistics on mercury releases.

Activity rate data

171. Main data sources are national trade and production statistics, economic statistics, energy statistics, labour statistics, international statistics, etc. They will vary in accuracy.

172. Often customs-derived statistics provide relatively good estimates. Customs departments are an important source of information because all chemicals and articles containing mercury that are used as raw materials in different activities are usually registered at the import phase, using custom tariff or custom nomenclature. If a full list of items containing mercury derived from activities in the country is provided to customs, or to statistical offices administering such statistics, the relevant quantities of raw material and products can be sorted from the registration system.

173. Many countries have adopted the Harmonized Commodity Description and Coding System (HS) as the tariff nomenclature system in their custom system. The HS is an internationally standardized system of names and numbers for classifying traded products in countries, developed and maintained by the World Customs Organization (WCO) (formerly the Customs Co-operation Council), an independent intergovernmental organization with over 170 member countries based in Brussels, Belgium. The HS is a six-digit nomenclature. Individual countries may add code numbers, extending to eight or ten digits for customs and for export purposes. However, countries that have adopted the Harmonized System are not permitted to alter in any way the descriptions associated to the first six digits.

174. The technical annex in Section 8.1 provides a list with HS codes for substances and raw material potentially containing mercury. It may be useful for the analysis of customs information to determine if the HS is adopted in the country and if it is adopted, to use this list as a basis for the investigation in the customs system. Countries may consider additional raw materials, according to their specific activities identified as potential sources of mercury releases. Care should be taken with data on commodities with small trade numbers as they are often more vulnerable to accidental misreporting (and yet may have significance for the mercury inventory).

175. As for chemicals substances with mercury contents, the technical annex in Section 8.2 provides a list of CAS numbers for such chemicals. The list may be helpful in the communication with companies and other stakeholders as regards the usage of mercury compounds.

176. Other activity rate data sources are industry and trade associations and sector institutes. Data from these organizations can be very helpful, however it may be appropriate to cross check these data with independent data, if feasible. Confident relationships between environmental authorities, other institutions performing inventories and the private sector is quite advantageous in this type of work, as it often yields much important information that perhaps cannot be obtained from other sources.

177. Information on public waste management systems is perhaps available from the authorities in charge of waste handling, or otherwise from the public or private companies performing waste collection and treatment.

Mercury input factors

178. Besides data given here in the Toolkit, in existing partial inventories and in other literature, again it is often useful to contact industry and trade associations, as well individual lead companies and research institutions. For raw materials and fuels with mercury impurities, it may be useful to request analyses of mercury content in the materials consumed, if possible. Sometimes such data may already exist with the stakeholders or their material suppliers.

179. For public handling of general and hazardous waste, information on specific content of mercury in waste fractions is rare. The best ways of estimating mercury inputs to waste are mercury inventories on the waste sources (products etc.), as described in this Toolkit, and - if available - data on mercury content in all the outputs from waste incineration. Companies collecting hazardous waste may sometimes have "hands on" indicative information, or even statistics, on what types and amounts of mercury waste they have collected. This may be useful information in the identification of which mercury waste type are currently dominating the flow etc.

Output distribution data

180. As mentioned earlier, the distribution of mercury outputs from production/manufacturing facilities may be very vulnerable to individual process configurations and conditions. Therefore, facility-specific data are often needed to establish a more precise picture of the output/release situation. This also applies for sector specific waste deposits.

181. Such data may in part be retrievable from existing partial inventories (if any), local operating and permitting records for industries, administered by the local authorities. Often, it may also be necessary to request data from the industry companies themselves.

182. Data on mercury content in the outputs/releases from waste incineration must often be requested from the waste incineration plants individually. Such data can sometimes help estimate mercury content in deposited waste of the same character.

183. Obtaining mercury data is analytically challenging. Locally obtained data should be used only if it is of adequate quality and is representative and trustworthy. This process includes carefully following the way the data was generated. Application of standard methods for sampling and analysis, proven laboratory experience and good documentation are pre-requisites for valid data. If these requirements are not met, then it is probably preferable to use the default release factors as provided by the Toolkit rather than own measured data of questionable quality. When using emission factors other than those provided in the Toolkit to estimate annual releases, this should be highlighted. Note that extrapolating one or two source test data that may not be representative of facilities annual operations may not yield quality data. It is then needed to use the best available data to estimate releases using monitoring, mass balance, emission factors and/or engineering calculations.

Incomplete data

184. There will be data gaps in all emission inventories. Incomplete information will result in the need to make assumptions about those sources where no specific information could be collected. Approaches will vary, but all assumptions should be transparent in order to, among others, facilitate estimation for future data years and re-evaluation in the light of improved information. Two approaches are presented:

- A “middle ground” approach assumes that missing data is distributed similarly to available data (*e.g.,* high *vs.* low emitters or state of compliance with technology requirements). For example, with this approach an average (mean) or median factor may be used to estimate emissions for plants with missing data.

- A “conservative” approach is based on a decision that it is better to overestimate emissions rather than underestimate emissions for sources with missing data. Therefore, under a conservative approach missing sources are assumed to be similar to the higher emitters. For example, the highest (or a high) emission factor in the database or the highest emission factor of those plants providing information could be used to generate a conservative estimate.

185. Assumptions should be based on best judgment making use of available data, presented clearly and reviewed externally. In some cases, additional data may be available from trade associations, equipment suppliers, regulators or experts on the industry.

Report data uncertainty

186. In most cases, precise data are hard to get or non-existent, or it may be more appropriate to report data as intervals for other reasons, for example due to changes in a relevant time period. Generally, it is recommended to use relevant data intervals, and report them. Alternatively, the "middle ground estimate" or conservative estimate (see above) may be reported accompanied by quantified or estimated uncertainty of the data, for example as "15 kg Hg/year ± 5 kg".

Report data origin

187. In all cases, it is important to report the year and the origin of data.

188. Internal records of all data, including year, location and name of data suppliers, should be kept, for possible future internal verification.

Confidential data

189. In a detailed inventory, it may often be necessary to request data from individual companies and institutions that do not want certain information to be available to the public. If necessary, such data can be aggregated and processed to a degree where they do not reveal industry secrets, and the data sources should be held anonymous and presented in reporting as "industry sources", "suppliers", "producers" etc., as relevant. Data sets submitted to receivers where they may be made publicly available, including UN Environment Chemicals, should be presented in such a way that specific, confidential data can not be disclosed.

190. Internal record of the detailed, confidential data, including year, location and name of data suppliers, should be kept (following proper confidential business information storage procedures) for possible future internal verification.

4.4.6 Balancing inputs and outputs of mercury for control of quantifications

191. For some mercury source sub-categories, it may be possible to crosscheck the mercury inventory when both inputs to the society and outputs/releases are measured/quantified.

192. This may, for example, be the case in countries where controlled waste incineration is significant or even dominant. There, measurements of mercury concentrations in exhaust air, bottom ash/slag and residues from flue gas cleaning may form the basis for estimates of total mercury content in the incoming wastes. These estimates can then be compared with the sum of the estimated amounts of mercury that lead to waste from the different mercury-bearing products. In this equation, it should be remembered that also high volume waste with very low trace concentrations of mercury contributes to the total mercury input. For consumer waste, however, products with intentional use of mercury will often dominate this balance.

193. Such balances have been performed in a limited number of countries, often in the form of a so-called substance flow analysis/assessment ("SFA"), where a total mapping of mercury flows in the society (and to the environment) is attempted. For references to such assessments, see the Global Mercury Assessment, chapter 6 (UNEP, 2002).

4.4.7 Examples of calculations of releases from various source types

194. In the section below, three hypothetical examples are given, illustrating how mercury releases for a coal-fired power plant in country ABC, for a municipal waste incineration facility in country XX and for use and disposal of mercury-containing batteries in country XYZ might be estimated, using the information provided in this Toolkit and some selected inpt and output distribution factors.

4.4.7.1 Example 1 - Coal-fired power plant in hypothetical country ABC

A. Plant characteristics, available data, and other considerations

- Located in country ABC, somewhere in South America;
- General type of combustion unit: pulverized-coal-fired unit;
- Type of fuel burned: bituminous coal from Brazil (no other fuel types are burned);
- Control devices: cold-side ESP for PM control;
- Coal is pre-washed using similar technique as that used in the USA, and the waste water discharge from coal-cleaning is sent to an on-site sewage treatment plant;
- Plant consumes 1 million metric tons of coal per year;
- No site specific data available for mercury concentration in coal used at plant, control device efficiency, or efficiency of coal cleaning;
- Flue gas residues are deposited to normal landfill and none of them are converted to marketable products;
- Two phases of the life cycle will be included in assessment: 1) coal pre-wash; and 2) coal combustion. (Note: As described in section 5.1.1, coal burning facilities can be evaluated using only one phase, especially if coal pre-wash is not included. See section 5.1.1 for more details.

B. Determination of activity rate, input factors, and output distribution factors for the different lifecycle phases

I. Phase 1 – Coal pre-wash

a) Determination of activity rate, input factors, and output distribution factors for Phase 1 – Coal pre-wash:

Activity rate = 1,000,000 metric tons coal per year;

Input factor: Site specific data cannot be gathered due to resource limitations. Therefore, it is decided that data in Table 5-4 can be used as an estimate of mercury concentration in the coal. Table 5-4 suggests a mean concentration of 0.19 mg mercury per kg coal for bituminous coal from Brazil. This value is judged to be the best choice for input factor, thus, the input factor = 0.19 mg Hg/kg coal.

Total mercury input before coal pre-wash can thus be calculated as follows:

	Total mercury input before coal pre-wash		*Activity rate*		*Input factor*		*Conversion factor*		*Conversion factor*		**190 kg Hg**
(1)		=	1,000,000 metric tons of coal	*	0.19 mg Hg/kg coal	*	1000 kg coal/metric tons coal	*	1 kg Hg/1,000,000 mg Hg	=	

Distribution factors: After reviewing information in section 5.1.1 and other reports, the mercury reduction from coal cleaning is judged to be similar to that used in USA, therefore, we assume 21% removal during pre-cleaning (the estimate from US EPA, 1997a). Also, all of the mercury removed during this process is assumed to flow with wastewater to a special on-site sewage treatment plant, assumed here to retain 100% of the mercury in the water and then convert into solid residues.

Therefore, distribution factors for coal pre-wash to the various pathways are as follows:

Water =	0.0
Air =	0.0
Land =	0.0
Products =	0.0

General Waste (residue from waste water treatment) = 0.21 (i.e. 21% Hg removed by pre-cleaning)

b) Estimation of mercury releases to each pathway for Phase 1 - Coal pre-wash:

Using the calculated total Hg input before pre-wash and the distribution factor above for pre-wash, the releases can be calculated as follows:

(2)	**Releases to general waste landfills from pre-wash process**	=	*Total Hg input*	*	*Distribution factor to residue from waste water treatment*	=	**39.9 kg Hg**	=	*Rounded up to* **40 kg Hg**
			190 kg Hg		0.21				

Thus, 40 kg mercury is estimated to be released during coal washing, with 100% of this amount assumed to go to general waste landfills (residue from waste water treatment).

II. Phase 2 – Coal Combustion

a) Determination of activity rate, input factors, and output distribution factors for Phase 2 – Coal Combustion:

Activity rate = 1,000,000 metric tons coal;

Input factor: 21% of mercury was removed during coal pre-cleaning, therefore 79% (i.e., 100% – 21%) of the mercury remains in the coal. So, the mercury concentration in the coal entering combustion (or new input factor after coal pre-wash) can be estimated as follows:

(3)	**New input factor after coal pre-wash**	=	*Input factor before coal pre-wash*	*	*% Hg remaining in coal after pre-wash*	=	**0.15 mg Hg/kg coal**
			0.19 mg Hg/kg coal		0.79		

Total mercury input to coal combustion after coal pre-wash can thus be calculated as follows:

(4)	**Total mercury input to coal combustion**	=	*Activity rate*	*	*Input factor*	*	*Conversion factor*	*	*Conversion factor*	=	**150 kg Hg**
			1,000,000 metric tons of coal		0.15 mg Hg/kg coal		1000 kg coal/metric tons coal		1 kg Hg/1.000,000 mg Hg		

Distribution factors: In Table 5-5, US EPA reports a mean removal efficiency of 36% for cold side ESPs, based on data from 7 plants in the USA. A suggested draft default value of 0.1 (or 10%) removal is presented for boilers with a "general ESP". After considering options, it is decided that the best estimate could be calculated using data from the USA for this hypothetical facility.

Based on review of the description and data presented in section 5.1.1, it is assumed that 36% of mercury input to the combustion unit is released with flue gas cleaning residues deposited on general waste landfills, and the remaining 64% is released to atmosphere.

Therefore, distribution factors for coal combustion to the various pathways are as follows:

Air = 0.64 (i.e., 64% Hg released to air)
General Waste (flue gas residues) = 0.36 (i.e., 36% Hg to residues)
Water = 0.0
Land = 0.0
Sector Specific Wastes = 0.0

b) Estimation of mercury releases to each pathway from Phase 2 - Coal combustion:

Using the total Hg input after coal pre-wash and the distribution factors above, the releases can be calculated as follows:

(5)	**Releases to air from coal combustion**	=	*Total Hg input*	*	*Distribution factor to air*	=	**96 kg Hg**
			150 kg Hg		0.64		

(6)	**Releases to general waste landfills from coal combustion**	=	*Total Hg input*	*	*Distribution factor to flue gas residues*	=	**54 kg Hg**
			150 kg Hg		*0.36*		

Thus, 96 kg mercury is estimated released to air and 54 kg to general waste landfills (as flue gas residues) from coal combustion after coal pre-wash at this facility.

C. Summary results – Total estimated releases to all pathways for all phases

Based on the above, total estimated releases to all pathways for all phases are as follows:

Air = 96 kg Hg;
Water = 0;
General waste landfills (flue gas residues) = 54 kg Hg;
General waste landfills (waste water treatment) = 40 kg Hg;
Sector specific wastes treatment = 0;
Products = 0;
Total releases to all media/pathways = 190 kg Hg.

D. Alternative approaches

Two alternative, but similar approaches that can be used and which result in the same estimates are described below.

a) Alternative #1:

This alternative approach follows same process as above, except that for phase 2, instead of recalculating the concentration of mercury in coal after pre-wash, the total amount of mercury remaining in the coal entering the combustion unit is calculated, as follows:

(7)	**Total Hg input entering combustion unit after pre-wash**	=	*Total Hg input before coal pre-wash*	-	*Hg removed by coal pre-wash*	=	**150 kg Hg**
			190 kg Hg		40 kg Hg		

Then, releases to each pathway from combustion can be calculated in the same way as in calculation (5) and (6) shown above, using the distribution factors for coal combustion after pre-wash.

b) Alternative #2:

Only one phase is included in this alternative approach, combining pre-wash and combustion into one single phase. Using this approach, the input factor would be 0.19 mg Hg/kg coal, activity rate would be 1,000,000 metric tons coal, and the distribution factors would be adjusted to account for removal during coal cleaning as follows:

Distribution factors for alternative approach #2 can be calculated, as follows:

General waste landfills (residues from waste water cleaning) =0.21
(due to 21% Hg removal from coal pre-wash);

As 21% of the mercury has been removed, then 79% (100% – 21%) remains in the coal entering the boiler, therefore the other distribution factors are:

Air = 0.64 * 0.79 = 0.51; (i.e., 64% of the mercury remains in the coal entering the combustion unit, after pre-wash);

Residues (general wastes) = 0.36 * 0.79 = 0.28; (i.e., 36% of the mercury remains in the coal entering the combustion unit, after pre-wash);

Water = 0.0;
Land = 0.0;
Products = 0.0;

Then, releases to each pathway from coal combustion can be calculated in the same way as above, using the distribution factors above, as follows:

(8)	**Releases to general waste landfills from coal pre-wash**	=	*Total Hg input*	*	*Distribution factor to general waste landfills*	=	**39.9 kg Hg**
			190 kg Hg		0.21		

(9)	**Releases to air from coal combustion after pre-wash**	=	*Total Hg input*	*	*Distribution factor to air*	=	**96.9 kg Hg**
			190 kg Hg		0.51		

(10)	**Releases to general waste from flue gas residues**	=	*Total Hg input*	*	*Distribution factor to general waste*	=	**53.2 kg Hg**
			190 kg Hg		0.28		

E. Summary table for total mercury releases from the coal-fired power plant in country ABC

Below find a table summarizing the estimated mercury releases for the example under consideration, using the table suggested in section 4.4.1.

Table 4-16 Example 1 – Coal Combustion - Summary of estimated mercury releases for country ABC

Coal Combustion (power plant)	**Life Cycle phase**		**Sum of releases to pathway from all phases of life-cycle**
	Coal pre-wash	**Coal combustion**	
Activity rate	1,000,000 metric tons coal	1,000,000 metric tons	-
Input factor for phase	0.19 mg Hg/kg coal	0.15 mg Hg/kg coal	-
Calculated input to phase	190 kg Hg	150 kg Hg	-
Output distribution factors for:			NA
- Air	0.0	0.64	NA
- Water	0.0	0.0	NA
- Land	0.0	0.0	NA
- Products	0.0	0.0	NA
- General waste treatment (including landfills)	0.21	0.36	NA
- Sector specific waste treatment	0.0	0.0	NA
Calculated outputs/releases to:	0.0		
- Air	0.0	96 kg Hg	96 kg Hg
- Water	0.0	0.0	0.0
- Land	0.0	0.0	0.0
- Products	0.0	0.0	0.0
- General waste treatment	40 kg Hg	54 kg Hg	94 kg Hg
- Sector specific waste treatment	0.0	0.0	0.0

Notes: NA – not applicable.

4.4.7.2 Example 2 - Municipal waste incineration facility in hypothetical country XX

A. Plant characteristics and site specific data

- Located in country XX, which is a developing country in Pacific Asia;
- 100,000 metric tons general waste incinerated each year;
- The facility has a spray dryer (SD) and an ESP for pollutant emission control;
- Type of burner is a "mass burn" unit;
- No site specific data are available on: 1) the specific content of the type of waste incinerated; and 2) control efficiency of the SD and ESP;
- Flue gas residues are deposited in normal landfill;
- It is determined that 1 phase of life cycle should be included (i.e., waste combustion);
- Given the uncertainties and data limitations, intervals will be used for input values and output distribution factors.

B. Determination of activity rate, input factors, and output distribution factors

Activity rate = 100,000 metric tons waste per year;

Input factor: Site-specific data is not available. Therefore, the information in chapter 5 of the Toolkit is reviewed, along with general information about the types of waste disposed in country XX, the types and amounts of waste that may contain mercury, and how that waste might compare with other countries where data are available (such as the USA). After careful consideration of available information, the waste is assumed to contain about 3 - 5 ppm mercury (4 ppm was the typical value in the USA in 1989). Thus, the input factor for this municipal waste incineration facility is in the range of 3-5 ppm (or 3-5 mg Hg/kg) mercury in the waste.

Total mercury input to municipal waste incineration can thus be calculated as follows:

Lower-end estimate -

(11)	**Total Hg input to municipal waste incinerator**	=	*Activity rate*	*	*Input factor*	*	*Conversion factor*	*	*Conversion factor*	=	**300 kg Hg**
			100,000 metric tons of waste		3 mg Hg/kg waste		1000 kg waste/metric ton waste		1 kg Hg/1.000,000 mg Hg		

Upper-end estimate -

(12)	**Total Hg input to municipal waste incinerator**	=	*Activity rate*	*	*Input factor*	*	*Conversion factor*	*	*Conversion factor*	=	**500 kg Hg**
			100,000 metric tons of waste		5 mg Hg/kg waste		1000 kg waste/metric ton waste		1 kg Hg/1.000,000 mg Hg		

Distribution factors: The following is considered when establishing distribution factors:

Data on control efficiency of the SD and ESP were not identified. The mercury reduction from the spray dryer and ESP is assumed to be in the range of 35% - 85% (i.e. 35 - 85 % of the mercury is captured by control device and the rest ends up in the flue gas residue), based on information from similar facilities in a neighbouring country.

Therefore, lower-end and upper-end estimates for distribution factors for releases to all pathways are as follows:

	Lower-end estimate	**Upper-end estimate**
Air =	0.15	0.65
Flue gas residues (general waste) =	0.85	0.35
Water =	0.0	0.0
Land =	0.0	0.0
Sector Specific Waste =	0.0	0.0

C. Calculation of estimated mercury releases to each pathway (or media)

Using the calculated lower and upper end ranges for total Hg input and distribution factors above, the releases from the municipal waste incineration plant to all pathways can be calculated as follows:

Lower-end estimate -

(13)	**Releases to air from municipal waste incineration**	=	*Total Hg input*	*	*Distribution factor to air*	=	**45 kg Hg**
			300 kg Hg		0.15		

(14)	**Releases to general waste landfills from municipal waste incineration**	=	*Total Hg input*	*	*Distribution factor to flue gas solid residues*	=	**255 kg Hg**
			300 kg Hg		0.85		

Upper-end estimate -

(15)	**Releases to air from municipal waste incineration**	=	*Total Hg input*	*	*Distribution factor to air*	=	**325 kg Hg**
			500 kg Hg		0.65		

(16)	**Releases to general waste landfills from municipal waste incineration**	=	*Total Hg input* 500 kg Hg	*	*Distribution factor to flue gas solid residues* 0.35	=	**175 kg Hg**

D. Summary results - Estimated release intervals to all pathways

Based on the above, total estimated releases to all pathways for all phases are as follows:

Air =	45 to 325 kg Hg
Waste water =	0
General waste landfills (flue gas residues) =	175 to 255 kg Hg
Sector specific waste treatment =	0
Products =	0
Total releases to all media/pathways =	**300 to 500 kg Hg.**

E. Summary table for total mercury releases from a municipal waste incinerator in country XX

Below find a table summarizing the estimated mercury releases for the example under consideration, using the table suggested in section 4.4.1.

Table 4-17 Example 2 – Waste Combustion - Summary of estimated mercury releases in country XX

Coal Combustion (power plant)	**Life Cycle phase - Waste Combustion**	**Sum of releases to pathway from all phases of life-cycle**
Activity rate	100,000 metric tons waste	-
Input factor for phase	3-5 mg Hg/kg waste	-
Calculated input to phase	300 to 500 kg Hg	-
Output distribution factors for:		NA
- Air	0.15 to 0.65	NA
- Water(/waste water)	0.0	NA
- Land	0.0	NA
- Products	0.0	NA
- General waste treatment (including landfills)	0.35 to 0.85	NA
- Sector specific waste treatment	0.0	NA
Calculated outputs/releases to:	0.0	
- Air	45 to 325 kg Hg	45 to 325 kg Hg
- Water (/waste water)	0.0	0.0
- Land	0.0	0.0
- Products	0.0	0.0
- General waste treatment	175 to 255 kg Hg	175 to 255 kg Hg
- Sector specific waste treatment	0.0	0.0

Notes: NA – not applicable.

4.4.7.3 Example 3 - Batteries with mercury for hypothetical country XYZ

A. Relevant information and country specific data

- A CIS-country with economy in transition, located in the Commonwealth of Independent States;
- One battery production plant located in the country produces 10 metric tons of mercury oxide batteries per year, with the following characteristics:
  - The production room air is ventilated to a fabric filter (FF) and a charcoal filter;

  - The charcoal filter is regularly replaced and the "spent filters" are treated as hazardous waste and deposited in special hazardous waste management locations according to Federal regulations;
  - The FF residues are disposed in normal landfill;
- During the last 4-5 years, the Plant owner (Company ABC) exported an average of 7 metric tons per year of the produced mercury oxide batteries to various countries around the world, and the remaining 3 metric tons of the produced batteries have been marketed and used within the country XYZ;
- Based on data/information presented in the Toolkit, it is assumed that these mercury oxide batteries contain about 32% mercury by wet weight;
- The facility reports purchasing about 2.0 metric tons of elemental mercury and 1.7 metric tons of mercuric oxide per year for input into the production process;
- No other site specific data are available for mercury capture by the FF or charcoal filter or other factors;
- No other batteries containing mercury are produced in country XYZ;
- Over the past decade or so, about 15 metric tons of other types of mercury-containing batteries (alkaline, silver oxide and zinc/air type batteries) have been imported and used in country XYZ each year;
- Based on data/information presented in the Toolkit, it is estimated that the alkaline, silver oxide and zinc/air type batteries contain about 1% mercury by wet weight;
- Available limited information indicates that about 5-10% of the spent batteries are collected separately and sent to special sector specific treatment facilities;
- About 80% are disposed of in general wastes collection systems;
- The remaining 10-15% is disposed of informally.

B. Determination of activity rate, input factors, and output distribution factors for the different life-cycle phases

I. Phase 1 - Production

a) Determination of activity rate, input factors, and output distribution factors for Phase 1 - Production:

Activity rate = 10 metric tons batteries produced per year;

Input factor: Based on information above, the total amount of batteries produced each year (i.e., 10 metric tons) contains about 3.2 metric tons (i.e., 32 %) of mercury. Half of this mercury (1.6 metric tons) is assumed to be elemental mercury and the other half (1.6 metric tons) is assumed to be mercuric oxide. The company also reports purchasing 2.0 metric tons of elemental mercury and mercuric oxide equalling an amount of elemental mercury of 1.7 metric tons of each year for input, or a total of 3.7 metric tons mercury. Therefore, about 0.5 metric tons (i.e., 3.7 – 3.2 = 0.5 metric tons mercury), or 13.5%, of the total mercury input is calculated to be "lost" during production, and 0.4 metric tons of the losses are assumed to be in elemental form and 0.1 metric tons in mercuric oxide form.

Based on this information above, the input factor is determined to be 0.5 metric tons mercury lost per 10 metric tons batteries produced or 0.05 metric tons mercury per metric ton batteries produced;

Total mercury input from battery production can thus be calculated as follows:

(17)	**Total mercury lost per year from battery production**	=	*Activity rate* 10 metric tons of batteries produced per year	*	*Input factor* 0.05 metric tons Hg lost/metric ton batteries produced	=	**0.5 metric tons Hg**

Distribution factors:

It is estimated that 0.1 metric tons (or 20%) of the total mercury releases during production are lost as mercuric oxide. All of this mercuric oxide release is assumed to be losses to air in the production room. Also, most (90%) of this mercuric oxide is assumed captured by the FF. Therefore, 18% (i.e., 0.20 * 0.90 = 0.18) is estimated released to FF residues (and ends-up in a landfill) and 2% (i.e., 0.20 * 0.10 = 0.02) is released to atmosphere through exhaust gas stack. Note: some of the mercury could be released to water or land, but no data on this issue is available, so it is assumed it all goes to air.

We estimate 0.4 metric tons (80%) of the mercury releases are released in production room air in elemental mercury form. We assume that most of this mercury (90%) is captured by the charcoal filter. Therefore, we calculate that 72% (0.80 * 0.90 = 0.72) of the mercury releases during production end-up in charcoal filter wastes (and is treated as sector specific regulated hazardous wastes) and that 8 % (0.80 * 0.10 = 0.08) is released to the atmosphere through exhaust gas stack.

Therefore, the following distribution factors for <u>production</u> can be developed:

Air =	0.10 (0.02 + 0.08);
General waste (landfill) =	0.18;
Sector specific special waste treatment =	0.72;
Water =	0.0;
Products =	0.0;
Land =	0.0;

b) Calculated outputs for Phase 1 - Production:

Using the calculated total Hg input from production and the distribution factors above, the releases from production of batteries can be calculated as follows:

(18)	**Releases to air from battery production**	=	*Total Hg input* 0.5 metric tons Hg	*	*Distribution factor* 0.10	=	**0.05 metric tons Hg**
(19)	**Releases to general waste landfills from battery production**	=	*Total Hg input* 0.5 metric tons Hg	*	*Distribution factor* 0.18	=	**0.1 metric tons Hg**
(20)	**Releases to sector specific waste treatments from battery production**	=	*Total Hg input* 0.5 metric tons Hg	*	*Distribution factor* 0.72	=	**0.36 metric tons Hg**

II. Phase 2 - Use phase

a) Determination of activity rate, input factors, and output distribution factors for Phase 2 - Use:

Very limited release can be expected during use, therefore, releases from this phase can be considered negligible and we can move on to phase 3 (disposal).

III. Phase 3 - Disposal

a) Determination of activity rate, input factors, and output distribution factors for Phase 3 - Disposal:

Activity rate: About 3 metric tons of mercury oxide batteries consumed (and disposed) each year in country XYZ, plus 15 metric tons of other types of mercury-containing batteries (alkaline, silver oxide and zinc/air type batteries) consumed (and disposed) in country XYZ each year. As no data on disposed battery amounts are available, and consumption is considered quite stabile through a number of years, consumption data are used as an approximation for disposal data.

Input factors: Mercury oxide batteries contain 32% mercury and the other mercury-containing batteries listed above contain about 1% mercury. The input factors for the two types of batteries are thus 0.32 metric tons Hg/metric ton mercury oxide batteries disposed and 0.01 metric tons Hg/metric ton other Hg-containing batteries disposed, respectively.

Total mercury input from disposal of batteries can thus be calculated as follows:

			Activity rate		*Input factor*		*Activity rate*		*Input factor*		
(21)	**Total mercury input from disposal of batteries**	=	3 metric tons HgO batteries	*	0.32 metric tons Hg/metric ton HgO batteries disposed	+	15 metric tons other Hg-containing batteries	*	0.01 metric tons Hg/metric ton other Hg-containing batteries disposed	=	**1.11 metric tons Hg**

Distribution factors: As mentioned above, about 5-10% of batteries is collected separately and sent to special sector specific treatment facilities, about 80% is disposed of with general wastes, and 10-15% is disposed of informally.

Therefore, the following distribution factors for disposal can be developed:

Air = 0.0;
Sector specific special waste treatment = 0.10;
General wastes collection systems = 0.80;
Water = 0.0;
Land = 0.10 (disposed informally, assumed to be to land);

b) Calculated outputs for Phase 3 - Disposal:

Using the calculated total Hg input from disposal of batteries and the distribution factors above, the releases from disposal of batteries can be calculated as follows:

			Total Hg input		*Distribution factor*		
(22)	**Releases to sector specific waste treatments from battery disposal**	=	1.11 metric tons Hg	*	0.10	=	**0.1 metric tons Hg**

			Total Hg input		*Distribution factor*		
(23)	**Releases to general waste collection systems from battery disposal**	=	1.11 metric tons Hg	*	0.80	=	**0.9 metric tons Hg**

			Total Hg input		*Distribution factor*		
(24)	**Releases to land from informal battery disposal**	=	1.11 metric tons Hg	*	0.10	=	**0.1 metric tons Hg**

C. Summary results - Estimated release intervals to all pathways

Based on the above, total estimated releases to all pathways for all phases are as follows:

Air =	0.05 metric tons mercury;
General waste (landfills) =	1.0 metric tons mercury;
Sector specific waste treatment =	0.46 metric tons mercury;
Water =	0;
Products =	0;
Land =	0.1 metric tons mercury;
Total releases to all media/pathways =	**1.61 metric tons mercury.**

D. Summary table for total mercury releases from use and disposal of mercury-containing batteries in country XYZ

Below find a table summarizing the estimated mercury releases for the example under consideration, using the table suggested in section 4.4.1.

Table 4-18 Example 3 – Production and use of batteries containing mercury - Summary of estimated mercury releases in country XYZ

Batteries with Mercury in Country XYZ	**Life Cycle phase**		**Sum of releases to pathway from all phases of life-cycle**
	Production	**Disposal**	
Activity rate	10 metric tons batteries produced per year	3 metric tons of mercury oxide batteries and 15 metric tons of other types of batteries consumed	-
Input factor for phase	0.05 metric tons Hg per metric ton of batteries produced.	0.32 kg Hg released per kg mercuric oxide batteries disposed of, and 0.01 kg Hg released per kg of other types of batteries disposed	-
Calculated input to phase	0.5 metric tons Hg lost during production	1.11 metric tons Hg	-
Output distribution factors for phase:			NA
- Air	0.10	0.0	NA
- Water (/waste water)	0.0	0.0	NA
- Land	0.0	0.1	NA
- Products	0.0	0.0	NA
- General waste treatment (including landfills)	0.18	0.8	NA
- Sector specific waste treatment	0.72	0.1	NA
Calculated outputs/releases to:			
- Air	0.05 metric tons Hg	0.0	0.05 metric tons Hg
- Water (/waste water)	0.0	0.0	0.0
- Land	0.0	0.1 metric tons Hg	0.1 metric tons Hg
- Products	0.0	0.0	0.0
- General waste treatment	0.1 metric tons Hg	0.9 metric tons Hg	1.0 metric tons Hg
- Sector specific waste treatment	0.36 metric tons Hg	0.1 metric tons Hg	0.46 metric tons Hg

Notes: NA – not applicable.

4.5 Step 4: Presentation of the inventory

195. In the fourth and final step, the mercury inventory is compiled using the results generated in steps 1 through 3. A standardized reporting template is given in the Toolkit as a separate document on UN Environment's Toolkit web page, ready to fill your information into. Using this template is recommended in order to ensure that all sources are considered (even if they cannot be quantified), data gaps are apparent and inventories are comparable and transparent. The presentation of inventory data is critical and should also be harmonized to allow for meaningful comparisons from one country to another.

196. In this section, guidance on what a full inventory report should present is given first, in order to give an understanding of the basic elements. Thereafter, suggestions for the preparation of interim reporting, which can be useful during the inventory work, is presented.

197. The guidance provided here is intended to assist in the assembly of reports that contain the crucial outputs from the inventory projects in formats that are immediately useful for the intended audiences.

4.5.1 Key elements of the inventory

198. The full inventory report will identify the major activities and processes leading to mercury releases, in order to provide information on the nature and extent of processes linked to releases and to identify those processes for which there are important data gaps that should be addressed in the future. It will also address releases to air, water, and land, in products and residues, to the best extent possible while recognizing, as relevant, that there are significant deficiencies in the coverage and quality of data in some areas. Cases where no measured data or where no appropriate activity information (such as statistics) are available should be highlighted for follow-up.

199. The key elements that the inventory report should include are given below.

Executive summary

200. The section should give a very brief summary of main results, including:

- Introduction: Who made this inventory, when and why?
- Results and discussion: i) Key results presented in the executive summary table and selected charts from the calculation spreadsheet, and ii) a brief listing and discussion of the mercury release sub-categories contributing with the highest mercury releases, and the highest inputs of new mercury to society, respectively.
- Data gaps and recommendations for follow-up work.

Mercury release source types present

201. A table showing confirmed presence, confirmed absence or uncertainty, as relevant of the sourse sub-categories of the Toolkit (see the report template).

Summary of mercury inputs to society

202. A table and discussion presenting mercury inputs by sub-category. Mercury inputs to society should be understood here as the mercury amounts made available for potential releases through economic activity in the country. This includes mercury intentionally used in products such as thermometers, blood pressure gauges, fluorescent light bulbs, etc. It also includes mercury mobilised via extraction and use of raw materials which contains mercury in trace concentrations. For waste categories, the "inputs" are calculated to show the distribution of mercury in waste through the different waste treatment activities and calculate releases from these activities, though waste is not an original source of input mercury into society (except in case of waste import).

Summary of mercury releases

203. A table and discussion providing a summary of mercury releases from all source sub-categories present. The key mercury releases here are releases to air (the atmosphere), to water (marine and freshwater bodies, including via waste water systems), to land, to general waste, and to sector specific waste. An additional output pathway is by-products which designate mercury flows back into the market with by-products with mercury impurities.

Identified hot-spots of mercury contamination

204. A list of all mercury hot-spot sites identified in the country should be given in table format with short summary descriptions of the sites, based on available information.

Background data and inventory by source category

205. For each source sub-category, present data and their origin with explicit and detailed reference to data sources for each data set.

206. Describe calculations and approximations made. Including conversion of data to needed units, approximation calculations such as extrapolations to national level from representative data, etc.

207. Describe actual detailed data gaps and how these data were attempted sought.

References

208. Give full reference to all data sources in your report as specified in the reporting template.

Appendices - Inventory Level 2 calculation spreadsheet

209. Publish/submit the final Inventory Level 2 spreadsheet in Excel format (or PDF , if desired) along with the report. The calculation spreadsheet is a vital part of the documentation of the inventory.

210. Other very detailed background data can also be presented in appendices, as relevant.

4.5.2 Spreadsheet for calculating releases

211. To supplement this Toolkit, a separate Excel spreadsheet is available electronically, intended to facilitate the calculation of inputs and outputs of the different source categories. Further information on this spreadsheet is provided in section 9.2 of this Toolkit.

4.5.3 Suggestions for interim reporting

212. Early on in the process, an interim inventory can be used to:

- Invite comments and review on the initial stages of the study before extensive resources are committed to the project;
- Provide valuable initial comparative information at the national, regional and international level;
- Show the potential size of releases from the significant sub-categories; and
- Prioritize needs for further data gathering efforts.

213. The development of a mercury inventory on Inventory Level 1 of this Toolkit can be recommended, should an interim inventory be desired. Inventory Level 1 has simpler and more standardised procedures, and can thus be finalised with less resources. Should Inventory Level 1 not be used and you still wish to perform an interim inventory, please observe the following recommendations.

214. The establishment of an interim inventory can take place after the main and sub-category sources present in country (or region) have been identified and the activity statistics have been generated (or other indications of their magnitude), but before completion of detailed information gathering exercises.

215. The interim inventory is designed to illustrate the potential size of releases from identified processes and thus, for early priority setting. For each source, the resulting output will be a very rough indicator of the size of the mercury releases.

216. An interim inventory might contain the following information:

- Listing of all known sub-categories that are present in the country;
- Summary tables of activity statistics for each sub-category, especially those sub-categories that are expected to be significant within the country, and to the extent this information can be obtained without extensive use of resources. Also, short remarks of how this information was found or estimated should be included;
- Summary table showing the range of relevant default factors by sub-category, and the range of potential releases calculated with these default factors (activity rate multiplied by low and high-end input and distribution factors);
- Illustration of the potential ranges of releases shown as a bar chart for each sub-category based on default emission factors.

217. The interim report would indicate the sub-categories that are likely to be significant sources of mercury uses and releases in the country, and those sub-categories for which additional information is needed, and can be used as a guide to where to place most effort in the next stages of the inventory compilation, as needed.

5 Detailed descriptions of sources of mercury releases and mercury input and output factors

218. Please note that, as it is not expected that section 5 would be read in one go, the detailed source descriptions in each sub-section have been drafted as free-standing sections, thus entailing some duplication of text. This approach was chosen, in order to allow a reader to find all the information necessary for a specific source without having to cross-reference other sections for additional information.

219. Comments on how to make use of the information in section 5 to quantify mercury releases for a specific source are given in section 4.4.

220. The fastest way of steering quickly to individual source descriptions is by using the Table of Contents in the beginning of this report (in the Word format version).

5.1 Extraction and use of fuels/energy sources

221. This main category includes power stations, industrial furnaces and installations for providing space heating, which are fired with fossil fuels (including the co-combustion of up to 1/3 of waste), biogas including landfill gas, and bio-mass. It also includes the extraction of natural gas, mineral oil and other fossil fuels. The seven sub-categories within this main source category are shown in Table 5-1 below. The main pathways of mercury releases are air, water and waste/residues. Land may also be a release pathway in domestic heating and cooking, either using biomass (mostly wood) or fossil fuels, and from extraction of mineral oil. Moreover, releases to land can occur if contaminated residues are dumped directly on the ground (UNEP, 2003).

Table 5-1 Extraction and use of fuels/energy sources: sub-categories with main pathways of releases of mercury and recommended inventory approach

Chapter	Sub-category	Air	Water	Land	Product	Waste/ residue	Main inventory approach
5.1.1	Coal combustion in large power plants	**X**	x	x	x	**X**	PS
5.1.2	Other coal combustion	**X**		x	x	x	OW
5.1.3	Extraction, refining and use of mineral oil	**X**	**X**	x	x	x	OW/PS
5.1.4	Extraction, refining and use of natural gas	**X**	**X**	**X**	x	**X**	OW/PS
5.1.5	Extraction and use of other fossil fuels	**X**	x	x		x	OW
5.1.6	Biomass fired power and heat production	**X**	x	x		x	OW
5.1.7	Geothermal power production	**X**					PS

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

5.1.1 Coal combustion in large power plants

5.1.1.1 Sub-category description

222. Coal is used for production of heat and electricity in different sectors with varying combustion technology. Natural raw materials, including coal, contain trace amounts of mercury, which is thermally released during the combustion.

223. This sub-category covers large combustion plants (typically with thermal boiler effect above 300 MW). Most of such plants are large-scale electricity production plants for public supply, some of which also supply heat (district heating, etc.). The reason for describing such large coal-fired power plants separately is that in many countries they represent large parts of the national coal consumption, and they are often equipped with extensive, individually configured emission reduction systems. Such equipment captures parts of the mercury output, which reduces direct release to the atmosphere. In many cases, smaller coal combustion plants are not equipped with emission reduction devices to the same degree.

224. Some fossil fuel power generation plants have possibilities for also firing with oil and other carbon fuels, but this section focuses on coal as this contains the highest concentrations of mercury. Oil and gas combustion is dealt with in section 5.1.3 and 5.1.4, respectively.

5.1.1.2 Main factors determining mercury releases and mercury outputs

Table 5-2 Main releases and receiving media from combustion in large power plants

Phase of life cycle	Air	Water	Land	Product	General waste	Sector specific treatment/ disposal
Combustion	**X**	x	x	x	**X**	**X**

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

225. The mercury concentrations in the coal used is the main factor determining the releases of mercury from this sector. Most of the mercury in the coal is thermally released in gaseous form during the combustion process. Pre-combustion coal wash used in some countries (which was originally introduced to remove part of the sulphur in the coal) can remove part of the mercury in the coal and requires adequate cleaning/retention systems to retain the washed out mercury

226. Another main factor is the applied emission reduction system (also called air pollution controls system). Post-combustion equipment for flue gas desulphurization, de-NO_x and particle retention, today applied widely in industrialized countries, retain parts of the otherwise emitted mercury. The retention varies between main filter types and coal types used. Filter configurations designed for optimal mercury retention is still not common, but has been introduced in the USA. The combustion technology and especially the coal types used influence the efficiency of the flue gas cleaning systems, and thereby the direct releases.

227. For example, coal types with high chloride content and combustion conditions favouring oxidation of mercury in the exhaust gas yield higher mercury retention in the emission reduction systems commonly used in industrialized countries. Units burning bituminous coal, or with high residual carbon in the flue gas, exhibit higher levels of mercury retention in particle filters and scrubbers (UNEP, 2002). For more detailed information on different combustion principles in coal combustion plants, see for example US EPA (1997a) and US EPA (2002a).

228. The outputs of mercury from this sector are distributed between 1) air emissions; 2) accumulation in solid incineration residues and flue gas cleaning residues; and 3) possibly smaller releases to water (only via wet flue gas cleaning technology systems or pre-washing of coals). It should be noted

that like other deposition of mercury-containing waste, solid residues from coal combustion power plants may result in future releases of mercury. The extent of these releases depends on the level of control of the deposit to minimize mercury releases to air, water and land over decades.

229. For the general situation in North America and Western Europe, about half of the mercury input is released with air emissions, while the other half is retained in flue gas cleaning residues and only a minor part is generally retained in bottom ashes/slag. Depending on the flue gas cleaning systems applied, the residues and by-products that contain mercury may be fly ash, solid sulphur-containing reaction product for deposition (from dry or wet scrubbers) and gypsum wallboards (which are marketed).

230. For coal combustion plants with no emission reduction equipment or with retention of larger particles only (ESP retention), all or most of the mercury inputs will be released directly to the atmosphere. This is because, contrary to most other heavy metals, a substantial part of the mercury in the exhaust gas is present as gaseous elemental mercury. Fabric filters and other high-efficiency particle filters, also retaining small particles, have, however, retained high percentages of the mercury inputs for some coal types favouring oxidation of the mercury in the flue gas, as oxidised mercury associates with particles and moisture.

5.1.1.3 Discussion of mercury inputs

Table 5-3 Overview of activity rate data and mercury input factor types needed to estimate releases from coal combustion in large power plants

Activity rate data needed	Mercury input factor
Amount of each main type of coal burned	Concentration of mercury in each main type of coal burned

231. The reason why the inputs are defined for each main type of coal is that the toolkit works (default) with four main types. This is because the efficiency of mercury retention of the air pollution control systems (and thereby the output distribution factors) varies with the coal type due to the coal chemistry.

232. Detailed estimates of national consumption of different fuel types, in totals and by sector, are available on the International Energy Agency's website at http://www.iea.org/stats/. For coal, the consumption is also distributed on the main coal types (anthracite, bituminous (including "coke coal"), sub-bituminous and lignite; on the website select country, "statistics" and "coal").

233. The concentration of mercury in coal varies considerably depending on the coal type, the origin of the coal and even within the same mine. For example, mercury concentrations may vary by an order of magnitude or more within the same mining field (Pirrone *et al.*, 2001). Available data indicate mercury concentrations in coals vary between 0.01 - 8.0 ppm. The US Geological Service (Bragg *et al.*, 1998) reported mean mercury concentrations in 7000 samples of US coal at 0.17 mg/kg, where 80% were below 0.25 mg/kg and the largest single value was 1.8 mg/kg. For more examples of mercury concentrations in coal, see Table 5-4 below, and the data sources referred to in the table.

Table 5-4 Examples of mercury concentrations in coal of different types and origin (mg/kg or ppmwt; data references in table notes)

Geographic origin	**Coal type**	**Mean Hg concentration**	**Standard deviation on mean**	**Range of Hg concentrations, with number of samples shown in parentheses**	**Notes**
Australia	Bituminous			0.03-0.4	Pirrone *et al.*, 2001
Australia	Anthracite and bituminous (various uses)	0.068			P. Nelson, as cited by UNEP/AMAP, 2012
Australia	Hard coal (industrial use)	0.042			P. Nelson, as cited by UNEP/AMAP, 2012
Australia	Lignite, sub-bituminous	0.032			P. Nelson, as cited by UNEP/AMAP, 2012
Australia	Brown coal used in industry	0.068			P. Nelson, as cited by UNEP/AMAP, 2012
Argentina	Bituminous	0.1		0.03 and 0.18 (2)	Finkelman, 2004
Botswana	Bituminous	0.09		0.04-0.15 (11)	Finkelman, 2004
Brazil	Bituminous	0.19		0.04-0.67 (4)	Finkelman 2004
Canada	Bituminous, sub-bituminous, lignite	0.07			Mazzi et al., 2006, as cited by UNEP/AMAP, 2012
China	Anthrac.+ Bituminous	0.15		<0.0-0.69 (329)	Finkelman, 2004
China	Bituminous for PP and hard coal for industrial use	0.149			UNEP, 2011c, as cited by UNEP/AMAP, 2012
China	Hard coal for diffuse uses (other)	0.19			UNEP, 2011c, Sloss, 2008, as cited by UNEP/AMAP, 2012
Colombia	Sub-bituminous	0.04		>0.02-0.17 (16)	Finkelman, 2004
Czech Rep.	Bituminous	0.25		<0.02-0.73 (24)	Finkelman, 2003
Egypt	Bituminous	0.12		0.04-0.36 (14)	Finkelman, 2003
Germany	Bituminous			0.7-1.4	Pirrone *et al.*, 2001
Germany	Lignite PP use	0.063			UNEP/AMAP, 2012
India	Bituminous and lignite (PP average)	0.14			UNEP/CIMFR-CSIR, 2012, as cited by UNEP/AMAP, 2012
India	Hard and brown coal (industry and diffuse use)	0.292			Mukherjee et al., 2008, as cited by UNEP/AMAP, 2012
Indonesia	Lignite	0.11		0.02-0.19 (8)	Finkelman, 2003
Indonesia ***2**	Sub-bituminous	0.03	0.01	0.01-0.05 (78)	"Burned in 1999" in USA; concentrations on dry weight basis; exact origin unknown, not presented if representative for origin
Japan	Bituminous			0.03-0.1	Pirrone *et al.*, 2001

Geographic origin	Coal type	Mean Hg concentration	Standard deviation on mean	Range of Hg concentrations, with number of samples shown in parentheses	Notes
Japan	Bituminous/hard coal	0.0454			National information submitted to UNEP/AMAP, 2012
Mexico	Sub-bituminous / brown coal	0.293			Non-washed coal, P. Maíz, 2008, as cited by UNEP/AMAP, 2012
New Zealand	Bituminous			0.02-0.6	Pirrone *et al*., 2001
Peru	Anth.+Bit.	0.27		0.04-0.63 (15)	Finkelman, 2004
Philippines	Sub-bituminous	0.04		<0.04-0.1	Finkelman, 2004
Poland	Bituminous			0.01-1.0	Pirrone *et al*., 2001
Romania	Lign. + Sub-bitum.	0.21		0.07-0.46 (11)	Finkelman, 2004
Russia	Bituminous	0.11		<0.02-0.84 (23)	Finkelman, 2003
Slovak Rep.	Bituminous	0.08		0.03-0.13 (7)	Finkelman, 2004
South Africa	Bituminous			0.01-1.0	Pirrone *et al*., 2001
South Africa	Bituminous/hard coal	0.31			Mesakoameng et al., 2010 as cited by UNEP/AMAP, 2012
South America ***2**	Bituminous	0.08	0.07	0.01-0.95 (269)	"Burned in 1999" in USA; concentrations on dry weight basis; exact origin unknown, not presented if representative for origin
Republic of Korea	Anthracite	0.3		<0.02- 0.88 (11)	Finkelman, 2003
Republic of Korea	Anthracite used in PP	0.082			Kim et al., 2010a, as cited by UNEP/AMAP, 2012
Republic of Korea	Bituminous used in PP and diffuse uses	0.046			Kim et al., 2010a and 2010b, as cited by UNEP/AMAP, 2012
Republic of Korea	Hard coal used in industry	0.069			Kim et al., 2010a, as cited by UNEP/AMAP, 2012
Russian Federation	Bituminous and lignite used in PP	0.063			UNEP, 2011d, as cited by UNEP/AMAP, 2012
Russian Federation	Hard and brown coal used in industry and diffusely	0.1			UNEP, 2011d, as cited by UNEP/AMAP, 2012
Tanzania	Bituminous	0.12		0.04-0.22 (15)	Finkelman, 2004
Taiwan	Anth./Bit.	0.67		0.07-2.3 (4)	Finkelman, 2004
Thailand	Lignite	0.12		0.02-0.57 (11)	Finkelman, 2003
Turkey	Lignite	0.11		0.03-0.66 (143)	Finkelman, 2004
Ukraine	Bituminous	0.07		0.02-0.19 (12)	Finkelman, 2003

Geographic origin	Coal type	Mean Hg concentration	Standard deviation on mean	Range of Hg concentrations, with number of samples shown in parenthe-ses	Notes
United Kingdom	Bituminous			0.2-0.7	Pirrone *et al.*, 2001
USA*1	Sub-bituminous	0.10	0.11	0.01-8.0 (640)	Same remark as for USA, bituminous
USA*1	Lignite	0.15	0.14	0.03-1.0 (183)	Same remark as for USA, bituminous
USA*1	Bituminous	0.21	0.42	<0.01-3.3 (3527)	Regarded in reference (US EPA, 1997a) as typical "in-ground" values for US coal, probably wet weight conc. (?)
USA*1	Anthracite	0.23	0.27	0.16-0.30 (52)	Same remark as for USA, bituminous
USA	Sub-bituminous PP use	0.055			UNEP, 2010a, A. Kolker, pers. com., as cited by UNEP/AMAP, 2012
Vietnam	Anthracite	0.28		<0.02-0-14 (3)	Finkelman, 2004
Zambia	Bituminous	0.6		<0.03-3.6 (12)	Finkelman, 2004
Zimbabwe	Bituminous	0.08		<0.03-0.5 (3)	Finkelman, 2004
Former Yugoslavia	Lignite	0.11		0.07-0.14 (3)	Finkelman, 2004

Notes: PP: Power plants. *1 Reference: US EPA (1997a); *2 US EPA (2002a); Appendix A.

234. Some coal combustion plants also burn wastes, which may contain mercury. For a description of mercury in wastes, see sections 5.8 (waste incineration). In cases where waste is incinerated in the coal-fired power plant assessed, the estimated mercury inputs from waste should be added to the other mercury inputs in order to estimate releases.

235. UNEP/AMAP (2012) worked with an intermediate mercury input factor (unabated emission factor) for power plants for the coal types anthracite, bituminous (hard coal), sub-bituminous and lignite (brown coal) of 0.15 g Hg/metric tonne of coal, based on literature study (including a previous version of this Toolkit) and country-specific information collected as part of that project.

5.1.1.4 Examples of mercury in releases and wastes/residues

236. If coal pre-wash is applied this may lower the mercury content of the coal by 10-50% compared to the original content (UNEP, 2002). The US EPA (1997a) reported a mean mercury removal value of 21% for coal pre-wash for plants in USA.

237. The efficiency of emission reduction systems to retain mercury from the exhaust gases of coal-fired power plants has been investigated in many studies and on many different equipment configurations. As mentioned, the efficiency varies considerably even within the same type of combustion conditions and emission reduction principles applied. Therefore, point source specific measurements of the control efficiency are the preferred approach for the inventory, whenever possible and feasible.

238. Pacyna reported that some **wet flue gas desulphurisation systems (FGD)** are unable to remove more than 30% of the mercury in the flue gas, but in general the removal efficiency ranges from 30 to 50% (Pacyna and Pacyna, 2000; as cited by UNEP, 2002). Data from the United States have shown some mercury removals of more than 80% when using wet FGD systems for control of

mercury emissions from coal-fired electric utility boilers (US EPA's Office of Research and Development, available at: http://www.epa.gov/ttn/atw/utility/hgwhitepaperfinal.pdf)

239. An example of the relative distribution of mercury among the different stages/outputs from one coal fired boiler is summarized in Figure 5-1 below (Pacyna and Pacyna, 2000; as cited by UNEP, 2002).

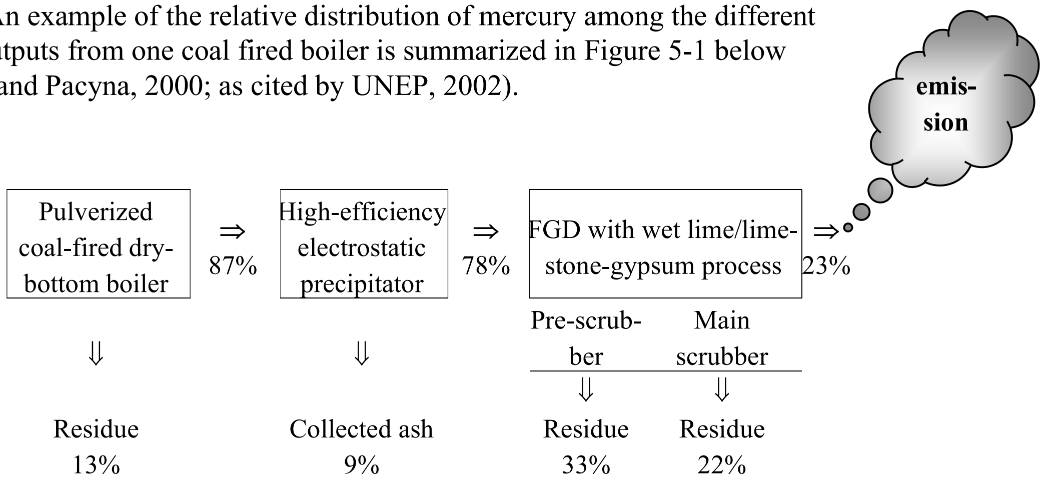


Figure 5-1 Reducing mercury emissions with wet FGD systems; mercury flows and outputs in % of mercury input to boiler based on Pacyna and Pacyna (2000) (figure from UNEP, 2002)

240. Retention of vapour phase mercury by **spray dryer absorption (SDA)** has been investigated in Scandinavia and the USA for coal combustors and for incinerators. In summary, the overall removal of mercury in various spray dry systems varied from about 35 to 85%. The highest removal efficiencies were achieved in spray dry systems fitted with downstream fabric filters (Pacyna and Pacyna, 2000; as cited by UNEP, 2002).

241. Under summarized Danish conditions (based on mass balances), the overall mercury output distribution on power plants with particle control (PM) and wet FGD was roughly estimated to 50% retained with PM control, 20% retained with FGD residues and 30% released to the atmosphere. Similar overall estimates for power plants with PM control and semi-dry FGD were roughly 50% retained with PM control, 25% retained with desulphurisation residues and 25% released to the atmosphere. For a few plants with PM control only, roughly 50% was retained by the PM control and the rest released to the atmosphere (Skårup *et al*., 2003).

242. As another example, US EPA (2002a) conducted investigations of mercury retention in a number of pulverized coal fired US utility boilers with different emission reduction equipment and different coal types burned in the USA. Their results are summarized in Table 5-5 below. For more details, see US EPA (2002a).

243. Several sets of emission factors for mercury from coal combustion in power plants to the atmosphere only, have been developed in, for example, the USA (see US EPA, 1997 or US EPA, 2002a) and Europe (EMEP/CORINAIR, 2001). These are, however, presented as single emission factors for several conditions, not split on input factors and output distribution factors as done in this Toolkit.

Table 5-5 Summarized results from US EPA's recent investigation of the mercury retention in different emission reduction systems. Average mercury capture in % of mercury input to reduction device (US EPA, 2002a).

Post-combustion Control Strategy	**Post-combustion Emission Control Device Configuration**	**Average Mercury Capture by Control Configuration (no. of tests in study in brackets)**		
		Coal Burned in Pulverized-coal-fired Boiler Unit		
		Bituminous Coal	**Sub-bituminous Coal**	**Lignite**
PM Control Only	CS-ESP	36 % (7)	3 % (5)	- 4 % (1)
	HS-ESP	9 % (4)	6 % (4)	Not tested
	FF	90 % (4)	72 % (2)	Not tested
	PS	Not tested	9 % (1)	Not tested
PM Control and Spray Dryer Adsorber	SDA+ESP	Not tested	35 % (3)	Not tested
	SDA+FF	98 % (3)	24 % (3)	0 % (2)
	SDA+FF+SCR	98 % (1?)	Not tested	Not tested
PM Control and Wet FGD System (a)	PS+FGD	12 % (1)	-8 % (4)	33 % (1)
	CS-ESP+FGD	74 % (1)	29 % (3)	44 % (2)
	HS-ESP+FGD	50 % (1)	29 % (5)	Not tested
	FF+FGD	98 % (2)	Not tested	Not tested

(a) Estimated capture across both control devices;
SCR - Selective catalytic reduction; CS-ESP - Cold-side electrostatic precipitator;
HS-ESP - Hot-side electrost. precipitator; FF - Fabric filter; PS - Particle scrubber;
SDA - Spray dryer adsorber system; FGD – Flue gas desulfurization.

244. Table 5-6 shows the medium mercury retention efficiencies for air pollution controls used with combustion of coal in power plants, as well as associated application rates, used by UNEP/AMAP (2012) in their inventory work. The data shown was based on a literature study (including a previous version of this Toolkit) and country specific information collected for that project. The retention rates for some air pollution controls vary somewhat with coal type; primarily due to the chemistry of the coal, for example the concentration of halogens and other constituents which influence the oxidation of mercury in the flue gas. Oxidised mercury associates with particles and moisture and can thus be retained better in particle filters, while elemental mercury gas is only effectively retained in mercury-specific filters like activated carbon injection (ACI) collected in fabric filters (FF).

Table 5-6 Mercury retention rates and application profile for coal combustion in power plants; developed by UNEP/AMAP (2012).

	Intermediate mercury retention rates, %, by coal type				Degree of application (%) by country group ***1**				
Air pollution controls	Anthracite	Bituminous	Sub-bituminous	Lignite	1	2	3	4	5
Level 0: None	0	0	0	0					
Level 1: Particulate matter simple APC: ESP/PS/CYC	25	25	10	2	30	75	70	100	100
Level 2: Particulate matter (FF)	50	50	50	5	5	20	30		
Level 3: Efficient APC: PM+SDA/wFGD	65	65	40	20	20				

	Intermediate mercury retention rates, %, by coal type				Degree of application (%) by country group ***1**				
Air pollution controls	Anthracite	Bituminous	Sub-bituminous	Lignite	1	2	3	4	5
Level 4: Very efficient APC: PM+FGD+SCR	70	90	25	20	40	5			
Level 5: Mercury specific	97	97	75	75	5				

Notes: *1: UNEP/AMAP (2012) distributed countries in five groups based on their development level as regards mercury abatement, with the most developed as group 1 and the least developed as group 5. See reference for further description of the grouping.

5.1.1.5 Input factors and output distribution factors

245. Based on the so far compiled examples of mercury concentrations in coal and information on emission reduction system efficiency given above, the following default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows. Also the presented default factors are based on summarized data only.

246. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

247. Bearing in mind the large variation presented above on both mercury concentrations in coal and the efficiency of emission reduction systems on mercury, the use of source specific data is the preferred approach, if feasible. For advice on data gathering, see section 4.4.5.

a) Default mercury input factors

248. Actual data on mercury levels in the particular coal composition used will lead to the best estimates of releases. If data are not available for the actual coal used, then average values or ranges from data on other similar coal types may be used (see examples in Table 5-4 above).

249. If no information is available on the mercury concentration in the coal used, a first estimate can be formed by using the default input factors selected in Table 5-7 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum). The intermediate value is used in the Toolkit's Inventory level 1. If it is chosen not to calculate as intervals, the use of the maximum value will give the safest indication of the possible importance of the source category for further investigation. Using a high end estimate does not automatically imply that actual releases are this high, only that it should perhaps be investigated further.

Table 5-7 Default input factors for mercury in coal for energy production in power plants.

Material	**Default input factors; g mercury per metric ton of dry coal; (low end, high end, (intermediate))**
Coal used in power plants (for all main types)	0.05 - 0.5 (0.15)

250. In line with UNEP/AMAP (2012), default output distribution factors are given below for each of the four main coal types. Note that the designation "coking coal" used in for example IEA's coal statistics is a sub-group of bituminous coal and can thus be calculated as such.

b) Default mercury output distribution factors

Table 5-8 Default distribution factors for mercury outputs from coal combustion in power plants.

Emission reduction system and coal type	**Distribution factors, share of Hg input**					
	Air	**Water**	**Land *2**	**Products *3**	**General waste *2**	**Sector specific treatment/disposal *2**
Coal wash ***1**		0.01		0.8 (in coal to be combusted)		0.19
Combustion of anthrasite:						
Level 0: None	1					
Level 1: Particulate matter simple APC: ESP/PS/CYC	0.75					0.25
Level 2: Particulate matter (FF)	0.5					0.5
Level 3: Efficient APC: PM+SDA/wFGD	0.35	?				0.65
Level 4: Very efficient APC: PM+FGD+SCR	0.3					0.7
Level 5: Mercury specific	0.03					0.97
Combustion of bituminous coal:						
Level 0: None	1					
Level 1: Particulate matter simple APC: ESP/PS/CYC	0.75					0.25
Level 2: Particulate matter (FF)	0.5					0.5
Level 3: Efficient APC: PM+SDA/wFGD	0.35	?				0.65
Level 4: Very efficient APC: PM+FGD+SCR	0.1					0.9
Level 5: Mercury specific	0.03					0.97
Combustion of sub-bituminous coal:						
Level 0: None	1					
Level 1: Particulate matter simple APC: ESP/PS/CYC	0.9					0.1
Level 2: Particulate matter (FF)	0.5					0.5
Level 3: Efficient APC: PM+SDA/wFGD	0.6	?				0.4
Level 4: Very efficient APC: PM+FGD+SCR	0.75					0.25
Level 5: Mercury specific	0.25					0.75
Combustion of lignite:						
Level 0: None	1					
Level 1: Particulate matter simple APC: ESP/PS/CYC	0.98					0.02
Level 2: Particulate matter (FF)	0.95					0.05
Level 3: Efficient APC: PM+SDA/wFGD	0.8	?				0.2
Level 4: Very efficient APC: PM+FGD+SCR	0.8					0.2
Level 5: Mercury specific	0.25					0.75

Notes: *1 If coal wash is applied, the input mercury to combustion is the calculated output to "products" from coal wash. Outputs to water can take place if not all Hg in wash media is retained in residues.

*2 In case residues are not deposited carefully, mercury in residues could be considered released to land. Sector specific disposal may include disposal on special secured landfills, disposal on special landfills with no securing of leaching, and more diffuse use in road construction or other construction works. The actual distribution between disposal with general waste (ordinary landfills) and sector specific deposition likely varies much among countries and specific information on the local disposal procedures should be collected.

*3 Depending on the specific flue gas cleaning systems applied, parts of the mercury otherwise deposited as residue may follow commercial by-products (primarily gypsum wallboards and sulphuric acid).

Abbreviations: CYC – Cyclones; DS – Dry scrubber; ESP – Electrostatic precipitator; FF - Fabric filter (or "bag filter"); FGD – Flue gas desulfurization; PM – Particulate matter (or PM filter); PS - Particle scrubber; SCR -

Selective catalytic reduction; SD - Spray dryer; SDA - Spray dryer adsorber; SNCR - Selective non-catalytic reduction; wFGD – Wet flue gas desulfurization.

c) Links to other mercury sources estimation

251. No links suggested.

5.1.1.6 Source specific main data

252. The most important source specific data would in this case be:

- Measured data or literature data on the mercury concentrations in the specific mix of coals (origin and type) burned at the plant;
- Data on quantity of each type of coal burned at plant; and
- Measured data on efficiency of emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

253. See also advice on data gathering in section 4.4.5.

5.1.1.7 Summary of general approach to estimate releases

254. The overall approach to estimate releases of mercury to each pathway from coal combustion in large power plants is as follows:

Input factor (concentration of Hg in the coal types used at plant)	*	**Activity rate** (amount of each type of coal burned per year)	*	**Distribution factor** for each pathway (by coal type and filter types present)

and the total releases are the sum of the releases to each pathway.

5.1.2 Other coal use

5.1.2.1 Sub-category description

255. This sub-category covers two groups of sources: 1) Coal fired industrial boilers and 2) other coal uses (coking as well as combustion).

Coal fired industrial boilers

256. The Minamata Convention will regulate the source type "coal fired industrial boilers". The Convention does not give a clear definition of the source type. Based on literature, boilers are enclosed devices using controlled flame combustion and having the primary purpose of recovering thermal energy in the form of steam or hot water (US EPA, 2013). The authors of this Toolkit assume that coal fired industrial boilers are all such boilers where coal (also in combination with other fuels) is used in manufacturing and processing in any industry. In practice this includes in the Toolkit context all coal use in boilers except for single house residential heating/coking and power plants. By way of example, coal fired district heating plants are thus considered industrial boilers included in this source sub-category in the Toolkit, whereas direct combustion (not in boilers) of coal and coke in for example ferrous/non-ferrous metal production and cement production are not included because they do not involve boilers (they are included elsewhere in the Toolkit).

257. According to the Community Strategy Concerning Mercury from the European Commission (European Commission, 2005) small combustion plants and residential coal burning are also significant mercury sources. In particular, small-scale combustion installations were identified, in the EU

context where many large plants are relatively well controlled, as one additional main contributor to the mercury problem, but available data are presently scarce.

258. Since industrial coal fired boilers were defined in the Minamata Convention, releases from this group are estimated separately in the Toolkit calculation spreadsheets.

Coke production

259. Coke is produced from hard coal or from brown coal by carbonization (heating under vacuum). In "coke ovens", coal is charged into large vessels, which are subjected to external heating to approximately 1,000 °C in the absence of air. Coke is removed and quenched with water. A major use of coke – at least in industrialized countries - is the metallurgical industry (ferrous and non-ferrous). Releases from coke production are estimated separately in the Toolkit calculation spreadsheets.

Other coal combustion

260. This group includes use of coal for residential heating (single house level only) as well as industrial coal uses that do not involve boilers (for example in metal smelting; see discussion above). Releases from this sub-group are estimated separately in the Toolkit calculation spreadsheets. Note that coal use in cement kilns are accounted under cement production in this Toolkit (since the 2017 version).

5.1.2.2 Main factors determining mercury releases and mercury outputs

Table 5-9 Main releases and receiving media from "other" coal combustion

Phase of life cycle	Air	Water	Land	Product	General waste	Sector specific treatment/ disposal
Other coal use	**X**		x	x	x	x

Notes: **X** -Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

261. The primary factors that determine releases for smaller coal combustion plants (such as industrial boilers) are similar to large coal-fired plants described above. However, application of flue gas cleaning equipment is less common in smaller combustion plants and practically non-existing in household combustion (COWI, 2002). Therefore, generally a larger portion of mercury in the coal is released to the air.

262. For sources with minimum, or no control technologies, nearly all the mercury present in the coal is likely to be emitted to the air. In heat and power production most of the mercury in the coal is thermally released in gaseous form during the combustion process. Post-combustion equipment for flue gas de-sulfurisation, de-NO_x and particle retention, may however be applied in some larger combustion facilities in this group, retaining parts of the otherwise released mercury. Besides the mercury content in the coal used, other factors including the coal type, the combustion technology, and particularly any flue gas cleaning systems applied (if applied), determine the mercury amounts released, and the distribution of the output of mercury between air emissions, accumulation in solid incineration and flue gas cleaning residues, and releases to water (only indirectly to water via some flue gas cleaning technology types) (COWI, 2002). For larger combustion plants in the group, flue gas cleaning technology may be similar to that of larger power plants described in section 5.1.1.

263. With regard to coke production, emissions to air can occur during charging and discharging of the coal/coke as well as during the heating. Since emissions are not released through a stack, the emission factors are hard to measure and are therefore subject to uncertainty. Releases to water can occur if effluents from quenching or wet scrubbing are discharged.

264. The outputs of mercury from this sub-category are primarily distributed between 1) air emissions; and 2) accumulation in solid incineration residues and flue gas cleaning residues. There may possibly also be some releases to water (only via wet flue gas cleaning technology systems or pre-wash of coals). It should be noted that like other deposition of mercury-containing waste, solid residues from coal combustion will likely give rise to future releases of mercury to some degree, depending on the disposal method or end-use of the residue and the level of control to minimize mercury releases to air, water and land over decades.

265. Generally, for sources in this sub-category, more than half of the mercury input is probably released with the air emissions, while the remainder is likely to be retained in flue gas cleaning residues (if controls are present), and maybe a little in bottom ashes/slag, depending on the source type. For industrial boilers and other combustion plants, very low concentrations of mercury are likely to be found in the bottom ash. However, for residential heating, levels may be somewhat higher.

266. For coal combustion plants with no emission reduction equipment or with retention of larger particles only (ESP retention), all or most of the mercury inputs will be released directly to the atmosphere. This is because the majority of the mercury in the exhaust gas remains in the gas phase, or is adsorbed to small particles. Fabric filters and other high-efficiency particle filters, also retaining small particles, have, however, retained high percentages of the mercury inputs under certain conditions.

5.1.2.3 Discussion of mercury inputs

Table 5-10 Overview of activity rate data and mercury input factor types needed to estimate releases from other coal combustion

Process	Activity rate data needed	Mercury input factor
Coke production	Amount of each main type of coal processed	Concentration of mercury in each main type of coal processed
Coal combustion (including industrial boilers)	Amount of each main type of coal burned	Concentration of mercury in each main type of coal burned

267. Detailed estimates of national consumption of different fuel types, in totals and by sector, are available on the International Energy Agency's website at http://www.iea.org/stats/. For coal, the consumption is also distributed on the main coal types anthracite, bituminous (including "coke coal"; all both hard coal), and sub-bituminous and lignite (both brown coal). On the website select country, "statistics" and "coal").

268. As with the large coal-fired plants, mercury is present as an impurity in the coal. The concentration of mercury in coal varies considerably depending on the coal type, the origin of the coal and even within the same mine. For more examples of mercury concentrations in coal, see section 5.1.1 and Table 5-4.

269. UNEP/AMAP (2012) worked with intermediate mercury input factors (unabated emission factor) for non-power plant use for the coal types anthracite, bituminous (hard coal) and sub-bituminous (brown coal) of 0.15 g Hg/metric tonne of coal, and 0.1 g Hg/metric tonne for lignite (brown coal). Their assessment was based on literature study (including a previous version of this Toolkit) and country-specific information collected as part of that project.

270. Some coal combustion plants also burn wastes. In such cases, estimating the quantity of mercury emissions can be more complicated. The concentration of mercury in the wastes (if known), along with the amount of wastes burned, and information on control technologies, can be used to estimate the mercury releases due to the waste combustion (see section 5.8 on waste incineration). This estimate would then be added to the estimate of mercury releases due to coal combustion.

5.1.2.4 Examples of mercury in releases and wastes/residues

271. The releases of mercury from the uncontrolled combustion boilers and similar sources in this sub-category are primarily (nearly 100%) to air in the form of gaseous mercury, or bound to fine particles (US EPA, 1997). If the source has add-on controls or utilizes coal-washing techniques, then some of the mercury will go to residues and/or water (see section 5.1.1 for more information on releases for various controls and coal washing).

272. Table 5-4 shows the medium mercury retention efficiencies for air pollution controls used with combustion of coal and associated application rates UNEP/AMAP (2012) used in their inventory work. The data shown was based on a literature study and country specific information collected for that project.

Table 5-11 Mercury retention rates and application profile developed by UNEP/AMAP (2012).

	Intermediate mercury retention rates, %, by coal type		Degree of application (%) by country group ***1**				
Air pollution controls	Hard coal (anthracite, bituminous)	Brown coal (sub-bituminous, lignite)	1	2	3	4	5
Industrial use (combustion):							
Level 0: None	0.0	0.0			25	50	75
Level 1: Particulate matter simple APC: ESP/PS/CYC	25.0	5.0	25	25	50	50	25
Level 2: Particulate matter (FF)	50.0	50.0	25	50	25		
Level 3: Efficient APC: PM+SDA/wFGD	50.0	30.0	25	25			
Level 4: Very efficient APC: PM+FGD+SCR	90.0	20.0	25				
Level 5: Mercury specific	97.0	75.0					
Other coal combustion:							
Level 0: None	0.0	0.0	50	50	100	100	100
Level 1: Particulate matter simple APC: ESP/PS/CYC	25.0	5.0	50	50			

Notes: *1: UNEP/AMAP (2012) distributed countries in five groups based on their development level as regards mercury abatement, with the most developed as group 1 and the least developed as group 5. See reference for further description of the grouping.

Abbreviations: APC – Air pollution controls; CYC – Cyclones; ESP – Electrostatic precipitator; FF - Fabric filter (or "bag filter"); FGD – Flue gas desulfurization; PM – Particulate matter (or PM filter); PS - Particle scrubber; SCR - Selective catalytic reduction; SDA - Spray dryer adsorber; wFGD – Wet flue gas desulfurization.

273. For coke production all or most of the mercury inputs are expected to be emitted to the atmosphere during the production itself (COWI, 2002). US EPA (1997a) mentions atmospheric mercury emission factors from German facilities of 0.01 - 0.03 g mercury/metric ton of coke produced. If precleaned coal is applied (the case in the USA), the atmospheric emissions may be slightly lower (about 21% lower), as some of the mercury content are washed out and treated or deposited in other ways (COWI, 2002).

5.1.2.5 Input factors and output distribution factors

274. Based on the so far compiled examples of mercury concentrations in coal and information on emission reduction system efficiency given above, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows. Also, the presented default factors are based on summarized data only.

275. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

276. Bearing in mind the large variation presented above on both mercury concentrations in coal and the efficiency of emission reduction systems on mercury, the use of source specific data is the preferred approach, if feasible. For advice on data gathering, see section 4.4.5.

a) Default mercury input factors

277. Actual data on mercury levels in the particular coal composition used will lead to the best estimates of releases. If data are not available for the actual coal used, then average values or ranges from data on other similar coal types may be used (see examples in Table 5-4 above).

278. If no information is available on the mercury concentration in the concentrates used in the extraction step, a first estimate can be formed by using the default input factors selected in Table 5-12 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum). The medium value is used in the Toolkit's Inventory level 1. If it is chosen not to calculate as intervals, the use of the maximum value will give the safest indication of the possible importance of the source category for further investigation. Using a high end estimate does not automatically imply that actual releases are this high, only that it should perhaps be investigated further.

Table 5-12 Default input factors for mercury in coal for energy production in industrial and other facilities.

Material	**Default input factors; g mercury per metric ton of dry coal; (low end, high end, (intermediate))**
Lignite	0.05 - 0.2 (0.1)
Other coal	0.05 - 0.5 (0.15)

b) Default mercury output distribution factors

279. For coke production, 100% of the mercury input with feed coal should, as default, be considered as releases to the atmosphere during the coking process (in oven venting).

280. For coal combustion, default mercury output distribution factor are suggested in Table 5-13 below.

Table 5-13 Default distribution factors for mercury outputs from coal combustion in industrial and other facilities.

Emission reduction device	**Distribution factors, share of Hg input**					
	Air	**Water**	**Land *2**	**Products**	**General waste *2**	**Sector specific treatment /disposal *2**
Coal wash ***1**		0.01	?	0.8 (in coal to be combus-ted)		0.19
Combustion of hard coal in industrial facilities:						
Level 0: None	1					
Level 1: Particulate matter simple APC: ESP/PS/CYC	0.75					0.25
Level 2: Particulate matter (FF)	0.5					0.5
Level 3: Efficient APC: PM+SDA/wFGD	0.5	?				0.5
Level 4: Very efficient APC: PM+FGD+SCR	0.1					0.9
Level 5: Mercury specific	0.03					0.97
Combustion of brown coal in industrial facilities:						
Level 0: None	1					
Level 1: Particulate matter simple APC: ESP/PS/CYC	0.95					0.05
Level 2: Particulate matter (FF)	0.5					0.5
Level 3: Efficient APC: PM+SDA/wFGD	0.7	?				0.3
Level 4: Very efficient APC: PM+FGD+SCR	0.8					0.2
Level 5: Mercury specific	0.25					0.75
Other combustion of hard coal:						
Level 0: None	1					
Level 1: Particulate matter simple APC: ESP/PS/CYC	0.75					0.25
Other combustion of brown coal:						
Level 0: None	1					
Level 1: Particulate matter simple APC: ESP/PS/CYC	0.95					0.05

Notes:

*1 If coal wash is applied, the input mercury to combustion is the calculated output to "products" from coal wash. Output to water can take place if not all Hg in wash media is retained in residues.

*2 In case residues are not deposited carefully, mercury in residues could be considered released to land. Sector specific disposal may include disposal on special secured landfills, disposal on special landfills with no securing of leaching, and more diffuse use in road construction or other construction works. The actual distribution between disposal with general waste (ordinary landfills) and sector specific deposition likely varies much among countries and specific information on the local disposal procedures should be collected.

Abbreviations: CYC – cyclones; DS – Dry scrubber; ESP – Electrostatic precipitator; FF - Fabric filter (or "bag filter"); FGD – Flue gas desulfurization; PM – Particulate matter (or PM filter); PS - Particle scrubber; SCR - Selective catalytic reduc-tion; SD - Spray dryer; SDA - Spray dryer adsorber; SNCR - Selective non-catalytic reduction; wFGD – Wet flue gas desulfurization.

c) Links to other mercury sources estimation

281. No links suggested.

5.1.2.6 Source specific main data

282. The most important source specific data would in this case be:

- Measured data or literature data on the mercury concentrations in the consumed mix of coals at the source,
- Data on quantity of each type of coal burned at plant; and
- Measured data on emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

283. Note that industrial coal fired boilers do not currently have separate entries in widely used data sources such as the International Energy Agency's statistics database (www.iea.org), and data on the amounts of coal used on in this source group therefore have to be collected through direct contact to owners of such facilities, or through expert estimates of the distribution of national coal use.

284. See also advice on data gathering in section 4.4.5.

5.1.2.7 Summary of general approach to estimate releases

285. The overall approach to estimate releases of mercury to each pathway from other coal combustion is as follows:

Input factor (concentration of Hg in the coal types used at plant)	*	**Activity rate** (amount of each type of coal burned per year)	*	**Distribution factor** for each pathway (by coal type and filter types present)

and the total releases are the sum of the releases to each pathway.

5.1.3 Mineral oils - extraction, refining and use

5.1.3.1 Sub-category description

286. This section includes extraction, refining, and uses of mineral oil (also called “petroleum oil” or “oil” in this document). This sub-category includes the combustion of oil to provide power, heat, and transportation, and other uses such as for example road asphalt (bitumen), synthesis of chemicals, polymer production, lubricants and carbon black production (black pigments). Like other natural materials, mineral oil contains small amounts of natural mercury impurities, which are mobilised to the biosphere by extraction and use. Mercury concentrations in oil may vary extensively depending on the local geology. Besides mercury naturally present in the oil, another input of mercury to oil extraction is the use of certain types of drilling mud.

287. Oil extraction is known to potentially cause significant releases of mercury and focus has increased on mercury releases from this sector in recent years. Mercury may be released to air, land or water during extraction, refining as well as through refinery products or by-products and various process wastes and sludges.

288. Combustion of oil products releases mercury primarily to air in the form of air emissions. Generally, no air pollution abatement systems are used on oil combustion facilities (some large combustion units designed for oil use may have emission reduction equipment)..

289. In refineries, the crude oil is separated by distillation (and cracking) into a number of refined oil products, including gasoline/petrol, diesel, jet fuel, kerosene, liquefied petroleum gas (such as propane), distillates (diesel, petrol and jet fuels), and "residuals". Refineries remove a portion of the impurities in the crude oil, such as sulphur, nitrogen, and metals. There are various types of fuel oil derived from crude oil. The two main groups are heavy fuel oil (also called residual oil) and light fuel oil (also known as distillate oils). These oils are also classified further into various grades, such as grade numbers 1 and 2 (types of distillate oils), and grades 4, 5 and 6 (residual oils) (US EPA, 1997a and US EPA, 2003b). The different oil products are separated by distillation by making use of the different

boiling temperatures of the constituents of the crude oil. Propane and petrol/gasoline are examples of products with low boiling points, diesel/gas oil and kerosene have slightly higher boiling points, heavy fuel oils have high boiling points, and bitumen ("asphalt") and petroleum coke are examples of the highest boiling (or residue) fractions.

290. In principle, mercury would be expected to primarily follow distillates with boiling points near mercury's boiling point, but data show a wider distribution. The differences in mercury concentrations in the feed crude oils may likely influence the mercury content of refined oil products significantly.

5.1.3.2 Main factors determining mercury releases and mercury outputs

Table 5-14 Main releases and receiving media during the life-cycle of extraction, refining and use of mineral oils

Phase of life cycle	**Air**	**Water**	**Land**	**Product**	**General waste**	**Sector specific treatment/ disposal**
Extraction	**X**	**X**	x	x		
Refining	**X**	x	x	x	x	x
Combustion	**X**					
Other Uses						

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

From extraction and refining of oil

291. One important factor determining releases of mercury from this sub-category is the concentration of mercury in the crude oil.

292. Mercury may be released to air, land, or water from the extraction process, during refining or other processes. Mercury may also be released through refinery products or by-products, and various process wastes and sludges.

293. While a type of drilling mud contains mercury as mentioned, data are not available for this Toolkit to quantify such releases.

From combustion of oil

294. The most important factors determining releases from oil combustion sources are the mercury levels in the oil and amount of fuel burned. The primary pathway of releases for these sources is to air. Since the entire fuel supply is exposed to high flame temperatures, essentially all of the mercury contained in the fuel oil will evaporate and exit the combustion chamber with the combustion gases. Unless these combustion gases are exposed to low-temperature air pollution control systems and high efficiency PM control systems, which typically are not found on these units, the mercury will be released in vapour phase through the combustion stack (US EPA, 1997a).

5.1.3.3 Discussion of mercury inputs

Table 5-13 Overview of activity rate data and mercury input factor types needed to estimate releases from extraction, refining and use of mineral oils

Life-cycle phase	**Activity rate data needed**	**Mercury input factor**
Refining	Amount of input crude oil	Concentration of mercury in crude oil mix used
Use	Amount of each type of oil	Mercury concentration in each type of oil burned/used

295. Detailed estimates of national consumption of different fuel types, in totals and by sector, are available on the International Energy Agency's website http://data.iea.org/stat/.

Mercury concentration in crude oils

296. Pirrone *et al.* (2001) report a general average concentration of 10 ppb in crude oil, but with some values as high as 30,000 ppb.

297. Table 5-15 below shows data from Wilhelm (2001), Wilhelm *et al.* (2007), PAJ (2012), Lassen *et al.* (2004) and IPIECA (2012) organised by country or region. The values are averages of data from various oilfields. From the values shown in the table, the average is 163 mg Hg/metric ton, the median is 2,3, the 10% percentile is 0.85 and the 90% percentile is 66 mg Hg/metric ton.

298. Measured mercury concentrations in crude oils are summarized in Table 5-15. The table illustrates the high variation of mercury concentration of the oil. However, the extraordinary high values may be represented by relatively few fields. For example, Wilhelm and Bigham (2002) note that samples from a small field in California, accounting for 0.2 % of crude oils processed in the USA, with extraordinary high mercury concentration, is included in several of the data sets cited by Wilhelm, 2001 and shown in Table 5-15. Wilhelm and Bigham (2002) state that if the samples from this field were excluded, the mean value reported in each case would decreases up to 1000 times for the three datasets with extraordinary high mean values (the datasets of Shah *et al*. 1970, Filby and Shah, 1975 on "U.S.A and imports").

299. For the data on mercury content of crude oils in CIS countries from Lassen *et al.* (2004), the mean is calculated from the mean value of the samples from each of the 42 analysed oil fields. The mean value for the whole dataset was 300 ppb, whereas the mean for 9 Russian fields was 180 ppb. The authors of that report indicated that the data set may be biased towards samples with relatively high mercury content, as many of the analyses have been done in order to study the presence of mercury in regions, mainly in Central Asia, with relatively high mercury concentration.

Table 5-15 Examples of mercury concentrations in crude oils by country or region.

Country/region	Average mercury concentration, mg/metric ton				
	Wilhelm *et al.*, 2007	PAJ, 2012	Wilhelm, 2001*1	Lassen *et al.*, 2004	IPIECA, 2012*2
Algeria	13.3				
Angola	1.6	1			
Argentina	16.1				
Australia	0.8	2.3			
Azerbaijan		1			
Brazil	1.1				
Brunei		2.6			
Canada			22		

Country/region	Average mercury concentration, mg/metric ton				
	Wilhelm *et al.*, 2007	PAJ, 2012	Wilhelm, 2001*1	Lassen *et al.*, 2004	IPIECA, 2012*2
"Canadian refineries"			1.6		
"Canada and imports"			8		
Chad	1.2				
China		6.5			
Columbia	3.4				
Ecuador	1.8				
Gabon	0.5	1			
Guinea	0.3				
Indonesia		65.1			
Iran		2.1			
Iraq	0.7	0.7			
Ivory Coast	0.3				
Kuwait	0.8	1			
Libya			3.1		
Malaysia		157.4			38
Nigeria	1.8	3			
North Africa	13.3				
Norway	19.5	1			
Oman		1.5			
Philippines		2			
Qatar		2			
Russia	3.1	2.4		180	
Saudi Arabia	0.9	1.5			
Sudan		34			
Thailand	593.1				
UAE		1.7			
UK	3.6				
Venezuela	4.2				
Viet Nam	66.5	48.6			
U.S.A.	4.3	3.6			
"U.S.A. and imports"			3200		
"U.S.A. and imports"			5803		
U.S.A states:					
AK	3.7				
CA	11.3				
GOM	2.1				
LA	9.9				
MT	3.1				
OK	1.4				
TX	3.4				
UT	2.2				
WY	2.7				
"NJ refineries"			3.5		
"West coast refineries"			65		
"Asia"*3			<1		
"CIS countries"				300	

Notes: *1: Citing: Tao et al., 1998; Duo et al., 2000; Musa et al., 1995; Liang et al., 2000; Morris, 2000; Cao, 1992; Hitchon and Filby, 1983; Magaw et al., 1999; Bloom, 2000; Shah et al., 1970; Filby and Shah, 1975.
*2: Production weighted mean as calculated by IPIECA (2012); two production fields are reportered to have 400 and 600 ppb, respectively, while the remaining fields are reported to have <10 ppb Hg.
*3: Counted as 1 in the statistics.

300. IPIECA (2012), the global oil and gas industry association for environmental and social issues, produced a survey for use in the negotiations of the global mercury treaty of 446 oil samples from a number of members across the world. The mercury concentration range in the samples were 0.1-1000

ppb. The majority of the observations were however below 2 ppb mercury in the oil and the median was 1.3 ppb; the average was not reported.

301. Based on the PAJ (2012) data in Table 5-15, PAJ reported a production weighted average mercury concentration of 5.7 ppb.

302. UNEP/AMAP (2012) calculated a production weighted global average of mercury concentration in crude oil at 3.4 mg/metric ton oil based on the concentration data from Wilhelm *et al.* (2007) and PAJ (2012) shown in Table 5-15 above (the unit ppb on weight basis equals mg/metric ton).

Mercury concentrations in refined oil products

303. Data on mercury concentrations in a variety of refined oil products, compiled by Wilhelm (2001), are presented in Table 5-16.

Table 5-16 Mercury concentrations in refined oil products (Based on Wilhelm, 2001)

Type	Mean (ppb)	Range (ppb)	Standard deviation	Number of samples	References *1	Notes
Kerosene	0.04	0.04	NR	1	Liang *et al.*, 1996	USA
Asphalt	0.27	NR	0.32	10	Bloom, 2000	USA
Diesel	0.4	0.4	NR	1	Liang *et al.*, 1996	USA
Heating Oil	0.59	0.59	NR	1	Liang *et al.*, 1996	USA
Utility fuel oil	0.67	NR	0.96	32	Bloom, 2000	USA
Gasoline	0.7	0.22 - 1.43	NR	5	Liang *et al.*, 1996	USA
Light distillates	1.32	NR	2.81	14	Bloom, 2000	USA
Gasoline	1.5	0.72 - 1.5	NR	4	Liang *et al.*, 1996	Foreign
Diesel	2.97	2.97	NR	1	Liang *et al.*, 1996	Foreign
Residential fuel oil	4	2-6		6	EPA, 1997b	
Naphtha	15	3 - 40	NR	4	Olsen *et al.*, 1997	
Naphtha	40	8 - 60	NR	3	Tao *et al.*, 1998	Asian
Petroleum coke	50	0-250	NR	1000	US EPA, 2000	USA
Distillate fuel oil	120			3	US EPA, 1997b	USA

Notes *1 All references as cited by Vilhelm (2001). NR: not reported.

304. UNEP/AMAP (2012) use so-called "unabated emission factors" (equivalent to input factors) for combustion in power plants of 10, 20 and 2 mg/metric ton for crude oil, heavy fuel oil and light fuel oil, respectively.

305. Data on mercury concentrations in selected oil types used in the USA (US EPA, 1997a) are shown in Table 5-17.

Table 5-17 Mercury concentrations (in ppm weight) in various oil types used in the USA (US EPA, 1997a)

Fuel Oil	**Number of samples**	**Range (ppm weight)**	**Typical Value**
Residual No. 6	??	0.002-0.006	0.004 ***1**
Distillate No. 2	??	??	<0.12 ***2**
Crude	46	0.007-30	3.5 ***3**

Notes: *1 Midpoint of the range of values;
*2 Average of data from three sites;
*3 Average of 46 data points was 6.86; if the single point value of 23.1 is eliminated, average based on 45 remaining data points is 1.75. However, the largest study with 43 data points had an average of 3.2 ppmwt. A compromise value of 3.5 ppmwt was selected as the best typical value;
References: Brooks, 1989; Levin, 1997; Chu and Porcella, 1994.

5.1.3.4 Examples of mercury in releases and wastes/residues

Extraction and refining

306. In general studies showing the fate of mercury by petroleum extraction and refining are scarce.

307. The quantitatively most important fluxes of mercury from offshore oil platforms are drilling fluids and produced water. Nearly all the mercury in drilling muds is associated with barite. Essentially all production systems employ separators to accomplish the primary phase separation so that produced water can be disposed of. Multiple stages of separation are typical as oil or gas is transported to a processing facility is that hydrocarbon liquid, natural gas and water phases are separated (Vilhelm, 2001). Mercury in produced water is further described under natural gas.

308. Vilhelm (2001) assumes that combustion of fuels accounts for the primary path of emission from petroleum refineries, and estimates the total atmospheric mercury emissions from refineries in the U.S.A. in 1999 to be no more than 1,850 kg or about 23% of the mercury in the processed crude oils. Total releases to waste water was estimated at 250 kg corresponding to 3% of the total input while some 15% was assumed to end in solid waste. According to the report the main part of the mercury ends up in the petroleum products; primarily petroleum coke and heavy oils. Newer data shows that the total amount of mercury processed in refineries in the USA is approximately 3 metric tons (Wilhelm *et al.,* 2007), but no new data on refinery emissions have been identified.

309. From Minnesota (USA) it is reported from the major refinery in the state that of 19 kg mercury in the crude oil, 23% was emitted from the facility, 24% ended up in a sulphur product sold as a commodity while only 13% of the mercury ended up in the petroleum products (MPCA, 2008). The remaining 16% could not be accounted for.

310. Mass balance summaries for refineries from the San Francisco Bay Area show that of 224 kg in the crude oils about 8% was emitted to air, 13% ended in the petroleum products including petroleum coke, 0.4% ended in waste water and the remaining part was disposed of with refinery waste (WSPA, 2009).

311. According to the Petroleum Associatio of Japan (PAJ, 2012), a mercury output distribution factor to air of 0.25 (25%) "seems quite accurate".

Combustion and other use

312. As a general assumption for oil use involving combustion, 100% of the mercury input from the oil products used can be considered released to air. Exceptions may be combustion systems equipped with flue gas cleaning systems run under conditions favouring oxidation of the mercury present in the

flue gas (based on experience from coal fired combustion systems), or otherwise suited for mercury retention.

313. The three types of control measures applied to oil-fired boilers and furnaces are boiler modifications, fuel substitution and flue gas cleaning. Only fuel substitution and flue gas cleaning systems may affect mercury emissions. Fuel substitution is used primarily to reduce sulphur dioxide (SO_2) and nitrogen oxides (NO_x) emissions. However, if the substituted fuels have lower mercury concentrations, the substitution will also reduce mercury emissions. Because emissions of particulate material from oil-fired units are generally much lower than those from coal-fired units, high-efficiency particle control systems are generally not employed on oil-fired systems.

314. In the USA, flue gas cleaning equipment generally is employed only on larger oil-fired boilers. Mechanical collectors, a prevalent type of control device in the USA, are primarily useful in controlling particles generated during soot blowing, during upset conditions, or when very dirty, heavy oil is fired. During these situations, high efficiency cyclonic collectors can achieve up to 85% control of particles, but negligible control of mercury is expected with mechanical collectors. Electrostatic precipitators (ESPs) are used on some oil-fired power plants. Based on test data from two oil-fired plants, the US EPA reports that mercury removal on ESP-equipped oil-fired boilers ranges from 42 - 83% (US EPA, 1997a). Scrubbing systems have been installed on oil-fired boilers to control both sulphur oxides and particles. Similar to systems applied to coal combustion, these systems can achieve particles control efficiencies of 50 - 90% (US EPA, 1997a). Because they provide gas cooling, some mercury control may be obtained, but no data have been obtained on the percent of mercury removed.

315. The only substantive output of atmospheric mercury emissions from fuel oil combustion operations is through the combustion gas exhaust stack. In the USA, three types of information were used to develop emission factors for oil combustion. First, data on fuel oil heating value and mercury content of fuel oils were used to develop emission factors by mass balance, assuming conservatively that all mercury fired with the fuel oil is emitted through the stack. Second, the emission factors developed for residual and distillate oil combustion and for residual oil combustion were evaluated. Third, rated emission test data were evaluated and summarized (US EPA, 1997a).

316. After the analyses of the available data, the US EPA estimated the "best typical" atmospheric mercury emission factors (EFs) for the combustion of US oils. These EFs are presented in table 5-17. See US EPA (1997a) for more information on the data and calculations.

317. The emission factors for distillate, residual and crude oil presented in Table 5-18 are for "uncontrolled" emissions. Data were judged to be insufficient to develop controlled emission factors for fuel oil combustion. There is considerable uncertainty in these emission factor estimates due to the variability of mercury concentrations in fuel oil, the incomplete data base on distillate oil and the uncertainty in sampling and analysis for detecting mercury (US EPA, 1997a). Therefore, these emissions factors should be used with caution and may not be appropriate to use for any particular plant. Moreover, for estimating releases from oil fired plants in another country, specific data for that country, and/or plant specific data would be preferable for estimating emissions rather than relying on data and emissions factors from the USA.

Table 5-18 The "best typical" atmospheric mercury emissions factors for fuel oil combustion in the USA, based on analyses by US EPA (US EPA, 1997a)

Fuel oil type	**Calculated mercury emission factors**		
	Kg/10^{15} J	**g/metric tons fuel oil**	**g/10^3 L fuel oil**
Residual No. 6	0.2	0.009	0.0085
Distillate No. 2	2.7	0.12	0.10
Crude	41	1.7	1.7

318. UNEP/AMAP (2012) worked with mercury retention rates of 50 percent for oil combustion in power plants equipped with cold side ESPs and flue gas desulphurisation, and 10 percent for oil combustion in industrial facilities with cold side ESPs or flue gas scrubbers.

5.1.3.5 Input factors and output distribution factors

319. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows. In many cases calculating releases intervals will give a more appropriate estimate of the actual releases.

320. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors), before any far-reaching action is taken based on the release estimates.

a) Default mercury input factors for oil use

321. The mercury input can be calculated by multiplying the mercury concentration in the oil product in question with the input amount of the same oil product. Actual data on mercury levels in the particular oil extracted, refined or combusted will lead to the best estimates of releases.

322. If no information is available on the mercury concentration in the oil used, a first estimate can be formed by using the default input factors shown in the table below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors have been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum). The medium value is used in the Toolkit's Inventory level 1. If it is chosen not to calculate as intervals, the use of the maximum value will give the safest indication of the possible importance of the source category for further investigation. Using a high end estimate does not automatically imply that actual releases are this high, only that it should perhaps be investigated further.

323. For refined oil products, please note that the mercury concentration in the crude oil used as raw material may perhaps influence the mercury concentration in the refined product more than the boiling point ("heaviness") of the type of oil product in question.

Table 5-19 Default input factors for mercury in crude oil and various oil products

Oil product	**Default input factors; mg mercury per metric ton of oil (= ppbwt); (low end; high end; (intermediate))**
Crude oil	1 - 66 (3,4)
Petrol/gasoline, diesel, distilled fuel oil, kerosene and other light distillates	1 - 10 (2)
Petroleum coke and heavy oil	10 - 100 (20)

b) Default mercury output distribution factors

Table 5-20 Default output distribution factors for mercury from extraction, refining, and uses of oil

Life Cycle Phase	**Distribution factors, share of Hg input**					
	Air	**Water**	**Land**	**Prod-ucts*2**	**General waste *3**	**Sector specific treatment/ disposal *3**
Extraction *1	?	0.2.	?.	-	?	?
Refining (fraction of mercury in crude oil for refineries)	0.25	0.01	?	-		0.25
Uses (fraction of mercury in petroleum products):						
All uses without emission control	1					
Oil combustion facility with PM control using an ESP or scrubber	0.9				0.1	
Power plant with (c)ESP and FGD	0.5					0.5

Notes:

*1 Some mercury may be released by the extraction of oils. In case specific data exist these should be used for estimation of mercury releases by extraction.

*2 The mercury output with products is calculated separately for the use of these products.

*3 The actual amount ending up in waste is dependent on the actual cleaning techniques applied. Abbreviations: (c)ESP – (coldside) Electrostatic precipitator; FGD – Flue gas desulfurization; PM – Particulate matter (dust) filter.

Sector specific depostion of solid flue gas residues is assumed for power plants, while deposition with general waste is assumed for other combustion facilities.

c) Links to other mercury sources estimation

324. No links suggested.

5.1.3.6 Source specific main data

325. The most important source specific data would in this case be:

- Measured data or literature data on the mercury concentrations in the types of oil extracted, refined, and used at the source;
- Amount of each type of oil extracted, refined, and used; and
- Measured data on emission reduction equipment applied on the sources (or similar sources with very similar equipment and operating conditions).

326. See also advice on data gathering in section 4.4.5.

5.1.3.7 Summary of general approach to estimate releases

From combustion of oil

327. As described above, the primary pathway of mercury releases from fuel oil combustion operations is the combustion exhaust stack. The primary information needed to estimate releases for oil combustion are: mercury concentration in the oil type used (in ppm or other units) and amount of each type of oil burned.

5.1.4 Natural gas - extraction, refining and use

5.1.4.1 Sub-category description

328. Natural gas is a fossil fuel used for various purposes, especially combustion to produce electricity and heat. Like many other natural materials, natural gas contains small amounts of natural mercury impurities, which are mobilized to the biosphere during extraction, refining and combustion. In some regions of the world, natural gas is known to have notable mercury concentrations (depending on geology). Mercury releases may occur during extraction, refining, gas cleaning steps and use (COWI, 2002 and US EPA, 1997b). In some countries, mercury in gas cleaning residues ("condensate" or specific Hg filter rejects) is recovered and marketed as a by-product mercury. In other countries, these residues are collected and treated as hazardous waste. For off-shore gas extraction, initial gas cleaning steps sometimes take place off-shore that may involve water discharged on site. The fate of the mercury content observed in natural gas is still poorly understood. This may be considered a major data gap in the description of mercury releases. In most countries, the gas delivered to consumers has been cleaned and contains - at that stage - only little mercury.

329. The natural gas power production process begins with the extraction of natural gas, continues with its treatment and transport to the power plants, and ends with its combustion in boilers and turbines to generate electricity. Initially, wells are drilled into the ground to remove the natural gas. After the natural gas is extracted, it is treated at gas plants to remove impurities such as hydrogen sulphide, helium, carbon dioxide, hydrocarbons moisture, and to some extend mercury (either in general treatment or as mercury-specific filters). Gas cleaning operations may take place off-shore. Pipelines then transport the natural gas from the gas plants to power plants, or via gas supply grids to residential burners, for combustion.

330. Other uses of natural gas include among others synthesis of chemicals, polymer production and carbon black production (black pigment).

331. Mercury is a particular problem for plants producing liquid natural gas (LNG) and in nitrogen rejection units (NRU) as it can cause deformation of aluminium heat exchangers due to mercury amalgamating with the aluminium. Mercury is also a poison for the precious metal catalysts used in many of the reactions used in hydrocarbon processing and many operators set tight limits on the level of mercury in feed materials to crackers. For these reasons, mercury is in some cases removed from the gas with mercury-specific filters (usually fixed bed filters with impregnated pellets). Some filters use absorbents which are deposited as waste (NCM, 2010), while others may be regenerated on-site along with regeneration of moisture filters (UOP, undated). In the latter case, the captured mercury-containing hydrocarbons may be fed from the regeneration filters back into marketed gas or liquid fuel streams, or it may be concentrated in a smaller filter from which the mercury-containing filter material is deposited as waste UOP (undated).

5.1.4.2 Main factors determining mercury releases and outputs

Table 5-21 Main releases and receiving media during the life-cycle of extraction, refining and use of natural gas

Phase of life cycle (/use)	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Extraction /Refining	**X**	**X**	**X**	x	x	**X**
Combustion	x					
Other uses						

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

332. The most important factors determining releases are the mercury levels in the natural gas and amount of gas extracted, refined or combusted.

333. Most of the mercury in the raw natural gas may be removed during the extraction and/or refining process, including during the removal of hydrogen sulphide (Pirrone *et al.*, 2001). Therefore, natural gas is generally considered a clean burning fuel that usually has very low mercury concentrations.

334. Also, little to no ash is produced during the combustion process at these facilities (US EPA, 1997b). During combustion, since the entire fuel supply is exposed to high flame temperatures, essentially all of the mercury remaining in the natural gas will be volatilized and exit the furnace with the combustion gases through the emissions stack. Gas-fired plants usually have no emissions control devices that would reduce mercury emissions (US EPA, 1997a).

5.1.4.3 Discussion of mercury inputs

Table 5-22 Overview of activity rate data and mercury input factor types needed to estimate releases from extraction, refining and use of natural gas

Life-cycle phase	Activity rate data needed	Mercury input factors
Extraction /Refining	Amount of natural gas produced	Concentration of mercury in extracted gas
Combustion/use	Amount of natural gas combusted	Concentration of mercury in natural gas combusted

335. Detailed estimates of national consumption of different fuel types, in totals and by sector, are available on the International Energy Agency's statistics website http://www.iea.org/stats/.

336. **Natural gas combustion**: Mercury concentrations in natural gas may vary depending on the local geology, however, mercury concentrations in consumer supplies ("pipeline gas") appear to be generally very low (COWI, 2002 and US EPA, 1997b).

337. Examples of mercury content of wellhead gas are shown in Table 5-23. The mercury content varies considerable between different regions of the world. It should be noted that it is unclear to what extent the presented data sets represent regions with particularly high mercury content.

Table 5-23 Examples of mercury concentrations in wellhead gas

Notes	**Range (μg/Nm^3)**	**Mean (μg/Nm^3)**	**Number of samples**	**Reference**
USA wellhead gas (estimated)		<1 ***1**		Wilhelm, 2001
Russian Federation, wellhead gas from oil wells	0.05-70 *1	2.4 ***1**	48	Lassen *et al.*, 2004
Russian Federation, free gas from gas wells (after primary condensate separator)	0.07-14 *1	3,4 ***1**	169	Lassen *et al.*, 2004
San Joaquin Valley, California	1.9-21			Bailey *et al.,*1961 ***2**
Middle East	<50			Hennico *et al.*, 1991 ***2**
Netherlands	0.001-180			Bingham, 1990 ***2**
South Africa	100			Hennico *et al.*,1991 ***2**
Netherlands	0-300			Gijselman, 1991 ***2**
Far East	50-300			Hennico *et al.*, 1991 ***2**
Sumatra	180-300			Muchlis, 1981; Situmorang and Muchlis , 1986 ***2**
Unknown, examples from gas filter industry	<0.01-120			UOP, undated

Notes *1 The references use the unit μg/m^3 without indicating whether the volume is normalized to Nm^3;
*2 As cited in OilTracers (1999-2004).

Table 5-24 Examples of mercury concentrations in pipeline gas (cleaned and as received at consumers)

Country	**Mercury concentration μg/m^3**	**Reference and notes**
USA	<0.02 - <0.2	Wilhelm, 2001; all results below the detection limit of the methods used for different analyses
Russian Federation	0.03 - 0.1	Lassen *et al.,* 2004
Denmark	<0.1 - 0.8	Skårup *et al.,* 2003

338. Pirrone *et al.* (2001) reported that “a reduction of mercury to below 10 μg/m^3 has to be obtained before the gas can be used”, which may indicate that mercury concentrations in consumer gas quality may be generally below this level in Europe (the geographical area of interest in the study), but that the raw natural gas may sometimes have higher mercury concentrations.

5.1.4.4 Examples of mercury in releases and wastes/residues

339. The significant part of the mercury content of the raw natural gas may generally be separated from the gas into the different gas cleaning waste waters or condensates. Table 5-25 shows an example of the distribution of mercury in a gas plant in the East Asia without mercury removal filter. The actual distribution will be highly dependent on whether mercury removal beds are installed. The cited paper present data on mercury concentration in 5 different plants, but present mass balance for one plant only. In three plants without mercury removal bed the sales gas contained up to 3000 ng/m^3; whereas for the two plants with mercury removal beds the concentration were 10 and 2 ng/m^3, respectively. In the specific plant 68% of the mercury ended up in the sales gas. It should be noted that the percentage ending up in the sales gas will be highly dependent on the initial mercury concentration of the raw gas as the target for the cleaning process is a certain concentration in the sales gas.

Table 5-25 Example of distribution of mercury in a gas plant without mercury removal bed (Carnell and Openshaw, 2004)

Process Stream	Mercury (Kg/year)	Percentage of mercury in raw gas
Raw Gas	220	100 %
Acid Gas Removal Vent	22	10 %
Dryer Vent	3	1 %
Condensate	45	20 %
Sales Gas	150	68 %

340. The term gas condensate refers to liquids that can originate at several locations in a gas processing scheme (Wilhelm, 2001). A generic unprocessed condensate is the hydrocarbon liquid that separates in the primary separator, either at the wellhead or at the gas plant. Processed condensate is the C5+ fraction (heavier hydrocarbons) that is a product from a gas separation plant.

Table 5-26 *Examples of mercury concentrations in* gas condensates

Reference	**Number of samples**	**Range (ppb)**	**Mean (ppb)**	**SD**	**Notes**
Olsen *et al*., 1997 ***1**	4	NR	15		Origins not reported
Shafawi *et al*., 1999 ***1**	5	9-63	30	18.6	S.E. Asia
Tao *et al*., 1998 ***1**	7	15-173	40		Asian
Lassen *et al*., 2004	5	60-470	270	270	Russian Federation
Bloom, 2000 ***1**	18	NR	3,964	11,655	Mostly Asian

Notes: *1 As cited by Wilhelm (2001); "NR" means not reported.

341. In an example from the Gulf of Thailand the produced water before cleaning in three fields was reported to contain 191-235 ppb, 155 ppb and 11 ppb, respectively (Gallup and Strong, 2006). After treatment with a 0.45 µm filtrate the concentration was reduced to <1-10 ppb. The main part of the produced water from the fields was injected in the fields while a minor part was discharged to the water. As example of the significance of the mercury discharges with production water, 40 – 330 kg Hg/year with an average value of 187 kg Hg/year was released with production water into the Gulf of Thailand between 1991 and 1996 (Chongprasith *et al.,* 2009). In recent years various treatment technologies have been employed to remove the mercury prior to discharge.

342. For pipeline gas, i.e. the gas received by consumers, all mercury inputs may be considered as released to air during use or combustion.

5.1.4.5 Input factors and output distribution factors

343. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that these default factors are based on a limited data base, and as such, they should be considered preliminary and subject to revisions. In many cases calculating releases intervals will give a more appropriate estimate of the actual releases.

344. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually, release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

a) Default mercury input factors

345. Actual data on mercury levels in the particular natural gas extracted, refined and used, will lead to the best estimates of releases.

346. If no indications are available on the mercury concentration in the gas used, a first estimate can be made by using the default input factors selected in Table 5-27 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors have been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum). If it is chosen not to calculate as intervals, the use of the maximum value will give the safest indication of the possible importance of the source category for further investigation. Using a high end estimate does not automatically imply that actual releases are this high, only that it should perhaps be investigated further.

Table 5-27 ***Preliminary*** *default input factors for mercury in various natural gas qualities*

Gas quality	**Default input factors; µg Hg/Nm^3 gas; low end - high end (intermediate)**
Raw or pre-cleaned gas	2 – 200 (100)
Pipeline gas (consumer quality)	0.03 – 0.4 (0.22)

347. Natural gas production data may be given as TJ (Terajoule), which can be converted to the unit needed in the Toolkit, Nm3 (normal cubic meters), by multiplying the TJ number with 25,600 Nm^3/TJ (an average gross calorific value of natural gas derived from http://www.iea.org/stats/docs/statistics_manual.pdf, p182).

b) Default mercury output distribution factors

348. For extraction processes and combustion/use of natural gas, the default factors shown in Table 5-28 below can be used to calculate an indicative mercury release estimate.

Table 5-28 ***Preliminary*** *default output distribution factors for mercury from extraction, refining and use of natural gas*

Phase of life cycle	**Output distribution factors, share of Hg input**					
	Air	**Water**	**Land**	**Products *1**	**General waste**	**Sector specific treatment/ disposal *2**
Extraction and processing - without mercury removal	0.2	0.2		0.5	0.1	
Extraction and processing - with mercury removal *2	0.1	0.2		0.1	0.6	?
Combustion/use	1					

*1: Includes both sales gas and condensate

*2: Actual fate of mercury in residues may vary between countries, and may be deposition, recovery or marketing of the mercury.

c) Links to other mercury sources estimation

349. No links suggested.

5.1.4.6 Source specific main data

350. The most important source specific data would in this case be:

- Measured data or literature data on mercury concentrations in the natural gas extracted, refined and combusted at the source;
- Amount of natural gas extracted, refined and burned; and
- Measured data on emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

351. See also advice on data gathering in section 4.4.5.

5.1.5 Other fossil fuels - extraction and use

5.1.5.1 Sub-category description

352. This category includes extraction and use of other fossil fuels such as peat (which is a very young form of coal) and oil shale. Oil shale is a type of shale from which a dark crude oil can be recovered by distillation. Like other fossil and non-fossil fuels these may contain traces of mercury, which can be mobilized by extraction and combustion.

353. Only limited data have been collected on these potential mercury release sources for this Toolkit version. If no other data can be found during inventory development work, an option is to measure mercury concentrations in the fuel types used and in any residues and releases produced.

5.1.5.2 Main factors determining mercury releases and outputs

Table 5-29 Expected release pathways and receiving media during the life-cycle of extraction and use of other fossil fuels

Phase of life cycle	Air	Water	Land	Product	General waste	Sector specific treatment/ disposal
Extraction						
Combustion	**X**	x	x		x	x

Notes: **X** - Release pathway expected to be predominant for the sub-category;

x - Additional release pathways to be considered, depending on specific source and national situation.

5.1.5.3 Example of mercury inputs

Table 5-30 Overview of activity rate data and mercury input factor types needed to estimate releases from extraction and use of other fossil fuels

Life-cycle phase	Activity rate data needed	Mercury input factor
Combustion	Amount of fuels used	Mercury concentration in fuels used

354. Mercury is known to be present in peat and oil shale. For example, one study in North Carolina, USA, reported total mercury concentrations from 40 - 193 ng/g (dry weight) in peat, based on measurement data (Evans *et al*., 1984).

355. Detailed estimates of national consumption of different fuel types, in totals and by sector, are available on the International Energy Agency's website http://data.iea.org/ieastore/statslisting.asp.

5.1.5.4 Examples of mercury in releases and wastes/residues

356. No data collected.

5.1.5.5 Input factors and output distribution factors

a) Default mercury input factors

357. Peat: If no other data are available, the mercury concentration mentioned in section 5.1.5.3 above may be used.

358. Oil shale: No factor was developed.

b) Default mercury output distribution factors

359. Peat: If nothing else is known, 100% of the mercury in the peat can be considered as released to air (as a rough estimate - minor amounts of mercury may likely follow combustion residues and ashes).

360. Oil shale: No factors were developed for this source sub-category.

c) Links to other mercury sources estimation

361. No links suggested.

5.1.6 Biomass fired power and heat production

5.1.6.1 Sub-category description

362. Many countries and regions rely heavily on the combustion of biomass for power and heat production. These sources combust wood, including twigs, bark, sawdust and wood shavings; and/or agricultural residues (such as straw, citrus pellets, coconut shells, poultry litter and camel excretes) (UNEP, 2003). Wood wastes are used for fuel in industry. In the residential sector, wood is used in wood stoves and fireplaces (Pirrone *et al.*, 2001). For this Toolkit, sources within this sub-category include wood-fired boilers, other types of biomass-fired boilers, wood stoves, fireplaces and other biomass burning. For the boilers, it is assumed that reasonably well-operated and maintained power steam generators are employed in order to maximize power output. This section does not address firing of contaminated wood.

363. Biomass is burned in a wide array of devices for power generation ranging from small stoker fired furnaces to large elaborate highly sophisticated boiler/burner systems with extensive air pollution control (APC) devices. The combustion of biomass for power generation takes place predominantly in

two general types of boilers (stokers and fluidized bed boilers), which are distinguished by the way the fuel is fed to the system (UNEP, 2003).

364. The stokers fired boilers use a stationary, vibrating or travelling grate on which the biomass is transported through the furnace while combusted. Primary combustion air is injected through the biomass fuel from the bottom of the grate. All these firing systems burn biomass in a highly efficient manner leaving the majority of the ash as a dry residue at the bottom of the boiler (UNEP, 2003).

365. The fluidized bed boilers use a bed of inert material (*e.g.,* sand and/or ash), which is fluidized by injecting primary combustion air. The biomass is shredded and added to the fluidized bed, where it is combusted. The fluidized ash, which is carried out with the flue gas, is commonly collected in a (multi-) cyclone followed by an ESP or baghouse and re-injected into the boiler. None or very little bottom ash leaves the boiler, since all the larger ash particles either remain within the fluidized bed or are collected by the cyclone separator. Thus, almost all the ash is collected as fly ash in the ESP or baghouse (UNEP, 2003).

366. Heating and cooking in residential households with biomass is common practice in many countries. In most cases the fuel of preference is wood, however, other biomass fuels may be used.

367. Biomass for residential heating and cooking is burned in a wide array of devices ranging from small, open pit stoves and fireplaces to large elaborate highly sophisticated wood burning stoves and ovens. The combustion of biomass for household heating and cooking occurs predominantly in devices of increasing combustion efficiency, as the gross national product and the degree of development of countries increase (UNEP, 2003).

5.1.6.2 Main factors determining mercury releases and outputs

Table 5-31 Main releases and receiving media from biomass fired power and heat production

Phase of life cycle	Air	Water	Land	Product	General waste	Sector specific treatment/ disposal
Combustion	**X**	x	x		x	x

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

368. The most important factors determining releases are the mercury levels in the fuel and amount of fuel burned. Mercury in biofuels originates from both naturally present mercury and mercury deposited from anthropogenic emissions (COWI, 2002). For example, trees (especially needles and leaves) absorb mercury from the atmosphere overtime. This mercury is readily released mostly to air when the wood and other biomass are burned (Friedli, H.R. *et al*., 2001).

369. Mercury releases from wood combustion and other biofuels may be significant in some countries (COWI, 2002). Most of the mercury in the biomass is expected released to the air from the combustion process. A smaller amount of mercury may be released to the ashes or residues, the extent of which depends on the specific material burned, type of combustion device, and any emission controls present.

5.1.6.3 Discussion of mercury inputs

Table 5-32 Overview of activity rate data and mercury input factor types needed to estimate releases from biomass fired power and heat production

Activity rate data needed	Mercury input factor
Type and amount of biomass burned	Concentration of mercury in the biomass burned

370. The main input factor needed is the concentration of mercury in the wood or other biomass burned at the source and the amount of each type of biomass that is burned.

371. For uncontrolled wood combustion sources, the US EPA developed an emission factor of 0.0021 grams of mercury per metric tons of wood, as burned (i.e., wet weight). Using the assumption that all of the mercury in wood from these uncontrolled sources is emitted to the air, it is estimated that the average concentration of mercury in wood burned in the USA is about 0.002 ppm (US EPA, 1997a and NJ MTF, 2002).

372. An average atmospheric emission factor of 0.0026 g mercury per metric tons burned wood is recommended by the US EPA as the so-called "best typical emission factor" for wood waste combustion in boilers in the USA (US EPA, 1997b).

373. In investigations in the USA, the mercury content of litter and green vegetation from seven locations in the USA ranged from 0.01 – 0.07 mg Hg/kg dry weight (Friedly *et al*., 2001).

374. According to Danish investigations the mercury content of wood and straw burned in Denmark is in the range of 0.007 - 0.03 mg/kg dry weight (Skårup *et al*., 2003).

375. Swedish investigations found mercury concentrations of 0.01 - 0.02 mg/kg dry weight in fuel wood; however, concentrations of 0.03 - 0.07 mg/kg dry weight in willow wood were found (Kindbom and Munthe, 1998). In bark, a mercury concentration of 0.04 mg/kg dry weight was found, whereas in fir needles the concentration was 0.3 - 0.5 mg/kg dry weight (Kindbom and Munthe, 1998).

376. Detailed estimates of national consumption of different fuel types, in totals and by sector, are available on the International Energy Agency's website http://data.iea.org/ieastore/statslisting.asp.

5.1.6.4 Examples of mercury in releases and wastes/residues

377. Although some wood stoves use emission control measures such as catalysts and secondary combustion chambers to reduce emissions of volatile organic compounds and carbon monoxide, these techniques are not expected to affect mercury emissions. However, some wood-fired boilers employ PM control equipment that may provide some reduction. Currently, the four most common control devices used in the USA to reduce PM emissions from wood-fired boilers are mechanical collectors, fabric filters, wet scrubbers, and electrostatic precipitators (ESP's). Of these controls, the last three have the potential for significant capture of mercury (US EPA, 1997a, US EPA, 2002a and US EPA, 1996).

378. The most widely used wet scrubbers for wood-fired boilers in the USA are venturi scrubbers. No data were identified on the control efficiency of these devices for mercury emissions on wood boilers. However, some control is expected. Fabric filters and ESP's are also employed on some of these wood boilers. Data were not identified for the control efficiencies of these devices on wood fired boilers. However, based on data from coal combustion plants, collection efficiencies for mercury by FFs may be 50% or more, and efficiencies for ESP's are likely to be somewhat lower, probably 50% or less (US EPA, 1997a and US EPA, 2002a).

379. The data on mercury releases from wood combustion are limited. A report by the National Council of the Paper Industry for Air and Stream Improvement (NCASI) in the USA provided a range

and average emission factor for boilers without ESP’s and for boilers with ESP’s (NCASI, 1995, as cited in US EPA, 1997a). The boilers without ESP’s had a variety of other control devices including cyclones, multiclones, and various wet scrubbers. The average emission factor reported for boilers without ESP’s was 3.5 x 10^{-6} kg/metric tons of dry wood burned. The average emission factor reported for boilers with ESP’s was 1.3 x 10^{-6} kg/metric tons of dry wood burned. For combustion of wood scraps in uncontrolled boilers, the US EPA established an average emission factor for mercury emissions (based on four emission tests) of 2.6 x 10^{-6} kg/metric tons of wet, as-fired wood burned (U.S EPA 1997a).

5.1.6.5 Input factors and output distribution factors

380. Based on the so far compiled examples of mercury concentrations in biomass and general information on emission reduction system efficiency, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

381. Bearing in mind the large variation presented above on both mercury concentrations in biomass and the efficiency of emission reduction systems on mercury, the use of source specific data is the preferred approach, if feasible.

a) Default mercury input factors

Fossil fuels, if used, will also contribute to mercury inputs, but fossil fuels are accounted for in other sub-categories.

*Table 5-33 **Preliminary** default input factors for mercury in coal for energy production*

Material	Default input factors; g mercury per metric ton of biomass (dry weight); (low end - high end)
Biomass used in combustion (principally wood)	0.007 - 0.07

b) Default mercury output distribution factors

*Table 5-34 **Preliminary** default distribution factors for mercury outputs from pulp and paper production (with own pulp production)*

Emission reduction device	Distribution factors, share of Hg input					
	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
None	1					

c) Links to other mercury sources estimation

382. No links suggested.

5.1.6.6 Source specific main data

383. The most important source specific data would in this case be:

- Measured data or literature data on the mercury concentrations in the types of biomass combusted at the source;
- Amount of each type of biomass burned; and
- Measured data on emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

384. See also advice on data gathering in section 4.4.5.

5.1.6.7 Summary of general approach to estimate releases

385. The overall approach to estimate releases of mercury to each pathway from biomass combustion is as follows:

Input factor (concentration of Hg in the biomass burned at plant)	*	**Activity rate** (amount of each type of biomass burned per year)	*	**Distribution factor** for each pathway

and the total releases are the sum of the releases to each pathway.

5.1.7 Geothermal power production

5.1.7.1 Sub-category description

386. Geothermal power plants exploit elevated underground temperatures for energy production and are mostly situated in areas with special geothermal activity, sometimes in areas with volcanic activity. These power plants are either dry-steam or water-dominated. For dry-steam plants, steam is pumped from geothermal reservoirs to turbines at a temperature of about 180 °C and a pressure of 7.9 bars absolute. For water-dominated plants, water exists in the producing strata at a temperature of approximately 270 °C and at a pressure slightly higher than hydrostatic. As the water flows towards the surface, pressure decreases and steam is formed, which is used to operate the turbines (US EPA, 1997a).

387. The mercury releases from geothermal power plants are caused by the human mobilisation of mercury naturally occurring under these geological conditions. Note that mercury releases may be expected to vary significantly depending on local geological conditions.

5.1.7.2 Main factors determining mercury releases and mercury outputs

Table 5-35 Main releases and receiving media during geothermal power production

Phase of life cycle	Air	Water	Land	General waste	Sector specific treatment/ disposal
Geothermal power production	X				

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

388. Mercury is released to the air from geothermal power plants, and possibly to other media. Mercury emissions at geothermal power plants are released via two outlet types: off-gas ejector and cooling towers (US EPA, 1997a).

5.1.7.3 Discussion of mercury inputs

Table 5-36 Overview of activity rate data and mercury input factor types needed to estimate releases from geothermal power production (example)

Life-cycle phase	Activity rate data needed	Mercury input factor
Geothermal power production	MWe/hour	Grams (g) Hg released per MWe/hour

5.1.7.4 Examples of mercury in releases and wastes/residues

389. For off-gas ejectors the US EPA presents a range of atmospheric emissions factors of 0.00075 - 0.02 grams of mercury per megawatt hour (g/MWe/hr) with an average of 0.00725 g Hg/MWe/hr. For cooling towers, EPA presents a range of 0.026 - 0.072 g Hg/MWe/hr for air emissions factors with an average of 0.05 g/MWe/hr (US EPA, 1997a). However, these factors are based on limited emissions data obtained in 1977 in the USA and process information was not provided and the data have not been validated. Therefore, the emissions factors should be used with caution (US EPA, 1997a).

5.1.7.5 Input factors and output distribution factors

390. No attempt was made so far to develop default input and output factors for this sub-category. If no specific data are available, release estimates might be based on the information given above.

5.2 Primary (virgin) metal production

Table 5-37 Primary (virgin) metal production: sub-categories with main pathways of releases of mercury and recommended inventory approach

Chapter	Sub-category	Air	Water	Land	Product	Waste/ residue	Main inventory approach
5.2.1	Primary extraction and processing of mercury	**X**	**X**	**X**	**X**	**X**	PS
5.2.2	Gold and silver extraction with mercury-amalgamation process	**X**	**X**	**X**			OW
5.2.3	Zinc extraction and initial processing	**X**	**X**	**X**	**X**	**X**	PS
5.2.4	Copper extraction and initial processing	**X**	**X**	**X**	**X**	**X**	PS
5.2.5	Lead extraction and initial processing	**X**	**X**	**X**	**X**	**X**	PS
5.2.6	Gold extraction and initial processing by other processes than mercury amalgamation	**X**	**X**	**X**	**X**	**X**	PS
5.2.7	Aluminum extraction and initial processing	**X**		x		**X**	PS
5.2.8	Extraction and processing of other non-ferrous metals	**X**	**X**	**X**		**X**	PS
5.2.9	Primary ferrous metal production	**X**				x	PS

Notes: PS = Point source by point source approach; OW = National/overview approach;

X - Release pathways expected to be predominant for the sub-category;

x - Additional release pathways to be considered, depending on specific source and national situation.

5.2.1 Mercury extraction and initial processing

5.2.1.1 Sub-category description

391. Mercury mining is known to have caused extensive mercury releases to terrestrial, atmospheric and aquatic environments, with both local and regional pollution as a consequence. There are examples of nations with former mercury mining activities struggling to manage such pollution many years after the mining activities have ceased. Release reduction technologies may perhaps be applied in some cases, possibly influencing the distribution of releases among the environmental compartments. Many mercury mines have ceased production during the last decades, due to the decreased demand in the western world.

392. Estimates for global primary production of mercury from dedicated mercury mining and mercury produced as a by-product from other mining or extraction processes, as reported by the US Geological Survey, are presented in Table 5-38. Only some of the countries listed in the table still had dedicated mercury mining in 2005; examples were Spain, Algeria and Kyrgyzstan. In 2009 this was only Kyrgyzstan and China . Reese (1999) notes, however, that most countries do not report their mercury production, resulting in a high degree of uncertainty on the presented world production numbers (UNEP, 2002). See UNEP (2002) for more information.

393. This sub-category covers only the processes involved in intended mining of mercury. Production and marketing of mercury as a by-product from other mining or extraction processes, as well as production of post-consumer recycled mercury, are covered in other sections of this document.

Table 5-38 Estimated world production of primary (mined) mercury (metric tons), as reported by the US Geological Survey (Jasinski, 1994; Reese, 1997; 1999; unless noted; aggregation as presented in the submission from the Nordic Council of Ministers) and by Hylander and Meili (2002) for the year 2000)

Country	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Algeria ***1**	459	414	292	368	447	224	200	240
China ***2**	520	470	780	510	830	230	200	200
Finland ***3**	98	89	90	88	63	80	80	45
Kyrgyzstan ***4**	1000	379	380	584	610	620	620	600
Mexico	12	12	15	15	15	15	15	25
Russia	60	50	50	50	50	50	50	-
Slovakia	50	50	0	0	0	20	0	0
Slovenia	?	6	0	5	5	5	0	0
Spain	643	393	1497	862	863	675	600	237 ***5**
Tajikistan	80	55	50	45	40	35	35	40
Ukraine	50	50	40	30	25	20	-	-
USA	W	W	w	65	w	-	-	15
Other countries	-	223	200	-	-	830	380	448
Totals for reported activity (rounded)	3000	2200	3400	2600	2900	2800	2200	

Notes: This table was adapted from table 7.2 of UNEP, 2002;
w Withheld in the references;
\- Not relevant or not available;

1 Numbers for Algeria in 2003 and 2004 (estimated) have been reported to be 300 and 400, respectively. Source: http://minerals.usgs.gov/minerals/pubs/commodity/mercury/mercumcs05.pdf
2 Numbers for Chine in 2003 and 2004 (estimated) have been reported to be 610 and 650, respectively. Source: Idem
3 Numbers for Finland from 1993-1997 are from Finnish Environment Institute (1999) and represent by-product mercury from zinc production;
4 Numbers for Kyrgyzstan in 2003 and 2004 (estimated) have been reported to be 300 and 300, respectively. Source: http://minerals.usgs.gov/minerals/pubs/commodity/mercury/mercumcs05.pdf
5 Spain has reported a production in 2000 of 237 metric tons from the Spanish mercury mines. Numbers for Spain in 2003 and 2004 (estimated) have been reported to be 150 and 200, respectively. Source: http://minerals.usgs.gov/minerals/pubs/commodity/mercury/mercumcs05.pdf

394. Despite a decline in global mercury consumption (global demand is less than half of 1980 levels), supply from competing sources and low prices, intended production of mercury from mining is still occurring in few countries. While about 25 principal mercury minerals are known, virtually the only deposits that have been harvested for the extraction of mercury are cinnabar (UNEP, 2002).

395. Mercury is extracted by the use of pyrometallurgical processes. For a description of processes involved, see European Commission (2001).

5.2.1.2 Main factors determining mercury releases and outputs

Table 5-39 Main releases and receiving media during the life-cycle of primary extraction and processing of mercury

Phase of life cycle	Air	Water	Land	Product	General waste	Sector specific treatment/ disposal
Extraction and processing	X	X	X	X		X

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

5.2.1.3 Discussion of mercury inputs

Table 5-40 Overview of activity rate data and mercury input factor types needed to estimate releases from primary mercury production.

Potential Activity rate data to be used to estimate releases	Possible input factor
Total amount of mercury produced	Mercury input per unit of mercury produced

396. Mercury is a natural component of the earth, with an average abundance of approximately 0.05 mg/kg in the Earth’s crust, with significant local variations. Mercury ores that are mined generally contain about 1% mercury, although the strata mined in Spain typically contained up to 12-14% mercury (UNEP, 2002).

397. Mercury balances have been made for one of the large mercury extraction facilities in the world in Idrija, Slovenia, which was closed down in 1995. For the total period of 1961-1995, 9777 metric tons of mercury was extracted from 4.2 million metric tons of ore. For the same period, an estimated 243 metric tons of mercury was lost to the environment, of which 168 metric tons were deposited in landfills as smelting residue, 60 tons was emitted to the atmosphere with flue gas, and 15 tons was released to the Idrija river with condensation water (Kotnik *et al.*, 2004).

5.2.1.4 Examples of mercury in releases and wastes/residues

398. Qi (1998) was cited by Pirrone and Mason (Eds., 2008) for an atmospheric emission factor of 45 Kg Hg/metric ton Hg produced (presumable from Chinese mercury smelters).

399. From the Khaidarkan mine of Kyrgyzstan it was estimated that over the last few years (before 2008) the facility emitted about 3.5 metric tons of mercury annually, and the annual production in 2008 was slightly less than 300 metric tons of mercury (Kyrgyzstan Mercury team of UN Environment, UNITAR and Zoï Environment Network (2009)).

400. See also information above.

5.2.1.5 Input factors and output distribution factors

401. Based on the limited information presented above, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. For this source category, it is highly recommended to try to get facility-specific data as the release situation likely differ significantly depending on local production setup and release prevention equipment in place. The primary purpose of using these default factors is to get a first impression of the significance of this sub-category in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

a) Default mercury input factors

402. If no site specific information is available, a first estimate can be formed by using the default input factors selected in Table 5-41 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum). If it is chosen not to calculate as intervals, the use of the maximum value is recommended in order to signal the possible importance of the source category for further investigation. Using a high end estimate does not automatically imply that actual releases are this high, only that it should perhaps be investigated further.

Table 5-41 ***Preliminary*** *default input factors for primary mercury production*

Material	Default input factors; kg mercury input per metric ton of mercury produced; low end - high end (intermediate)
Mercury in ore	1,020 – 1,040 (1,030)

b) Default mercury output distribution factors

403. A preliminary set of default output distribution factors based on the Slovenian data presented above is shown in the table below. Site-specific distribution factors should be applied, if available.

Table 5-42 ***Preliminary*** *default output distribution factors for primary mercury production*

Phase of life cycle	Air	Water	Land *1	Product	General waste *1	Sector specific treatment/ disposal *1
Production of mercury from ore *2	0.0073	0.0017	0.0201	-	?	?

Notes *1: Actual distribution of residues between deposition forms may vary between countries; here it is assigned to land to signal a possible worst case (local tailings deposit with no membranes). Adjust with facility-specific information, if available.

*2: The total mercury input to the process is what we calculate as the "Calculated Hg input", but for this specific source sub-category, only the part of the mercury actually being released during production is included in the release estimates. Therefore, the output distribution factors only sum up to the share of mercury being released. The output distribution factors shown correspond to air: 25%, water: 6% and land: 69% of total releases.

c) Links to other mercury sources estimation

404. No links suggested.

5.2.1.6 Source specific main data

405. The most important source specific data would in this case be:

- Measured data on the mercury concentrations in the ores and concentrates extracted and processed at the source;
- Amount of ore extracted and processed; and

- Measured data on the distribution of mercury outputs with (preferably all) output streams, including mercury percentages retained by emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

5.2.1.7 Source specific main data

406. The most important source specific data would in this case be:

- Amount of ore processed and mercury concentrations in these ores;
- Amount of mercury recovered;
- Amount of mercury lost per unit ore processed or per unit mercury recovered; and
- Control technologies present and the performance of these controls.

5.2.2 Gold (and silver) extraction with mercury-amalgamation processes (ASGM)

5.2.2.1 Sub-category description

407. Mercury has been used in gold and silver mining since Roman times. Generally, this mining process involves the following: the wet ore (or mud or ore concentrate) is mixed with metallic (liquid) mercury; the mercury dissolves (algamates) the gold or silver in the mud; the remaining mud is washed away leaving a mercury-gold (-silver) amalgam; and the amalgam is then heated ("burned") to release the mercury, with impure gold (and silver) remaining. Mercury released to the biosphere due to this ancient activity of gold and silver extraction with mercury amalgamation may have reached over 260,000 metric tons in the period from 1550 to 1930, after which known, easily exploitable gold and silver reserves were nearly exhausted, and the mercury amalgamation process was partly replaced by the more efficient large scale cyanidation process, enabling extraction of gold (and/or silver) from large deposits of low-concentration ores (UNEP, 2002). Some ASGM miners also use cyanidation, sometimes in combination with mercury amalgamation which has the potential of spreading mercury more readily to waterways and the ground.

408. Note that ASGM where mercury amalgamation is not used (such as traditional panning of gold nuggets in rivers), should not be counted here.

409. Increases in gold prices and the prevailing difficult socio-economic situation in the 1970’s, resulted in new rises of the gold rush, especially in the southern hemisphere, involving more than 10 million people on all continents. Presently, mercury amalgamation is used for gold extraction in many countries in South America, Asia and Africa. By way of example, in Brazil, mercury amalgamation was used for the production of 5.9 metric tons of gold in 1973. In 1988, this figure had increased to over 100 metric tons per year. During the 1990’s this figure decreased again due to falling gold prices and exhausted deposits (Uppsala University, as cited in UNEP, 2002); yet the activity persists in many countries throughout the developing world and has again been on the rise with increasing gold prices.

410. Based on studies by various researchers, it was estimated that somewhere between 350 and 1000 tons of mercury have been used globally per year in the 1990s for artisanal small-scale gold mining (ASGM) (UNEP, 2002). An estimate for the mercury supply ("consumption") in 2010 for ASGM was some 990-2,200 metric tons (Mercurywatch.org, 2012).

5.2.2.2 Main factors determining releases and mercury outputs

Table 5-43 Main releases and receiving media from gold and silver extraction with the mercury-amalgamation process

Phase of life cycle	**Air**	**Water**	**Land**	**Product**	**General waste**	**Sector specific treatment/ disposal**
Gold and silver extraction with the mercury-amalgamation process	X	X	X			

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

411. Mercury is released directly from these mining activities to the air, water, sediments and soils. The mercury-gold amalgam from the extraction process releases mercury as vapour to the air when heated in one of the steps in the purification. The evaporation is often done with no retention of the evaporated mercury. Sometimes the evaporation step is done in "retorts", in which parts of the evaporated mercury are condensed, cleaned ("re-activated") and re-used. Mercury is also present in mine tailings, which can lead to future releases to land, water and air. Mercury is found at extraction sites, trading posts, and in soil, plants, sediments and waterways in the area of these operations. This gold extraction process is simple and cheap, but not very efficient either in terms of gold recovery or mercury retention. The process has lead to intense mercury pollution of the terrestrial, aquatic and atmospheric environment in large areas around these operations, and has also contributed significantly to the levels of mercury in the global environment (COWI, 2002).

5.2.2.3 Discussion of mercury inputs

Table 5-44 Overview of activity rate data and mercury input factor types needed to estimate releases from gold and silver extraction with the mercury-amalgamation process

Potential Activity rate data to be used to estimate releases	**Possible input factor**
Total amount of gold (and silver) produced using such techniques	Estimate of average ratio of mercury consumed per unit of gold (/silver) produced with feed materials and technology prevailing in the area investigated
Or Total annual mercury purchases (consumption) for ASGM	(Factor is 1, as mercury consumption is the actual input)

Note *1: The default mercury input calculations in the Inventory Level 2 spreadsheet are based on amount of gold produced, but in case total annual mercury purchase data are available, they can be introduced directly in the calculations. For most countries with ASGM activities, estimates of mercury consumption can be found at www.mercurywatch.org.

412. Desk studies of mercury use and releases from artisanal and small-scale gold mining (ASGM) can only give very rough estimates, and whenever possible, field studies are recommended. Indicative estimates of potential mercury inputs to small-scale mining may be estimated from simple thumb's rules, but more factors can be involved when attempting to qualify mercury inputs and release estimates further in a country or region. These factors are discussed here. Note that many ASGM areas have been investigated by field experts, and assessments of mercury consumption may exist and should be included in the research made. Also, for most countries with ASGM activities, estimates of mercury consumption can be found at www.mercurywatch.org, and these numbers can be used for a first estimate of the total mercury releases from ASGM.

413. Main factors influencing mercury inputs and releases are:

- Total gold produced per year per miner using mercury
- Total number of miners (distinguish between people actually in the shaft or pit, and total number of people engaged on the mining site; take care to use the same basis for this and the above number)
- Mercury consumed to gold produced (Hg:Au) ratio - this varies depending on the methods used; whole ore amalgamation consumes much more mercury than concentrate amalgamation.
- Percent of mercury recycled (0% with no retorts, up to 95% with retorts or fume hoods).

414. The amount of mercury used per unit gold (or silver) extracted varies according to methods and equipment used and other factors. For example, if mercury is used to extract gold from the whole ore, and no recovery devices are utilized, the ratio of amount of mercury used to amount of gold extracted (Hg_{used}:$Au_{extracted}$) is >3:1 (i.e., more than 3 kg of mercury used per 1 kg of gold obtained). If mercury is used on ore concentrates (instead of whole ores) the (Hg_{used}:$Au_{extracted}$) ratio is about 1.3:1. If a retort is used, the amount of mercury used is lower, because some of the mercury is captured during amalgam burning and reused (Telmer, 2012; UNIDO, 2003). Lacerda (1997) reviewed literature on estimated mercury amounts consumed per kg of gold produced with the amalgamation process and reported that while such input factors varied widely, most fell in the interval of 1-2 kg mercury consumed per 1 kg gold produced. But since then, other observations have shown mercury consumption rates of 20 Hg :1 Au when mercury is placed directly in the grinding circuit (whole ore amalgamation), and as high as 50 Hg :1 Au when ores also contain significant concentrations of silver, which forms a poorer amalgam with higher mercury concentrations in it. Anecdotal evidence from Southeast Asia indicate that even higher rates have been observed for whole ore amalgamation. According to the practical guide on baseline estimates (Artisanal Gold Council, 2015) a typical mercury to gold ratio for whole ore amalgamation is however 5:1. Due to the high variation in this factor, it is recommended to make measurements of the factor, whenever possible.

415. In addition to the intentional use of mercury, another - yet generally much smaller - source of mercury from gold mining is the mobilization of naturally occurring mercury impurities in gold ore (COWI, 2002).

5.2.2.4 Examples of mercury in releases and wastes/residues

416. The percent of mercury lost and the pathways of release vary with amalgamation method. If no controls are used and the amalgam is burned in open containers to evaporate the mercury, then all of the mercury in the amalgam is released to air and no mercury is recovered. On the other hand, if a retort is used, the atmospheric releases will be smaller, because some of the mercury is recovered in the retort and re-used. According to UNIDO (2003) mercury recovery from the process ranges from about 51 - 99%. Telmer (2012) states that average recovery is about 80-95%.

417. According to Lacerda, an estimated 65-87% of the mercury inputs were deemed emitted to the atmosphere (likely with no or little retort use), and the rest was released to soil and aquatic environments (Lacerda, 1997, as cited in UNEP, 2002).

418. According to 2012 estimates by Telmer and associates described in UNEP/AMAP (2012), on average 45% of mercury used in ASGM is emitted to the atmosphere with the remainder released to land and water. In regions where concentrate amalgamation is practised, 75% of the mercury used is considered emitted to the atmosphere, whereas localities that practice whole ore amalgamation use much more mercury per unit gold produced, but release a much larger portion of the mercury to aquatic and terrestrial systems. Eventually, much of the mercury lost to water will be emitted to the atmosphere over the years due to secondary evaporation. Estimates from Australia and Canada suggest

that a large proportion of the mercury used in historical gold mining operations in the 1800's has been remobilised.

419. Telmer (2012) adds that when whole ore amalgamation is practiced, a smaller percentage of the total use is emitted to air (25%), because much ends up in the tailings and other wastes. But the magnitude of what is released to air is still very large because the intensity of mercury use is so much higher. The distribution of mercury releases between water and land will vary depending on local conditions and is difficult to say anything general about.

420. With the use of retorts, mercury captured can be re-used after "re-activation", a process where impurities are cleaned out of the recycled mercury to make it amalgamate better in the next use cycle. A 5% mercury loss (to water and land) from each re-activation is assumed.

421. In several countries, there are examples of programmes to promote less polluting mercury-based extraction equipment, raise awareness of hazardous qualities of mercury and provide other assistance and information regarding environmental, social and business aspects. Some projects are also assessing or attempting to enhance the possibilities and capabilities of authorities to enforce environmental regulations in small-scale gold mining areas (see examples at the web page of the Global Mercury Partnership on artisanal and small-scale gold mining at http://www.unep.org/hazardoussubstances/Mercury/GlobalMercuryPartnership/tabid/1253/Default.aspx).

422. A useful reference on how mercury is used in ASGM is UN Environment's Practical Guide: Reducing mercury use in artisanal and small-scale gold mining: http://www.unep.org/hazardoussubstances/Portals/9/Mercury/Documents/ASGM/Techdoc/UNEP%20Tech%20Doc%20APRIL%202012_120619%20with%20links_web.pdf.

423. For an overview of inputs and emissions/releases with the different amalgamation methods, please see below under input factors and output distribution factors.

Recommendations for estimating mercury releases from mining operations

424. Telmer in UNEP/AMAP (2012) states the following about mercury release estimation from ASGM: "The total amount of mercury used in ASGM can be estimated using 4 main approaches: (1) direct measurements – using a balance to directly weigh amounts of mercury used; (2) applying a mercury/gold (Hg:Au) ratio to estimates of gold production based on the type of processing in use (whole ore amalgamation or concentrate amalgamation or the use of emission controls like retorts, etc.); the estimates of gold production can come from the number of miners actively mining and their average yearly gold production, or from other sources such as government reports on gold production or mining populations; (3) interviewing miners and gold merchants who buy or sell mercury; (4) using official trade data. The first three approaches involve directly working with miners and gold merchants. This information can then be used to constrain, through triangulation, a more robust estimate of the amount of mercury used and released to the environment and the amount emitted to the atmosphere. A detailed guideline for such estimation is given by Artisanal Gold Council (2015).

425. The most reliable results are rooted in field work and relationships with stakeholders. In order to do this, personnel making the estimation must be capable of understanding mining practices and gold trade. Mercury use practices and gold production are key pieces of information. Determining these requires combining information from field data, miners, mining communities, buyers, traders, geological surveys, ministries responsible for mining, mining commissions, the private sector, exploration company press releases, industry magazines, environmental ministries, and others. This information must be analysed to understand what is reasonable based on expert knowledge of geology, mining, ASGM practices, mining communities, and socio-economics. The results of the analysis should be discussed with stakeholders such as miners, concession holders, local governments, and national governments to obtain their input and help constrain the analysis.

426. The fundamental questions that need to be answered in order to make an annual estimate of mercury use and emissions are:

1. Is mercury used?

2. What are the practices in use ?(Consider: Whole ore amalgamation? Concentrate amalgamation? Mercury recycling/re-activation?)

3. How much mercury is consumed per unit gold? – grams of mercury lost per grams of gold produced? (Consider: Do miners discard used mercury?; Do the miners use retorts or recycle mercury?)

4. How much gold do miners produce per year, individually, collectively?

5. What is the total number of miners?

427. The format of the questions needs to be adapted to local conditions. For example, it is often necessary to convert the amount of gold produced per day into an annual number by taking into account further information about work habits throughout the year – for example, how work varies seasonally."

428. It should be noted that the wide-spread traditional panning of alluvial deposits of gold nuggets (e.g. by the river beds) should not be counted, if it is certain that mercury is not added intentionally. However, if there is doubt about whether mercury is used intentionally, a conservative approach may be applied assuming that mercury is used, and stating this in the inventory report and allocating this gold production to the present source sub-category of gold extraction with mercury amalgamation in the release estimations performed.

429. For more advice, see for example the detailed guideline for estimation of mercury inputs to artisanal and small-scale gold mining is given by Artisanal Gold Council (2015).

5.2.2.5 Input factors and output distribution factors

430. Based on the information compiled above on inputs and outputs and major factors determining releases, the following generalised default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows.

431. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually, release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

a) Default mercury input factors

432. As mentioned above, specific information on the gold extraction methods used will give the best mercury input estimates. If no specific information on the mercury inputs is available, the default input factor indicated below can give a rough indication of potential mercury inputs to this sector. If no information on whether whole ore or concentrates are extracted upon, and whether retorts are used, it is recommended to calculate an interval using the lowest and the highest input factors shown below to indicate the possible range of the inputs.

Derivation of input factors for amalgamation with retort use:

433. As mentioned above, when using retorts, some of the mercury is captured in the retort and re-used after re-activation. Therefore a separate derivation of input factors is necessary for this situation. The box below shows the derivation for retort use with concentrate amalgamation. Similar calculations can be made for amalgamation without retorts. The resulting default factors can be seen in the tables further below.

Table 5-45 Example of derivation of default factors for ASGM with amalgamation.

Retort use with concentrate amalgamation:	Numbers	Remarks
Default input factor **without** use of retort, kg Hg used/kg Au produced	1.3	Based on data presented above
Mercury concentration in well squeezed mercury/gold amalgam, kg Hg/kg Au	1	=50% Hg in amalgam. Field observations from Telmer (2016)
Resulting mercury lost to tailings (land and water) , kg Hg/kg Au	0.3	1.3 – 1 = 0.3
Resulting mercury emitted to air if **no** retort is used, kg Hg/kg Au	1	1.3 – 0.3 = 1
Assumed average retort efficiency, mercury retention rate, unitless *1	0.75	Share of otherwise released Hg; equal to 75%. Based on Telmer (2016)
Resulting mercury emitted to air if retort **is** used, kg Hg/kg Au	0.25	1 – (1 * 0.75) = 0.25
Total loss of mercury **with** retort use, **equalling the calculated input factor**, kg Hg/kg Au	0.55	0.3 + 0.25 = 0.55
Resulting output distribution factor to air **with** use of retort, unitless	0.45	0.25 / 0.55 = 0.45
Resulting output distribution factor to land + water **with** use of retort, unitless	0.55	0.3 / 0.55 = 0.55 For defaults to land and water, this number is assumed distributed equally to these two pathways (depends on actual mining situation)
Retort use with whole ore amalgamation:	Numbers	Remarks
Default input factor without use of retort, kg Hg used/kg Au produced	5	Based on data presented above
Resulting mercury lost to tailings (land and water), kg Hg/kg Au	4	5 – 1 = 4
Resulting mercury emitted to air if **no** retort is used, kg Hg/kg Au	1	5 – 4 = 1
Resulting mercury emitted to air if retort **is** used, kg Hg/kg Au	0.25	1 – (1 * 0.75) = 0.25
Total loss of mercury **with** retort use, equalling the calculated input factor, kg Hg/kg Au	4.25	4 + 0.25 = 4.25
Resulting output distribution factor to air **with** use of retort, unitless	0.06	0.25 / 4.25 = 0.06
Resulting output distribution factor to land + water **with** use of retort, unitless	0.94	4 / 4.25 = 0.94 Assumed distributed equally to land and water (depends on actual mining situation)

*Note: *1 A little mercury is often left in the so-called sponge gold after amalgam burning (about 5%), and if fume hoods are not used in the later gold refining steps, this may be emitted to air. Considering the uncertainty involved, this is assumed included in the overall retention rate.*

*Table 5-46 **Preliminary** default input factors for mercury consumption for gold extraction with the mercury amalgamation process*

Process	Default input factors; kg mercury per kg gold produced;
Extraction with whole ore amalgamation (no retorts)	5
Extraction with concentrate amalgamation (no retorts)	1.3
Extraction with whole ore amalgamation **with** use of retorts and mercury recycling	4.25
Extraction with concentrate amalgamation **with** use of retorts and mercury recycling	0.55

b) Default mercury output distribution factors

434. Based on the description given above, the following default output distribution factors are suggested for gold (and silver) mining using the mercury amalgamation method.

*Table 5-47 **Preliminary** default distribution factors suggested for gold (and silver) extraction with mercury-amalgamation.*

	Air	Water *1	Land *1	Products	General waste	Sector specific treatment/ disposal
Extraction with whole ore amalgamation (no retorts)	0.2	0.4	0.4			
Extraction with concentrate amalgamation (no retorts)	0.77	0.12	0.11			
Extraction with whole ore amalgamation **with** use of retorts and mercury recycling	0.06	0.47	0.47			
Extraction with concentrate amalgamation **with** use of retorts and mercury recycling	0.45	0.28	0.27			

Notes: 1* The distribution here between water and land is an assumption made here. Actual distribution will vary depending on local conditions.

c) Links to other mercury sources estimation

435. No links suggested.

5.2.2.6 Source specific main data

436. As mentioned, desk studies of mercury use and releases from artisanal and ASGM can only give very rough estimates, and whenever possible, field studies are recommended. Note that many ASGM areas have been investigated by field experts, and assessments of mercury consumption may exist and should be included as central parts in the inventory development.

437. ASGM is an activity with a lot of variation in methods and techniques. Only ASGM with mercury amalgamation should be counted here, whereas small-scale mining with heavy machinery where mercury is not used may be counted under the sub-category "Gold extraction by methods other than

mercury amalgamation." Small-scale operations with heavy machinery may process significant amounts of ore material, where trace quantities of mercury naturally present in the ore is released.

438. Note also that for most countries with ASGM activities, estimates of national mercury consumption for ASGM activities can be found at www.mercurywatch.org.

5.2.2.7 Summary of general approach to estimate releases

439. See discussions above.

5.2.3 Zinc extraction and initial processing

440. Schwarz (1997) estimated that global zinc production gives rise to mobilisation of several hundred metric tons of mercury per year - a low end estimate for 1995 was 600 metric tons - making zinc production rank among the largest sources of mercury outputs in terms of marketed by-product mercury and potential releases. According to the zinc industry (IZA, 2022), the by-product mercury amounts marketed have however been reduced in recent years due to a decline in mercury demand. Emissions to the atmosphere from non-ferrous metal production has, however, been reduced significantly in some countries in the last few decades (Environment Canada, 2002; UNEP, 2002). Hyland and Herbert (2008) estimated that around 275 metric tons mercury were emitted to the atmosphere from the production of zinc, cupper and lead, about half of which was from zinc production, and that some 228 metric tons of mercury were retained by flue gas cleaning systems in the zinc production globally.

441. The processes involved in extraction of non-ferrous metals are well described. See for example (European Commission, 2001), (Environment Canada, 2002), (Rentz *et al*, 1996) and (Zhang et al, 2012). Quantitative descriptions of mercury mass balances over such operations - corresponding input and output distribution estimates - seem, however, to be rarely published.

442. Large scale industrial mining and metal extraction operations are few in number in any country where they operate, their feed materials and production configurations vary significantly, and they may be potent mercury release sources. Given these factors, it is highly recommended to use a point source approach in the inventory, and, if feasible, compile point source specific data from the operating companies themselves, as well as from other relevant data sources with knowledge of the specific production facilities.

5.2.3.1 Sub-category description

443. Ore for extraction of zinc (mainly sulphidic ore) can contain trace amounts of mercury. In the process of extracting the zinc from the ore, processes are used which release this mercury from the rock material. This mercury may evaporate and follow the gaseous streams in the extraction processes (in most cases) or follow wet (liquid) process streams, depending on the extraction technology used. Unless the mercury is captured by process steps dedicated to this purpose, significant parts of it may likely be released to the atmosphere, land and aquatic environments. Retained mercury may be sold in the form of "calomel" (Hg_2Cl_2), for off site extraction of metal mercury or on-site processed metal mercury, or it may be stored or deposited as solid or sludgy residues (Environment Canada, 2002), with deposition becoming increasingly more common, according to IZA (2022). Marketing of recovered by-product mercury from extraction of zinc and other non-ferrous metals accounts for a substantial part of the current global mercury supply. Besides these output pathways, part of the mercury input follows co-produced sulphuric acid (Outotec, 2012; European Commission, 2001; IZA, 2022).

444. Primary production of zinc generally includes the following processes: Concentration from zinc ore, oxidation (roasting or sintering) of zinc concentrate, production of zinc (by means of electrochemical or thermal processes), and refining of zinc. Production of primary zinc is usually accompanied by production of sulphuric acid using standard processes, and also a number of by-product metals

are produced (such as Cu, Pb, Ag and Au among several others depending on the ore/concentrate types used).

445. In order to illustrate the principles influencing the mercury releases from large scale non-ferrous metal extraction, the types of processes involved are described in the following in a bit more detail with zinc production as an example.

Mining of ore and production of concentrates

446. Ore is mined from open pit or underground mines, and zinc-rich minerals are separated from the waste rock - after grinding and milling to reduce particle sizes - by mechanical separation processes, usually floatation or other processes employing suspension in water. This process is called concentrating.

447. Different zinc ore types exist and their use vary somewhat depending on the extraction technology employed as described below, but the sulphidic mineral ZnS, named "zincblende" or "sphalerite" is by far the most economically important ore type for zinc extraction (Ullmann, 2000; IZA, 2022).

448. The produced concentrate is transported to the extraction plants, which may be receiving concentrate from mines nearby, but also from the global market. For example, some plants in Canada receive mainly concentrate from local mines, while large parts of the concentrate processed in European zinc production plants are imported from the global market (Environment Canada, 2002; European Commission, 2001).

449. Waste rock with no or low metal content, is usually stored on site in tailings ponds, tailings piles/heaps or back-filled into the mines. The reject ore material which has been separated from the zinc-rich concentrate (parts of the so-called tailings) are typically disposed off in tailings ponds on the mining site.

450. The waste rock and tailings may - just like the generated concentrates - contain trace amounts of mercury. This material is much more susceptible to weathering than the original deposits, due to the reduced particle sizes and higher accessibility for air and precipitation. For sulphidic ores, which are important ore types for production of several base metals, this weathering liberates and oxidizes the contained sulphur and produce sulphuric acid. The acid renders the constituents (most likely including mercury) more soluble and may thus potentially increases leaching of the metal to the environment as compared to the untouched mineral deposit. This process is called "acid rock drainage" (or ARD) and is considered a serious environment risk (European Commission, 2003). However, according to IZA (2022), the rejects from the concentration process is fine-grained material with minimal through-flow, and most of the process water as well as incoming precipitation will leave the tailings ponds as overflow from the ponds. IZA (2022) does not present data for the fate of mercury in percolating water, except that mercury is considered primarily present as fine HgS particulates which have very low solubility in water. The (surface) water is normally partly re-circulated into the process and partly discharged after dedicated wastewater treatment to reach discharge limits in the site-specific environmental permits. The wastewater treatment process typically includes hydroxide precipitation, sulphide precipitation and settling. Limit values for Hg in discharged waters are typically <2µg/l, but in many jurisdictions, lower values are imposed. This corresponds to a mercury fraction equivalent to about 0.062 % of the mercury being present in the concentrate, being discharged with wastewater effluents according to IZA (2022, corrected).

451. Few data have been identified on mercury concentrations in crude ore and reject material, whereas more data on zinc concentrates has recently been published. Only little quantitative data on release of mercury from waste rock and mining tailings to air, water and land have been identified.

452. IZA (2022) states that mercury (as HgS) typically follows the zinc-rich Sphalerite fraction into the concentrate. Based on typical recovery rates of zinc into the concentrate, IZA proposes “15% as a top of the range conservative value to estimate the share of mercury going into tailing ponds” from the

concentrating step. They note however, that “Zinc deposits were typically in the range 6-15% Zn, with recovery rates rate ranging from 60% to 95%”, with the low end representing some older operations. The site-specific recovery rates vary depending on the ores used and the economy of the concentrating step. In some cases, old tailings are today re-processed to reach overall zinc recovery rates of some 80-85% (IZA,2022). IZA considers a zinc extraction rate of 75% as low end of range for existing operations.

453.

Extraction of zinc from concentrate

454. A zinc extraction plant is a complex mechanical/chemical production plant comprising a chain of unit operations, generally following one of the two principles called "hydrometallurgical" and "pyrometallurgical" production, which however have similarities as regards the mercury release pattern, because most of the mercury evaporates in the initial oxidation of the mercury containing mineral concentrates. The following description is focusing narrowly on aspects relevant to mercury inputs and releases. Additional overview and technical description can be found in for example (European Commission, 2001), (Environment Canada, 2002), (Rentz *et al*, 1996) and (Fugleberg, 1999).

Roasting or sintering

455. Common for the two principles is an initial oxidization (roasting or sintering) of zinc concentrate to eliminate most of the sulphur in the concentrate prior to further treatment. Sintering requires addition of fuels (oil or natural gas), which may be a source of minor additional mercury inputs, whereas roasting produces energy (by oxidation of sulphur) and requires no addition of fuels (European Commission, 2001). Both sintering and roasting take place at high temperatures (roasting at up to 1000 ^{o}C; Rentz *et al.*, 1996), and most of the mercury present in the concentrate evaporates in this oxidation step. If the production plant is equipped with a sulphuric acid production plant (which may often be the case), most of the mercury initially follows the gas stream to the acid plant.

456. Dust generating processes, including drying of wet concentrates, breaking of sinters and roasted material, may be equipped with fabric filters or other filters (Rentz *et al.*, 1996) retaining (part of) the dust, which may possibly contain a portion of the mercury inputs. Such retained dusts are often recycled back into the process, whereby any retained mercury is re-introduced in the materials flow and may become subject to releases to the environment.

Exhaust gas cleaning from roasting and sintering

457. First, the gas is passed through a sequence of particle filters, typically cyclones (retaining larger particles), hot electrostatic precipitators - ESP's (fine particles), and wet ESP's. Moisture and particles may also be controlled by the use of scrubbers. Cyclones and hot ESPs generate dry solid wastes, which may contain mercury, and wet ESP's and scrubbers generate sludges, which may likely contain more mercury than the initial residues due to lowered temperatures and content of fine particles. These residues may be recycled into other steps of the extraction operations, or disposed off on site, depending on plant configuration and content of sellable metals in the residues. Waste water from wet sludges will contain mercury and needs treatment to isolate the mercury and other hazardous components from the waste water discharge.

458. It should be noted that mercury is expected to primarily be present in the gas phase in exhaust gas cleaning steps and other decisive process steps of the smelter/extraction operations. Contrary to most other heavy metals, substantial parts of mercury is present in gaseous elemental phase which is not be associated with particles in the exhaust gases, and these parts will not be retained well in particle filters. Other parts are oxidised and can be retained in particle filters and scrubbers present.

459. If the smelter is not equipped with a dedicated mercury removal step after the particle filters, the remaining mercury - still a substantial part of mercury inputs - is released to the atmosphere or absorbed in the marketed sulphuric acid by-product.

460. If the smelter is equipped with a mercury removal step before the acid plant, mercury is separated from the gas here by specific methods for this purpose, for example in the form of "calomel" (Hg_2Cl_2 - often used for later mercury metal production). Different methods employed for this are described below.

461. Sometimes mercury concentrations are further reduced in the produced sulphuric acid before sale, for example by the use of the so-called "Superlig Ion Exchange" process (reduces mercury concentrations to < 5 ppm or mg/l)) or the "Potassium Iodide" process. In the EU BREF note on non-ferrous metal production it is mentioned, that the sulphuric acid "product specification is normally < 0.1 ppm (mg/l)" (European Commission, 2001). This value should be seen in a European perspective. Anecdotal evidence indicates that sulphuric acid with higher mercury concentrations may have a market for some technical purposes in some regions of the World.

462. IZA (2022) states the following about mercury concentrations in sulphuric acid products from zinc smelter: ""In Western world, mercury specifications in commercially traded sulphuric acid is <2pp, most often 1ppm with a trend to go for lower specs at 0.5ppm or 0.1ppm as much is used in agricultural and food industry." "This can only be achieved with a dedicated mercury filter unless refining is restricted to concentrates with <2ppm Hg. In China, much acid is traded at a spec <10ppm Hg but grades up to <100 ppm Hg exist. Larger Chinese zinc smelters have installed mercury filters but no exact data on how much of the total Chinese refining capacity has now mercury filters installed. With recent more stringent environmental regulation and enforcement in place, the number of plants with no mercury filter installed in China, that process mercury containing concentrates, is expected to drop to zero in very near future."

463. If the zinc smelter is neither equipped with a mercury removal step nor with a sulphuric acid plant (if they exist today (IZA 2022)), a substantial part will be released to the atmosphere, while other parts will be retained by particle filters/scrubbers present.

464. One extraction method called "direct leaching", or "pressure leaching" does not involve initial roasting or sintering. Here, the concentrate is lead directly to leaching in sulphuric acid solutions. In this process the mercury content of the concentrates do not evaporate, but follow the precipitated sludges from the leaching and purification steps.

Mercury removal in the gas stream to the sulphuric acid plant

465. A number of processes may be used to remove mercury from the sulphuric gasses from roasting/sintering of non-ferrous metal concentrates before they reach the sulphuric acid plant. The most commonly used is the so-called Boliden/Nordzink (Outotec, 2012; European Commission, 2001). The following process types are listed in (European Commission, 2001); see this reference for more details:

> **Boliden/Norzink process**: The process implemented in about 80% of the world's non-ferrous metal smelter with mercury removal. This process is based on a wet scrubber using the reaction between mercuric chloride and mercury to form mercurous chloride (calomel), which precipitates from the liquid. The process is placed after the washing and cooling step in the acid plant (but before the acid extraction step), so the gas is dust and SO_3 free and the temperature is about 30 °C. The gas is scrubbed in a packed bed tower with a solution containing $HgCl_2$. This reacts with the metallic mercury in the gas and precipitates it as calomel (Hg_2Cl_2). The calomel is removed from the circulating scrubbing solution and partly regenerated by chlorine gas to $HgCl_2$, which is then recycled to the washing stage. The mercury product blend is either used for mercury production or stored.
>
> **Outokumpu process**: In this process the mercury is removed before the washing step in the acid plant. The gas, at about 350 °C, is led through a packed bed tower where it is washed counter currently with an about 90% sulphuric acid at about 190 °C. The acid is formed in situ from the SO_3 in the gas. The mercury is precipitated as a mercury-selenium-chloride compound. The mercury

sludge is removed from the cooled acid, filtered and washed and sent to the production of metallic mercury. Part of the acid is then recycled to the scrubbing step.

Bolchem process: Wet process. Mercury sulphide is produced and other reagents are recycled back into the same process.

Sodium thiocyanate process: Wet process. Mercury sulphide is produced and sodium thiocyanate is regenerated.

Activated carbon filter: Dry process. Produces mercury containing activated carbon. Probably mainly used in secondary (recycled) metal smelters (Outotec, 2012), but also in large scale gold production.

Selenium scrubber: Wet process. Product not described in (European Commission, 2001), but may presumably be mercury-selenium compounds.

Selenium filter: Dry process. Mercury selenide is produced.

Lead sulphide process: Dry process. Produces mercury containing lead sulphide nodules.

466. The produced residues are toxic and should be handled with great care. If mercury containing residues are deposited, significant secondary releases to land, air and aquatic environments may possibly occur unless proper techniques are used to prevent such releases; for example by precipitating mercury as stable compounds and/or lining and covering the waste deposit area.

467. Retained mercury from the mercury removal processes is often marketed as crude mercury compounds or mercury containing material for subsequent production of by-product mercury metal, or as technical grade mercury compounds.

468. In the wet processes and processes where the retained mercury compounds are washed before dispatch from the plant, the washing water contain mercury, which may be led to aquatic environments if it is not treated. If it is treated, generated sludge or solids may contain mercury and this mercury may leach to land and water unless proper environmental management practices are applied to prevent these releases.

469. As an example, the sludge from wastewater treatment from one German zinc production plant has to be deposited in an underground deposit due to its high mercury and selenium content (Rentz *et. al*., 1996).

Leaching, purification and electrolysis (hydrometallurgical process only)

470. Leaching involves solubilisation and neutralization in multiple steps. By leaching, the desired metals are dissolved and iron - and probably solid waste material present in the ore - is separated from the solution. An iron-containing residue is produced from these processes. Depending on the principles applied, it may be in the form of "jarosite" sludge or "haematite" (Fe-oxide). The jarosite is often deposited, while the haematite can sometimes be further processed to yield a lead-silver concentrate used in lead smelters, or used in the cement or steel industries (Rentz *et. al*., 1996). Part of the remaining mercury after sintering/roasting - if any - is expected to follow these residues to recycling processes or deposition.

471. In the purification step, the solute produced by leaching is purified further. This is done by adding zinc dust causing precipitation of pure metals (copper, cadmium etc.), which are further processed on site or in other smelters (Rentz *et. al*., 1996). Parts of any remaining mercury may follow these precipitates to further processing (Bobrova *et al*., 1990, as cited by Lassen *et al*., 2004).

472. In the electrolysis step zinc is recovered in metal form. The dissolved $ZnSO_4$ in the sulphuric acid solution is decomposed by a direct electric current and zinc metal is deposited on aluminium cathodes, while oxygen is produced at the anodes, and sulphuric acid is produced in the solution. Hardly any mercury is left prior to this process step. The produced zinc can be melted and cast into desired zinc alloys and products.

Smelting (pyrometallurgical process only)

473. The dominating pyrometallic process type is the so-called Imperial Smelting process, which can co-produce zinc and lead (as well as other metals present in the feed). Generally the feed is composed of zinc concentrates and lead concentrates or zinc-lead-mix concentrates. The pyrometallic process feed can include secondary zinc/lead material (Rentz *et. al.*, 1996). Such secondary material could in principle represent a minor input source of mercury, but inputs are not deemed significant.

474. In the furnace, zinc oxide (the sinter produced in the sintering step) reacts with carbon monoxide (from added coke) at temperatures around 1,100 ºC and the zinc is evaporated and leaves the furnace with the waste gases. The zinc is then condensed with, and dissolved in, (colder) molten lead drops in the so-called splash condenser. The molten mix is cooled further and separated in liquid raw zinc and lead. The produced raw zinc is directly cast into ingots or transferred to zinc refining. Lead from the separator is fed back into the splash-condenser, and lead is tapped as "lead bullion" from the furnace bottom and treated further. Slags are also tapped at the furnace bottom and are transferred to further processing (Rentz *et. al.*, 1996). At the temperatures prevailing in the furnace and the splash condenser, mercury in the sinter input is expected to primarily follow the exhaust gasses from the furnace and condenser steps, and most likely little or no mercury follows the raw zinc and the lead bullion to further processing.

475. Exhausts gases from the smelting furnace, the splash condenser and the slag granulation may be treated in particle filters to retain particulate material (Rentz *et al.*, 1996; Environment Canada, 2002). Parts of the retained particles may be recycled back in the process, other parts - which could possibly contain mercury - may be deposited (Environment Canada, 2002). Deposition of mercury containing residues: Mercury may be released to land, air and aquatic environments from these residues unless proper techniques are used to prevent such releases.

5.2.3.2 Main factors determining mercury releases and mercury outputs

476. The main factors determining releases and other outputs of mercury from zinc mining and extraction are the following, derived from the sector description above.

Table 5-48 Main releases and receiving media during the life-cycle of mercury in zinc extraction and initial processing

Phase of life cycle	**Air**	**Water**	**Land**	**Products**	**General waste**	**Sector specific treatment/ deposition**
Mining and production of concentrates	x	**X**	**X**	**X *2**		**X**
Extraction of primary zinc from concentrate	**X**	**X**	**X**	**X *3**		**X**
Manufacture of zinc products ***1**						
Use of zinc						
Disposal of zinc						

Notes: *1: Mercury releases could in principle happen due to fossil fuel usage, but the zinc metal is not expected to be a mercury input source to the manufacturing steps;

*2: In the produced zinc concentrate;

*3: In sulphuric acid, mercury by-products, and perhaps other process-derived by-products; see text;

X - Release pathway expected to be predominant for the sub-category;

x - Additional release pathways to be considered, depending on specific source and national situation.

477. The concentration of mercury in the ore/concentrate, and the amount of ore/concentrates used are important factors determining mercury releases. As indicated below, the first aspect can - in principle - be controlled to some degree through the choice of types of ore and concentrates applied.

478. The use of the direct leaching method, avoiding the roasting/sintering step, directs mercury otherwise released to air to releases to water, land and waste deposits.

479. The presence of a dedicated mercury removal step will influence the distribution between output pathways considerably. Releases to the atmosphere and by-product acid (if produced) will be converted to by-product outputs and releases to land, waste deposition and water. The presence of an acid plant alone - with no mercury specific removal - will also influences the release pattern as some of the mercury otherwise released directly to the atmosphere will follow the marketed sulphuric acid and ultimately lead to secondary releases elsewhere.

480. Since part of the mercury input is retained with particles in exhaust gas particle filters, the presence of high efficiency ESP's and fabric filters will also reduce atmospheric mercury releases significantly (if filter dust is not recycled back into the process) and convert the retained mercury to solid, suspended and/or liquid residues.

481. Waste water from different process steps can contain mercury. The extent of releases of mercury with the discharge water to aquatic environments depends on how well the wastes are treated and managed.

482. The extent of releases to the environment from waste material deposition, including waste rock, tailings from concentrating steps, extraction process residues, exhaust gas cleaning residues and waste water treatment residues, is very dependent on how carefully the waste deposits are managed. Poorly managed deposits may result in secondary releases to air, water and land.

5.2.3.3 Discussion of mercury inputs

Table 5-49 Overview of activity rate data and mercury input factor types needed to estimate releases from zinc extraction and initial processing

Life-cycle phase	Activity rate data needed	Mercury input factor
Mining and production of concentrates	Metric tons of reject material produced per year	g mercury/metric ton in reject material produced ***1**
Extraction of primary zinc from concentrate	Metric tons of concentrate used per year	g mercury/metric ton concentrate

Notes: *1 Such waste may include lower grade material (lower zinc concentrations), and the mercury concentrations may be different from that in the input ore material. If no concentration data for reject materials are available however, concentration data for ore used may be applied to form a rough estimate.

483. Hylander and Herbert (2008) collected data for mercury concentrations in concentrates for zinc, copper and lead production for all mines globally, for which data were available through market studies published by BrookHunt and Associates Ltd. (2005, 2006a; 2006b). The individual data are proprietary, but data were aggregated in charts showing the distribution of mercury concentration in relevant concentrates; see Figure 5-2 for data on zinc concentrates. The authors note that no data from Chinese mines were available for that study.

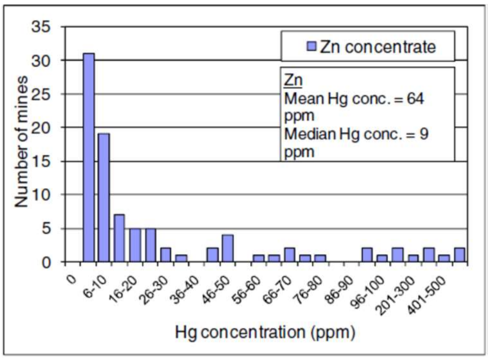


Figure 5-2 Distribution of mercury concentrations in zinc concentrates globally (reprinted with permission from Hylander and Herbert, 2008. Copyright 2008 American Chemical Society).

484. Some other examples of mercury in ore, reject material, and concentrate for zinc production from the literature are given in Table 5-50 below.

485. Schwarz (1997) presents a review of estimated mercury concentrations in sphalerite (ZnS, the main mineral for zinc production) from mineral deposits across 19 countries of the Americas and the Eurasian continent (Canada, Sweden, Finland, Australia, Japan, Kazakhstan, Norway, Russia, Spain, USA, Germany, Czech Republic, Ukraine, Bulgaria, Peru, Serbia, Slovenia, Ireland, Italy). See the detailed mercury concentration estimates in sphalerite in the technical annex in section 8.3. These estimates indicate mercury concentrations in different types of sphalerit-rich ores and concentrates (sphalerite concentrations can be high in zinc concentrates based on this mineral). They also give hints of which mineral deposit types are rich/low in mercury, which might be used to direct exploration towards deposits with low mercury concentrations. As mentioned above, Schwarz estimated that global zinc production gave rise to mobilisation of several hundred metric tons of mercury in 1995 (a low end estimate for 1995 was 600 metric tons), making zinc production rank among the largest sources of mercury outputs. Based on an analysis of the mercury/zinc relationships and the geological formation history of the mineral deposits, he concluded the following:

- Proterozoic volcanic associated deposits have high mercury concentrations in the sphalerite (reported range 4-4680; averages 182-757 g Hg/metric ton sphalerite)
- Phanerozoic exhalative and vein type deposits have moderate mercury concentrations in the sphalerite
- Mississippi Valley Type deposits have low mercury concentrations in the sphalerite (range 0.05-186; averages 9-14 g Hg/metric ton sphalerite)

Table 5-50 Examples of mercury concentration in ore, rejects and zinc concentrates

Country	**Location**	**Type**	**Average Hg concentration, g/metric ton**	**Range of Hg conc. in samples, g/metric ton**	**Data source**
In ore					
Canada	Brunswik Works		2.1		Klimenko and Kiazimov (1987)
Finland	Kokkola		2.8		Maag (2004)
Russian Federation	Ural		10-25		Kutliakhmetov (2002)
In reject material from production of concentrates					
Canada	Brunswik Works	From production of zinc, copper, lead and compound concentrates	0.69 (at ore Hg conc. 2.1)		Klimenko and Kiazimov (1987)
Russian Federation	Ural	From production of zinc, copper and compound concentrates	1-9 (at ore Hg conc. 10-25)		Kutliakhmetov (2002)
In concentrates					
Canada	Brunswik Works		13.5		Klimenko and Kiazimov (1987)
Dominican Republic	Pueblo Viejo	Sphalerite separates from high-sulphidation epithermal deposit		"Up to 350"	Kesler *et. al.* (2003, in press)
Russian Federation	Ural (7 individual concentration works)	Zinc concentrates		20-93 ***1**	Mustafin *et. al.* (1998)
	Ural	Zinc concentrates	76-123		Kutliakhmetov (2002)
	Middle Ural	Zinc concentrate from pyrite and/or pyrite-and-polymetallic deposits		1-4.5 ***2**	Ozerova (1986)
	South Ural	Pyrite and pyrite-and-polymetallic deposits		10-75 ***3**	Ozerova (1986)
	Caucasus	Pyrite and pyrite-and-polymetallic deposits		1-18 ***4**	Ozerova (1986)
World market		General range for zinc concentrates		10-2000	Fugleberg (1999)
		Global average and range	64 (median 9)	(see Figure 5-2)	Hylander and Herbert (2008)
China		Two zinc smelters		48 and 268	Zhang et al (2012)
		Typical medium value	65		Outotec (2012)

Notes: *1: Range of average concentrations between concentration works, numbers of samples not cited;
*2: Range between averages in three locations;
*3: Total range of samples from four individual deposits; averages are not reported;
*4: Total range of samples from two individual deposits; averages are not reported.

486. Summary data from Schwarz (1997) are given in Table 5-51 below. See more detailed information in the technical annex in section 8.1; also, many useful details are given in the reference.

Table 5-51 Estimated average mercury concentrations in the mineral sphalerite in some mineral deposit main types (extracts from Schwarz, 1997)

Mineral deposit type	**Average Hg concentration in sphalerite, ppm (g/metric ton)**	**Number of deposits included in estimation**	**Share of mine zinc production in the mid 1980's,% *1**
Exhalative (including Proterozoic volcanic associated deposit types)	180	101	61
Exhalative (excluding Proterozoic volcanic associated deposit types)	64	75	-
Mississippi Valley Type deposits	9	61	25
Vein and other types	81	86	14
Production weighted mean ***2**	123 (53)	248 (222)	

Notes: *1 According to Tikkanen (1986);

*2 Proterozoic volcanic associated deposit types are excluded in the numbers in brackets.

487. UNEP/AMAP (2012) proposed the following default mercury input factors for zinc extraction based on (Hylander and Herbert, 2008) as well as other information: Minimum:5; medium: 65, and maximum: 130 g/metric ton of concentrate used. Converted to a basis of zinc produced, the corresponding factors were respectively 8.6, 123.3 and 342.1 g/metric ton zinc produced, when using a concentrate used/Zn produced ratio of 1.72-2.63 (intermediate value 1.90).

488. IZA (2022) considers 65 g Hg/metric ton concentrate (ppm) as “a correct conservative value for the purposes of the calculations with the toolkit”.

5.2.3.4 Examples of mercury in releases and wastes/residues

Examples of outputs from production of concentrates

489. In Table 5-52 and Table 5-53 below, two examples of mercury distribution in the outputs from combined production of several non-ferrous metal concentrates are given. The examples are quite different and serve only as indications here; common features are, however, that the percentage of the mercury inputs following zinc concentrates is rather high and the mercury concentrations in the reject materials (tailings) are somewhat lower than the mercury concentrations in the original ore.

Table 5-52 Example of mercury distribution in outputs from production of concentrates, from Brunswik works, Canada (Klimenko and Kiazimov, 1987)

Product	**Quantity of processed**	**Content of Hg**		**Extraction**
	Ore, metric ton per day	**mg/kg**	**Kg per day**	**%**
Input ore	8,575	2.1	18.24	100
Copper concentrate	73.7	2.3	0.15	0.87
Lead concentrate	400	2.7	1.09	5.97
Compound concentrate	70	9.1	0.64	3.5
Zinc concentrate	900	13.5	12.22	67.0
Reject material	7,140	0.69	4.94	27.0

Table 5-53 Example of mercury distribution in outputs from production of concentrates, from Uchalinsky works, Russian Federation (Kutliakhmetov, 2002)

Ore, concentrate, waste	Average , gram Hg /metric ton	Relative quantity of mercury, %
Ore	10-25	100
Pyrite concentrate	5-15	36-50
Copper concentrate	28-41	10-14
Zinc concentrate	76-123	35-48
Reject materials	1-9	2-3

490. IZA (2022) mention two examples of reported mercury concentrations in tailings with no further reference: Data from Swedish mines indicates less than 2% of mercury ends up in tailings. From Iberian mercury rich deposits, 6.5% ends up in tailings. As mentioned above, IZA (2022) considers about 85% of the mercury in ores following the concentrate from the concentrating step to be a reasonable estimate, meaning that about 15% would follow the tailings from the concentrating step. Yet they mention that the number will vary depending on local ores and production conditions. In operations where tailings ponds are operated as described by IZA (2022) above, this flow can be considered an output to sector-specific waste treatment. It is not known if all zinc mining operations globally are operated with these safety precautions, and if not, such outputs may in the worst case be considered releases to land.

491. As regards releases to water from the concentrating step, it can be observed in Pollution Releases and Transfer Registers from USA (TRI), Canada and the European Union 8E-PRTR) that such releases are reported from some facilities, however generally with low amounts of mercury per year (kg/y range). However, these regions are also among the most regulated globally, and mercury releases to water from zinc mining operations other places in the world may not necessarily be as low as that.

492. IZA(2022) state the following regarding water releases from the concentrating step:

493. "Mercury releases to water from mining sites are very low. Any water release is subject to environmental regulations. Typically, addressing the release of zinc in wastewater is the main driver for wastewater treatment as zinc is present in much higher concentration in tailings than mercury and also more soluble than HgS. Much water is recirculated internally. Excess wastewater is treated in a dedicated wastewater treatment plant to reduce metal content prior to discharge into surface. This process includes hydroxide precipitation, sulphide precipitation and settling. Limit values for Hg in discharged waters are <2µg/l but in many jurisdictions, lower values are imposed. As an annual average, Hg concentrations in released wastewater from these WWTP are <1µg/l and often <0.1µg/l. A conservative estimate of discharged water from zinc mining is 10 m^3 per ton of zinc in concentrate. This would apply for mining in an area with high rainfall and significant mine pit drainage. In dryer and arid areas, the amounts are at least 10 to 100 times less. Assuming a conservative 2µg Hg/l in discharged waters, only 0.015% of mercury ends up in discharged water (expressed as % of Hg in zinc concentrate.)."

494. It is not known if all zinc tailings ponds globally have the same level of wastewater cleaning and mercury discharge concentrations.

Examples of outputs from production of zinc metal

495. As mentioned above, quantitative descriptions of mercury mass balances for non-ferrous metal extraction works - i.e. corresponding inputs and output distribution estimates - are scarce in the literature.

496. Outotec (2012) presented a "typical" mercury balance for a zinc smelter with and without a dedicated mercury removal step shown in Figure 5-3. Note that: Only a small fraction follows the

roasted concentrates (so-called calcines), that wet roaster off-gas cleaning is depicted as retaining about half of the mercury input in sludges, and that most of the remaining mercury is captured in the produced sulphuric acid, if no dedicated mercury removal step is present. In case there was neither mercury removal nor an acid plant, this mercury would be emitted to the atmosphere.

497. According to Outotec (2012), most of the pyrometallic smelters using sulphidic ore (many zinc, copper and lead smelters) have acid plants, but part of these do not have a dedicated mercury removal equipment.

498. The web site "Sulphuric acid on the web" (http://www.sulphuric-acid.com/Sulphuric-Acid-on-the-Web/Acid%20Plants/Acid-Plant-Database-Home.htm) includes information about the presence of acid plants, and in some cases mercury-specific emission abatement, on named smelters by country and may thus be useful in the selection of output distribution factors for your inventory.

Capacity:	330.00 ton/year of zinc concentrate equal to a production of approx. 165.000 ton/year of zinc
Mercury content of the concentrate:	65 ppm, equal to 21.450 kg/year

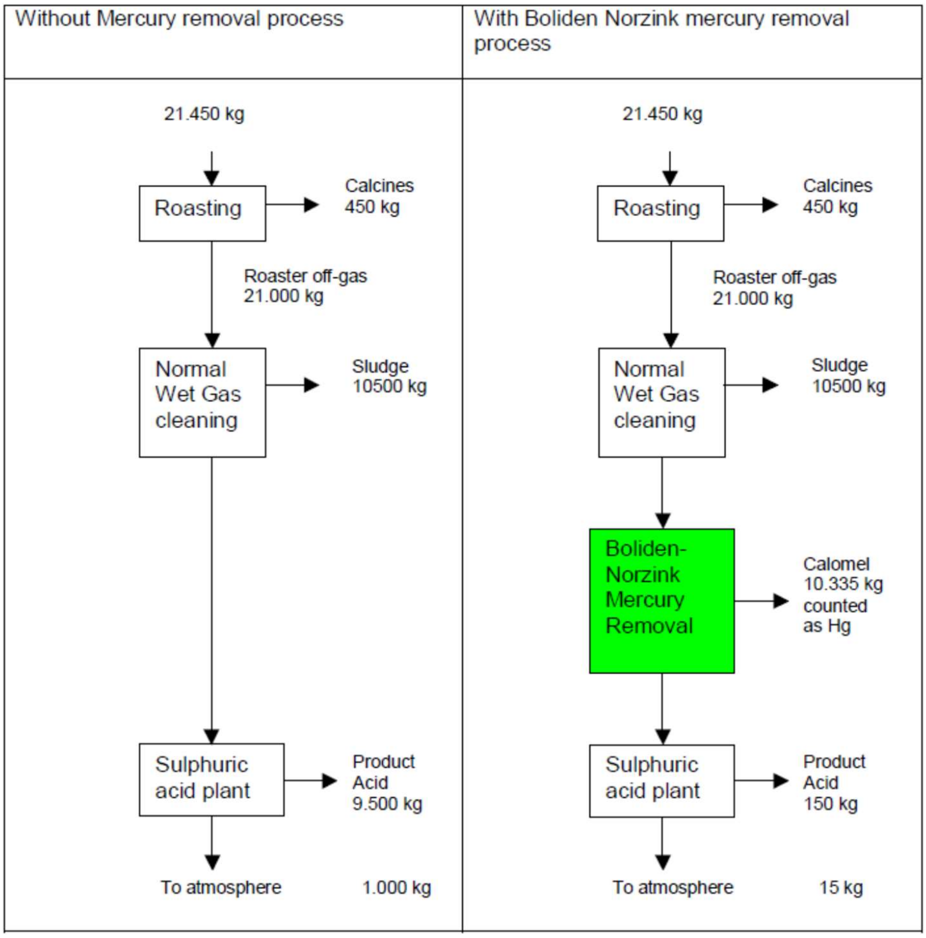


Figure 5-3 Typical mercury mass balance for a zinc smelter with or without a dedicated mercury removal filter (Outotec, 2012, with permission).

499. IZA (2022) summarise the mercury flow in the production of zinc from concentrates as follows:

500. **Wet gas cleaning:**
When a mercury filter is installed, mercury recovery in the wet gas cleaning can be 40-50% of the input to the process, depending on settings of preceding gas cleaning and intentions to recover Hg for sales.

With no mercury filter installed, 75-85% of mercury can be captured in the wet gas cleaning, as the process can be adjusted to attain higher recovery rates. Less than 20% of all zinc refineries have no dedicated mercury filter. An estimated 80% of these plants process zinc concentrates with low mercury content, typically 5ppm or lower.

Wastewater is partly recycled and partly send to wastewater treatment plant.

501. **Mercury filter:** recovers up to 50-60% of the input to the process, reducing Hg output to ppm levels.

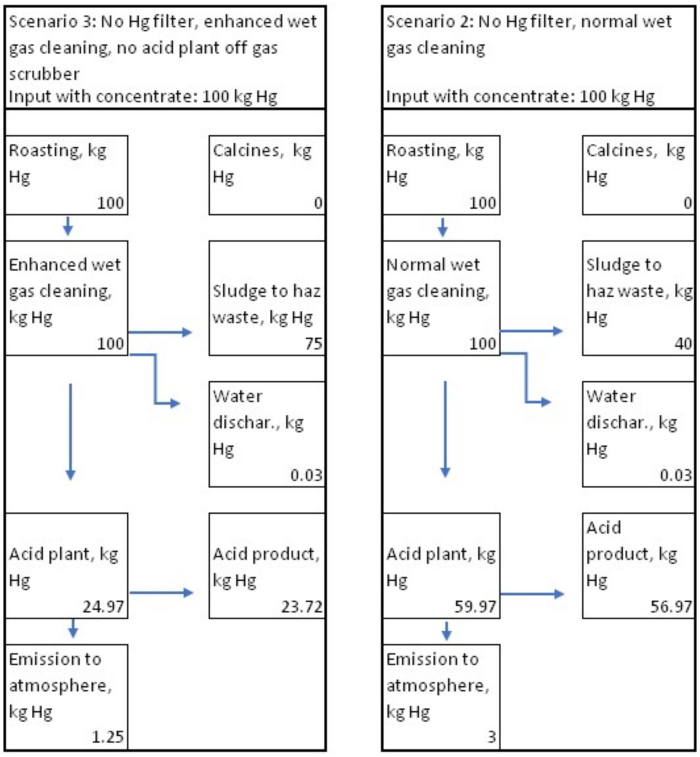
502. **Acid plant absorption:** 95% of mercury in the gas in-flow is scrubbed (removed) in the absorption towers.

503. **Acid plant off gas scrubber** reduces Hg level from the in-flow with 90%.

504. IZA (2022) also mentions that the absence of an acid plant in zinc smelters is “purely hypothetical”, indicating that there may be no or few zinc smelters without an acid plant today.

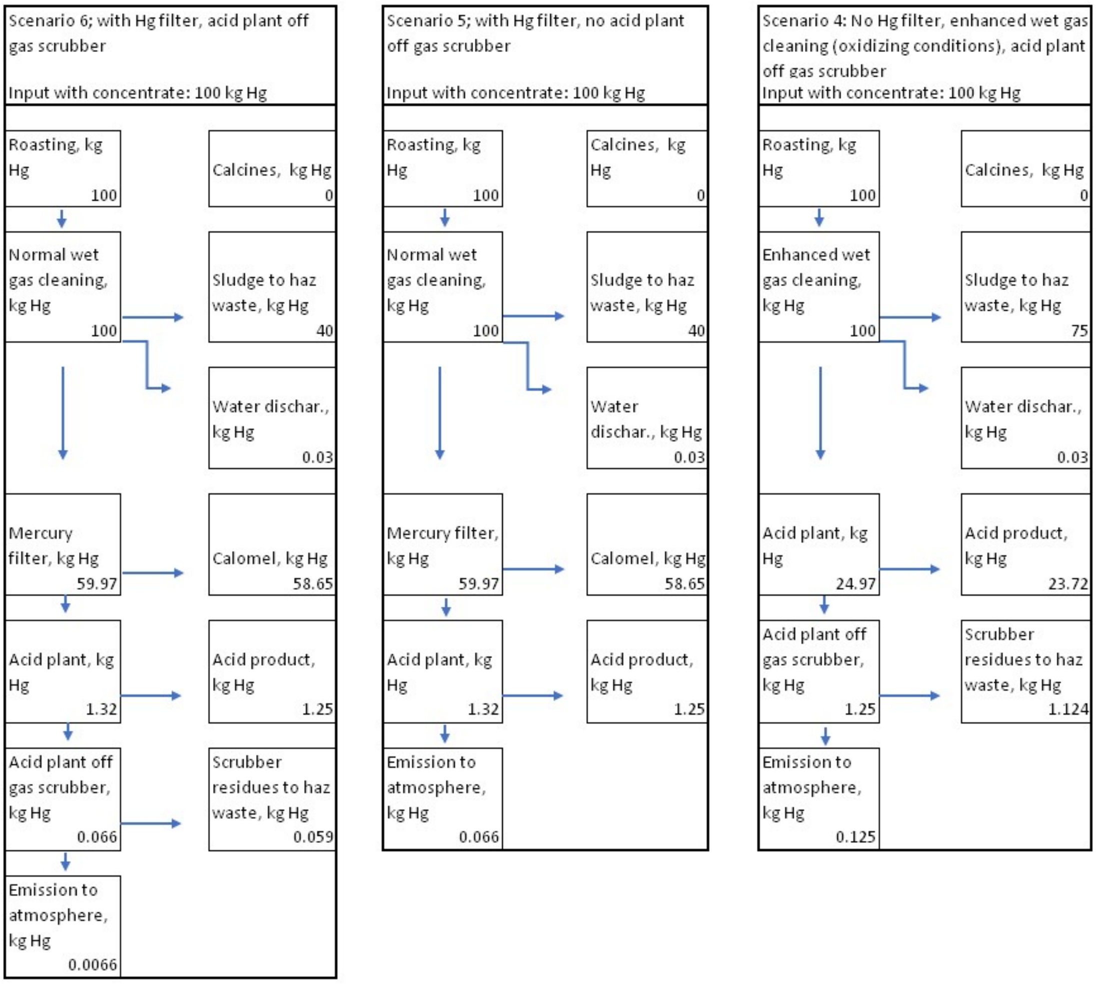
505. Figure 5-4 and Figure 5-5 illustrate the mercury flows for different zinc roasting process configurations derived by Toolkit authors from IZA (2022), considering the possible variation globally.

*Figure 5-4 Mercury flows for zinc smelters with low-end retention technology, derived from IZA (2022) by Toolkit authors*1.*



Note: *1: Scenario 1 (absence of acid plant) not shown, as IZA (2022) considers it hypothetical.

Figure 5-5 Mercury flows for zinc smelters with high-end retention technology, derived from IZA (2022) by Toolkit authors.



506. An example from a Russian zinc production plant indicates that about 7% of the mercury inputs with zinc concentrate follow the sinters through the additional steps of the zinc extraction processes, while about 93% follow the gases generated from the sintering. In the example, an estimated 24% of the mercury inputs are retained in the electrostatic filter dusts which serve as input to copper and lead production (cyclone filters also retain mercury containing dust but this is fed back in the sintering line). The remaining 69% follow the gas to the acid plant where it is distributed between Hg/Se scrubber sludges, the sulphuric acid product, and water residues from a purification of the acid (Bobrova et al., 1990). There appears to be some uncertainty whether mercury releases to the atmosphere are adequately accounted for in the example (Lassen et al., 2004), so the numbers may likely be considered as illustrating the flow of the parts of the mercury inputs which are not directly released to the atmosphere from the sintering.

507. In an example from Finland, mercury removed from the processes is sold as by-product metallic mercury. Mercury releases to water, from the production as a whole, are reported at 0.02 g Hg/metric ton zinc produced. Mercury outputs with deposited jarosite sludge are reported at below 100 g/metric ton jarosite sludge (Fugleberg, 1999) - roughly corresponding to below 40g Hg/metric ton Zn produced (calculated, based on Fugleberg, 1999). Mercury outputs with deposited sulphur are not reported. Mercury releases to air per zinc amounts produced are not reported in (Fugleberg, 1999), but appear to be low (Finnish Environment Institute, 2003).

508. Examples of atmospheric mercury emission factors for direct atmospheric emissions from zinc production are given in Table 5-54 below. Low atmospheric emission factors would generally indicate that a large part of the mercury inputs are transferred to marketed by-product mercury (metal or

compounds), and/or to on-site waste deposits with a potential for future releases to all media. Some minor parts of the mercury inputs may be transferred to releases to aquatic environments as a consequence of wet processes in the emission reduction systems.

Table 5-54 Examples of atmospheric emission factors for direct atmospheric emissions from zinc production

Country/ Region	**Facility/ location**	**Reported mercury releases to the atmosphere per product output**	**Indications of emission reduction technology level (atmospheric releases)**	**Remarks**	**Data reference**
Canada	Teck Cominco, British Columbia;	0.41 g Hg/metric tons of product (zinc, lead etc.)	Appears to be high level: Cyclones, ESP's, scrubbers, Hg removal, acid plant.	Parallel, semi-integrated hydromet. zinc and pyromet. lead extraction, data do not allow an allocation on zinc vs. lead	Environment Canada, 2002
	Noranda CEZ, Québec	0.002 g Hg/metric tons of product (zinc, etc.)	Appears to be high level: Cyclones, ESP's, scrubbers, Hg removal, acid plant.	Hydrometallurgical zinc production	Environment Canada, 2002 and 2004

509. According to the European Commission (2001), output of by-product mercury in the production of other non-ferrous metals amounted to an estimated 350 metric tons mercury in Europe in 1997. These processes generally produce mercury or calomel in the range of 0.02 - 0.8 kg mercury per metric ton of (other) metals produced; depending of the mercury content of the input concentrates. For zinc production more specifically, examples are shown in table 5-54. These general numbers/examples presumably refer to EU (or European) conditions with regard to the level of implemented atmospheric emission reduction systems, where mercury retention may possibly be in the high end compared to the general global situation.

Table 5-55 Examples of by-product mercury outputs from zinc production (presumed to be EU or European conditions), from TU Aachen (1999), as cited in European Commission (2001)

Production step and type	**Mercury by-product, Kg by-product /metric ton of Zinc produced *1**
Roaster/sulphuric acid plant in hydrometallurgical plants	0.3-0.8
Sintering/sulphuric acid plant in Imperial Smelter Furnace process (pyrometallurgical process)	0.15

510. The European Commission (2001) presented indicatory mercury concentrations in "typical gas cleaning effluents" (wastewaters) at 0.1-9 mg/l, again this likely refers to the EU (or European) situation.

511. Feng *et al.* (2004) report that extensive local ambient mercury contamination from zinc production with indigenous technology has taken place in the Hezhang area in the Guizhou province in China. Feng *et al.* measured mercury concentrations in ores and coals used, and in smelting residues and coal ashes, and calculated the following atmospheric emission factors for zinc production at the given circumstances: From sulphidic ore: 155 g Hg/metric ton of zinc produced; from oxide ore: 78.5 g Hg/metric ton of zinc produced. These numbers are much higher than Western estimates from the late 1980's, 25 g Hg/metric ton of zinc produced (Nriagu and Pacyna, 1988).They demonstrated also

that mercury in zinc smelting residues is easily leachable by water. Unfortunately they did not report the release factors to land and water, or the mercury concentrations in the input ores.

512. Zhang et al. (2012) have reported detailed mass balances for six non-ferrous smelters (zinc, lead and copper) with relatively low atmospheric emissions in China. They were all equipped with electrostatic precipitators (ESP) producing dry solid residues (fly ash), wet flue gas cleaning producing sludges, and acid plants. In these smelters, relatively much of the mercury present was oxidised and hence the mercury retention in the filters placed before the acid plant was relatively high. The study presents detailed mass balances confirming that, while other outlets exist, the vast majority of the mercury follows the flue gas from sintering/roasting of the concentrate (called "primary smelting" in the reference). However, as the mercury retention in primary smelting flue gas stream is high, the smaller atmospheric mercury outlets from concentrate drying and downstream metal refining steps, equipped with particle retention only, constitute a significant part of the total atmospheric releases. Table 5-56 summarises the mercury output distribution for the six smelters. The sums of outputs indicate the recovery in the mass balances performed in the study. Unfortunately the study does not quantify the distribution of mercury measured in sludge between solids deposited on hazardous waste deposits (probably local) and waste water discharges. Presumably, most of the mercury in the sludge will follow the solid phase to deposition, but this will depend heavily on the waste water cleaning systems present. The results indicate that the variability in the output distribution among the involved smelters does not seem to be so dependent on the type of primary metal produced, but rather on differences in the acid plant technology used and perhaps other un-explained factors. As regards the acid plant technology, the smelter called Pb5 is equipped with a single conversion single absorption unit which does not convert elemental mercury as efficiently to oxidised mercury, and therefore has lower mercury retention, whereas the other smelters have double conversion, double absorption with higher oxidation rates and thus higher mercury retention rates. The study also gives other information about the Chinese metal extraction sector.

Table 5-56 Mercury output distribution from six Chinese smelters, in percent (Zhang et al, 2012).

Smelter	Zn1	Zn2	Pb3	Pb5	Cu4	Cu6	Average
Scrubber sludge (deposited solids + water discharge)	70	85	82	73	78	97	81
Sulphuric acid	9.2	0.68	0.17	12	17	0.69	6,6
Fly ash and other solids	21	14	15	4.4	1.7	1.8	9,7
Flue gas	0.024	0.68	2.5	11	3.1	0.44	3,0
Sum of outputs*1	118	85	106	102	105	105	

Note *1: The sums of outputs indicate the recovery in the mass balances performed in the study, and need therefore not sum up to 100 percent. The larger the deviation from 100, the larger the uncertainty involved in the mass balance and measurements made.

513. UNEP (2011) show the mercury output distribution from a Canadian zinc/cupper smelter with low mercury inputs and no mercury specific emission abatement (mercury recovery). The distribution is shown in Figure 5-6 below. Note that here, a substantial part of the mercury follows the produced acid.

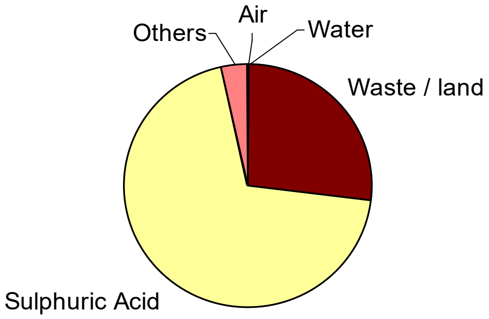


Figure 5-6 The mercury output distribution from a Canadian zinc/cupper smelter with low mercury inputs and no mercury specific emission abatement (UNEP, 2011).

Direct leach process for zinc extraction

514. As regards the so-called direct leach method (leaching of zinc without prior roasting of the concentrate), IZA (2022) states the following:

515. "This process is applied to avoid investment in roasting capacity and avoiding the need to manage sulphuric acid shipment and sales. Furthermore, direct leach process can be used to manage complex raw materials that do not fit so well to roasting. Direct leaching is applied in closed reactors. Mercury entering the process all ends up in the waste leach residue with negligible releases to air or water. Residue from direct leaching is sent to waste treatment, where it is washed, neutralized and stabilized by sulphidation. Mercury in waste to be sent to for final deposit present in stable form of HgS with very low dissolution rate. For mercury entering the direct leach process, we suggest assigning all the mercury output to disposed hazardous waste in stabile form (HgS)."

516. Considering the 0.03% mercury release from the wet gas cleaning step, as described above, it is however here assumed that a similar release may take place from the direct leach process.

5.2.3.5 Input factors and output distribution factors

517. Based on the information compiled above on inputs and outputs and major factors determining releases, the following default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows. Also, the presented default factors are expert judgments based on summarized data only.

518. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

519. Due to lack of data, no default factors can be set for the mining and concentrating processes. Note that this implies that the mercury release estimates calculated from default factors may likely tend to underestimate the total releases from the sector.

a) Default mercury input factors

520. Actual data on mercury levels in the particular concentrate composition used will lead to the best estimates of releases.

521. If no information is available on the mercury concentration in the concentrates used in the extraction step, a first estimate can be formed by using the default input factors selected in table 5-56 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end

default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum). The intermediate estimate is used in the default calculations in Inventory level 1 of the Toolkit. If it is chosen not to calculate as intervals, the use of the maximum value will give the safest indication of the possible importance of the source category for further investigation. Using a high end estimate does not automatically imply that actual releases are this high, only that it should perhaps be investigated further.

Table 5-56 ***Preliminary*** *default input factors for mercury in concentrates for zinc production*

Material	**Default input factors; g mercury per metric ton of concentrate; (low end - high end (intermediate)**
Zinc concentrate (input factor for both concentrating and zinc processing steps)	5 - 130 (65)

522. If desired, these default factors can be converted to a basis of mercury inputs per zinc produced, by the use of a concentrate used/Zn produced ratio of 1.72-2.63 (intermediate value 1.90 ton concentrate used per ton zinc produced) as derived by UNEP/AMAP (2012). The corresponding factors are low end: 8.6, medium 123.3 and high end 342.1 g mercury/metric ton zinc produced. Note that the default Toolkit spreadsheet calculations are based on mercury per concentrate.

b) Default mercury output distribution factors

523. Data enabling the definition of default output distribution factors for zinc extraction form concentrates are scarce, as indicated above. A revised set of default output distribution factors for this subcategory was, however, defined, based on the available data.

524. For zinc extraction facilities only employing the direct leach technology, the actual atmospheric releases may be lower than the set default factor, while releases to solid residues may be higher.

Table 5-57 Default output distribution factors for mercury from extraction of zinc from concentrates, including the concentrating step

Phase of life cycle	**Air**	**Water *3**	**Land *1**	**Product *2**	**General waste**	**Sector specific treatment/ disposal*1, *2**
Concentrating step with wastewater treatment	?	0.00062	?	0.82 (*4	?	0.17938
Production of zinc from concentrate in smelters:						
L1: Smelters with only normal wet gas cleaning and no wastewater treatment	0.49	0.02	?	?	?	0.49
L2: Smelters with normal wet gas cleaning, acid plant and wastewater treatment	0.05	0.0003		Acid: 0.57		0.3797
L3: Smelters with enhanced wet gas cleaning, acid plant and wastewater treatment	0.013	0.0003		Acid: 0.24		0.7467
L4: Smelters with enhanced wet gas cleaning, acid plant, acid plant off gas scrubber and wastewater treatment	0.0013	0.0003		Acid: 0.24		0.7584
L5: Smelters w. normal wet gas cleaning, Hg specific filter, acid plant and wastewater treatment	0.0007	0.0003		Acid: 0.013 (*2		0.986 (hereof as Hg/calomel: 58.65)*2
L6: Smelters w. normal wet gas cleaning, Hg filter, acid plant, acid plant off gas scrubber and wastewater treatment (b	0.00007	0.0003		Acid: 0.013 (*2		0.98663 (hereof as Hg/calomel: 58.65)*2
Direct leach; zinc extraction and initial processing		0.0003				0.9997

Notes: *1 Deposition of non-marketed residues are according to IZA (2022) typically to on-site tailings ponds. It may however vary between countries, and may be on land, in the mine, in impoundments, often on-site.

*2: Marketed by-products with mercury content include, among others, calomel, elemental mercury, low grade washing acids, higher grade sulphuric acid, sludge for off-site mercury recovery, liquid sulphur and filter cake or other residues sold or transferred to other metal production activities or other sectors. According to IZA (2022) calomel from Hg-specific filters is increasingly deposited as hazardous waste, rather than marketing it as compound or metal mercury. Hg/calomel are here shown in the Sector-specific waste output, but should be assigned to products if marketed from the specific facilities.

*3: Based on water discharge limit of 2µg Hg/l. If actual limit is different, the output factors for water can be adjusted relatively (with documentation provided in inventory report).

*4: The output to products from the concentrating step is the Hg following the concentrates to the smelter or direct leach processes.

c) Links to other mercury sources estimation

525. In case of combined smelters producing several non-ferrous metals from the same concentrate, it is suggested to assign the mercury releases to the metal produced in the largest amounts. In case of parallel processing of different concentrates in parallel production lines, assign the mercury releases separately to the major metal produced in each line.

5.2.3.6 Source specific main data

526. The most important source specific data would in this case be:

- Measured data or literature data on the mercury concentrations in the ores and concentrates extracted and processed at the source;
- Amount of ore/concentrates extracted and processed; and
- Measured data on the distribution of mercury outputs with (preferably all) output streams, including mercury percentages retained by emission reduction equipment applied on the mercury source (or similar sources with very similar equipment and operating conditions).

527. The presence of a mercury removal unit at a specific extraction plant may indicate that a major share of the mercury outputs is not released to the atmosphere, but is instead marketed as by-product or stored on-site.

5.2.4 Copper extraction and initial processing

528. Like for zinc, quantitative descriptions of mercury mass balances over copper extraction operations - corresponding input and output distribution estimates - seem not to be easily available. Therefore, the quantitative aspects of the description in this section have been put together piece by piece from different sources.

529. Large scale industrial mining and metal extraction operations are few in number in any country where they operate, their feed materials and production configurations vary significantly, and they may be significant mercury release sources. Given these factors, it is highly recommended to use a point source approach in the inventory, and compile point source specific data from the operating companies themselves, if feasible, as well as from other relevant data sources with knowledge of the specific production facilities.

5.2.4.1 Sub-category description

530. Ore for extraction of copper (mainly sulphide ore) can contain trace amounts of mercury. In the extraction of the copper from the ore, processes are used which release this mercury from the rock material. This mercury may evaporate and follow the gaseous streams in the extraction processes (in most cases) or follow wet (liquid) process streams, depending on the extraction technology used. Unless the mercury is captured by process steps dedicated to this purpose, major parts of it may likely be released to the atmosphere, land and aquatic environments. Retained mercury may be sold in the form of "calomel" (Hg_2Cl_2), normally sold for off site extraction of metal mercury) or on-site processed metal mercury, or it may be stored or deposited as solid or sludgy residues (Environment Canada, 2002). Marketing of recovered by-product mercury from extraction of non-ferrous metals represent a substantial part of the current global mercury supply. Besides these output pathways, parts of the mercury input follows co-produced sulphuric acid (European Commission, 2001; Zhang et al., 2012; Outotec, 2012).

Processes involved

531. The principal steps in copper extraction include production of copper-rich concentrate from raw ore, roasting of the concentrate (to produce "calcine"), and smelting in a furnace, which both occur at high temperatures. The overall process includes numerous steps, including a final step called "converting", with the purpose of eliminating the remaining iron and sulphur present in the process material, leaving molten "blister" copper (US EPA 1997a). Facilities that conduct this overall process of producing copper from ore are commonly called "primary copper smelters". For a thorough description of the process, see US EPA (1997a) or European Commission (2001). Further refining of the blister copper is not expected to cause significant mercury releases (at least as regards mercury originating from the copper ore).

Mining of ore and production of concentrates

532. Ore is mined principally from open pit mines, and copper-rich fractions are separated from the waste rock after grinding and milling to reduce particle sizes by mechanical separation processes; usually floatation or other processes employing suspension in water are employed.

533. Different copper ore types exist, but the most economically important are the sulphidic minerals chalcopyrite, bornite and chalcocite (Ullmann, 2001). In some cases copper is mined from mineral deposits also containing other metals, for example copper-and-nickel deposits and copper-zinc-pyrite deposits (Krivtsov and Klimenko, 1997).

534. The produced concentrate is transported to the extraction plants, which may be receiving concentrate from mines nearby, but also from the global market.

535. Waste rock with no or low metal content and the parts of the reject ore material which has been separated from the copper-rich concentrate (parts of the so-called tailings), is usually stored on site in tailings ponds, tailings piles/heaps or back-filled into the mines.

536. The waste rock and tailings may - just like the generated concentrates contain trace amounts of mercury. This material is much more susceptible to weathering than the original deposits, due to the reduced particle sizes and higher accessibility for air and precipitation. For sulphidic ores, which are important ore types for production of several base metals, this weathering liberates and oxidizes the contained sulphur and produce sulphuric acid. The acid renders the constituents more soluble and thus increases leaching of the metal to the environment many fold as compared to the untouched mineral deposit. This process is called "acid rock drainage" (or ARD) and is considered a serious environment risk (European Commission, 2003).

537. Few data has been identified on mercury concentrations in crude ore and reject material, where as more data have recently been published on mercury concentrations in copper concentrates. Quantitative data on release of mercury from waste rock and mining tailings to air, water and land has not been identified. But this release source should not be neglected, because even moderate mercury concentrations in the material may possibly render substantial mercury amounts mobile because of the enormous amounts of materials handled in mining operations.

Extraction of copper from concentrate

538. As mentioned, copper extraction involves a complex network of processes, which will not be described in details here. With regard to mercury flow and release pathways, copper extraction normally roughly resembles the "pyrometallurgical" process path described for zinc, see section 5.2.3 for the description. One major difference is that some copper smelters do not employ roasting/sintering before the concentrate is fed to the furnace, but only drying. As a consequence, more of the sulphur - and possibly also mercury - in the feed stays in the molten material lead to the next process step, the so-called converting in such facilities, where it is vented by a blow-through of air/oxygen. Another difference from zinc production is the so-called fire-refining step, which takes place after the converting. Hydrocarbons (gas) or sometimes "green" timber logs are added to the molten copper containing material to reduce metal oxides to elemental metal and other constituents (European Commission, 2001). These carbon sources are additional sources to mercury inputs to the extraction processes; no data are, however, available to quantify their contributions to mercury releases.

539. Recycled copper scrap may be added to the feed material to the smelting steps, but is not considered a major input source of mercury to the process. Copper and zinc, or copper and nickel, (and other metals) are sometimes produced in parallel, semi-integrated process lines in the same smelters (Environment Canada, 2002).

540. The primary releases of mercury from the feed materials happen during the drying/roasting step (if present) and from the smelting furnace. In addition, converters and refining furnaces may emit any residual mercury left in the material flow through the copper extraction process (US EPA, 1997a).

If no mercury removal step is included in the off gas treatment before the acid plant, most of these releases will be lost to the atmosphere. If exhaust gases from the drying/roasting, furnace and/or converter steps are lead through highly efficient particle filters (ESPs and/or fabric filters) and in some cases mercury-specific filters, part of the mercury in the gas may be retained with the particles or in mercury by-products.

5.2.4.2 Main factors determining mercury releases and mercury outputs

Table 5-58 Main releases and receiving media during the life-cycle of copper extraction and initial processing

Phase of life cycle	Air	Water	Land	Products *2	General waste	Sector specific treatment/ disposal
Wastes from mining and production of concentrates	x	X	X			X
Extraction of primary copper from concentrate	X	X	X	X		X
Manufacture of refined copper and products ***1**						
Use of copper						
Disposal of copper						

Notes: *1: Mercury releases could in principle happen due to fossil fuel usage, but the copper metal is not expected to be a mercury input source to the refining and manufacturing steps;

*2: In sulphuric acid, mercury by-products, and perhaps other process-derived by-products;

X - Release pathway expected to be predominant for the sub-category;

x - Additional release pathways to be considered, depending on specific source and national situation.

541. The concentration of mercury in the ore/concentrate, and the amount of ore/concentrates used are important factors determining mercury releases.

542. The presence of a dedicated mercury removal step will influence the distribution between output pathways considerably. With mercury removal, releases to the atmosphere will be converted to by-product outputs and releases to land, waste deposition and water. In case sulphuric acid is produced, releases to sulphuric acid (a marketed by-product) will also be converted in the mercury removal step to the same output pathways.

543. Since part of the mercury input may be retained with particles in exhaust gas particle filters, the presence of high efficiency ESP's and fabric filters may also reduce atmospheric mercury releases significantly - if filter dust is not recycled back into the process - and convert the retained mercury to solid, suspended and/or liquid residues.

544. Waste water from different process steps can contain mercury and must be treated carefully to avoid or minimise releases to aquatic environments.

545. The extent of releases to the environment from waste material deposition, including waste rock, tailings from concentrating steps, extraction process residues, exhaust gas cleaning residues and waste water treatment residues, is very dependent on how carefully the waste deposits are managed. Poorly managed deposits may result in substantial releases to air, water and land.

5.2.4.3 Discussion of mercury inputs

Table 5-59 Overview of activity rate data and mercury input factor types needed to estimate releases from copper extraction and initial processing

Life-cycle phase	Activity rate data needed	Mercury input factor
Wastes from mining and production of concentrates	Metric tons of reject material produced per year	g mercury/metric ton in reject material produced ***1**
Input to extraction of primary copper from concentrate	Metric tons of concentrate used per year	g mercury/metric ton concentrate

Notes: *1 Such wastes may include lower grade material (lower lead concentrations), and the mercury concentrations may be similar to concentration in the input ore material. If no concentration data for reject materials are available, concentration data for the ore used may be applied for forming a rough estimate.

546. Hylander and Herbert (2008) collected data for mercury concentrations in concentrates for zinc, copper and lead production for all mines globally, for which data were available through market studies published by BrookHunt and Associates Ltd. (2005, 2006a; 2006b). The individual data are proprietary, but data were aggregated in charts showing the distribution of mercury concentration in relevant concentrates; see Figure 5-7 for data on cupper concentrates. The authors note that no data from Chinese mines were available.

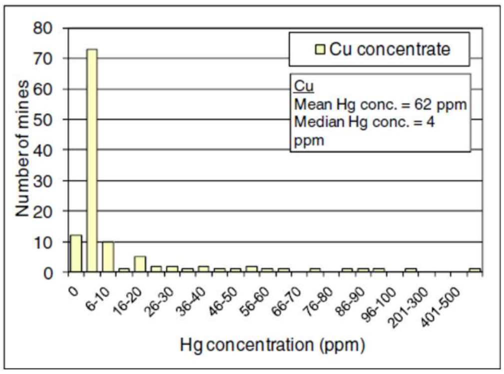


Figure 5-7 Distribution of mercury concentrations in cupper concentrates globally (reprinted with permission from Hylander and Herbert, 2008. Copyright 2008 American Chemical Society).

547. UNEP/AMAP (2012) proposed the following default mercury input factors for copper extraction based on (Hylander and Herbert, 2008; Outotec, 2012) as well as other information: Minimum: 1; medium: 30, and maximum: 100 g mercury/metric ton of concentrate used. Converted to a basis of copper produced, the corresponding factors were respectively 2.1, 107.5 and 716.8 g mercury/metric ton copper produced, when using a concentrate used/Cu produced ratio of 2.11-7.17 (intermediate value 3.58).

Table 5-60 Examples of mercury concentration in copper concentrates, as well as in ore and rejects

Country	Location	Type	Average Hg concentration, g Hg/metric ton	Range of Hg concentration in samples, g/metric ton	Data source
In ore					
Canada	Brunswik Works		2.1		Klimenko and Kiazimov (1987)
Russian Federation	Ural		10-25		Kutliakhmetov (2002)
	South Ural, 4 locations	Copper and pyrite, massive	9.8-13 ***1**		Fursov (1983)
Kazakhstan	Kusmurun	Copper and pyrite, massive	9.2	4.3-16.70 (11 samples)	Fursov (1983)
	Dzhezgazgan	Cuprous limestone, massive (chalcopyrite)	3.2	2.8-3.68 (15 samples)	Fursov (1983)
	Dzhezgazgan	Cuprous limestone, disseminated (bornite)	1.5	1.23-1.87 (11 samples)	Fursov (1983)
	Counrad	Copper and porphyry, disseminated (primary)	0.9	0.76-1.02 (8 samples)	Fursov (1983)
In reject material from production of concentrates					
Canada	Brunswik Works	From production of zinc, copper, lead and compound concentrates	0.69 (at ore Hg conc. 2.1)		Klimenko and Kiazimov (1987)
Russian Federation	Ural	From production of zinc, copper and compound concentrates		1-9 (at ore Hg conc. 10-25)	Kutliakhmetov (2002)
In concentrates					
Canada	Brunswik Works		2.3		Klimenko and Kiazimov (1987)
Russian Federation	Ural	From copper pyrite type ore		28-41	Kutliakhmetov (2002)
	Unknown	From pyrite and polymetal type		0.22 - 65	Bobrova *et al.*, (1990); Ozerova (1986)
	Unknown	From stratiformic lead-and-zinc type		2 - 290	Bobrova *et al.*, (1990); Ozerova (1986)
	Unknown	From copper pyrite type		0.3 - 150	Bobrova *et al.*, (1990); Ozerova (1986)
	Unknown	From cupriferous sandstone		4	Bobrova *et al.*, (1990); Ozerova (1986)
	Unknown	From vanadium-iron-copper type		70	Bobrova *et al.*, (1990); Ozerova (1986)
	Unknown	From copper-molybdenum type		0.02	Bobrova *et al.*, (1990); Ozerova (1986)
	Unknown	From copper-nickel type		0.14 – 0.4	Bobrova *et al.*, (1990); Ozerova (1986)
General, coverage unknown	Unknown geography		0.5 - 8		Confidential European data source
Global		Global average	62 (median 4)	(see Figure 5-7)	Hylander and Herbert (2008)
China		2 copper smelters		1.48 and 4.23	Zhang et al. (2012)
		Typical medium value	30		Outotec (2012)

Notes: *1: Range between averages in several locations, 38 samples in all.

5.2.4.4 Examples of mercury in releases and wastes/residues

Examples of outputs from production of concentrates

548. Two examples of mercury distribution in the outputs from production of non-ferrous metal concentrates (including copper concentrates) are given under the same heading in the zinc extraction section (see Table 5-52 and Table 5-52in section 5.2.3). The two examples are quite different and may not necessarily be representative; they serve only as indications here.

Examples of outputs from production of copper metal

549. As mentioned above, quantitative descriptions of mercury mass balances over copper extraction works - corresponding inputs and output distribution estimates - are scarce in the literature.

550. Zhang et al. (2012) have reported detailed mass balances for six non-ferrous smelters (zinc, lead and copper) with relatively low atmospheric emissions in China. UNEP (2011) reported on the output distribution of mercury from a combined zinc/copper smelter. These data are described in the section on zinc extraction above. The few data available do not indicate major differences in the mercury output distribution pattern between different base metals production.

551. An attempt of developing a complete output distribution overview was, however, made by Yanin (in Lassen *et al.*, 2004) for Russian crude copper smelters; the estimated output distribution is shown in Table 5-61. The estimates are based on theoretical considerations and should be regarded as indicative only.

552. For comparison with the air emission factors described below, an example can be calculated using Yanins estimates above. At a mercury concentration of 13.8 g/metric ton in the concentrate used, a copper concentration of 15% in the same concentrate, and an extraction rate of 93% of the copper input, the calculated air emission factor would be 13.8 g Hg/metric ton conc. / 0.15 metric ton Cu/metric ton conc. * 0.93 = 11.7 g Hg/metric ton of copper produced. This is comparable to the atmospheric emission factor for the Hudson Bay smelter in Canada, shown in Table 5-62 below.

Table 5-61 Indicative estimates of the output distribution (in relative terms) of mercury from copper smelters under Russian conditions (Yanin, in Lassen et al.*, 2004).*

Release pathway	**Atmos-phere**	**Waste water**	**Slag dumped**	**Sludge dumped**	**"Arsenate cake" dumped**	**"Lead cake" sold to Pb extraction**	**Liquid sulphur *2**	**Washing acid *2**	**Sum**
Share of Hg inputs ***1**	0.12	0.02	0.04	0.38	0.06	0.11	0.14	0.14	1.00
Outputs in g Hg/ metric ton produced copper, for an example with input of 13.8 g Hg/metric ton concentrate	0.12	0.02	0.04	0.38	0.06	0.11	0.14	0.14	1.00

Notes: ***1** Corrected here for internal recycling of filter dust to the furnace (steady state assumed);
***2** Liquid sulphur - a by-product - and washing acid is most likely sold; this is, however, not mentioned in the reference.

553. A few examples of emission factors are available, but only for atmospheric emissions of mercury, and with no links to corresponding mercury inputs with concentrates or ore.

554. Examples of emission factors for direct atmospheric emissions from copper production are given in Table 5-62 below. Low atmospheric emission factors would generally indicate that a large part of the mercury inputs are transferred to marketed by-product mercury (metal or compounds), and/or to on-site waste deposits with a potential for future releases to all media. Some minor parts of the mercury inputs may be transferred to releases to aquatic environments as a consequence of wet processes in the emission reduction systems. For the nickel/copper smelter mentioned, produced slag is used for road and railroad construction.

555. Based on self reported emissions data from 7 primary copper smelters in the USA for year 1993, US EPA estimated total atmospheric mercury releases at 57 kg per year in 1994, from smelters with a metal production capacity of approximately 1.4 million metric tons (1995/96 capacity)(US

EPA, 1997b). Corresponding atmospheric release rates per product output can be calculated to approximately 0.04g Hg/metric ton of metal production "capacity".

Table 5-62 Examples of emission factors for direct atmospheric releases from copper production

Country/ Region	Facility/ location	Reported mercury releases to the atmosphere per product output	Indications of emission reduction technology level (atmospheric releases)	Remarks	Data reference
USA	National average	0.04g Hg/metric ton of metal production "capacity"		Self-reported atmospheric Hg releases. Unclear if "capacity" mirrors actual production.	US EPA (1997a)
Canada	Hudson Bay M&S, Manitoba	8.2 g Hg/metric tons of product (zinc, copper etc.)	Appears to be moderate: ESP's, but no Hg removal or acid plant		Environment Canada (2002)
	Noranda Horn	1.8 g Hg/metric tons of product (copper etc.)	Furnace and new converter line equipped with ESPs, Hg removal and acid plant; old converters processing parts of the feed is only equipped with ESPs	Also processes recycled copper.	Environment Canada (2002)
	Inco Copper Cliff	0.01 g Hg/metric tons of product (Copper, nickel etc.)	Furnace off gas line with wet PM filter and acid plant, but no Hg removal; Drying + converting steps off gas with ESPs only	Combined nickel/copper smelter. Part of slag from furnace is used for railway and road construction. Apparently feed may have lower Hg concentrations than for other Canadian smelters mentioned here (Toolkit authors remark)	Environment Canada (2002)

556. According to the European Commission (2001), output of by-product mercury in the production of non-ferrous metals (other than dedicated mercury mining) amounted to an estimated 350 metric tons mercury in Europe in 1997. These processes generally produce mercury or calomel in the range of 0.02-0.8 kg mercury per metric ton of (other) metals produced; depending of the mercury content of the input concentrates.

5.2.4.5 Input factors and output distribution factors

557. Based on the information compiled above on inputs and outputs and major factors determining releases, the following default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows. Also, the presented default factors are expert judgments based on summarized data only.

558. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

559. Due to lack of data, no default factors can be set for the mining and concentrating processes. Note that this implies that the mercury release estimates calculated from default factors may likely tend to underestimate the total releases from the sector.

a) Default mercury input factors

560. Actual data on mercury levels in the particular concentrate composition used will lead to the best estimates of releases.

561. If no information is available on the mercury concentration in the concentrates used in the extraction step, a first estimate can be formed by using the default input factors selected in Table 5-63 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low

end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum). The medium estimate is used in the default calculations in Inventory level 1 of the Toolkit. If it is chosen not to calculate as intervals, the use of the maximum value will give the safest indication of the possible importance of the source category for further investigation. Using a high end estimate does not automatically imply that actual releases are this high, only that it should perhaps be investigated further.

Table 5-63 Default input factors for mercury in concentrates for crude copper production

Material	Default input factors; g mercury per metric ton of concentrate; (low end - high end (intermediate)
Copper concentrate (input factor for both concentrating and metal processing steps)	1 - 100 (30)

Note: *1: The asymmetric medium value is due to the uneven distribution of mercury concentrations in concentrates on the global market; see the description of (Hylander and Herbert, 2008) above.

562. If desired, these default factors can be converted to a basis of mercury inputs per copper produced, by the use of a concentrate used/copper produced ratio of 2.11-7.17 (intermediate value 3.58 ton concentrate used per ton copper produced) as derived by UNEP/AMAP (2012). The corresponding factors are low end: 2.1, medium 107.5 and high end 716.8 g mercury/metric ton copper produced. Note that the default Toolkit spreadsheet calculations are based on mercury per concentrate.

b) Default mercury output distribution factors

563. Based on the data on mercury output distribution presented in this section, as well as in the section above on zinc, the following default factors are suggested.

Table 5-64 Default output distribution factors for mercury from extraction of copper from concentrates.

Phase of life cycle	Air	Water	Land *1	Product *1, *2	General waste	Sector specific treatment/ disposal *1
Concentrating step with wastewater treatment (discharge limit 2µg Hg/l) *3	?	0.00062	?	0.82	?	0.17938
Production of copper from concentrate:						
Smelter with no filters or only coarse, dry PM retention	0.90		?			0.10
Smelters with wet gas cleaning	0.49	0.02	?			0.49
Smelters with wet gas cleaning and acid plant	0.10	0.02	?	Acid: 0.57		0.31
Smelters with wet gas cleaning, acid plant and Hg specific filter	0.02	0.02	?	Acid: 0.013		0.947 (hereof Hg/calomel 58.65)

Notes: *1 Deposition of residues will likely vary much between countries and perhaps even between individual facilities, and may be on land, in the mine, in impoundments, often on-site.

*2: Marketed by-products with mercury content include, among others, calomel, elemental mercury, low grade washing acids, higher grade sulphuric acid, sludge for off-site mercury recovery, liquid sulphur and filter cake or other residues sold or transferred to other metal production activities or other sectors. Like for zinc, calomel from Hg-specific filters is considered increasingly deposited as hazardous waste, rather than marketing it as compound or metal mercury. Hg/calomel are here shown in the Sector-specific waste output, but should be assigned to products if marketed from the specific facilities.

*3: Assumed similar to zinc concentrating presented above, as no specific data are available for lead production. Based on water discharge limit of 2µg Hg/l. If actual limit is different, the output factors for water can be adjusted relatively (with documentation provided in inventory report).

c) Links to other mercury sources estimation

564. In case of combined smelters producing several non-ferrous metals from the same concentrate, it is suggested to assign the mercury releases to the metal produced in the largest amounts. In case of parallel processing of different concentrates in parallel production lines, assign the mercury releases separately to the major metal produced in each line.

5.2.4.6 Source specific main data

565. The most important source specific data would in this case be:

- Measured data or literature data on the mercury concentrations in the ores and concentrates extracted and processed at the source;
- Amount of ore/concentrates extracted and processed, and
- Measured data on the distribution of mercury outputs with (preferably all) output streams, including mercury percentages retained by emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

566. The presence of a mercury removal unit at a specific extraction plant may indicate that a major share of the mercury outputs is not released to the atmosphere, but is instead marketed and sold as a by-product or stored on-site.

5.2.5 Lead extraction and initial processing

567. Large scale industrial mining and metal extraction operations are few in number in any country where they operate, their feed materials and production configurations vary significantly, and they may be significant mercury release sources. Given these factors, it is highly recommended to use a point source approach in the inventory, and compile point source specific data from the operating companies themselves, if feasible, as well as from other relevant data sources with knowledge of the specific production facilities.

5.2.5.1 Sub-category description

568. Lead is extracted from a sulphide ore, primarily galena (lead sulphide), which also contains some mercury (US EPA, 1997a). The levels of mercury in the ores vary, and in some cases can be elevated compared to other natural raw materials (COWI, 2002).

569. Like described for zinc (section 5.2.3), the waste rock and tailings may, just like the generated concentrates, contain trace amounts of mercury. This material is much more susceptible to weathering due to the reduced particle sizes and higher accessibility to air and precipitation. For sulphidic ores, which are important ore types for production of several base metals, this weathering liberates and oxidizes the contained sulphur and produces sulphuric acid. The acid renders mercury and other constituents more soluble and thus increases leaching of the metal to the environment many fold as compared to the untouched mineral deposit. This process is called "acid rock drainage" (or ARD) and is considered a serious environment issue (European Commission, 2003).

570. In the extraction of the lead from the ore/concentrate, processes are used which release this mercury from the rock material. This mercury may evaporate and follow the gaseous streams in the extraction processes (in most cases) or follow wet (liquid) process streams, depending on the extraction technology used. Unless the mercury is captured by process steps dedicated to this purpose, major parts of it may likely be released to the atmosphere, land and aquatic environments. Retained mercury may be sold in the form of "calomel" (Hg_2Cl_2), normally sold for off site extraction of metal mercury) or on-site processed metal mercury, or it may be stored or deposited as solid or sludgy residues (Environment Canada, 2002). Besides these output pathways, parts of the mercury input follows co-produced sulphuric acid at trace concentrations (European Commission, 2001).

571. The principal steps in lead extraction generally resemble the "pyrometallurgical" extraction process described for zinc (section 5.2.3), and include production of lead-rich concentrate from raw ore, roasting of the concentrate, and smelting/reduction of the metal oxides in a furnace, which both occur at high temperatures. In some production facilities, the concentrate is not sintered prior to the introduction in the furnace. In these cases, most of the mercury present in the concentrate is expected to evaporate and follow the gas streams of the downstream process steps. Like for zinc and copper, mercury present in the off gasses from sintering and smelting may be removed in a dedicated mercury removal step before the gasses are lead to the sulphuric acid recovery plant (if present; see the detailed process description in section 5.2.3). Lead is sometimes co-produced with zinc or other non-ferrous metals. For a thorough description of the processes of lead extraction see for example (European Commission, 2001).

572. Recycled lead scrap may be added to the fed material to the sintering or smelting steps, but is not considered a major input source of mercury to the process. Metallurgical coke (or gas fuel) is used in the reduction step in the furnace, but is not expected to be major mercury input sources to the processes, as (in the case of metallurgical coke) most of the mercury present in the coal used evaporates in the coke production process.

5.2.5.2 Main factors determining mercury releases and mercury outputs

Table 5-65 Main releases and receiving media during the life-cycle of lead extraction and initial processing

Phase of life cycle	**Air**	**Water**	**Land**	**Products *2**	**General waste**	**Sector specific treatment/ disposal**
Wastes from mining and production of concentrates	x	**X**	**X**			**X**
Extraction of lead from concentrate	**X**	**X**	**X**	**X**		**X**
Manufacture of refined lead and products ***1**						
Use of lead						
Disposal of lead						

Notes: *1: Mercury releases could in principle happen due to fossil fuel usage, but the lead metal is not expected to be a mercury input source to the refining and manufacturing steps;

*2: In sulphuric acid, mercury by-products, and perhaps other process-derived by-products;

X- Release pathway expected to be predominant for the sub-category;

x- Additional release pathways to be considered, depending on specific source and national situation.

573. The concentration of mercury in the ore and amount of ore mined are important factors determining mercury releases.

574. Extraction and primary processing of lead (also called “primary lead smelting”) may lead to releases of the mercury to the atmosphere, to aquatic and terrestrial environments, and to accumulation of substantial quantities of mercury-containing mineral waste which may in turn lead to additional releases. The extent of releases is very dependent on how carefully the waste deposits are managed (COWI, 2002). US EPA (1997a) describe that the sintering reactions occur at very high temperatures (about 1000 ºC) and controls devices used at most plants (in the USA) are expected to have minimal effectiveness at capturing the mercury. Therefore, most of the mercury in the ore was expected to vaporize and be emitted to air during this sintering process. Improvements in this regard may however have happened since then in the sector. Any residual mercury remaining in the roast from the sintering process is generally expected to be released during the reduction step (US EPA, 1997a).

575. As with other non-ferrous metals desctribed above, extraction and processing of lead is often equipped with a variety of release reduction devices, with the potential to reduce direct releases of mercury to the atmosphere as well as to aquatic and terrestrial environments. Such technologies can involve retention of particulate matter and gaseous releases from flue gas, waste water treatment and in some cases mercury specifc filters. Atmospheric release reduction technology present normally yields additional solid or fluid residues (COWI, 2002).

5.2.5.3 Discussion of mercury inputs

Table 5-66 Overview of activity rate data and mercury input factor types needed to estimate releases from lead extraction and initial processing

Life-cycle phase	**Activity rate data needed**	**Mercury input factor**
Wastes from mining and production of concentrates	Metric tons of reject material produced per year	g mercury/metric ton in reject material produced ***1**
Input to extraction of primary lead from concentrate	Metric tons of concentrate used per year	g mercury/metric ton concentrate

Notes: *1 Such wastes may include lower grade material (lower lead concentrations), and the mercury concentrations may be similar to concentration in the input ore material. If no concentration data for reject materials are available, concentration data for the ore used may be applied for forming a rough estimate.

576. The two most important input factors needed to estimate emissions from a facility in this subcategory are: an estimate of the average concentration of mercury in the lead ore concentrate used at the facility; and the annual capacity of the plant (in units such as metric tons of lead ore concentrate processed per year).

577. The concentration of mercury in lead ores can vary considerably. Hylander and Herbert (2008) collected data for mercury concentrations in concentrates for zinc, copper and lead production for all mines globally, for which data were available through market studies published by BrookHunt and Associates Ltd. (2005, 2006a; 2006b). The individual data are proprietary, but data were aggregated in charts showing the distribution of mercury concentration in relevant concentrates; see Figure 5-8 for data on lead concentrates. The authors note that no data from Chinese mines were available.

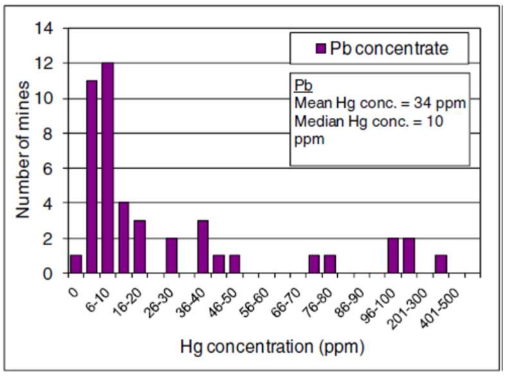


Figure 5-8 Distribution of mercury concentrations in lead concentrates globally (reprinted with permission from Hylander and Herbert, 2008. Copyright 2008 American Chemical Society).

578. UNEP/AMAP (2012) proposed the following default mercury input factors for lead extraction based on (Hylander and Herbert, 2008; Outotec, 2012) as well as other information: Minimum: 2; medium: 30, and maximum: 60 g mercury/metric ton of concentrate used. Converted to a basis of lead produced, the corresponding factors were respectively 2.8, 75 and 214.3 g mercury/metric ton lead produced, when using a concentrate used/Cu produced ratio of 1.39-3.57 (intermediate value 2.50).

579. Some other data on mercury concentrations in lead concentrates are presented in Table 5-67.

Table 5-67 Examples of mercury concentrations in concentrates for lead production

Country	Location	Type	Average Hg concentration, g Hg/metric ton	Range of Hg concentration in samples, g/metric ton	Data source
In concentrates					
Canada	Brunswik Works	Lead concentrate	2.7		Klimenko and Kiazimov, 1987
USA	Missouri	Lead concentrate	0.2		US EPA, 1997a
Russian Federation	Unknown	Concentrate of stratiformic lead-and-zinc type		2 - 290	Bobrova *et al.*, 1990; Ozerova, 1986
Global		Global average	34 (median 10)	(see Figure 5-8)	Hylander and Herbert (2008)
China		2 lead smelters		2.15 and 18.7	Zhang et al (2012)
		Typical medium value	30		Outotec (2012)

5.2.5.4 Examples of mercury in releases and wastes/residues

580. Zhang et al (2012) have reported detailed mass balances for six non-ferrous smelters (zinc, lead and copper) with relatively low atmospheric emissions in China. The study results are described in the section on zinc extraction above. The few data available do not indicate major differences in the mercury output distribution pattern between different base metals production.

581. Klimenko and Kiazimov (1987) report mercury concentrations in reject material at 0.69 g/metric ton from combined production of lead, zinc, copper and compound concentrates (with mercury concentration in the input ore at 2.1 g Hg/metric ton ore), indicating that mercury concentrations in reject material may be significant.

582. The US EPA estimated that 0.10 metric tons of mercury was emitted from lead smelters in the USA for year 1994. Assuming that all mercury in the ore is released to the air, this emissions estimate can be calculated by multiplying total capacity (370,000 metric ton) times the average mercury concentration in these ore concentrates (0.2 ppm). However, US EPA actually used a somewhat more complicated equation (which can be viewed in Appendix A of the US EPA, 1997a report).

5.2.5.5 Input factors and output distribution factors

583. Based on the information compiled above on inputs and outputs and major factors determining releases, the following default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that these default factors are based on a limited data base, and as such, they should be considered subject to revisions.

584. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

585. Due to lack of data, no default factors can be set for the mining and concentrating processes. Note that this implies that the mercury release estimates calculated from default factors may likely tend to underestimate the total releases from the sector.

a) Default mercury input factors

586. Actual data on mercury levels in the particular concentrate composition used will lead to the best estimates of releases.

587. If no information is available on the mercury concentration in the concentrates used in the extraction step, a first estimate can be formed by using the default input factors selected in Table 5-91

below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum). The medium estimate is used in the default calculations in Inventory level 1 of the Toolkit. If it is chosen not to calculate as intervals, the use of the maximum value will give the safest indication of the possible importance of the source category for further investigation. Using a high end estimate does not automatically imply that actual releases are this high, only that it should perhaps be investigated further.

Table 5-68 Default input factors for mercury in lead concentrates used for extraction of lead

Feed material	Default input factors; g mercury per metric ton of concentrate; (low end - high end (intermediate)
Lead concentrate (input factor for both concentrating and metal processing steps)	2 – 60 (30)

588. If desired, these default factors can be converted to a basis of mercury inputs per lead produced, by the use of a concentrate used/Pb produced ratio of 1.39-3.57 (intermediate value 2.5 ton concentrate used per ton lead produced) as derived by UNEP/AMAP (2012). The corresponding factors are low end: 2.8, 75 and 214.3 g mercury/metric ton lead produced. Note that the default Toolkit spreadsheet calculations are based on mercury per concentrate.

b) Default mercury output distribution factors

589. Based on the data on mercury output distribution presented in this section, as well as in the section above on zinc, the following default factors are suggested.

Table 5-69 Default output distribution factors for mercury from extraction of lead from concentrates

Phase of life cycle	Air	Water	Land *1	Product *1, *2	General waste	Sector specific treatment/ disposal *1
Concentrating step with wastewater treatment (discharge limit 2µg Hg/l) *3	?	0.00062	?	0.82	?	0.17938
Production of lead from concentrate:						
Smelter with no filters or only coarse, dry PM retention	0.90		?			0.10
Smelters with wet gas cleaning	0.49	0.02	?			0.49
Smelters with wet gas cleaning and acid plant	0.10	0.02	?	Acid: 0.57		0.31
Smelters with wet gas cleaning, acid plant and Hg specific filter	0.02	0.02	?	Acid: 0.013		0.947 (hereof Hg/calomel 58.65)

Notes: *1 Deposition of residues will likely vary much between countries and perhaps even between individual facilities, and may be on land, in the mine, in impoundments, often on-site.

*2: Marketed by-products with mercury content include, among others, calomel, elemental mercury, low grade washing acids, higher grade sulphuric acid, sludge for off-site mercury recovery, liquid sulphur and filter cake or other residues sold or transferred to other metal production activities or other

sectors. Like for zinc, calomel from Hg-specific filters is considered increasingly deposited as hazardous waste, rather than marketing it as compound or metal mercury. Hg/calomel are here shown in the Sector-specific waste output, but should be assigned to products if marketed from the specific facilities.
*3: Assumed similar to zinc concentrating presented above, as no specific data are available for lead production. Based on water discharge limit of 2µg Hg/l. If actual limit is different, the output factors for water can be adjusted relatively (with documentation provided in inventory report). The output to products is the Hg following the concentrates.

c) Links to other mercury sources estimation

590. In case of combined smelters producing several non-ferrous metals from the same concentrate, it is suggested to assign the mercury releases to the metal produced in the largest amounts. In case of parallel processing of different concentrates in parallel production lines, assign the mercury releases separately to the major metal produced in each line.

5.2.5.6 Source specific main data

591. The most important source specific data would in this case be:

- Measured data or literature data on the mercury concentrations in the ores and concentrates extracted and processed at the source;
- Amount of ore/concentrates extracted and processed; and
- Measured data on the distribution of mercury outputs with (preferably all) output streams, including mercury percentages retained by emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

592. The presence of a mercury removal unit at a specific extraction plant may indicate that a major share of the mercury outputs is not released to the atmosphere, but is instead marketed as by-product or stored on-site.

5.2.6 Gold extraction and initial processing by methods other than mercury amalgamation

593. This source sub-category includes large and small scale gold mining using cyanidation or other methods besides mercury amalgamation for extraction of the gold. However, as all gold ores may contain natural contents of mercury, small-scale mining with heavy machinery where only gravitational methods are used may also be included in the present sub-category due to the potentially high volume of ore material processed. The emphasis in the description here is however on large scale industrial gold extraction.

594. Traditional panning of gold nuggets (e.g. by rivers often), should not be counted here due to the small amount of ore material processed.

595. Like for other non-ferrous metal extraction, quantitative descriptions of mercury mass balances over gold extraction operations - corresponding input and output distribution estimates - seem not to be easily available. Therefore, the quantitative aspects of the description in this section have been put together piece by piece from different sources. Large scale industrial mining and metal extraction operations are few in number in any country where they operate, their feed materials and production configurations vary significantly, and they may be significant mercury release sources. Given these factors, it is highly recommended to use a point source approach in the inventory, and compile point source specific data from the operating companies themselves, if feasible, as well as from other relevant data sources with knowledge of the specific production facilities.

5.2.6.1 Sub-category description

596. Ore for extraction of gold, can contain trace amounts of mercury which may in some cases be elevated compared to other natural raw materials. In some gold ores, mercury concentrations may be as high as the gold concentrations. Mercury content in gold ore has in some cases been high enough to motivate the recovery of the mercury from solid residues from gold extraction for commercial purposes. Such recovery and marketing of by-product mercury from extraction of gold has been a significant source of mercury to the global market, and may perhaps still be so. This recovery may also partly be motivated by the desire to reduce releases of the same mercury from the gold production and because this mercury may serve as a substitute for dedicated primary mercury mining.

597. Gold extraction processes can be significant sources of mercury releases, even if no deliberate mercury use (amalgamation) takes place. Industrial gold extraction is one of the largest sources of mercury releases among metal extraction activities in the Arctic countries (Maag, 2004). Both releases to land and the atmosphere may be significant.

598. The extraction procedures for gold recovery involves several steps at temperatures high enough to thermally releases mercury, as well as steps where significant amounts of solid or liquid residues which may contain mercury are produced and may be disposed of.

599. Note that in some countries gold is produced by re-processing old mine tailings, where the mercury amalgamation process was formerly used, with the modern cyanide process which is more effective (Lassen *et al.*, 2004). This may give rise to substantial mercury releases, if the mercury is not retained by effective pollution control methods. It is not known how widespread this production form is in a global perspective.

Processes involved

600. The extraction processes are a combination of general physiochemical unit operations (as described in more detail for zinc) and specific chemical processes designed to separate the gold from other constituents of the ore/concentrate used. According to Renner (2000), the processes can involve gravity concentration and/or flotation, but whole ore is also processed directly in some cases (Booz Allen & Hamilton, 2001). Roasting, or wet oxidisation ("autoclaving") of the ore or concentrates is applied, except on naturally oxidized ores that can be processed by direct leach methods (see description of roasting in section 5.2.3 on zinc extraction). The main step is leaching of the ore (or concentrate) with sodium cyanide in an aqueous alkaline slurry. The cyanide dissolves the gold from the rock material. The subsequent steps mainly follow one of the two lines: 1) The solid residues are filtered of, and the solution is treated with zinc chips to precipitate gold, which is thereafter treated with sulphuric acid and dried, and roasted at 800 °C to oxidize lead, zinc and iron. Borax flux material is added, and the material is melted to produce raw gold with 80-90% gold content. 2) Carbon is added to the cyanide concentrate slurry in a multiple step process, the gold is absorbed in the carbon material ("Carbon-in-pulp" process), whereafter the gold-containing carbon is separated from the slurry. The gold is eluted from the carbon again with a caustic-cyanide solution, from which the gold is finally separated by electrolysis ("electro-winning", see section 5.2.4). The carbon is washed with acid, reactivated at high temperatures in a kiln and recycled back into the process. Even when the cyanidation process is used as the main process, a side stream of coarse or sulphidic gold ore material may sometimes be treated by mercury amalgamation (Renner, 2000; Booz Allen & Hamilton, 2001).

5.2.6.2 Main factors determining mercury releases and mercury outputs

Table 5-70 Main releases and receiving media during gold extraction and initial processing by methods other than mercury-amalgamation

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Wastes from mining and production of concentrates	x	X	X		x	X
Extraction of gold from whole ore or concentrate	X	x	X	X	x	X
Manufacture of refined gold and products						
Use of gold						
Disposal of gold						

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

601. Mercury and mercury compounds may be processed as a trace constituent or recovered as a by-product from gold ores. Many mines extract, move, store, process, and dispose off large amounts of waste rock and ore-materials, which often contain low concentrations of mercury originating from the ore material. The vast majority of this material is placed in surface impoundments or on the land, and the metals are sometimes reported as on-site releases to land. This previously buried material is exposed to potential leaching by rain, snow, and acid mine drainage, and must be carefully managed and monitored to prevent any surface water or groundwater contamination. There can also be air releases of mercury from ore pre-processing and refining operations.

602. Extraction and primary processing of gold may lead to releases of the mercury to the atmosphere, to aquatic and terrestrial environments, and to accumulation of substantial quantities of mercury-containing mineral waste which may in turn lead to additional releases. The extent of releases is very dependent on how carefully the waste deposits are managed.

603. Large scale gold production sites may use air pollution abatement systems. Some of the technologies mentioned for zinc extraction are applied. The techniques may involve both general multipollutant retention systems (dust filters, etc.) as well as mercury specific filters such as activated carbon filters which may be more used in large scale gold extraction facilities than in other primary non-ferrous metal production. Release reduction technology normally yields additional solid or fluid residues, which can also lead to releases (COWI, 2002). The extent of these releases depends on how well the residues are managed.

Discussion of mercury inputs

Table 5-71 Overview of activity rate data and mercury input factor types needed to estimate releases from large scale gold extraction and initial processing (by methods other than mercury amalgamation)

Life-cycle phase	Activity rate data needed	Mercury input factor
Extraction and processing	Amount of material/ore processed per year or amount of gold produced	Concentration of Hg in material/ore processed or amount of mercury released per metric ton of gold produced

604. Booz Allen & Hamilton (2001) reports, based on review of literature, that typical concentrations of mercury in gold ore in the Western USA range from 1-200 g/ton ore. Jones and Miller (2005) stated that mercury concentrations can range from less than <0.1 to above 100 g mercury/metric ton of ore. According to the US (2010) submission to UN Environment for the so-called §29 study on

mercury, the gold mercury concentration in mined ores in the USA varies, from less than 0.1 parts per million (ppm = g/ton ore) to about 30 ppm. The gold mine ores in Nevada have the higher mercury concentrations. The mines in other States have lower mercury in the ores. Outotec (2012) inform that mercury concentrations in gold ore vary; examples of countries with high mercury concentrations are the USA and Australia.

UNEP/AMAP (2012) used an input factor of 5.5 g Hg/metric tonne of ore, based on the same evidence as cited above combined with expert judgement. Based on the data shown in Figure 5-9, a value of 4 g Au/t ore was assumed, yielding a ratio of 250,000 metric tons ore for one metric ton of gold on which they derived equivalent emission factors for mercury per produced metric ton of gold.

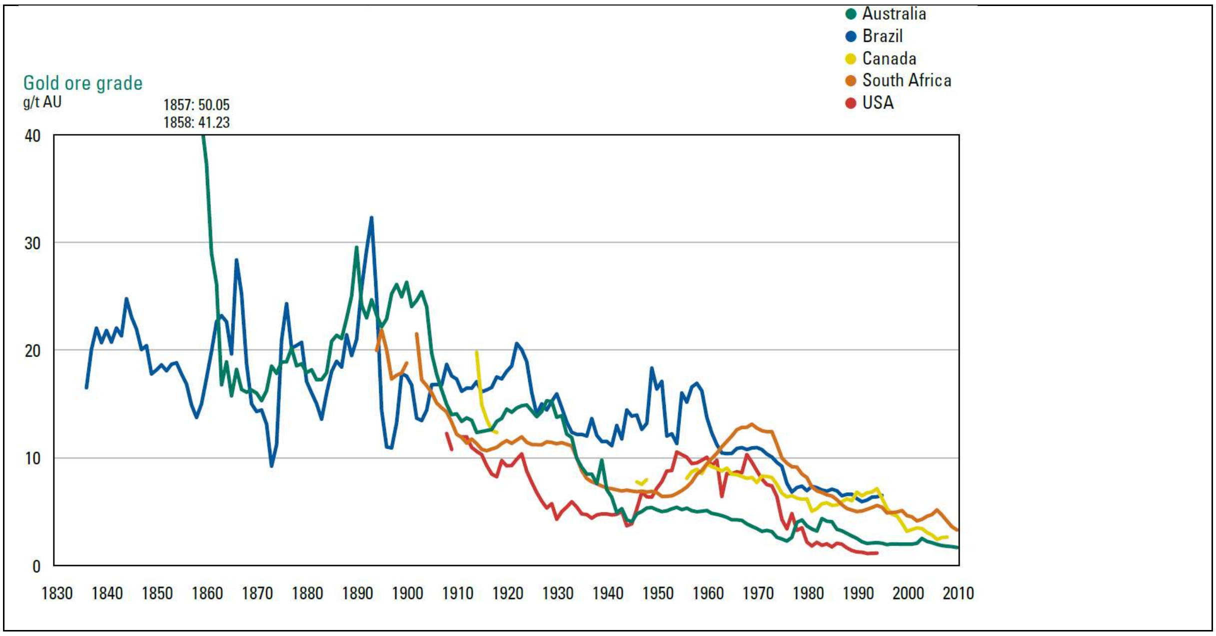


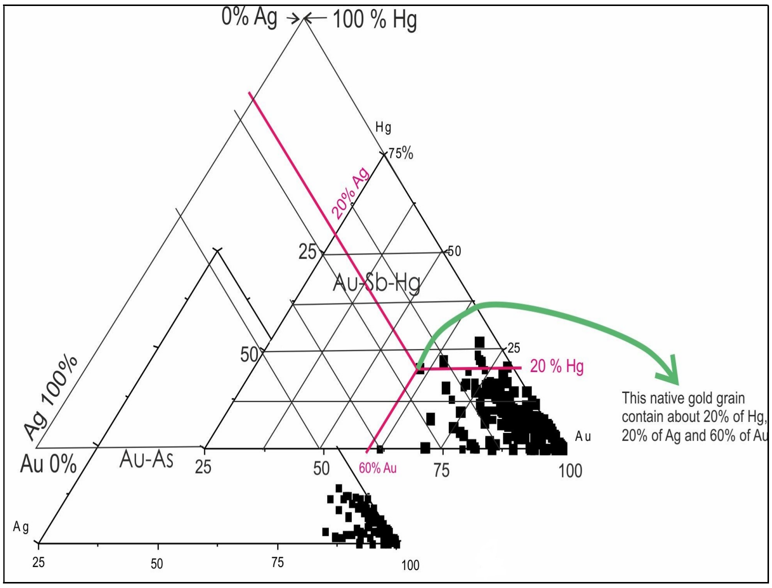
Figure 5-9 The development in gold concentration in gold ore from various countries (UNEP, 2011c citing Giurco et al, 2010).

605. According to NRH Research, the average gold grades mined in 2013 was down at 1.18 gAu/t ore, but grades vary significant from about 0.3 to about 28 gAu/t in the mined ores. Top 10 country grade averages were from South Africa (average 6.04 gAu/t) to Papua New Guinea (1.29 gAu/t).

606. Mercury concentrations in gold ores used in industrial gold extraction outside the USA are very hard to find in the literature. The International Council for mining and Metals, ICMM, have been contacted several times in the course of the development of this toolkit, but had not shared data on the subject at the time of finalisation of the 2019 Toolkit update.

607. Gold and gold-containing minerals as found in gold ores often have natural mercury contents in it, this may be in the form of multi-metal alloys (for example Au-Ag-Hg) or as natural gold-mercury amalgams; however, mercury can also be present in other minerals in the same ore, as cinnabar or in other minerals (Naumov, 2019). Overview data reviewed by Goldfarb et al (2016), indicate that there is sometimes some correlation between gold and mercury concentrations in gold ores, however examples from China (Guanqing Lu, 1994) and Mexico (INECC, 2017) illustrate that this is not always the case; see both below.

608. As regards mercury-bearing native gold mineral (isolated gold grains, not whole ore) it usually contains from 0.1% up to 3-5 % of mercury; in some cases mercury contents can reach 10-30% (Naumov, 2019; Borisenko et al, 2004, 2006). Examples of mercury concentration in gold ores of Au-Sb-Hg, Au-As, gold-skarn, gold-cupper-quarts and gold-copper-mercury mineral types (gold alloy grains) are shown in **Error! Reference source not found.** (Borisenko et al, 2006) and Figure 5-11 (Borisenko et al, 2004).



This native gold grain contain about 20% of Hg, 20% of Ag and 60% of Au

Figure 5-10 Mercury, gold and silver concentrations in natural gold grains of gold-antimony-mercury and gold-silver mineral types (from Borisenko et al (2006) with help for reading the figure from Naumov, 2019).

609.

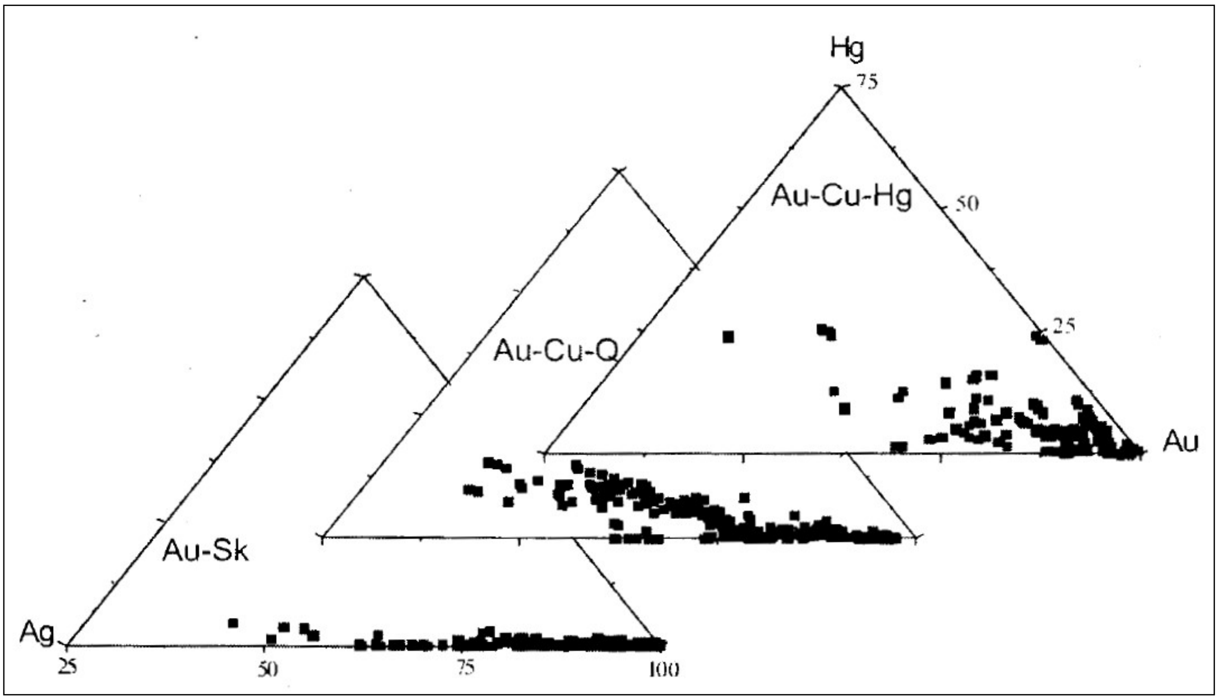


Figure 5-11 Mercury, gold and silver concentrations in natural gold grains of gold-skarn, gold-cupper-quarts and gold-copper-mercury mineral types from (Borisenko et al, 2004).

610. According to MacKenzie and Craw (2005), most orogenic gold deposits (meaning deposits formed in areas with tectonic activity) have gold alloy with high fineness (>90% Au), the other metals of the alloy being predominantly silver and mercury (citing Morrison et al. 1991; Knight et al. 1999). MacKenzie and Craw (2005) sampled and analysed a large number of gold grains isolated from ore in quartz vein (hard rock) deposits of the Otago Schist, New Zealand and found mercury concentrations in the gold (alloy) grains between the detection limit of 0.5 wt% and 8 wt%. They gave an example of gold versus ore mercury concentration from the Macraes mine from the same region in New Zealand.

The ore of this mine typically contains between 0.1 and 1 ppm Hg (0.1-1gHg/t ore), while in the area that hosts the mine, gold grains had mercury concentrations ranging from 1 to 4 wt% (meaning lower than the ore Hg concentrations).

611. For another orogenic gold deposit, the Dickenson mine at Red Lake, Ontario Canada, Goldfarb et al (2016) show an enrichment factor for gold of about 15 compared to average earth crust mercury concentrations. Using the NPI (2012) average mercury concentration of 0.05 gHg/t, this corresponds to a mercury concentration around 0.8 gHg/t ore.

612. MacKenzie and Craw (2005) also cite an example of placer (sediment derived) gold ore in New Zeeland with mercury concentrations up to 10 wt%, presented in context as “mercury-rich” (citing Youngson et al. (2002) and Falconer (2003). Placer, or alluvial, gold deposits consists of gold-rich sediments from weathering and water transport from hard-rock gold deposits.

613. According to Goldfarb et al (2016), Carlin-type/Carlin-like gold ores, prevalent in Nevada USA, but also present in North Macedonia and China, are mined by both open-pit and underground operations, with gold grades as low as less than 1 g/t mined from the former and as high as 34 g/t from the latter. Because most of the gold resides in pyrite (iron sulphide), it must be first oxidized in a roaster or autoclave to allow recovery of gold with cyanide solutions. Natural weathering and oxidation of the pyritic ores eliminate this step and permit direct recovery of gold by cyanide heap leaching methods. Pyrite is a key mineral in the Carlin-type ores. Goldfarb et al (2016) show median mercury concentrations in pyrite (iron suphide) as 200 ppm (200g Hg/t pyrite; median of 1150 samples); note that this is the mediam concentration in the pyrite mineral, and not in the whole ore (where it will be lower). Goldfarb et al (2016) also show median concentrations of gold, 8 ppm, and mercury, 10 ppm, in three formations in the Goldstrike property in the northern Carlin trend of Nevada USA.

614. Goldfarb et al (2016) present so-called enrichment factors (local concentration compared to average earth crust concentrations) of mercury in Carlin-type/-like gold ores in two locations in China, of 200-400 (Dian-Qian-Gui), and in 200-2000 (West Qinling); these values are within the range experienced in Nevada from the same ore type. Goldfarb et al do not mention the mercury earth crust concentration they have used for their presentation, but if a value of 0.05 gHg/t is assumed (NPI, 2012), this corresponds to mercury concentrations in the gold ores of around 10-20 g Hg/t ore and 10-100 g Hg/t ore, respectively in the two Chinese locations.

615. Guanqing Lu (1994) presents measurements of gold and mercury (and other metals) concentrations in ore samples from the Carlin-like Danzhai Gold-Mercury Deposit in China. Of a data set of 37 samples analysed, average mercury concentrations was 267 gHg/t (excluding one outlier of 60900 gHg/t), but if only samples with gold (Au) concentrations above 1 gAu/t are included (relevant for gold exploitation), the averages for the remaining 18 samples are 37 gAu/t and 121 (11-475) gHg/t, meaning a Hg:Au ratio of about 15; observed Hg:Au ratios for these 18 samples ranged from 1 to 51.

616. Goldfarb et al (2016) state that mercury concentrations in epithermal (near-surface volcanic) gold-silver (Au-Ag) deposits generally range between 100 ppb and 50 ppm (meaning 0.1-50 gHg/t ore). Goldfarb et al also mention Bonanza epithermal Au-Ag vein mineralization at the Manhattan mercury mine that contained tens to hundreds of ppm Hg, as well as several modern hot-spring areas in New Zealand and in the United States known to be active sites of mercury mineralization that contain 0.2 to 5% Hg (meaning 2-50 kg Hg/t) (citing White, 1981 and others not fully referenced). For comparison, Goldfarb et al state that the Almaden mercury mine of Spain cannot be classified as an epithermal deposit (it is difficult to classify).

617. Ivan (2019) reports that analysis of a small number of samples of (ASGM) polymetallic quarts vein gold ore from Nigeria showed mercury concentrations of 1 ppm (gHg/t ore) and gold concentration of 3.4 g/t, meaning a Au:Hg ratio of 3.4:1.

618. Sources within the hazardous waste treatment sector who have looked into the topic state that Hg:Au ratios from industrial gold mining are often near 1:1, but ratios between 1:3 and 3:1 are also

often observed. It is not known if these observations are representative for all of the global industrial gold mining sector.

619. Hruschka (2019) notes that particularly for polymetallic vein type deposits, the Hg:Au ratio probably depends on many more geologic parameters than just gold grade (as also described here above), but that a ratio of 1:1 may not be far from a global average. He also mentions Nigerian ASGM gold ore with a (natural) Hg:Au ratio of 1:3, as well as anecdotal reports from Yanacocha, Peru suggesting a ratio of 1:1.

620. Veiga (2019) states that in the majority of the ores, he has worked with, natural mercury concentrations have been much less than 1 ppm (g/t), and that Hg:Au ratios of 1:1 or higher are not common outside Nevada, USA.

621. Naumov (2019) states that the concentration of mercury in gold ores can vary from 1-2 ppm to 1-2% (1- 20,000 gHg/t ore).

622. INECC (2017) presents analysis results of gold ores, gold concentrates and deposit drillings from different states in Mexico; see Table 5-72 below.

Table 5-72 Concentrations of mercury, gold and silver in ore, drilling and concentrate samples in different mining estates in Mexico (source: INECC, 2017).

No.	State	Type of sample	Hg (mg/Kg)	Au (mg/kg)	Ag (mg/kg)	Hg:Au ratio	Remarks
1	Zacatecas	Fine crushing (main ore)	**26**	0.22	312	116.6	Composite, May 2017
2	Zacatecas	Fine crushing (main ore)	**10**	0.4	<1.0	25.0	Mixed material of different days
3	Zacatecas	Fine crushing (main ore)	**4**	0.5	<1.0	8.0	Mixed material of different days
4	Chihuahua	Compound grinding material (ore)	**4**	0.67	49	6.0	30-day composite, July 2017
5	Sonora	Concentrate	26	110	10	0.2	Daily composite, June 2017
6	Sonora	Fine crushing (main ore)	**4**	0.83	<1.0	4.8	Daily sample
7	Durango	Fine crushing (main ore)	**0.6**	0.2	<1,0	3.0	Mixed material of different days
8	Durango	Fine crushing (main ore)	**0.6**	0.11	<1,0	5.6	Mixed material of different days
9	Durango	Drilling pulp (ore)	0.6	0.16	<1,0	3.7	15 holes composite
10	Durango	Drilling pulp (ore)	1.1	0.13	<1,0	8.5	20 holes composite
12	Chihuahua	Grinding material (ore)	**1.3**	1.8	37	0.7	Composite, f July 2017
14	Aguascalientes	Concentrate	6.4	14.6	1751	0.4	15-day composite, June

623. The draft Argentina (2017) Minamata Initial Assessment inventory report of presented mercury concentrations in industrial gold ores of two projects in the country ranging between 0.68 and 10 ppm (= 0.68 - 10 g Hg / t ore).

624. UN Environment (2019) extracted data from Minamata Initial Assessment (MIA's) inventories implemented by them, which were unpublished at the time of the finalization of the 2019 Toolkit update. The extract showed that one major mining country in the LAC region used documented mercury input factors in gold ore of 12.7 gHg/t ore, while two countries in Africa used undocumented input factors of 1 and 2 gHg/t ore respectively.

625. Naumov et al (2002) state that what they call gold-mercury deposits have become gold-ore objects in Russia and are also exploited many other places globally, for example: Carlin, Cortez, Bell

(Nevada, USA); Knoxvill, New Idria (California, USA); Hemlo (Canada); Alsar (North Macedonia); and Vorontsovskoe (Urals, Russian Fed.); Kyuchus, Galkhaya, Svetloe (Yakutia, Russian Fed.); Tas-Uryakh (Khabarovsk Territory, Russian Fed.); Konchock, Dzhalama (Central Asia); Murzinskoe (Altai, Russian Fed.); Soloneshnoe, Tunga ore cluster (Transbaikalia, Russian Fed.) and many others. See examples globally in Figure 5-12 (from Borisenko et al, 2004).

626.

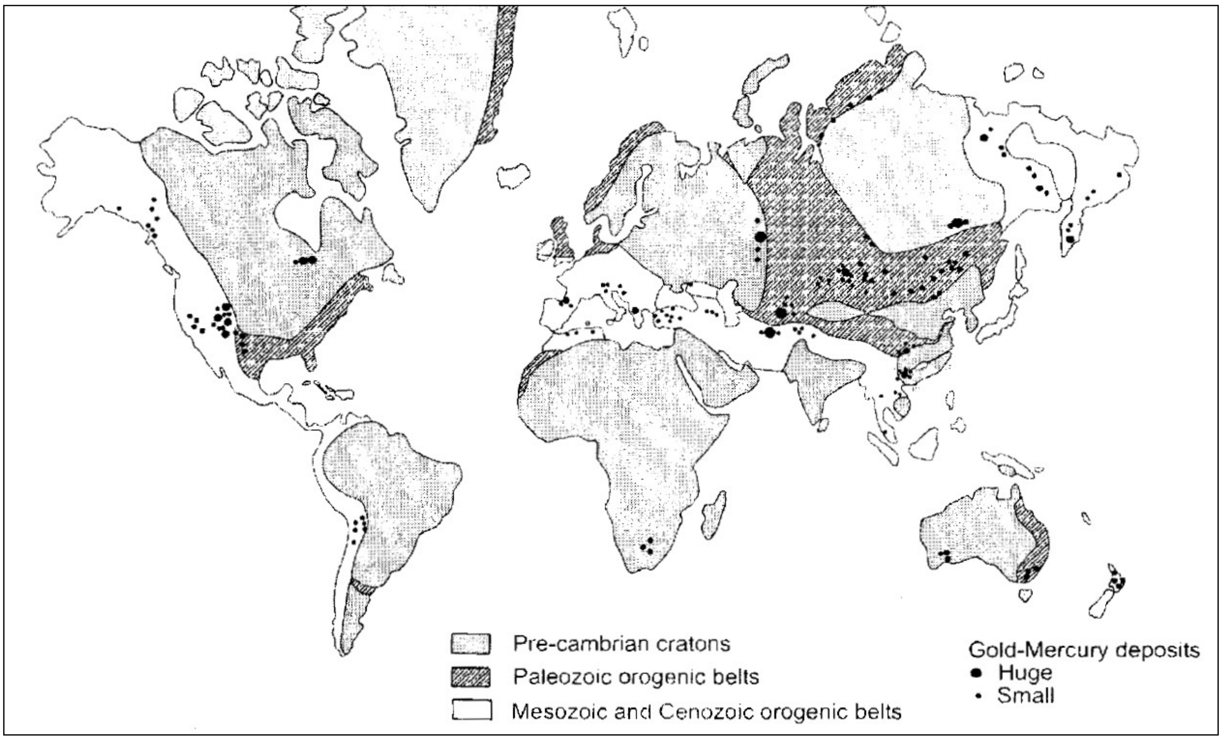


Figure 5-12 Examples of gold-mercury deposits from Borisenko et al (2004).

5.2.6.3 Examples of mercury in releases and wastes/residues

627. Based on data reported by 25 gold mines in the western USA, a total of 5474 kg of mercury were emitted to air, 0.4 kg to water, 1,886,921 kg to land on-site, and 594 kg were released off-site (US EPA, 2003a).

628. In a newer data set from the USA (TRI, 2008), 24 gold mines in the USA reported that a total of 1,991 kg of mercury compounds were emitted to air, 0.4 kg to water, 2,430,750 kg to land on-site, and 808 kg were transferred off-site, mainly for recovery of mercury. These numbers indicate along with other evidence, a decrease in atmospheric releases from modern gold mining in the USA, a development which should not necessarily be seen as general world-wide, as US facilities have extensive coverage with flue gas cleaning systems. The releases from the top 10 mercury releasing facilities are shown in the table below. Note that the basis "mercury compounds" was reported in TRI, introducing an uncertainty whether all releases can be considered on the same basis. This may also bias the presented relative distribution of releases towards higher fractions released to land than actually being the case counted on a pure mercury basis.

629. The 10 gold mines in the USA with the highest reported releases are shown in the table below.

630. According to Jasinski (1994), 114 metric tons of mercury was produced as by-products ("recovered") from gold mining operations in 1990.

Table 5-73 Releases in kg of "mercury compound" from the 10 highest releasing gold mines in the USA (TRI, 2008)

Facility	Total Air Releases	Surface Water Discharges	Total On-site Land Releases	Total Transfers Off-site for Further Waste Management (mainly recycling)	Total Releases
1	492	0	826,871	0	827,362
2	51	0	589,670	0	589,721
3	833	0	540,988	0	541,821
4	206	0.2	180,530	219	180,955
5	20	0	133,531	0	133,552
6	42	0	36,542	436	36,585
7	138	0	34,622	0	34,760
8	4	0	31,885	28	31,889
9	2	0	31,751	0	31,753
10	99	0	9,019	0	9,118
Top 10 sum	1.886	0.2	2,415,410	684	2,417,516
Percentage of grand total	0.08%	0.00001%	99.91%	0.03%	100%

Notes: ND = no data identified.

*1 The reason for the inconsistency between the reported numbers for "total on-site releases", "total off-site releases" and "total on- and off-site releases" is not clear in the reference.

631. The 1998 Toxic Release Inventory (TRI) information submitted by gold mining companies in the USA revealed that these mines are significant sources of mercury air emissions (US EPA, 2003a). However, as shown in table above, the vast majority (> 99%) of total reported releases were on-site releases to land. TRI data on releases to water are scarce. For the mines where releases to water are reported, they appear to comprise a tiny fraction of the total releases. The reported releases to air are likely direct releases from the production. In principle, additional diffuse releases to air may happen from the material constituting the release to land. No information is, however, available on the form of the releases to land, the mobility of the mercury in the releases, or the mercury concentrations in the releases to land.

632. The reported production of gold from mines in the USA in 1999 - 2003 ("from about two dozens of mines") is shown in Table 5-74 (USGS, 2004).

Table 5-74 Reported production of gold from mines in the USA in 1999 - 2003; metric tons/year (USGS, 2004)

	1999	**2000**	**2001**	**2002**	**2003 *1**
Mine production, metric tons gold	341	353	335	298	266

Notes: *1 2003 estimated by USGS.

633. Assuming that the total mercury releases reported by US EPA (2003) from 25 gold mines in the USA, originate from the same "about two dozens of mines" for which the USGS (2004) reported gold production, rough estimates of the average mercury releases per metric ton of gold produced can be calculated. The US EPA release data most likely describe the situation around 1999-2001, where the annual reported gold production from mines was 343 metric tons/year on average. Thus calculated,

rough estimates of the average mercury releases per metric ton of gold produced are shown in Table 5-75.

Table 5-75 Calculated estimates of the average reported mercury releases per produced metric ton of gold in the USA; kg Hg/metric tons gold produced

	Releases to air	**Releases to land**
Reported kg mercury releases per produced ton of gold ***1**	20	6000

Notes: *1 Rounded to reflect associated uncertainty.

5.2.6.4 Input factors and output distribution factors

634. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default mercury release factors are suggested for use in cases where source specific data are not available. It is emphasized that these default factors are based on a limited data base, and as such, they should be considered preliminary and subject to revisions.

635. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

a) Default mercury input factors

636. Actual data on mercury levels in the particular concentrate composition used will lead to the best estimates of releases.

637. If no information is available on the mercury concentration in the concentrates used in the extraction step, a first estimate can be formed by using the default input factors selected in Table 5-76 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors have been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum). The medium estimate is used in the default calculations in Inventory level 1 of the Toolkit. If it is chosen not to calculate as intervals at Level 2, the use of the maximum value will give the safest indication of the possible importance of the source category for further investigation. Using a high end estimate does not automatically imply that actual releases are this high, only that it should perhaps be investigated further.

638. In earlier versions of the Toolkit, default inputs factors of 1-30 (mid 15) gHg/t gold ore were applied based on the data available for the Toolkit at that time. For the 2019 Toolkit update, additional information has been collected on both mercury concentrations in ores and typical gold concentrations (“grades”) mined (as described above). No correlated datasets with both production volume and concentrations of mercury and gold have been available however, and therefore production-weighted averages cannot be formed. Besides, both mercury concentrations and Hg:Au ratios vary significantly in the little data available, due to geological variation, even within the same gold deposit. It is therefore still very important to try to get point source-specific input (and output) factors when developing mercury emissions/releases inventories for the sector. For default input factors, omitting the very low and the very high values as usually in the Toolkit, we have therefore suggested to keep the 1-30 gHg/t ore range used previously, but with the intermediate value of 5.5 gHg/t ore suggested in the 2012 Global Mercury Assessment. This is also consistent with such concentration data often being log-normal (or similar) distributed, meaning that the expected average value would be in the low end of the observations’ range. But again, please remember that actual concentrations in a country could be in the full range of some 0-100 gHg/t gold ore.

Table 5-76 ***Preliminary*** *default input factors for mercury in concentrates for gold production without the use of mercury amalgamation.*

Material	**Default input factors;** **g mercury per metric ton of ore;** **(low end - high end (intermediate)**
Gold ore	1 - 30 (5.5)

639. If desired, these default factors can be converted to a basis of mercury inputs per gold produced, by the use of a ore used/Au produced ratio of 250000 ton ore used/ton gold produced as derived from Figure 5-9 above. The corresponding input factors are low end: 250, medium; 3750 and high end: 7500 kg (kilogram) mercury/metric ton gold produced. Note that the default Toolkit spreadsheet calculations are based on mercury per ore.

b) Default mercury output distribution factors

640. Data enabling the definition of default output distribution factors for gold extraction without the use of mercury amalgamation are scarce, as indicated above. A preliminary set of default output distribution factors for this sub-category was, however, defined, based on the available data. Slightly higher outputs to land, water and products than in the 2008 data from the USA are suggested here to signal that substantial mercury amounts may follow these pathways in cases where atmospheric releases are not retained as effectively as in the USA (in 2008).

Table 5-77 ***Preliminary*** *default output distribution factors for mercury from extraction of gold from ore without amalgamation*

Phase of life cycle	**Air *1**	**Water *1**	**Land *1**	**Product *1**	**General waste**	**Sector specific treatment/ disposal *1**
Mining and production of gold from ore	0.04	0.02	0.9	0.04	?	?

Notes: *1 Mercury retention and deposition of residues will likely vary much between countries and individual facilities. The releases to land may likely be dominating (see data above); the distribution of the remaining mercury outputs on air, water and product (mercury for marketing) is based on very few data, and is only aimed at raising the signal that substantial mercury amounts may follow these pathways.

c) Links to other mercury sources estimation

641. No links suggested.

5.2.6.5 Source specific main data

642. The most important source specific data would in this case be:

- Measured data or literature data on the mercury concentrations in the ores extracted and processed at the source;
- Amount of ore extracted and processed, and

  Measured data on the distribution of mercury outputs with (preferably all) output streams, including mercury percentages retained by emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

5.2.7 Aluminum extraction and initial processing

643. Aluminum ore, most commonly bauxite, is refined into aluminum oxide trihydrate (alumina) and then electrolytically reduced into metallic aluminium. In the process, feed ore and fossil fuels and hydrocarbon auxiliary materials are used, which may contain trace concentrations of mercury. The mercury may be released to the environment. Production of aluminium rank among the top mercury sources to the atmosphere in Australia, a country with substantial activity in this sector (Australian submission to the Global Mercury Assessment - UNEP, 2002; and NPI, 2004).

Production of alumina from bauxite

644. Globally, alumina production is dominated by a few countries where bauxite deposits are abundant. For example, alumina production from bauxite is among the major mercury release source categories in Australia (a big alumina and aluminium producer). Four facilities reported atmospheric releases in the range of 220-430 kg mercury each in 2004 and no or marginal releases to land and water (NPI, 2004). In 2008 five facilities reported atmospheric releases in the range of 140-360 kg mercury each (NPI, 2009).

645. The following description is based on an Australian emission estimation guiding document for alumina production (NPI, 1999a): Bauxite processing includes grinding, digestion, drying, and calcining. These processes give rise to air emissions, and the formation of spent process material. In the digestion process finely ground bauxite is slurried with sodium hydroxide solution and lime and reacted at high pressure and temperature to remove iron oxides, and silicon oxides. Sodium aluminate is formed, and silicon, iron, titanium, and calcium oxides form the insoluble components of the solid waste residual. During the digestion process, volatile organic components of the ore are vented and emitted to air as fugitives. In the drying/calcination the coarse alumina is calcined in rotary kilns or fluid-bed calciners at about 1000°C. Calciners produce hot flue gases containing alumina and water vapour. Two types of kilns are used in the refining industry: oxalate, and liquor burning. Typical control equipment includes cyclonic separators, followed by ESPs. The control equipment can also be used to recover product as well as to minimise emissions. Note that the emissions associated with this activity depend on the specific fuel being used.

Production of aluminium from alumina

646. Aluminum production facilities are usually placed at locations with inexpensive electricity supply (for example from hydro power), and the raw material alumina is traded globally. However, sometimes the facilities are placed close to the sources of alumina.

5.2.7.1 Main factors determining mercury releases and mercury outputs

Table 5-78 Main releases and receiving media during the life-cycle of aluminium extraction and alumina production

Phase of life cycle	Air	Water	Land	General waste	Sector specific treatment/ disposal
Extraction and processing	**X**		x		**X**

Notes: **X**- Release pathway expected to be predominant for the sub-category;

x- Additional release pathways to be considered, depending on specific source and national situation.

Table 5-79 Overview of activity rate data and mercury input factor types needed to estimate releases from aluminium extraction and initial processing

Life-cycle phase	Activity rate data needed	Mercury input factor
Production of alumina from bauxite	Metric tons of bauxite used per year	g mercury/metric ton bauxite used
Production of aluminium from alumina	Metric tons of feedstock used per year	g mercury/metric ton in feedstock

Notes: *1 Such wastes may include lower grade material (lower lead concentrations), and the mercury concentrations may be similar to concentration in the input ore material. If no concentration data for reject materials are available, concentration data for the ore used may be applied for forming a rough estimate.

Production of alumina from bauxite

647. The Australian emission estimation guiding document for alumina production (NPI, 1999a) does not give a clear answer to which raw materials are the primary input source of mercury to the process, but does, however, indicate (by providing emission factors for heavy oil types and gas types used) that the fuels used for heat production for the process are major input sources. Likewise, NPI (2004) gives general mercury concentration data for bauxite (<0.03 g/metric ton) and "red mud" (<0.05 g/metric ton), the solid residue formed from alumina production.

648. In Suriname, mercury in 5 types of bauxite ranged from 0.18 to 2.2 g/metric tons and the bauxite accounted for 99.98% of mercury input to the alumina refinery (Suralco, 2007). Output in 2005 was 70% with residues, 7% with waste water, 15% (9% in 2003) collected and 8% atmospheric emissions (16% in 2003). Reduced emissions were due to the instalment of mercury collection system.

649. According to Alcoa (2009) African-mined bauxite has mercury levels around 0.2 g/metric tons while Australian bauxite averages 0.070 g/metric tons.

650. During the traditional refining process, the mercury is dissolved with the bauxite in a caustic soda solution called liquor. In the final stages of the process, alumina is calcined-or roasted-at high temperature to drive off water. In some alumina refineries, most mercury is emitted to the atmosphere through the calcination stacks (Alcoa, 2009). By use of mercury reduction technology mercury emissions can be reduced by 80% (Alcoa, 2009).

Production of aluminium from alumina

651. In an Australian emission estimation guideline for aluminium production (NPI, 1999b), mercury is mentioned as an output from both the anode baking process and the electrolytic reduction of alumina, but mercury emission factors are not given. In the reduction process the anodes are consumed and aluminium is produced at temperatures around 970 ^{o}C. The anode material petroleum coke, a by-product of oil refining, and pitch, a by-product from the coking of coal to metallurgical coke, produced by the distillation of the coal tar, may possibly both contain mercury originating from mercury naturally present in the used oil and coal. At this temperature mercury remaining, if any, in the anode or alumina is expected to be released thermally.

652. In the context of this Toolkit, mercury releases originating from fossil fuels would generally fall under the sub-categories described in section 5.1 (extraction and use of fuels/energy sources), but with these limited indications a clear distinction based on mercury input source is not possible.

5.2.7.2 Input factors and output distribution factors

653. If no information is available on the mercury concentration in the raw materials a first estimate can be formed by using the default input factors selected in Table 5-80 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and

report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum). If it is chosen not to calculate as intervals, the use of the maximum value is recommended in order to signal the possible importance of the source category for further investigation. Using a high end estimate does not automatically imply that actual releases are this high, only that it should perhaps be investigated further.

No specific default factors were developed for production of aluminium from alumina.

a) Default mercury input factors

Table 5-80 ***Preliminary*** *default input factors for mercury in bauxite*

Process	**Default input factors; g mercury per metric ton of bauxite; low end - high end (intermediate)**
Production of alumina	0.07 – 1 (0.5)

654. Note: If desired, these default factors can be converted to a basis of mercury inputs per raw aluminium produced, by the use of a bauxite used/Al produced ratio of 3.8-4.7 (intermediate value 4.25 ton concentrate used per ton aluminium produced) as derived by UNEP/AMAP (2012).If no specific data on mercury input with ore and other feed materials used are available, mercury inputs from bauxite may be roughly estimated by multiplying bauxite amounts used annually by the conservative mercury concentration of 0.03 g/kg (30 g/metric ton) bauxite used. Calculate mercury input from fossil combustion fuels by multiplying the amounts of fuels of each type used by default input factors cited in section 5.1 for the respective fuel types. All mercury inputs may - as a first estimate - be considered released to the atmosphere.

655. No data are available to form default factors for aluminium production from alumina, but the process may possibly be a mercury release source.

b) Default mercury output distribution factors

656. For aluminium production, default mercury output distribution factor are suggested in Table 5-81 below.

Table 5-81 ***Preliminary*** *default output distribution factors for mercury from aluminium production*

Phase of life cycle	**Air**	**Water**	**Land**	**Product**	**General waste**	**Sector specific treatment/ disposal**
Production of alumina from bauxite	0.15	0.1	?			0.75
Aluminium production from alumina	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

5.2.7.3 Source specific main data

657. The most important source specific data would in this case be:

- Amounts of fossil fuels/ hydrocarbon materials used and mercury concentrations in these fuels/materials;
- Measured data or literature data on the mercury concentrations in the ores extracted and processed at the source;
- Amount of ore extracted and processed; and

- Measured data on emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

5.2.8 Other non-ferrous metals - extraction and processing

5.2.8.1 Sub-category description

658. This sub-category includes extraction and processing of other non-ferrous metals which can be a source of mercury releases, such as silver, nickel, cobalt, tin, antimony, molybdenum and tungsten and others.

659. Except the below mentioned, no specific data were collected on these potential mercury release sources. The extraction processes involved likely resemble the processes involved for other non-ferrous metals described in this Toolkit.

5.2.8.2 Main factors determining mercury releases and mercury outputs

Table 5-82 Main releases and receiving media during the life-cycle of extraction and processing of other non-ferrous metals

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Extraction and processing	X	X	X		X	X

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x -Additional release pathways to be considered, depending on specific source and national situation.

5.2.8.3 Examples of mercury in releases and wastes/residues

660. Based on the US EPA's TRI, there is a silver mine in Nevada that reported releases of 6.4 kg mercury to air and 15911 kg to land on-site for year 2001. Releases to other media (such as water) may possibly be quite low since no releases were reported for these other media for this mining facility (US EPA, 2003a).

661. No efforts were invested in collecting additional information on mercury releases from this sub-category. Some data are expected to be available on mercury releases from production some of these metals.

5.2.8.4 Source specific main data

662. The most important source specific data could typically be:

- Measured data or literature data on the mercury concentrations in the ores extracted and processed at the source;
- Amount of ore extracted and processed;
- Amounts of fuels and auxiliary materials used and mercury concentrations in these materials; and
- Measured data on the distribution of mercury outputs with (preferably all) output streams, including mercury percentages retained by emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

5.2.9 Primary ferrous metal production

5.2.9.1 Sub-category description

663. The iron and steel industry is highly material and energy intensive. Considerable amounts of the mass input become outputs in the form of off-gases and residues. This industry comprises establishments primarily engaged in smelting iron ore to produce pig iron in molten or solid form; converting pig iron into steel by the removal, through combustion in furnaces, of the carbon in the iron. These establishments may cast ingots only, or also produce iron and steel basic shapes, such as plates, sheets, strips, rods and bars, and other fabricated products.

664. Sinter plants are associated with iron manufacture, often in integrated iron and steel works. The sintering process is a pre-treatment step in the production of iron where fine particles of metal ores are agglomerated by combustion. Agglomeration is necessary to increase the passage for the gases during the blast furnace operation. Typically, sintering plants are large (up to several hundred square meters) grate systems used to prepare iron ore (sometimes in powder form) for use in a blast furnace. In addition to iron ore, there is usually a carbon source (often coke) and other additions such as limestone. In some cases wastes from various parts of the steel making process are present. In the sintering process, burners above the grate belt heat the material to the required temperature (1,100-1,200 °C), which causes the fuel in the mixture to ignite. The flame front passes through the sintering bed as it advances along the grate causing agglomeration. Air is sucked through the bed. The process is finished once the flame front has passed through the entire mixed layer and all fuel has been burned. Cooled sinter is transferred to screens that separate the pieces to be used in the blast furnace (4-10 mm and 20-50 mm) from the pieces to be returned to the sinter process (0-5 mm as "return fines", 10-20 mm as "hearth layer") (UNEP, 2003).

665. Mercury may possibly be emitted from a number of points at integrated iron and steel facilities, including sinter plants that convert raw materials into an agglomerated product (sinter) that is used to fuel the blast furnace, blast furnaces that produce iron, and basic oxygen process (BOP) furnace shops that produce steel. For convenience and in the absence of detailed data, the sintering and blast furnace processes are treated as one process with pig-iron as the output. The subsequent basic oxygen process is not considered a significant mercury source and is not treated further in this Toolkit.

5.2.9.2 Main factors determining mercury releases and outputs

Table 5-83 Main releases and receiving media from primary ferrous metal production

Process phase	Air	Water	Land	General waste	Sector specific treatment/ disposal
Sintering and blast furnace	**X**				x

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

666. The main factors determining mercury releases from this sector is the mercury concentrations in the different feed materials, especially the ore/concentrate and the lime.

5.2.9.3 Discussion of mercury inputs

667. The concentration of mercury in the iron ore/concentrates, and the amount of ore/concentrates used are important factors determining mercury releases. By the concentration of the ore a significant part of the mercury ends up in tailings which are landfilled.

668. The mercury content of iron ore and concentrates varies considerably.

669. The content of mercury in concentrates from Kursk Magnetic Anomaly deposits, the main source of iron ore in the Russian Federation is reported to be within 0.01-0.1 mg/kg; whereas

concentrates from the Korshunovsk deposit in Siberia contain 0.02-0.085 mg/kg (Lassen *et al.*, 2004). For an assessment of the releases of mercury from pig iron production in the Russian Federation an average mercury content in concentrates of 0.06 mg/kg were assumed (Lassen *et al.*, 2004).

670. The mercury concentration in freshly crushed, non-beneficiated taconite ore, the main iron ore mined in the US, from different mining operations in Minnesota ranged in value from 0.0006 up to a maximum of 0.032 mg/kg (average values for each operation) (Berndt, 2003). The concentration of mercury in the concentrate ranged from 0.001 to 0.016 mg/kg whereas it in the tailings ranged form 0.001 to 0.040 mg/kg (Berndt, 2003). Compared to the data from the Russian Federation the mercury content of the taconite concentrate is approximately ten times lower.

671. An assessment of all raw materials for the pig iron production in the Russian Federation revealed that 20% of the mercury originated from limestone (with an average content of 0.05 mg Hg/kg), 75% from the concentrate (average content of 0.06 mg Hg/kg) and the remaining 5% from other raw materials. The resulting emission factor was estimated at 0.04 g per metric tons produced pig iron assuming that 99% of the mercury was released to the air. The emission factor is identical to the factor used by Pacyna and Pacyna (2000) for the estimates of mercury emission from pig iron production in the Russian Federation (Pacyna and Pacyna, 2000).

672. The EMEP/CORINAIR emission guidebook use a default emission factor for the process "Sinter and pelletizing plants" of 0.05 g per metric tons sinter (EMEP/CORINAIR, 2001)

Table 5-84 Overview of activity rate data and mercury input factor types needed to estimate releases from primary ferrous metal production

Process phase	Activity rate data needed	Mercury input factor
Sintering and blast furnace	Metric tons of pig-iron produced	g mercury released/metric ton of pig-iron produced

5.2.9.4 Examples of mercury in releases and wastes/residues

673. The total mercury release to the air in Minnesota from iron ore mining and sintering was 342 kg in 2000 (Berndt, 2003). As mentioned above the mercury concentrations in the concentrate used for iron production in Minnesota (USA) ranged from 0.001 to 0.016 mg/kg. The mercury emissions to the atmosphere from the operations were correlated with the mercury concentration of the concentrates and the releases correspondingly ranged from a value of 1.8 kg per million metric tons pellets produced at the eastern edge of the mined area to about 17 kg per million metric tons on the western side of the district. (Berndt, 2003).

674. According to Berndt (2003) it is generally assumed that the mercury that is emitted from stacks is predominantly in elemental form. Although this has not been verified at every plant, a study conducted at one of the plants in Minnesota indicated that an average of 93.3% of mercury emissions were in Hg(0) form, with almost all of the remainder emitted as oxidized mercury, Hg(II) (HTC, 2000). 70-80% of the oxidized mercury was being collected by the wet scrubber, corresponding to about 5% of the total.

675. Berndt (2003) quote studies (Benner, 2001) that demonstrate that some emission control may be obtained by modifying the current practice in Minnesota of recycling the dust from wet scrubbers into the indurating furnaces. Benner (2001) found that this dust contains extremely high mercury concentrations, and if this material, particularly the fine fraction, was channelled into the waste stream (rather than recycled to the indurator), mercury emissions could be reduced. The reported decrease in mercury emission by this measure is in the order of magnitude of 10-20%.

676. In the assessment of mercury releases from pig iron production in the Russian Federation it is roughly presumed that 99% of the mercury content of the raw materials is sublimed and potentially released to the air by the operations.

5.2.9.5 Input factors and output distribution factors

677. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that these default factors are based on a limited data base, and as such, they should be considered preliminary and subject to revisions.

678. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

a) Default mercury input factors

679. Actual data on mercury levels in the feed materials used, will lead to the best estimates of releases.

680. For this source sub-category, a simplified approach is used, which sums up the total mercury inputs with all feed materials (based on the two examples described above).

681. Default input factor for pig iron production (sintering and blast furnace): 0.05 g Hg/ metric ton of pig iron produced.

b) Default mercury output distribution factors

Table 5-85 ***Preliminary*** *default output distribution factors for mercury from primary ferrous metal production*

Phase in life-cycle	**Distribution factors, share of Hg input**				
	Air	**Water**	**Land**	**General waste**	**Sector specific treatment/ disposal**
Pig iron production	0.95				0.05

Notes: The fate of mercury in filter residues has not been investigated in detail; it may vary between countries and in principle could include controlled or informal disposal, or re-use in other processes.

c) Links to other mercury sources estimation

682. No links suggested.

5.3 Production of other minerals and materials with mercury impurities

Table 5-86 Production of other minerals and materials with mercury impurities: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Chapter	Sub-category	Air	Water	Land	Product	Waste/ residue	Main inventory approach
5.3.1	Cement production	**X**		x	x	x	PS
5.3.2	Pulp and paper production	**X**	x	x		x	PS
5.3.3	Lime production and light weight aggregate kilns	**X**			x		PS
5.3.4	Others minerals and materials						PS

Notes: PS = Point source by point source approach; OW = National/overview approach;

X - Release pathway expected to be predominant for the sub-category;

x - Additional release pathways to be considered, depending on specific source and national situation.

683. Besides the source sub-categories mentioned in Table 5-86 above, production and use of other large volume minerals and materials, such as for example mineral fertilisers, may be potential sources of mercury releases. Such other sources are, however, not described in detail in the Toolkit.

5.3.1 Cement clinker production

5.3.1.1 Sub-category description

684. The raw materials and fuels used for the production of cement contain trace concentrations of mercury: 1) mercury naturally present in virgin raw materials used (lime, coal, etc.), 2) mercury content in solid residues from other sectors used as raw materials (e.g. fly-ashes and gypsum from combustion of coal in which mercury concentrations may be elevated compared to virgin materials), 3) mercury in any fossil fuels used, and 4) mercury in wastes sometimes used as fuels in cement manufacturing. The use of waste products as feed materials may increase the total input of mercury to the cement production (depending on the waste type). The primary output paths of mercury fed in with raw materials is releases to the atmosphere, and trace mercury levels in the produced cement. This source sub-category is a potential mercury release source of the type involving materials with low mercury concentrations, but in very large amounts.

Processes involved

685. The principal raw materials (clay and limestone) are first acquired from quarry operations. The raw materials are brought to site, are then mixed, crushed and ground to produce a raw meal of the correct particle size and chemical properties. There are four main process types for the manufacture of cement: the dry, semi-dry, semi-wet and wet processes (UNEP, 2003). In the dry process, the raw materials are ground and dried to raw meal, which is fed to the pre-heater or pre-calciner kiln (or more rarely into a long dry kiln). The dry process requires about 40% less energy than the wet process. In the wet process, the raw materials are ground in water to form a pumpable slurry, which is fed directly into the kiln or first into a slurry dryer (UNEP, 2003).

686. Pyroprocessing (thermal treatment) of the raw material is carried out in the kiln, which is the heart of the Portland cement manufacturing process (US EPA, 1997a). The pyroprocessing system involves two or three steps: 1) drying or preheating (if applied); 2) calcination (a heating process in which calcium oxide is formed), and; 3) burning (sintering).

687. After the drying or preheating step, if used, the actual cement manufacture begins with the calcination step, which is the decomposition of calcium carbonate ($CaCO_3$) at about 900 °C to leave

calcium oxide (CaO, lime) and carbon dioxide (CO_2). After calcination, the sintering step occurs, whereby lime reacts at temperatures typically around 1,400-1,500 °C with silica, alumina, and ferrous oxide to form silicates, aluminates, and ferrites of calcium (also known as the "clinker"). The last stage involves cooling the clinker. As the hot clinker comes off the kiln it is rapidly cooled in a clinker cooler, such as on a travelling grate with under-grate fans that blow cool air through the clinker.

688. Finally, the cooled clinker is ground or milled together with gypsum ($CaSO_4$) and into a fine powder and mixed with other additives to produce the final cement product, which is stored in silos prior to bulk transportation or bagging.

689. According to CEMBUREAU (2010), mercury-containing filter dust from air exhaustes can be fed back into the process, by reintroducing it into the raw material preparation system (dry process), by insufflations into the sintering zone (wet kilns), or by feeding the dust into the final cement mixing mill (if allowed by the cement standards).

690. Please be aware that cement final production (grinding and bagging) is done from imported clinker in some countries; such cement produced from imported clinker should not be included in the calculations of mercury releases estimations.

5.3.1.2 Main factors determining mercury releases and mercury outputs

Table 5-87 Main releases and receiving media from cement production

Process/stage	Air	Water	Land	Products	General waste *1	Sector specific treatment/ disposal *1
Raw material production/handling						
Cement production (clinker formation)	**X**			x		x
Disposal of cement (as buildings or demolition wastes)			x		x	x

Notes: *1 Demolition waste may be disposed of on general waste landfills or re-used in road construction and similar works.

X -Release pathway expected to be predominant for the sub-category;

x - Additional release pathways to be considered, depending on specific source and national situation.

691. Important factors for mercury releases could include: the amount of raw materials processed, mercury concentration in the raw materials, amount of clinker and cement produced, amounts and types of fuel burned, and concentrations of mercury in each of the fuels burned at the facility.

692. The only potential release pathway of mercury from raw material acquisition would be due to wind blown mercury-containing particulate from the quarry operations, but concentrations are very low at this stage, so mercury emissions are expected to be negligible from these initial steps in Portland cement production (US EPA, 1997a). As described above, the raw material processing differs somewhat for wet- and dry-processes. Mercury emissions can occur during the drying process but are anticipated to be low because the drying temperature is generally well below the boiling point of mercury. However, some dryers attain a temperature above the boiling point of mercury, which would result in emissions.

693. Because mercury evaporates at approximately 350 ºC, most of the mercury present in the raw materials can be expected to be volatilized during the calcination step which occurs in the kiln (US EPA, 1997a; CEMBUREAU, 2010). However, as mentioned above, some mercury may also be

released during the drying and preheating steps. Processing steps that occur after the calcining process in the kiln would be expected to be a much smaller source of emissions (US EPA, 1997a).

694. Various fuels are burned at cement plants to generate heat for the kiln process. Typical fuels used are coal, oil, gas or petroleum coke (= pet coke). Mercury is present in these fuels and is released during combustion. In many cases a variety of waste fuels (called alternative or secondary fuels) are also used to supplement the fossil fuel. The wastes used may include: tyres, waste oils, solvents, certain industrial wastes, and in some cases hazardous wastes. Mercury may also be present in these waste fuels. Most of these will be fired at the burner (hot) end of the kiln. Tyres may be added to the kiln some distance from the hot end as whole tires or chipped (UNEP, 2003). Also CEMBUREAU (2010) states that besides fossil fuels, alternative fuels (tyres, "animal meal", waste-derived fuels, etc.) are used in the cement manufacturing process. Mercury concentrations vary among fuel types, but also within the same fuel type. According to CEMBUREAU, alternative fuels are regularly analysed for their mercury content. CEMBUREAU's data show mercury concentrations in alternative fuels from 0.005 (below detection limit) to about 10 mg/kg.

695. In their dataset for atmospheric mercury emissions from cement production, CEMBUREAU (2010) found that the arithmetic average emission was 0.009 mg/Nm^3 for kilns under 10% of thermal substitution with waste, 0.010 mg/Nm^3 for kilns between 10 and 40% of substitution and 0.013 mg/Nm^3 for kilns with more than 40% of substitution. These differences were not statistically significant according to the report.

696. Data collected by UNEP/AMAP (2012) indicate that many cement plants substitute a limited amount of the input energy with wastes (alternative fuels); typically up to 6 percent, while fewer use higher substitution of waste; perhaps because of the needed waste handling infrastructure or due to other regulation for waste incinerating facilities. UNEP/AMAP however used a medium alternative fuel input of 12 percent n their emission estimates for facilities using waste for fuel.

697. The mercury present in raw materials fed to the kiln and in the fuels is mixed up in the kiln. Note that some raw materials e.g. gypsum are mixed with the clinker after the thermal step and the mercury in these raw materials consequently ends up in the final cement product.

5.3.1.3 Discussion of mercury inputs

Table 5-88 Overview of activity rate data and mercury input factor types needed to estimate releases from cement production

Life-cycle phase	Activity rate data needed	Mercury input factor
Cement production	Metric tons of cement produced from nationally produced clinker per year or Amounts of the feed materials used per year	g Hg per metric ton of cement produced or g mercury/metric ton in each of the feed materials

698. Calcium, which is the element of highest concentration in Portland cement, is obtained from a variety of calcareous raw materials, including limestone, chalk, marl, sea shells, aragonite, and an impure limestone known as "natural cement rock". The other raw materials: silicon, aluminium, and iron, are obtained from ores and minerals, such as sand, shale, clay, and iron ore. Mercury is present in the ores and minerals extracted from the earth. In some countries in addition waste products like fly ash (e.g. from coal power plants), copper slag, pyrite ashes and blast furnace slag are used as raw materials.

699. As described above, mercury is also present in fuels and combustible wastes burned at these plants. See chapters 5.1 and 5.8 for information on mercury concentrations in these fuels and wastes.

700. The table below shows examples of mercury content of raw materials for cement production from a number of countries.

Table 5-89 Examples of mercury content of raw materials for cement production (mg Hg/Kg).

Source	**Limestone or marl**	**Sand and siltstone**	**Clay or shale**	**Waste products**	**Other raw materials**	**Raw meal**
Schäfer and Hoenig, 2001 (Germany) ***1**						0.03-0.13
Sprung, 1982 (Germany) ***1**	0.03		0.45			
Schneider and Oerter, 2000 (Germany) ***1**	0.005-0.13		0.02-0.15			0.02-0.5
Adriano, 2001 ***1**	0.04-0.22		0.005-3.25	0.04 and 0.1 (fly ash)		
Kanare, 1999 (USA) ***1**	<0.01-0.03					
Klemm, 1993 ***1**						<0.1 and 0.14
Kirchartz, 1994 (Germany) ***1**	0.005-0.05		0.02-0.15			>1.0 (when alternative materials are used)
Fukuzaki *et al.*, 1986 (Japan) ***1**	0.12		0.013	0.17 (copper slag)		
Airey, 1982 ***1**	0.04 and 0.46					
Bowen, 1979 ***1**	0.16					
BUWAL, 1997 (Switzerland) ***1**	0.03 and 0.02		0.45			0.02-0.6
Kitamura *et al.*, 1976 (Japan)***1**	0.01-0.22					
Fujinuki, 1979 (Japan) ***1**	0.07 and 0.04					
Saupe, 1972 ***1**	0.033 and 0.048					
Russia, 2003 ***2**	0.031 (average of 131 samples)	0.039 (average of 45 samples)	0.035 (average of 58 samples)			
Denmark, 2002 ***3**	0.01			0.13-0.39 (fly ash)		
Kakareka *et al.*, 1998 (CIS countries) ***4**	<0.01-0.17			0.19-4.0 (pyrite ash) 0.01-0.12 (blast-furnace slag)		

Source	**Limestone or marl**	**Sand and siltstone**	**Clay or shale**	**Waste products**	**Other raw materials**	**Raw meal**
Hills and Stevenson, 2006 (57 cement plants in USA and Canada)	Limestone >0.001-0.391 (average 0.017)	Sand <0.001-0.556 (av. 0.029)	Clay 0.001-0.27 (av. 0.052) Shale 0.002-0.436 (av. 0.057)	Slag 0.002-0.054 (av. 0.012) Bottom ash 0.003-0.382 (av. 0.048 Iron ore 0.002-0.672 (av. 0.078) Fly ash 0.002-0.685 (av. 0.205) Recycled cement kiln dust 0.005-24.56 (av. 1.53)		
CEMBUREAU, 2010***5**	<0.005-0.4	< 0.005 – 0.55	Clay: 0.002 - 0.45 Shale: 0.002 – 3.25	Waste as fuel: 0.005 - 10 Fly ash: < 0.002 – 0.8 Burned oil shale: 0.05 – 0.3 Blast furnace slag: < 0.005 – 0.2	Iron ore: 0.001 – 0.68 Pouzzolana: < 0.01 – 0.1 $CaSO_4$: < 0.005 – 0,02 Gypsum (natural): < 0.005 – 0.08 Gypsum (artificial)***6**: 0.03 – 1.3 Aggregates: < 0.01 – 0.1	
CEMBUREAU, 2010 ("Cement_Company_B, 2008")	0.01	0.00		Pyrite ashes: 0.54		0.18
CEMBUREAU, 2010 ("Cement_Company_D, 2008")	"Up to 2"		"Up to 2"			
CEMBUREAU, 2010 ("Cement_Company_F, 2008")	Limestone: 1.0 Marl: "Generally below 0.3"		Clay: "Generally below 0.3"			

Notes: *1 As cited by Johansen and Hawkins (2003); *2 Lassen *et al.*, 2004;
*3 Skårup *et al.*, 2003; *4 Kakareka *et al.*, 1998;
*5 CEMBUREAU, 2010 citing various sources;
*6 Presumably flue gas cleaning product from coal fired power plants.

701. The contribution of the raw materials and fuels to the total mercury input varies considerably depending on materials and fuels uses. As indicated by the data in the table above, the use of waste products like fly ash or pyrite ash may in some cases increase the total input of mercury.

702. Complete mass balances of mercury in cement production are scarce. Below is as an example showing the different raw materials' contributions to total mercury inputs to two Belarusian cement plants. See also the two examples in Figure 5-13 deep below.

Table 5-90 Mercury content of raw materials for cement production in two Belarusian cement plants (Kakareka et al.*, 1998)*

	Krichevcementnoshiver Amalgamation		**Krasnoselskcement JSC**	
	Mercury concentration mg/kg dry weight	**Contribution of total input, %**	**Mercury concentration mg/kg dry weight**	**Contribution of total input, %**
Chalk	0.05 *1	38.9	0.05	30.5
Clay	0.1	11.2	0.066	12.7
Pyrite cinders	2.16	49.6	2.043	55.9
Granulated blast furnace slag	0.012	0.1	0.01	0.5
Gypsum stone	0.013	0.2	0.014	0.4
Residual oil	-	-	-	-
Lignosulphate	-	-	-	-
Total		100		100

Notes: *1 Estimated from the reported total contribution by chalk.

703. UNEP/AMAP used the mercury input factor ("unabated emission factors") for cement production shown in Table 5-91, based on a clinker content of 80 percent in the final cement product (as also suggested by CEMBUREAU, 2010). Note that they based their factors partly on default input factors from the previous 2011 version of this Toolkit.

*Table 5-91 Mercury input factors ("unabated emission factors") used for cement production by UNEP/AMAP (2012)*1.*

	Unabated Emission Factor (UEF)				Notes
	low	Intermediate	high	units	
Generic default factor (limestone only)	0.003	0.087	0.4	g/t cement	Based on 2011 Hg Toolkit version; BREF Cement (2010) and country-specific data. Applicable if main fuel is coal, oil, gas or renewable source (excluded) and there is no waste co-incineration.
Generic default factor (limestone + waste)	0.05	0.118	0.8		Based on 2011 Hg Toolkit version; BREF Cement (2010) and country-specific data. Applicable if main fuel is coal, oil, gas or renewable source (excluded) and there is waste co-incineration (included).
Generic default factor (limestone + pet.coke, no waste co-incineration)	0.005	0.091	0.6	g/t cement	Based on 2011 Hg Toolkit version; BREF Cement (2010) and country-specific data. Applicable if main fuel is pet. coke (included) and there is no waste co-incineration.
Generic default factor (limestone + pet.coke + waste)	0.01	0.105	1.5		Based on 2011 Hg Toolkit version; BREF Cement (2010) and country-specific data. Applicable if main fuel is pet. coke (included) and there is waste co-incineration (included).

Note *1: The term "generic default factor" was used by UNEP/AMAP (2012) and is not to be confused with default factors recommended in this Toolkit.

Input of mercury from fossil fuels

704. The mercury contributions from fossil fuels combusted in the cement production process were in earlier versions of this Toolkit attributed to the relevant fuels and included in 5.5 Fuels (up to and including the April 2015 version), but in line with the Minamata Convention definitions, fossil fuels use were since 2016 included under cement production. Be careful not to count such mercury amounts double. In the inventory calculations they should be subtracted manually under the relevant fuels. Waste used as fuel in cement production is attributed to cement production in this Toolkit. Mercury input with fossil fuels can be calculated using actual or generalised data for main fossil fuel inputs and actual or Toolkit default factors for mercury contents in the fuels in question. A generalised procedure is proposed in the Toolkit calculation spreadsheets, using default factors derived from 1) average fossil fuel energy input per tonne cement in combination with 2) average primary energy contents in the relevant fossil fuels and 3) Toolkit default mercury input factors for the fuels in question (i.e. mercury content of the fuel).

705. Table 5-92 (overleaf) presents the calculated mercury inputs from fossil fuels usage and the key data used in the calculations. As shown, the mercury contributions from fossil fuels are calculated as low end, high end and intermediate contributions. The intermediate mercury contributions are pre-entered in the Toolkit calculation spreadsheets. As can be seen when comparing the fuels inputs in Table 5-92 with the raw materials inputs in Table 5-93, mercury contributions from the various coal types are moderate (generally considerably below mercury input from other raw materials in cement production), whereas contributions from pet coke, oil and natual gas are marginal.

Table 5-92 Calculated generalized mercury inputs from fossil fuels in g mercury per t cement produced (and background data).

	Energy contents of fossil fuels *1				Mercury concentrations in fuels *2			**Fuel contribution without waste as alternative fuel *3**			**Fuel contribution with waste as alternative fuel *4**		
Fossil fuel type	Gross calorific value (**GCV**), MJ/kg (=GJ/t) reported	Low end GCV, GJ/t	High end GCV, GJ/t	Intermediate GCV, GJ/t	Low end Toolkit defult factor, g Hg/t fuel	High end Toolkit defult factor, g Hg/t fuel	Intermediate Toolkit default factor, g Hg/t fuel	Calculated low end fuel input, g Hg/t cement	Calculated high end fuel input, g Hg/t cement	Calculated intermediate fuel input, g Hg/t cement	Calculated low end fuel input, g Hg/t cement	Calculated high end fuel input, g Hg/t cement	Calculated intermediate fuel input, g Hg/t cement
Hard coal (Anthracite, coking coal or other bituminous):		24	31	28	0.05	0.5	0.15	0.006	0.048	0.016	0.005	0.042	0.014
Anthracite hard coal	29.65 - 30.35	29.65	30.35	30	0.05	0.5	0.15	0.005	0.049	0.015	0.004	0.043	0.013
Coking coals	27.80 - 30.80	27.8	30.8	29	0.05	0.5	0.15	0.005	0.048	0.015	0.005	0.042	0.013
Other bituminous coal	23.85 - 26.75	23.85	26.75	25	0.05	0.5	0.15	0.006	0.055	0.018	0.005	0.049	0.016
Sub-bituminous (brown) coal	17.44 - 23.87	17.44	23.87	21	0.05	0.5	0.15	0.008	0.062	0.021	0.007	0.055	0.019
Lignite (brown coal)	< 17	17	17	17	0.05	0.2	0.1	0.009	0.035	0.017	0.008	0.031	0.015
Petroleum coke	30.5 - 35.8	30.5	35.8	33	0.01	0.1	0.02	0.001	0.008	0.002	0.001	0.007	0.002
Fuel oil	43.76 - 44.40	43.8	44.4	44	0.01	0.1	0.02	0.0007	0.007	0.001	0.0006	0.006	0.001
Natural gas (assumed pipeline gas quality (cleaned))*1,*2	37.5 - 40.5 MJ/m3	37.5	40.5	39	3E-08	4E-07	2.2E-07	2.4E-06	2.9E-05	1.7E-05	2.1E-06	2.6E-05	1.5E-05

Notes: *1: For gas: MJ/Nm³. Energy content data for fuels from IEA (2005) and IEA (2016). *2: For gas: g Hg/Nm3 gas. *3: Taking into account an average 80% clinker share in cement and an assumed average primary energy demand per ton clinker produced of 3.7 GJ/t (European Commission, Joint Research Centre, 2013). *4: For co-incineration of waste: Taking into account an average 80% clinker share in cement, an assumed average primary energy demand per ton clinker produced of 3.7 GJ/t (European Commission, Joint Research Centre, 2013) and an assumed 12% primary energy substitution by waste as fuel (mercury contribution from waste not included in this table).

5.3.1.4 Examples of mercury in releases and wastes/residues

706. The principal output path of mercury to the air is expected to be the kiln.

707. Depending on the applied flue gas cleaning technology present, a part of the mercury is captured by dust removal systems e.g. fabric filters and ESPs. The efficiency of mercury capture is depending on the actual filters used and the temperature by the inlet to the filter. The lower the exhaust gas temperature is at the filter inlet, the higher is the proportion of mercury attached to dust particles that can be removed from the exhaust gas (Cembureau, 1999). Information in the mercury removal efficiency of the different emission reduction systems applied in cement plants is scarce, but compared to other heavy metals the efficiency of the systems on mercury is relatively low.

708. According to data collected by CEMBUREAU (2010), kilns equipped with ESP have higher mercury emission values than those with bag filters (also called fabric filters, FF). The arithmetic mean emissions were 0.015 mg/Nm^3 for ESP and 0.009 mg/Nm^3 for bag filters.

709. In the United States and Canada the kiln emissions are reduced with either fabric filters (FFs) or ESPs, but only limited information is available on the efficiency of these devices with respect to the mercury removal. One source indicates (US EPA, 1993 referred in Pirrone *et al*., 2001) that ESPs capture about 25% and FFs capture up to 50% of the potential mercury emissions as particulate matter. When the filter dust is recycled however, a major part of most heavy metals finally end up in the clinker, but for mercury, which is relatively volatile, the result of the recycling may be that an increased part of the mercury is ultimately emitted to the air (VDZ, 2001), unless part of the dust is regularly or continuously purged from the process and mixed into the cement product in the final mixing stages after the kiln operation (CEMBUREAU, 2010).

710. Based on review and analyses of available data in the USA for mercury emissions to air for cement plants, the US EPA developed an average atmospheric emissions factor of 0.065 g mercury per metric tons of clinker produced (US EPA, 1997a). Based on data reported to the TRI for year 2001, it appears that most mercury releases occur to air, and to land on-site (US EPA, 2003a). Releases to other media appear to be minimal based on data reported to the TRI.

711. The EMEP/CORINAIR emission guidebook recommended for a "simpler methodology" (where limited information is available) an atmospheric mercury emission factor of 0.1 g/metric ton cement produced (EMEP/CORINAIR, 2001).

712. In a study of mercury releases from the Russian Federation an average emission factor of 0.045 g/metric ton cement produced was derived from information on mercury in raw materials and an assumption that on average 80% of the mercury in the raw materials was emitted to the air (Lassen *et al.,* 2004).

713. In a response from the European Cement Association to the calculated mercury emission from cement production in Europe in the EU position paper on mercury (Pirrone *et al*, 2001), the association estimates atmospheric mercury emission from four European countries based on actual measurements in Austria (1996), Germany (1998), United Kingdom (1999) and Spain (2000). Based on the presented data the following average atmospheric emission factors can be derived: 0.03 g/metric ton cement produced (Austria), 0.03 g/metric ton (Germany), 0.01 g/metric ton (United Kingdom) and 0.01 g/metric ton (Spain).

714. CEMBUREAU (2010) suggested an average atmospheric emission factor for cement production of around 0.035 g Hg/ton cement produced.

715. The mercury emission from cement production varies among others depending on the amount of hazardous waste co-incinerated in the kilns. Data from the U.S.A. of cement kilns co-incinerating hazardous waste show that for 16 kilns, the hazardous waste on average accounted for 77% of the total mercury input (US EPA 2002 as cited by Senior and Eddings, 2006). For the individual kilns, the input with hazardous waste varies from 9% to 99% of the total input depending on the mercury in the waste,

the other fuels and the raw materials. The authors note that the relative magnitude of the hazardous waste cannot be accurately inferred from the data, due to data uncertainty, but the data are here used as the best available data illustrating the possible magnitude of the mercury input with hazardous waste.

716. In general, only a minor part of the mercury ends up in the clinker. The mercury content of the final cement will to a large extent depend on the mercury content of the other materials which is mixed with the clinker after the pyroprocessing steps; especially of any addition of filter dust from previous production steps; see example in Figure 5-13.

717. The mercury concentration of gypsum produced from acid flue gas cleaning residues, e.g. from coal-fired power plants, may exceed the mercury concentration of natural gypsum. If gypsum from acid flue gas cleaning is used for the cement production it may increase the mercury content of the final cement product.

718. From a German MSW incinerator it is reported that the mercury concentration of gypsum from the acid flue gas treatment of the plant in the 2000-2003 period ranged from 0.26 to 0.53 mg/kg (annual averages). The concentration in the incinerator gypsum is in the report compared to the typical mercury concentration of naturally occurring gypsum and gypsum from coal-fired power plants of 0.09 mg/kg and 1.3 mg/kg, respectively (with reference to Beckert *et al.*, 1990).

719. The average mercury concentration of 418 samples of cement produced in Germany in 1999 was 0.07 mg/kg (VDZ, 2000). The concentration ranged from <0.02 mg/kg (detection limit) to 0.3 mg/kg. The total mercury content of the 36.7 million metric tons cement produced in Germany in 1999 can be estimated at 2.6 metric ton; significantly more than the 0.72 metric tons mercury emitted to the air from the production estimated by the European Cement Association (included in Pirrone *et al.*, 2001). Considering that the mercury concentration in clinkers (the unprocessed output from the kiln) is usually very low, the mercury apparently originates from the other materials mixed into the final cement product - for example filter dust from the production or solid residues from other sectors (fly ashes).

720. The average mercury content of cement produced in Denmark in 2001 was estimated at 0.02-0.05 mg/kg (Skårup *et al.*, 2003).

721. CEMBUREAU (2010) reported two examples of complete external mass balances of cement production plants (named Case study 1 and 2 in reference). In Figure 5-13, the inputs and outputs for "case study 1" - a facility with moderate co-incineration of waste (seconday fuels) - are shown with and without "bleeding" (mixing) of mercury-containing filter dust to the marketed cement. The figure also shows mercury inputs and outputs for "case study 2", a facility with 70 percent fuel substitution (by energy content) with waste (secondary fuels).

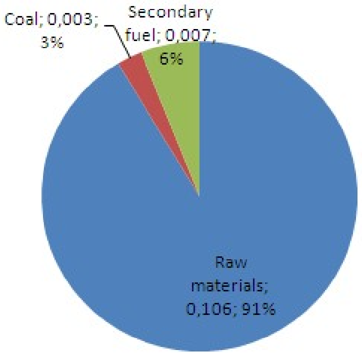
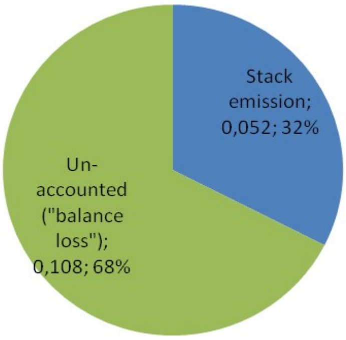
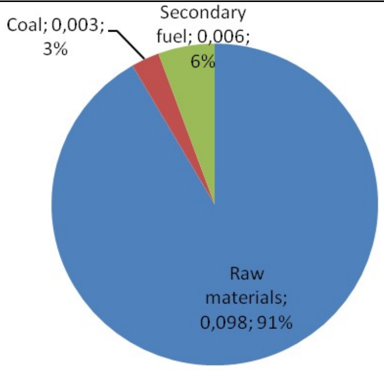
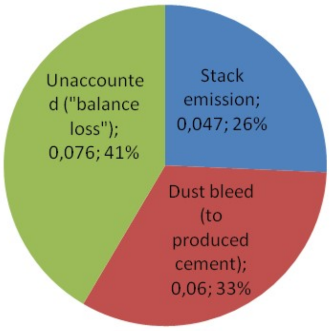
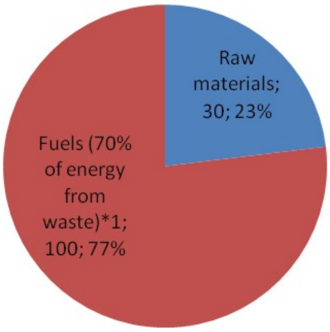
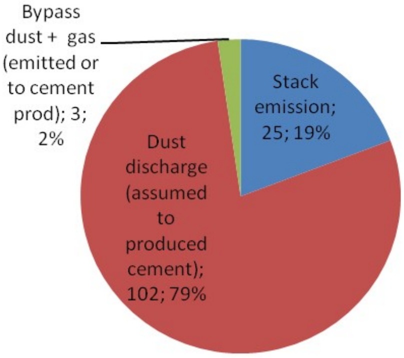
	Mercury inputs	**Mercury outputs**
"Case study 1"	g Hg/t clinker produced; and percent	g Hg/t clinker produced; and percent
- without dust bleed to cement		
- with dust bleed to cement		
"Case study 2"	kg Hg/year; and percent	kg Hg/year; and percent
		

*Figure 5-13 Mercury inputs and output distributions from two cement production facilities (data from CEMBUREAU, 2010. Note*1: Based on other data given in the reference, fossil fuel Hg contributions are assumed minimal).*

722. UNEP/AMAP (2012) used the following mercury retention efficiencies for filter configurations on cement production plants based on various data sources. Level 0 and Level 1 were considered predominant in developing countries, and Level 1 was considered predominant in developed countries, where only a minor fraction (20 percent) were considered with levels higher than 1, and only 1 percent in Level 4 (with ACI, activated carbon injection):

Level 0: None: 0 percent
Level 1: Particulate matter simple APC: FF/ESP/PS: 25 percent
Level 2: Particulate matter optimized/ combination APC: FF+SNCR/FF+WS/ESP+FGD/optimized FF: 55 percent.
Level 3: Efficient APC: FF+DS/ESP+DS/ESP+WS/ESP+SNCR: 75 percent.
Level 4: Very efficient APC: wFGD + /ACI / FF + scrubber+ SNCR: 95 percent retained.

5.3.1.5 Input factors and output distribution factors

723. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default input and output distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that these default factors are based on a limited data base, and as such, they should be considered preliminary and subject to revisions.

724. The default factors suggested mirror the factors used by UNEP/AMAP (2012), except that mercury added with non-clinker materials in the cement mixing stage is included and assumed equal to the mercury input with other raw materials.

725. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

a) Default mercury input factors

726. If no information is available on the mercury concentration in the raw materials, fuels and co-incinerated waste feed into the kilns a first estimate can be formed by using the default input factors selected in Table 5-93 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors have been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum). The medium estimate is used in the default calculations in Inventory level 1 of the Toolkit. If it is chosen not to calculate as intervals, the use of the maximum value will give the safest indication of the possible importance of the source category for further investigation. Using a high end estimate does not automatically imply that actual releases are this high, only that it should perhaps be investigated further.

*Table 5-93 **Preliminary** default input factors for mercury in feed material and fuels for cement production (excluding fossil fuel contributions).*

Gas quality	**Default input factors; g Hg per metric ton of cement produced (low end, high end (intermediate))**
Cement kilns without co-incineration of waste (excluding fossil fuel contributions)	0.004 - 0.5 (0.11)
Cement kilns with co-incineration of waste (excluding fossil fuel contributions)	0.06 - 1 (0.15)

Besides mercury contributions from raw materials and waste used as fuel, fossil fuels used in the production of cement also contribute with mercury inputs. Default mercury inputs from fossil fuels used in cement production are shown in Table 5-92 above, and are pre-entered in the Toolkit calculation spreadsheets. Note that the fossil fuels inputs are lower, when waste is used as supplementing fuel in the cement clinker production.

b) Default mercury output distribution factors

727. For cement clinker production, default mercury output distribution factor are suggested in Table 5-94 below.

Table 5-94 ***Preliminary*** *default distribution factors for mercury outputs from cement clinker production*

Emission reduction device	**Distribution factors, share of Hg input**					
	Air	**Water *1**	**Land**	**Prod-ucts**	**General waste *3**	**Sector specific treatment/ disposal *3**
None	0.8			0.2		
With air pollution controls and no filter dust recycling:						
Simple particle control (ESP / PS / FF)	0.6			0.2		0.2
Optimized particle control (FF+SNCR / FF+WS / ESP+FGD / optimized FF)	0.4	?		0.2		0.4
Efficient air pollution control (FF+DS / ESP+DS / ESP+WS / ESP+SNCR)	0.2	?		0.2		0.6
Very efficient Hg pollution control (wetFGD+ACI / FF+scrubber+SNCR)	0.04	?		0.2		0.76
With air pollution controls and filter dust recycling *2:						
Simple particle control (ESP / PS / FF)	0.7			0.3		
Optimized particle control (FF+SNCR / FF+WS / ESP+FGD / optimized FF)	0.6	?		0.4		
Efficient air pollution control (FF+DS / ESP+DS / ESP+WS / ESP+SNCR)	0.5	?		0.5		
Very efficient Hg pollution control (wetFGD+ACI/FF+scrubber+SNCR)	0.04	?		0.5		0.46

Notes: *1 In case of wet flue gas cleaning systems (WS, wet FGD), discharges of mercury-containing water may take place.

*2 For cement production with recycling of filter dust, it is assumed that part of the otherwise deposited mercury-containing dust is bled to the marketed cement in the final mixing. The hereby recycled mercury is assumed split 50/50 percent on air emissions and the marketed cement. An exception is the filter configuration with ACI, activated carbon injection, for which the mercury is assumed retained in the carbon downstream of particle filters and deposited (not recycled). Data are scarce on these issues and the default factors suggested should be considered associated with substantial uncertainty.

*3 Sector specific disposal may possibly include disposal on special secured landfills, disposal on special landfills with no securing of leaching, and more diffuse use in road construction or other construction works. The actual distribution between disposal with general waste (ordinary landfills) and sector specific deposition may vary, and specific information on the local disposal procedures should be collected.

Abbreviations: ACI – Activated carbon injection; DS – Dry scrubber; ESP – Electrostatic precipitator; FF - Fabric filter (or "bag filter"); FGD – Flue gas desulfurization; PM – Particulate matter (or PM filter); PS - Particle scrubber; SCR - Selective catalytic reduction; SD - Spray dryer; SDA - Spray dryer adsorber; SNCR - Selective non-catalytic reduction; wetFGD – Wet flue gas desulfurization; WS – Wet scrubber.

c) Links to other mercury sources estimation

728. Other sub-categories that are relevant to cement clinker production include: fossil fuel combustion, waste incineration, lime production, and possibly others.

5.3.1.6 Source specific main data

729. The most important source specific data would in this case be:

- Measured data on the mercury concentrations in various types of raw materials, fuel and co-incinerated waste;
- Amount of each type of raw material, fuel and waste used;
- Amount of cement produced and mercury concentration in the cement; and
- Measured data on emission reduction equipment applied on the source, or on similar sources with very similar equipment and operating conditions.

5.3.2 Pulp and paper production

5.3.2.1 Sub-category description

730. In the pulp and paper industry, wood pulp is produced from raw wood via chemical or mechanical means or a combination of both. The source of input mercury is trace levels of mercury in the wood raw material, in fuels used for energy production, and - most likely - in the chemicals applied in the processes (NaOH, chloride, and possibly other). Earlier, the use of mercury-containing slimicides contributed to mercury releases from pulp and paper production in the West. This use may have ceased or been reduced in the West, but may perhaps continue in other parts of the world. Atmospheric emissions from combustion processes, involving fossil fuels, bark and other wood wastes, and carbon containing process liquids (for chemicals recycling and energy production), disposal of solid wastes and aqueous releases from the processes are among the output pathways of mercury from pulp- and paper manufacture. This source sub-category is a potential mercury release source of the type involving materials with very low mercury concentrations, but in very large quantities.

Process summaries

731. Four principal chemical wood pulping processes currently in use are (1) kraft, (2) soda, (3) sulfite, and (4) semichemical (US EPA, 1997a). In the kraft pulping process, wood chips are "cooked" under pressure in a digester in an aqueous solution of sodium hydroxide (NaOH) and sodium sulphide (Na S), referred to as "cooking liquor," or "white liquor." Various processes (not described here) take place and a washed pulp is produced. The washed pulp may enter a bleaching sequence, before being pressed and dried to yield the finished product. Some of the mercury that is present in the wood chips may also be present in the finished product, and the rest will be present in the spent cooking liquor. The levels of mercury in the product and in the liquor are expected to be relatively low because the levels of mercury in the wood chips are relatively low. The amount of mercury that is present in the wood chips is expected to vary somewhat from mill to mill based on the origin of the wood that the mills process. Emissions of mercury are associated with combustion units located in the chemical recovery area. The chemical recovery area at a kraft pulp mill includes chemical recovery furnaces, smelt dissolving tanks (SDT's), and lime kilns (US EPA, 1997a).

732. The other chemical pulping processes are similar to the kraft pulping processes but with some distinct differences. The soda pulping process is essentially the same as the kraft process, except that soda pulping is a non-sulphur process ($Na_2 CO_3$ is used alone, or a mixture of Na_2CO_3 and NaOH is used), and, therefore, does not require black liquor oxidation to reduce the odorous sulphur emissions (US EPA, 1997a).

733. The sulfite pulping process is also carried out in a manner similar to the kraft process, except that an acid cooking liquor is used to cook the wood chips. Similar to kraft pulp mills, the spent liquor is recovered at sulfite pulp mills by being burned in a type of combustion unit. Combustion units used

at sulfite pulp mills include recovery furnaces and fluidized-bed reactors. Typical combustion temperatures for sulfite combustion units are about 704 to 760 ºC. These temperatures are sufficiently high to volatilize any mercury present (US EPA, 1997a).

734. The semichemical pulping process is used to produce for example corrugating medium (the inside layer of corrugated containers), or news paper qualities. The semichemical pulping process uses a combination of chemical and mechanical pulping methods. Wood chips first are partially softened in a digester with chemicals, steam, and heat; once chips are softened, mechanical methods complete the pulping process. Three types of chemical pulping methods are currently in use at semichemical mills--neutral sulfite semichemical (NSSC) (sodium-based sulfite process), kraft green liquor, and non-sulphur (Na_2CO_3 only or a mixture of Na_2CO_3 and NaOH). Semichemical and kraft pulping processes are co-located at some mills. At those mills in the USA, the spent liquor from the semichemical pulping process is burned in the kraft recovery furnace (US EPA, 1997a).

735. Some mills use the semichemical pulping process only. Those mills, referred to as "stand-alone semichemical pulp mills", use a variety of chemical recovery equipment for combusting the spent liquor. Types of chemical recovery equipment used at stand alone semi chemical pulp mills include fluidized-bed reactors, recovery furnaces, smelters, rotary liquor kilns, and pyrolysis units. Typical combustion temperatures in the recovery furnaces and smelters are similar to those for kraft and soda, while typical combustion temperatures in the fluidized-bed reactors and rotary liquor kilns are about 704 to 760 ºC. Similar to the kraft process, cooking liquor chemicals at semichemical mills are recovered from the chemical recovery combustion equipment as ash or smelt, which is mixed with water in a dissolving tank to form green liquor. The green liquor is then combined with makeup chemicals to form fresh cooking liquor. A typical temperature at the dissolving tank vent would be 85 ºC, which is well below the volatilization temperature for mercury. Therefore, mercury is expected to be in particulate form at the dissolving tank vent (US EPA, 1997a).

5.3.2.2 Main factors determining mercury releases and mercury outputs

Table 5-95 Main releases and receiving media from pulp and paper production

Processes	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Production of pulp and paper	**X**	x	x		x	x
Disposal of paper						

Notes: **X**- Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

736. Mercury can be introduced into the pulping process through the wood which is being pulped, in the process water used in the pulping process, and as a contaminant in makeup chemicals added to the process. The mercury concentration in the wood and the other input materials are important factors determining releases.

737. If the mercury is not purged from the process in the wastewater or as dregs, it can accumulate in the chemical recovery area and subsequently be emitted from the chemical recovery combustion sources. The amount of mercury emitted may depend on how tightly closed the pulping process is (such as the degree to which process waters are recycled and reused) (US EPA, 1997a).

5.3.2.3 Discussion of mercury inputs

Table 5-96 Overview of activity rate data and mercury input factor types needed to estimate releases from pulp production

Life-cycle phase	Activity rate data needed	Mercury input factor
Production	Amounts of used feed materials	Mercury concentrations in the used feed materials

738. Mercury is present in wood and other input materials at various concentrations.

739. An average emission factor of 0.0026 g mercury per metric tons burned wood is recommended by the US EPA as the so-called "best typical emission factor" for wood waste combustion in boilers in the USA. (US EPA, 1997b).

740. In investigations in the USA, the mercury content of litter and green vegetation from 7 locations in the USA ranged from 0.01-0.07 mg Hg/kg dry weight (Friedly *et al*., 2001).

741. According to Danish investigations the mercury content of wood and straw burned in Denmark is in the range of 0.007-0.03 mg/kg dry weight (Skårup *et al*., 2003). Swedish investigations found mercury concentrations of 0.01-0.02 mg/kg dry weight in fuel wood; however, concentration of 0.03-0.07 mg/kg dry weight in willow wood was found (Kindbom and Munthe, 1998). In bark, a mercury concentration of 0.04 mg/kg dry weight was found whereas in fir needles the concentrations was 0.3-0.5 mg/kg dry weight (Kindbom and Munthe, 1998).

5.3.2.4 Examples of mercury in releases and wastes/residues

742. In the USA, mercury emissions data are only available from combustion units at kraft pulp mills. Detectable mercury emissions data are available for eight recovery furnaces, one smelt dissolving tank (SDT), and three lime kilns, located at 11 kraft pulp mills. Average mercury emission factors were estimated for recovery furnaces, SDT's, and lime kilns based on the available mercury emissions data. The average mercury emission factors for these units which include recovery furnaces, SDTs, and lime kilns are shown in the table below.

Table 5-97 Atmospheric emissions factors for various units at pulp and paper mills in USA (US EPA, 1997a)

Kraft combustion unit	Emissions factor (Kg/metric ton)	Number of units tested/control device
Recovery furnace	2×10^{-5} ***1**	8 recovery furnaces, each controlled with an ESP
Smelt dissolving tank	2.6×10^{-8} ***2**	1 SDT, controlled with a mist eliminator
Lime kiln	1.5×10^{-6} ***2**	3 lime kilns, each controlled with a wet scrubber

Notes: *1 – kg Hg emitted per metric tons of black liquor solids fired in the recovery furnace or SDT;
*2 – kg Hg emitted per metric tons of lime produced in the kiln.

743. The total annual mercury emissions (for 1994) in the USA (for 153 facilities) was estimated using these emission factors for kraft and soda recovery furnaces, SDT's, and lime kilns. The total mercury emissions were estimated to be 1.6 metric tons. Since there are 153 facilities, the average emissions are estimated to be about 0.01 metric tons per facility. The single largest source of mercury emissions in the chemical recovery area is the recovery furnace (US EPA, 1997a).

744. Nearly all of the mercury emissions from pulp and paper manufacturing are from kraft and soda recovery processes (approximately 99.9%) (US EPA, 1997a). Estimated emissions from all of the facilities were summed together to arrive at the 1996 estimated mercury emissions of 1.7 metric tons per year for the USA inventory as a whole. (US EPA, 1997b)

745. Releases of mercury compounds and mercury by all release paths in the USA in 2002 are shown in Table 5-98. The main paths are releases to the air and releases to solid waste disposal. The specific mercury compounds are not reported and it is based on the data not possible to estimate a total mercury release.

Table 5-98 Releases of mercury and mercury compounds from kraft and paper production in the USA, 2002 (TRI, 2004)

Release path	**Mercury compounds**		**Mercury (elemental)**	
	kg/year	**%**	**kg/year**	**%**
Air	2,098	71	319	39
Surface water	36	1	19	2
Land treatment and surface impoundments	217	7	20	2
Off-site waste water treatment	3	0	0	0
Off-site solid waste disposal	594	20	451	56
TOTAL (rounded %)	2,948	100	809	100

5.3.2.5 Input factors and output distribution factors

746. Based on the so far compiled examples of mercury concentrations in biomass and general information on emission reduction system efficiency, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

747. Bearing in mind the large variation presented above on both mercury concentrations in biomass and the efficiency of emission reduction systems on mercury, the use of source specific data is the preferred approach, if feasible.

a) Default mercury input factors

Note that due to lack of data, the default input factor includes inputs from the biomass use only, and not other non-fuel feedstock materials. Fossil fuels, if used, will contribute to mercury inputs, but fossil fuels consumption is accounted for in other sub-categories.

Table 5-99 ***Preliminary*** *default input factors for mercury in coal for energy production*

Material	Default input factors; g mercury per metric ton of biomass (dry weight); (low end - high end)
Biomass used in production (principally wood)	0.007 - 0.07

b) Default mercury output distribution factors

Table 5-100 ***Preliminary*** *default distribution factors for mercury outputs from pulp and paper production (with own pulp production)*

Emission reduction device	Distribution factors, share of Hg input					
	Air	Water	Land *1	Products	General waste *1	Sector specific treatment/ disposal *1
None	1	?		?		
PM control with general ESP, or PS	0.9	?	?	?	0.1	?

Notes: *1 The actual distribution between disposal with general waste (ordinary landfills), land and sector specific deposition likely varies much among countries, and specific information on the local disposal procedures should be collected.

Abbreviations: PM – Particulate matter; ESP – Electrostatic precipitator; PS – Particle scrubber.

c) Links to other mercury sources estimation

748. No links suggested.

5.3.3 Production of lime and light weight aggregates

5.3.3.1 Sub-category description: Lime Production

749. This sub-category includes the production of lime in lime kilns (other than the lime produced at cement plants and pulp and paper mills, which are described in previous sections of this document) and light weight aggregate kilns.

750. Lime is produced in various forms, with the bulk of production yielding either hydrated lime or quicklime. In 1994, 17.4 x 10^6 metric tons of lime was produced at 109 plants in the USA. Lime is used in steelmaking, pulp and paper manufacturing, and treatment of water, sewage, and smokestack emissions (US EPA, 1997a).

751. Lime is produced by calcining limestone (i.e., removing CO_2 from the limestone) at high temperature (US EPA, 1997a). Calcinating, which involves burning calcium carbonate at high temperatures, is the primary process at lime production facilities that release mercury (NESCAUM, 1998).

752. The product of the calcining operation is quicklime; this material can be hydrated with water to produce hydrated lime or slaked lime. The product of calcining dolomite is dolomitic quicklime; it also can be hydrated (US EPA, 1997a).

753. Lime manufacturing is carried out in five major steps. These are: 1) quarrying raw limestone; 2) preparing the limestone for calcination; 3) calcining the limestone; 4) processing the lime by hydrating; and 5) miscellaneous transfer, storage, and handling processes.

754. The manufacturing steps in lime production are very similar to that of the dry Portland cement process, which was discussed in a previous section of this document.

755. During calcination, kiln temperature may reach 1820 ºC. About 90% of the lime produced in the USA is manufactured by calcining limestone in a rotary kiln. Other types of lime kilns include the vertical or shaft kiln, rotary hearth, and fluidized bed kilns (US EPA, 1997a).

756. Fuel, such as coal, oil, petroleum coke, or natural gas, may be used to provide energy for calcination. Petroleum coke is usually used in combination with coal; oil is rarely used as a fuel source. Auxiliary fuels such as chipped rubber and waste solvents may potentially be used as auxiliary fuels (US EPA, 1997a).

757. Mercury is expected to be present in very small quantities in the limestone and in some of the fuels. The mercury content in coal and oil and other fuels are discussed in section 5.1. Similar to the production of Portland cement, any mercury present in the raw materials is expected to be released to the air from the lime kiln. Combustion of fuel in the lime kiln is a primary source of mercury emissions.

758. Other emission sources from lime manufacturing can include process emissions or fugitive emissions. The primary pollutants resulting from these fugitive sources are PM. US EPA reported in 1997 that no specific control measures for the lime industry in the USA were reported in the literature for the fugitive sources (US EPA, 1997a).

759. The reduction measures used for fugitive dust sources at Portland cement manufacturing facilities may also be applicable at lime manufacturing industries. Air pollution control devices for lime kilns are primarily used to recover product or control fugitive dust and PM emissions. Calcination kiln exhaust is typically routed to a cyclone for product recovery, and then routed through a fabric filter or ESP's to collect fine particulate emissions. Other emission controls found at lime kilns include wet scrubbers (typically venturi scrubbers). How well these various air pollution control devices perform, relative to vapour phase mercury emissions in lime production, is not well documented. The control efficiencies are expected to be similar to those observed in the production of Portland cement because of the similarities in the process and control devices (US EPA, 1997a).

760. Mercury emissions from fuel combustion will occur from the lime kiln (calcination). Mercury present in the limestone will also be emitted from the kiln. All other potential emission sources in the process are expected to be very minor contributors to overall mercury emissions.

5.3.3.2 Sub-category description: Light weight aggregates

761. Light weight aggregate kilns process a variety of raw materials (such as clay, shale, or slate) which, after thermal processing, can be combined with cement to form concrete products. This light-weight aggregate concrete is produced for structural purposes or for thermal insulation purposes. A light weight aggregate facility is generally composed of a quarry, a raw material preparation area, a kiln, a cooler, and a product storage area. The material is obtained and moved from the quarry to the raw material preparation area, and then is inserted into the rotary kiln (US EPA, 1997a).

762. In light weight aggregate kilns, there is a rotary kiln consisting of a long steel cylinder, lined internally with refractory bricks, which is capable of rotating about its axis and is inclined at an angle of about 5 degrees to the horizontal. The length of the kiln depends in part upon the composition of the raw material to be processed, but is usually 30 - 60 meters. The prepared raw material is fed into the kiln at the higher end, while firing takes place at the lower end. The dry raw material fed into the kiln is initially preheated by hot combustion gases. Once the material is preheated, it passes into a second furnace zone where it melts to a semiplastic state and begins to generate gases which serve as the bloating or expanding agent. In this zone, specific compounds begin to decompose and form gases such as SO , CO , SO , and O that eventually trigger the desired bloating action within the material. As temperatures reach their maximum (approximately 1150 ºC), the semiplastic raw material becomes viscous and entraps the expanding gases. This bloating action produces small, unconnected gas cells,

which remain in the material after it cools and solidifies. The product exits the kiln and enters a section of the process where it is cooled with cold air and then conveyed to the discharge (US EPA, 1997a).

763. Kiln operating parameters such as flame temperature, excess air, feed size, material flow, and speed of rotation vary from plant to plant and are determined by the characteristics of the raw material. Maximum temperature in the rotary kiln varies from about 1120 - 1260 °C, depending on the type of raw material being processed and its moisture content. Typical exit temperatures may range from about 427 - 650 °C, again depending on the raw material and on the kiln's internal design. Approximately 50 to 200% excess air is forced into the kiln to aid in expanding the raw material (US EPA, 1997a).

764. The principal source of mercury emissions from lightweight aggregate kilns is the flue gas (combustion gas) exhaust stack.

765. Light weight aggregate kilns may use one or a combination of air pollution control devices, including fabric filters, venturi scrubbers, cyclones and dry scrubbers. All of the facilities in the USA utilize fabric filters as the main type of emissions control, although a spray dryer, venturi scrubber and dry scrubber may be used in addition to a fabric filter (US EPA, 1997a). These control devices may capture some of the mercury in the gas stream and therefore reduce emissions to air.

5.3.3.3 Main factors determining mercury releases and mercury outputs

Table 5-101 Main releases and receiving media from production and processing of other raw materials

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Production	X			x		

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

766. The main factors determining releases will be the mercury concentrations in the raw materials used and the release control measures in place.

5.3.3.4 Discussion of mercury inputs

Table 5-102 Overview of activity rate data and mercury input factor types needed to estimate releases from lime production

Life-cycle phase	Activity rate data needed	Mercury input factor
Production	Amounts of used feed materials	Mercury concentrations in the used feed materials

767. Mercury is present in the limestone that is processed to make lime (NESCAUM, 1998).

5.3.3.5 Examples of mercury in releases and wastes/residues

768. An atmospheric emissions factor of 0.055 g of mercury per metric ton of lime output was calculated for lime kiln using a mass balance approach based on information about mercury content in limestone from 5 lime kilns in Wisconsin (Miller, 1993, as cited in NESCAUM, 1998). This emissions factor was used by NESCAUM (1998) to estimate releases to air of 15 kg per year from 1 lime production facility in Massachusetts, USA.

769. There were 109 lime production plants in the USA in 1994 (US EPA, 1997a). Based on data from the US EPA, these 109 plants released a total of 37.8 metric tons mercury to soils, 0.1 metric tons mercury to air, and less than 0.05 metric tons to water. The largest emitting lime plant in the USA reported releases of 37500 kg to land and about 1 kg to air (US EPA, 2003a, TRI releases data for year 2001).

770. Data are available for two facilities in the USA and one in Canada (US EPA, 1997a). At the Canadian facility, two different kilns were tested; one was a coal/coke-fired rotary kiln and the other was a natural gas-fired vertical kiln. For the coal/coke-fired rotary kiln, the results from the tests showed an average mercury emission factor of 9 milligrams (mg) of mercury per metric ton of lime produced (or 9 mg Hg/metric tons lime produced); the emission factors ranged from 8 mg to 10 mg Hg/metric tons of lime produced over the four test runs. For the natural gas-fired vertical kiln, the results showed an average mercury emission factor of 1.5 mg Hg/metric tons of lime produced. Process data from the tests at the Canadian facility were used to calculate the quantity of limestone fed required to produce 0.91 metric tons of lime. Based on process data for the rotary kiln, the average ratio of limestone feed to lime produced was 0.50 (i.e., 2 tons of limestone are required to produce 1 ton of lime). The average ratio for the vertical kiln was calculated to be 0.51. The results of the tests for one of the USA facilities showed an average mercury emission factor of 1.9 mg Hg/metric tons of limestone feed. Based on the 2:1 limestone feed to lime produced ratio, this corresponds to an emission factor of 3.8 mg Hg/metric tons of lime produced. At the other facility, the results showed an average mercury emission factor of 4.7 mg/metric tons of limestone feed. Using the 2:1 conversion ratio, this corresponds to a mercury emission factor of 9.4 mg Hg/metric tons of lime produced (US EPA, 1997a).

771. The average atmospheric mercury emission factors for the coal-fired rotary kilns from the one Canadian facility and the two U. S. facilities were combined and showed an overall average atmospheric mercury emission factor of 7.4 mg Hg/metric tons of lime produced (US EPA, 1997a).

5.3.3.6 Input factors and output distribution factors

772. No attempts were made to establish default factors for this sub-category.

5.3.4 Others minerals and materials

773. Other potential mercury sources may exist. Include any data observed on such sources in the inventory. No attempts were made to describe any such sources in this Toolkit report.

5.4 Intentional use of mercury in industrial processes

Table 5-103 Intentional use of mercury in industrial processes: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Chapter	Sub-categories	Air	Water	Land	Product	Waste/ residue	Main inventory approach
5.4.1	Chlor-alkali production with mercury-technology	**X**	**X**	**X**	**X**	**X**	PS
5.4.2	VCM (vinyl-chloride-monomer) production with mercury-dichloride ($HgCl_2$) as catalyst	x	x			**X**	PS
5.4.3	Acetaldehyde production with mercury-sulphate ($HgSO_4$) as catalyst	?	?	?	?	?	PS
5.4.4	Other production of chemicals and polymers with mercury compounds as catalysts	?	?	?	?	?	PS

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.;
? - Releases may occur, but no data are available on this aspect.

5.4.1 Chlor-alkali production with mercury-technology

5.4.1.1 Sub-category description

774. At a mercury cell chlor-alkali facility, elemental mercury is used as a fluid electrode in an electrolytic processes used for production of chlorine and sodium hydroxide (NaOH) or potassium hydroxide (KOH) from salt brine (the electrolysis splits the salt, NaCl). Hydrogen is also made as a by-product. The process is sometimes referred to as the "mercury cell" process. Note that two other (non-mercury) methods are also used widely: the membrane process and the diaphragm process. The share of national production capacity based on the mercury-cell process varies between countries, and is generally decreasing in many countries. In many countries, the industry has committed themselves to not base new chlor-alkali facilities on the mercury-cell process, and the Minamata Convention requires its Parties to phase out the technology by 2025. In some countries/regions conversion/shut-down of mercury-cell facilities are planned or already implemented.

775. Mercury is released to the environment with air emissions, water releases, in solid wastes (sludges and building debris) and to a minor degree in products (such as NaOH and H_2).

Processes involved

776. Each mercury cell production loop includes an elongated electrolyser cell, a decomposer, a mercury pump, piping, and connections to other systems (Anscombe, 2004). The electrolyser produces chlorine gas, and the decomposer produces hydrogen gas and caustic solution (NaOH or KOH). The electrolyser is usually an elongated steel trough enclosed by side panels and a top cover. A typical electrolyser holds about 3,600 Kg mercury. The decomposer is a cylindrical vessel located at the outlet of the electrolyser. The electrolyser and decomposer are typically linked by an inlet end box and an outlet end box. Brine and a shallow stream of liquid elemental mercury flow continuously between the electrolyser and the decomposer. While each cell is an independent production unit, numerous cells are connected electrically in series. A plant usually has many cells. For example, in the USA each plant has from 24 to 116 cells, with an average of 56 (US EPA 2002b). Many metric tons of mercury

may be in use at a facility. For comprehensive descriptions of processes, releases etc. see for example the EC Reference Document on Best Available Techniques in the Chlor-Alkali Manufacturing industry (European Commission, 2001b; or see the 2011 draft update at http://eippcb.jrc.es/reference/).

777. In the electrolyser, an electric current is applied that causes a separation of chlorine gas from salt (sodium chloride brine), and the sodium (or sometimes potassium) binds with mercury to form an amalgam (Na-Hg or K-Hg amalgam). The chlorine gas is collected and the mercury amalgam exits via the outlet end box and enters the decomposer. In the decomposer, the amalgam (Na-Hg or K-Hg) is converted, through another electrolytic reaction, to caustic (NaOH or KOH), hydrogen gas, and elemental mercury. The caustic and hydrogen are transferred to other equipment, and the mercury is pumped back into the inlet end of the cell.

5.4.1.2 Main factors determining mercury releases and mercury outputs

Table 5-104 Main releases and receiving media from chlor-alkali production with mercury-technology

Phase of life cycle	Air	Water	Land	Product *3	General waste *2	Sector specific treatment/ disposal *1
Mercury cell chlor-alkali production	X	X	X	X	X	X

Notes: *1 May include treatment to recover mercury, safe landfilling as hazardous waste. On-site and off-site dumping is considered here as direct releases to land;

*2 Only in cases where production waste is disposed of at general waste landfill;

*3 Significant amounts of mercury can be lost to the caustic product in some cases;

X -Release pathway expected to be predominant for the sub-category;

x - Additional release pathways to be considered, depending on specific source and national situation.

778. Mercury is released to the environment with air emissions, water releases, in solid wastes and in products (such as NaOH). These releases can occur at various stages and locations of the process. The degree of release to each media (air, water, land), from various stages and release points in the process, is highly dependent on level of controls present, workplace/management practices, waste treatment/disposal procedures, and other factors. A part of the mercury follows the produced products and may subsequently be released when the caustic or hydrogen is used later.

779. Most mercury releases occur as fugitive emissions from the cell room and other locations. Preventive measures and good management practices can significantly reduce these fugitive emissions (UNEP, 2002). The primary specific points of mercury outlets to air are the end box ventilation system and the hydrogen gas vent. Several control techniques may be employed to reduce mercury levels in the hydrogen streams and in the end box ventilation systems. The most common techniques are (1) gas stream cooling, (2) mist eliminators, (3) scrubbers, and (4) adsorption on activated carbon or molecular sieves. Gas stream cooling may be used as the main mercury control technique or as a preliminary step to be followed by a more efficient control device. The proper use of these devices can remove more than 90% of the mercury from the gas streams (Pacyna and Pacyna, 2000). Each of the important processes and/or locations, where releases may occur, are discussed below.

780. **End-box Ventilation**. An end box ventilation system is used at many plants to vent the air from the end boxes, and sometimes other equipment as well. The concentration of mercury in end-box ventilation systems before any steps are taken to remove mercury varies greatly depending on the vacated equipment. The collected gases are most often cooled and then treated with control equipment. However, some mercury remains in the treated stream leaving the end-box ventilation system and is released to air (US EPA 1997a). The extent of releases from this system is highly dependent on the type of controls used.

781. **Hydrogen Stream.** Hydrogen gas exiting the decomposer contains high concentrations of mercury vapour (as high as 3,500 mg/m^3). In most situations, each decomposer is equipped with an

adjacent cooler through which the hydrogen gas stream is routed to condense mercury and return it to the mercury cell. After initial cooling, the hydrogen gas from each decomposer is collected into a common header. Additional mercury is removed from the combined gas by additional cooling and adsorption (or absorption) control equipment. However, some mercury remains in the treated stream, which is vented to the atmosphere (or in some cases burned as fuel in a boiler or transferred to another process as a raw material).

782. **Fugitive Air Emissions**: Humans cannot smell or see mercury vapour (under normal lighting). Mercury vapour can be detected by commercially available vapour analysers. In addition, when liquid elemental mercury is visibly accessible to open air, it will give off some vapour, at rates depending on temperature and other factors. Therefore, visual inspection for visible mercury is one effective work practice for curtailing air emissions. However, mercury vapour can also be generated from leaks in pressurized equipment, maintenance work and dysfunction, absent of any visual appearance of liquid mercury. Thus, another work practice is visual inspection for vapour leaks from production equipment by means of ultra-violet spectrum lights. When vapour leaks are identified, workers can take remedial steps to plug them. Some other methods of reducing potential fugitive air emissions include cleanup of freestanding liquid mercury and air tight enclosure of mercury containing wastes.

783. **Solid Wastes.** Various solid wastes are produced that are contaminated with mercury. The safety level of the management of solid wastes varies and may include treatment on-site with mercury recovery processes, use of hazardous waste landfills, or disposal on-site or at general waste landfills. Some of the solid wastes generated include: waste water treatment sludge (described below), and various non-specific wastes including graphite from decomposers, cell room sump sludges, and spent carbon adsorption devices. Also, various larger contaminated waste items are disposed of including hardware, protective gear, piping, and equipment.

784. Some mercury in the solid wastes may be recovered and recycled to the production process – often as an on-site integrated part of the production facility. For example, in the USA, 9 (out of 12) mercury cell chlor-alkali plants had mercury recovery processes on-site in 2002. The most common type is thermal recovery (retorting), where mercury-containing wastes are heated to volatilise the mercury which is then condensed, recovered and then used again as input into the mercury cell process (US EPA, 2002b). However, not all of the mercury is captured through this process. Some mercury is released to the air through the off-gas vent. Other plants use a chemical process or a batch purification process (US EPA, 2002b). Moreover, plants in some other countries and regions may not utilize such solid waste treatment. In these cases, releases from solid wastes could be significant.

785. In addition, some solid wastes (containing mercury) are generated from the mercury recovery processes. For example, the retorting process produces retort ash, which generally contains low levels of mercury. Other recovery processes also generate some solid wastes such as a chemical process in which mercuric sulphide and elemental mercury are transformed to mercuric chloride (US EPA, 2002b).

786. **Mercury in Products.** The caustic product contains low levels of mercury in the form mercuric chloride, which has relatively low vapour pressure. Therefore emissions to air are minimal. The concentration of mercury in the caustic stream leaving the decomposer ranges from about 3 to 15 ppm (these values may reflect the situation in the USA around 2002). Mercury is removed by cooling and filtration. Some mercury-containing waste water is produced from this process, which is typically subject to appropriate waste water treatment. Residual mercury contained in the caustic product is probably typically low. For example, in the USA caustic products usually have levels about 0.06 ppm (US EPA, 2002b). About 2.26 metric tons of 50% caustic soda is produced for every ton of chlorine produced (Eurochlor, 1998). The chlorine gas product typically has levels less than 0.03 ppm.

787. Although mercury is released as a contaminant in products, the levels appear to be low in the USA based on available data (US EPA, 1997b). However, the levels in these products could perhaps be higher in some other countries if similar purification and cleaning steps are not employed.

788. For example, in a comprehensive review of the chlor-alkali industry in India, the Center for Science and Environment (CSE) reported that 10.6% of the mercury lost via production would be found in the products (or 15.5 grams/ton of caustic soda produced). Most of this mercury (10 grams/ton of caustic soda produced) was in the caustic soda product, but a large amount (5.25 g/ton of caustic produced) was in the hydrogen product as well (CSE, 2002, as cited in NRDC comments to UNEP Chemicals, 2005).

789. **Waste Water.** Mercury cell chlor-alkali plants generate a variety of aqueous waste streams that contain mercury and are often treated in a wastewater treatment system. These wastewaters originate from a variety of sources, ranging from wastewaters produced from cell room washdowns and cleanup activities to liquids or slurries produced from purged brine and backwash water from the filtration equipment used for caustic purification (US EPA, 2002b). In the USA, by way of example, most plants use a process that converts the mercury in the wastes to mercuric sulphide, which has a very low vapour pressure. The mercuric sulphide is removed from the waste water through precipitation and filtration. The end result is a sludge that is predominantly mercuric sulphide filter cake. In the USA this sludge must be treated according to hazardous waste regulations which minimize releases. If a particular plant does not utilize an effective waste water and sludge treatment process, mercury releases through waste water may perhaps be significant.

790. **Retorts**. In the USA, 3 mercury recovery units employ oven retorts. The best performing unit treats the off gases with a wet scrubber and condenser followed by a carbon adsorber. Based on 134 tests conducted at this facility of mercury levels in the final emitted gas, the 3 highest values were 20.4, 22.1, and 26.4 mg/m^3 (US EPA, 2002b). Two plants in the USA utilize rotary kiln retorts. Data from one of these plants shows mercury concentrations in air emissions of 1.4 mg/m^3 to 6.0 mg/m^3, with an average of 2.8 mg/m^3 from these retorts. One plant in the USA utilizes a hearth retort. The concentrations range from 0.2 to 10.8 mg/m^3, with a mean of 1.6 mg/m^3 for this unit (US EPA, 2002b).

Table 5-105 Overview of processes, equipment or activities at chlor-alkali plants where significant releases of mercury can occur, and potential receiving media

Release source (process, equipment, or activity) *1	**Air**	**Water**	**Land**	**Product**	**Source Specific Wastes**
Hydrogen stream	**X**	x		x	x
End box ventilation air	**X**				x
Cell room ventilation air	**X**				x
Fugitive releases, especially from cell room	**X**		x		x
Mercury recovery unit	**X**				**X**
Waste water (from cell room cleaning, brine system, caustic purification and other activities)	**X**		x		**X**
Solid wastes and sludges from waste water treatment	**X**		**X**	**X**	**X**
Chlor gas, NaOH, KOH products sold				**X**	

Notes: *1 The extent and type of releases for each of these processes, equipment, or activities depends on the degree of controls used, waste treatment methods, management practices, and other factors;

X - Release pathway expected to be potentially significant;

x - Additional release pathways to be considered, depending on specific source and national situation.

5.4.1.3 Discussion of mercury inputs

Table 5-106 Overview of activity rate data and mercury input factor types needed to estimate releases from chlor-alkali production with mercury-technology

Activity rate data needed	**Mercury input factor**
Amount of chlorine (or NaOH) produced per year (e.g., metric tons Cl_2).	Amount of mercury input per unit of chlorine (or NaOH) produced (g Hg per metric ton Cl_2).

791. Large amounts of mercury are used as input materials in this industry. For example, the annual consumption in the USA in 1996 was about 136 metric tons of mercury among 14 plants. The Global consumption (input) of mercury in this industry has been estimated to be about 1344 metric tons for 1996 (Sznopek and Goonan, 2000, as cited in UNEP, 2002). Typically many tons of mercury are continuously in use at these facilities. During 2002, 39 Western European factories reported to OSPAR mercury consumption totalling 109 tons. Nine factories in the USA reported consumption totalling 30 tons, in the same year. Yet, these factories have been pursuing mercury stewardship programs for many years. It is plausible that factories in some other countries could experience higher capacity-adjusted consumption (Anscombe, 2004).

792. Chlor-alkali plants vary significantly in the amount of mercury input used per unit of product (chlorine gas, or Cl_2) produced. This input is usually expressed in units such as grams mercury per metric ton of Cl_2, (g Hg/metric ton Cl_2), or grams mercury per metric ton of caustic (g Hg/metric ton caustic; for conversion between a Cl_2-basis and a caustic basis, the following factor can be used: Hg used per metric ton caustic produced = [g Hg/metric ton NaOH] = [g Hg/metric ton Cl_2.)/**1.128]**; based on European Commission, 2001b, p.7**)**. This input of mercury is required to replace the amount of mercury "lost" per unit Cl_2 produced. Therefore, this input could also be considered as g mercury lost per Cl_2 produced. The best performing facilities, with world class state-of-the-art production technology and work place practices, used in the early 2000's about 6 grams elemental mercury as input per metric ton of chlorine produced (6 g Hg/metric ton Cl_2).

793. Facilities that use less effective production technologies and work practices will consume more mercury per metric ton of chlorine produced. For example, facilities in India used an average of about 125 g Hg/metric ton Cl_2 in 1999 (Srivastava, 2003). During 2002, this had reportedly been reduced to about 80 g Hg/metric ton Cl_2, a consumption rate similar to US factories during the mid-1990s, before they thereafter undertook further mercury stewardship actions (that have yielded a more than 70% reduction in mercury consumption to about 22 g Hg/metric ton Cl_2 during 2002). For further perspective, two factories in Russia reported consumption of 250 and 580 grams mercury per metric ton of output product (Treger in Lassen *et al.*, 2004), a consumption rate not dissimilar to factories in Western Europe and North America before 1970 (Anscombe, 2004). No updated data have been identified for the Russian plants.

794. In 1990, the average input for US facilities was about 75 g Hg/metric ton Cl_2. However, after about a decade of substantial efforts to reduce releases (largely focused on better work place practices to control fugitive emissions), US facilities used an average of about 18 g Hg/metric ton Cl_2 in the early 2000's.

795. The activity rate (or amount of chlorine produced per year) also varies among chlor-alkali plants. For example, in the USA in 1997 of the existing 12 plants, the highest activity rate was 234,056 metric tons chlorine per year, and the lowest was 43,110 metric tons chlorine per year, with an average of 121,615 metric tons per year.

796. In their emission estimates, UNEP/AMAP (2012) used so-called generic unabated emission factors corresponding to total input factors of 50-100 g Hg/metric ton Cl_2 production capacity, except for a fewcountries with specific reported factors.

797. According to Toxics Link (2012), citing the Alkali Manufacturers Association of India, the remaining two facilities using mercury cell technology (of a total of 36 facilities) have a mercury consumption (presumably including all Hg purchases) of 1.54 metric tons per year for the production of approximately 160 metric tons per year of caustic, in other words, approximately 10 g Hg/ton caustic produced (or 11g Hg/ton Cl2 produced, using the conversion factor mentioned above).

5.4.1.4 Examples of mercury in releases and wastes/residues

798. As discussed above, the amount of mercury released to each pathway depends on the type of technology present, extent of management practices to limit and prevent releases, and other factors. The most significant outcomes for mercury which is consumed may be in-factory build-up, solid wastes, and air emissions, which are all difficult to quantify. In some factories, mercury could plausibly also be significantly lost to water and products, based on the experience in the USA and western Europe, prior to 1970 (Anscombe, 2004).

799. Data on mercury outputs from chlor-alkali plants in France, indicate that 3 to 14% of the mercury input is released to air, 16 to 90% is released through solid wastes (or other types of semi solid wastes such as sludges), 10 to 70% of the losses are considered internal losses (releases not accounted for in other release pathways) and less than 2% is released to the remaining 3 pathways (water discharge, land, and products) (OSPAR, 2002).

800. Based on data reported to the US EPA Toxics Release Inventory (TRI) for year 2001, (which apparently does not include internal losses) about 26-67% of quantified reported releases are emitted to air, about 32-73% is released through wastes, and less than 2% goes to water and land (US EPA, 2003d). If internal losses where included, these percent values would be somewhat lower. But, the TRI data provide useful information on the relative magnitude of releases to these selected media.

801. Atmospheric emissions estimates have been developed in the USA based on stack test data for hydrogen streams and end box vents at 10 plants. The values range from 0.067 grams of mercury per metric ton chlorine produced (0.067 g Hg/metric tons Cl_2) to 3.41 g Hg/metric tons Cl_2. The average for the best performing five plants was 0.14 g Hg/metric tons Cl_2. In addition, there were 2 plants in the USA that have no end box ventilation system. For these 2 plants, tests were conducted on the

hydrogen stream only. The 2 values were 0.033 g Hg/metric tons Cl_2 and 0.17 g Hg/metric tons Cl_2, with an average of 0.1 g Hg/metric tons Cl_2. US EPA has emissions factors for cell hydrogen vents and from end boxes. These factors may be useful for estimating emissions from some sources, however, these factors are based on tests from only 2 plants, conducted in 1973, and therefore have significant limitations (see US EPA, 1997a for details). Later studies in the USA indicate that measured mercury releases to the atmosphere are very dependent of where in the cell rooms the air samples are taken.

802. The relatively low emission factors reported in recent years (such as from the EU and USA) are not deemed applicable in general (in a regional/global perspective) because facilities in some other countries/regions release more mercury per metric ton of chlorine produced (or per metric tons sodium hydroxide produced) than the typical facility in the USA and EU (UNEP, 2002).

803. Treger reports in (Lassen *et al.*, 2004) the mercury balances for the four mercury cell chlor-alkali facilities remaining in Russia in 2002, see Table 5-107.

Table 5-107 Mercury balances for mercury cell chlor-alkali facilities in the Russian Federation in 2002 (Treger in Lassen et al.*, 2004)*

Plant	Mercury consumption, g/metric ton Cl capacity	Mercury purchased, metric tons *1	Emissions to atmosphere, metric tons	Discharged to water bodies, metric tons	Un-accounted amounts, metric tons	Disposed at landfills, metric tons	Losses with commodity products, metric tons
1	251	15.1	0.15	0.0001	0.015	14.9	0.03
2	52	7.3	0.39	0.0008*	4.5	1.4	0.08
3	42	10.0	0.44	0.0001	4.2	0.007	0.02
4	582	70.8	0.24	No data	47.6	22.9	0.08
Total	-	103.2	1.22	>0.001	56.3	39.3	0.22

Notes: * To water system (ponds-evaporators);

*1 Purchased mercury amounts may differ from consumption in the same year due to internal mercury stock changes.

804. In Table 5-108 the same data from Russia are converted to relative output distribution.

Table 5-108 Russian chlor-alkali facilities 2002, total outputs and distribution of outputs in share of reported outputs (based on Treger in Lassen et al.*, 2004)*

Plant	Sum of outputs + unaccounted amounts, metric tons Hg	To air, share	To water, share	To products, share	To landfills, share	Unaccounted amounts, share
1	15	0.01	0.000007	0.002	0.99	0.001
2	6	0.06	0.0001	0.01	0.22	0.71
3	5	0.09	0.00002	0.004	0.001	0.90
4	71	0.003	No data	0.001	0.32	0.67
Total	97	0.013	0.00001	0.002	0.40	0.58

805. Data on mercury cell facilities which have been shut down in Russia in the 1980's and 1990's indicate that mercury amounts in the soil at the facilities may be significant (Treger in Lasssen *et al.*, 2004). Leaks, handling losses, as well as on-site storage of mercury waste have been sources of this mercury.

806. Clean-up of chlor-alkali plant sites in the United States that either have closed or continue to operate can cause significant challenges, including generation of mercury-contaminated groundwater; surface water; soils and sediments; debris; and stockpiles of elemental mercury (see http://www.epa.gov/epaoswer/hazwaste/mercury/cleanup.htm ; Southworth *et a.l* (2004) ; Kinsey *et al.* (2004); Kinsey *et al.* (2004); all as cited in review comments from the NRDC, 2005).

807. **Overall Mercury Losses.** Even with mercury recovery systems and good emissions controls, mercury is still lost. Mercury must be periodically added to the process to replenish these losses. Reported releases to air, water, waste and products do often not account for the full mercury input to the mercury cell process, and sometimes a "not accounted for" balance is reported to mirror this. Some outputs of mercury are relatively amenable for measurement (water discharge, products, stack air emissions). Other estimates of mercury outputs are not so readily measured or quantifiable (the mass of mercury adhering to metallic debris, contained within solid wastes, fugitive air emissions, and in-factory build-up of mercury). Because of uncertainties pertaining to measuring some outputs, a possibility for evaluating the overall performance of a factory is by the performance metric of mercury consumption per metric ton of product produced. This is a holistic measure that encompasses all ways mercury can be consumed during the production process. It is relatively reliable, based on the simple economic data of mercury replenishment to make up for mercury consumed during production. The linking of mercury consumption to metric ton of output allows direct comparison among factories within one country and across countries, since this adjusts for differences in factory size (Anscombe, 2004). In some cases where such high-quality assessment is not possible, indications of for example fugitive emissions can be obtained through measurements done with handheld mercury monitors.

5.4.1.5 Input factors and output distribution factors

808. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered preliminary and subject to revisions as the data base grows. Also, the presented default factors are expert judgments based on summarized data only.

809. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

a) Default mercury input factors

810. The appropriate input factors to use for calculating releases will vary depending on the control devices present, pollution prevention techniques, and specific management practices used. Site specific data and information are preferred. All relevant information available for the plant under evaluation should be used to determine the most appropriate input factors.

811. If no information is available on the mercury consumption per production capacity, a first estimate can be formed by using the default input factors selected in Table 5-109 below (based on the data sets presented in this section). Because consumption factors vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum). The intermediat estimate is used in the default calculations in Inventory level 1of the Toolkit. If it is chosen not to calculate as intervals, the use of the maximum value will give the safest indication of the possible importance of the source category for further investigation. Using a high end estimate does not automatically imply that actual releases are this high, only that it should perhaps be investigated further.

Table 5-109 ***Preliminary*** *default input factors to estimate releases from chlor-alkali production*

Process	**Default input factors;** **g mercury per metric ton of chlorine produced;** **(low end - high end (intermediate)) *1**
Chlor-alkali production with mercury cells	10 - 200 (100)

Notes: 1* The mercury input can also be expressed in grams mercury per metric ton of caustic (g Hg/metric ton caustic); for conversion between a Cl_2-basis and a caustic basis, the following factor can be used: Hg used per metric ton caustic produced = [g Hg/metric ton NaOH] = [g Hg/metric ton Cl_2.)/**1.128];** based on European Commission, 2001b, p.7**).**

b) Default mercury output distribution factors

812. The appropriate distribution factors to use for calculating releases will vary depending on the control devices present, pollution prevention techniques, and specific management practices used. Site specific data and information are preferred. All relevant information available for the plant under evaluation should be used to determine the most appropriate distribution factors. It should be noted that mercury amounts "not accounted for" are often considerable, and may in some cases in fact be releases which are not otherwise quantified. The question of whether such amounts are actually recycled or released on a specific site is there of paramount importance in the inventory. For this reason two optional output scenarios are presented. In the upper scenario, unaccounted mercury amounts will be reported along with recycled or otherwise treated mercury outputs. In the lower scenario, unaccounted mercury amounts are shown as if they were released through the output pathways mentioned. Due to the uncertainty and varying production conditions, this output scenario was formed as an optional choice for presentation of potential mercury outputs. The main purpose of the scenario is to signal possible releases, and does not pretend to be accurate in any way. It is up to the individual inventory development team to decide which presentation they want to use.

813. If site specific data and other significant information are not available to estimate the distribution of releases to various media for the plant, then the suggested draft default distribution factors shown below could be used to estimate releases to various media; in that case a note should however be made in the inventory report, that actual releases could very well be higher in reality.

Table 5-110 ***Preliminary*** *default distribution factors for mercury outputs from mercury cell chlor-alkali production facilities*

Phase in life cycle	**Default output distribution factors, share of Hg input**					
	Air	**Water**	**Land *1**	**Products**	**General waste**	**Sector specific treatment/ disposal/ unaccounted**
Production of chlor and NaOH/KOH with the mercury cell process *2	0.1	0.01	0.01	0.01	?	0.87
Mercury cell Cl/NaOH/KOH prod. - if unaccounted considered released *3	0.2	0.02	0.38	0.1	?	0.3

Notes: *1 Mercury releases to land may be significant, and some of the mercury not accounted for may likely actually be releases to the soil under the mercury cell facility. As these releases are generally not quantified, they must, however, be represented here as unaccounted for;

*2 Sector specific mercury outputs may be on-site or off-site mercury recycling or dumping. On-site or off-site storage or dumping should be considered direct releases to land. In this scenario mercury amounts "not accounted for" are also designated here to "sector specific treat ment/disposal/unaccounted" to enable compatibility with other source categories in the overall reporting of the inventory results; it should be noted that mercury amounts "not accounted for" are often considerable, and may in some cases in fact be releases which are not otherwise quantified. The question of whether such amounts are actually recycled or re leased is therefore of paramount importance in the inventory.

*3 In this scenario, unaccounted mercury amounts are presented as if they were released through the output pathways mentioned. Due to the uncertainty and varying production conditions, this output scenario was formed as an optional choise for presentation of potential mercury outputs. The main purpose of the scenario is to signal possible releases, and does not pretend to be accurate in any way. It is up to the individual inventory development team to decide which presentation they want to use.

c) Links to other mercury sources estimation

814. No links suggested.

5.4.1.6 Source specific main data

815. The most important source specific data would in this case be:

- Actual data on amount of mercury used per year at facility. This could be obtained by records on how much mercury is purchased and/or input into process for the year;
- Data on the amount of chlorine and/or caustic soda produced per year at facility (metric tons Cl_2 per year);
- Information on types of control equipment used and the extent of pollution prevention practices;
- Measured data on emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions);
- Actual emissions stack test data, measurements of g mercury released per metric tons of chlorine produced for various release points (hydrogen stream, end box vent, cell room vent, etc.).

816. See also advice on data gathering in section 4.4.5.

5.4.1.7 Summary of general approach to estimate releases

817. The input factors described above along with the distribution factors can be used to estimate the releases of mercury to each of the media (air, water, land, wastes, products, and sector specific treatment/disposal/unaccounted for) and total releases. For example, the estimated average total releases (to all media/pathways) from a facility in the USA can be estimated by multiplying the average activity rate (i.e., 121,615 metric tons Cl_2) by the low end input factor (25 g Hg/metric ton Cl_2). This yields an average estimate of total mercury releases of 3 metric tons of Hg per year for the “low end" releases to all pathways (including unaccounted losses). However, estimating accurate total releases for actual individual plants in the USA and other countries requires knowledge about the activity rate for the specific facility and, even more importantly, a representative input factor (in g Hg per metric ton Cl produced). Moreover, estimating the releases to each media is an additional challenge because of the variability and uncertainty about the distribution of the releases among the various possible pathways (air, sector specific wastes, water, land, products and internal losses).

818. When mercury release data and/or estimates are available they are often reported in g Hg/metric tons Cl_2. Subsequently, to estimate annual mercury releases (for the entire plant), the g Hg/metric tons Cl_2 is multiplied by the total metric tons chlorine produced per year; according to the following equation:

$$\text{g Hg/metric tons } Cl_2 \quad * \quad \text{metric tons } Cl_2\text{/year} \quad = \quad \text{g mercury released per year.}$$

Then, application of output distribution factors could be used to estimate releases to each media.

5.4.2 VCM (vinyl-chloride-monomer) production with mercury-dichloride ($HgCl_2$) as catalyst

5.4.2.1 Sub-category description

819. Two processes are used to manufacture vinyl chloride: the acetylene process uses mercuric chloride on carbon pellets as a catalyst, and the other is based on the oxychlorination of ethylene (without mercury use). One facility in the USA used the mercuric chloride process in 1997 (US EPA, 1997a) and worldwide around 100 facilities are using this technology (Chemical and Engineering News, 2010). The number has been increasing in for example China, where the availability of coal as feedstock favours the use of this technology. And the mercury consumption for this application is deemed considerable. China has however issued a strategy to reduce mercury releases from the sector. No information was found concerning specific control measures for mercury emissions from the production of vinyl chloride, most of the mercury is however deemed deposited with used mercury catalysts.

820. In the Russian Federation, four enterprises use mercury-dichloride. Their total input and out balance is presented below.

5.4.2.2 Main factors determining mercury releases and mercury outputs

Table 5-111 Main releases and receiving media from VCM production with mercury dichloride as catalyst

Phase of life-cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
VCM production	x	x				**X**

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

5.4.2.3 Discussion of mercury inputs and releases

Table 5-112 Overview of activity rate data and mercury input factor types needed for VCM production with mercury-dichloride as catalyst

Activity rate data needed	Mercury input factor
Annual production of VCM	Consumption of mercury (in catalyst) per unit of VCM produced

821. Lassen *et al*. (2004) estimated the total mass balance of VCM production with mercury catalysts in 2002 in the Russian Federation. A summary of the data is presented in Table 5-113.

Table 5-113 Estimated mass balance of VCM production with mercury catalysts in 2002 in the Russian Federation (Lassen et al.*, 2004)*

Inputs	
Annual Hg consumption with catalyst, metric tons/year	16

Annual VCM production, metric tons/year	130,000
Calculated g Hg input per metric ton of VCM produced, average, rounded	100-140
Output distribution	**Share**
Spent catalyst for external recycling	0.62
Low grade HCl acid sold	0.37
Direct releases to air	0.003
Direct releases to waste water	0.003

822. An OSPAR Convention decision in 1985 (Decision 85/1) defined recommended thresholds for mercury releases to the aquatic environment from VCM production with mercury catalysts at 0.05 mg Hg/l effluent, and 0.1 g Hg/metric ton VCM production capacity. These values may perhaps indicate the order of magnitude of mercury releases to water from this sector at about 1985 in the West European situation, and they correspond to the 2002 level presented for Russian VCM production above.

5.4.2.4 Input factors and output distribution factors

823. Based on the information presented above from Russia on inputs and outputs, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that these default factors are based on a limited data base, and as such, they should be considered preliminary and subject to revisions.

824. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

a) Default mercury input factors

825. Actual data on mercury consumption with catalyst for VCM production in the specific facilities will lead to the best estimates of releases. If no information is available on the mercury concentration in the concentrates used in the extraction step, a first estimate can be formed by using the default input factors selected in Table 5-114 below (based on the Russian data set presented in this section).

*Table 5-114 **Preliminary** default input factor for mercury in catalyst to VCM production*

Material	Default input factors; g mercury used per metric ton of VCM produced;
Hg consumption in catalyst for VCM production	100 – 140

b) Default mercury output distribution factors

*Table 5-115 **Preliminary** default mercury output distribution factors suggested for VCM production with mercury catalyst *1*

Life cycle phase	Air	Water	Land *4	Products *3	General waste	Sector specific treatment/ disposal *2
Share of total mercury input to VCM production	0.02	0.02	?	0.36		0.60

Notes: *1 Based on national data for Russian Federation only; may be associated with substantial uncertainties;
*2 In Russia this is external recycling of the catalyst;
*3 In the form of low technical grade HCl acid sold for restricted purposes
*4 Releases to land from on-site storage and handling can not be ruled out.

c) Links to other mercury sources estimation

826. No links suggested.

5.4.2.5 Source specific main data

827. The most important source specific data would in this case be:

- Annual consumption of catalyst with mercury, and mercury concentration in catalyst; and
- Measured data on distribution between all output pathways, preferably based on a mass balance approach.

5.4.3 Acetaldehyde production with mercury-sulphate ($HgSO_4$) as catalyst

5.4.3.1 Sub-category description

828. Mercury-sulphate can be used in the production of acetaldehyde, although alternative, non-mercury processes are available. Earlier in the twentieth century mercury was used for acetaldehyde production in the USA and other countries. This process is no longer used in the U.S, and is probably not used any longer in many other countries. However, information has not yet been obtained (in the process of drafting this draft report) with regard to the use of mercury for producing acetaldehyde in other countries.

829. The liquid-phase oxidation of ethylene using a catalytic solution of palladium and copper chlorides was first used commercially in the USA in 1960 and more than 80% of the world production of acetaldehyde in recent years has been made by this process. The remainder is produced by the oxidation of ethanol and the hydration of acetylene. Acetaldehyde is produced by a limited number of companies over the world. The total production of acetaldehyde in the USA in 1982 amounted to 281 thousand metric tons. Total acetaldehyde production in Western Europe in 1982 was 706 thousand metric tons, and the production capacity was estimated to have been nearly 1 million metric tons. In Japan, the estimated production in 1981 was 323 thousand metric tons (Hagemeyer, 1978; IARC, 1985, as cited in WHO, 1995).

830. The potential releases of mercury from this type of facility were well illustrated in the famous mercury pollution tragedy that occurred in 1950s-1960s in Minamata Bay Japan. For 20 years, a chemical plant had been making acetaldehyde, which is used to make plastics, drugs, and perfume. As part of its normal operations, the plant dumped waste products, including large amounts of mercury, into Minamata Bay. Many people died or suffered permanent disabilities as a result of this pollution. In 1968, the plant stopped using mercury in its manufacturing process and stopped dumping waste into the bay. Today, the plant produces liquid crystals, preservatives, fertilizers, and other chemical products using environmentally safe technology.

831. Another incident occurred in Kazakhstan, where release of mercury from an acetaldehyde plant in the Karaganda region of central Kazakhstan has resulted in serious contamination of the surrounding region and in particular the River Nura (reference: Management of Mercury Pollution of the River Nura, research at University of Southampton, United Kingdom, available at: http://www.soton.ac.uk/~env/research/pollution/).

832. If no other data are available, the default factors presented for VCM production can be used as a signal value for acetaldehyde as well. This mercury use may however have ceased globally today.

5.4.4 Other production of chemicals and polymers with mercury compounds as catalysts

5.4.4.1 Sub-category description

833. Vinyl acetate can be produced using mercury salts as a catalyst (reference: ATSDR, Toxicological Profile for vinyl acetate). The mercuric process for this application is however not believed to be in use during recent decades.

834. Lassen *et al.* (2004) report that in the Russian Federation mercury sulphate (II) has been used as catalyst in production of the cube (1-amino anthrachion) colours (/pigments), with an annual consumption of several metric tons of mercury with catalyst until 2000.

5.4.4.2 Examples of mercury in releases and wastes/residues

835. An OSPAR Convention decision in 1985 (Decision 85/1) defined recommended thresholds for mercury releases to the aquatic environment from selected chemical industry activities involving the handling of mercury. The thresholds are summarised in Table 5-116. These values may perhaps indicate the order of magnitude of mercury releases to water from these mercury applications at about 1985 in the West European situation. Note that VCM production is described in section 5.4.2 above; it is only mentioned here for comparison.

Table 5-116 OSPAR recommendations for threshold values for aquatic releases of mercury from selected chemical production (www.ospar.org, 2004)

Activity	**Threshold values for mercury releases**
VCM production with Hg catalysts	0.05 mg Hg/l effluent; 0.1 g Hg/ metric tons VCM production capacity
Other chemical production using Hg catalysts	0.05 mg Hg/l effluent; 5 g Hg/kg Hg used
Production of Hg catalysts for VCM synthesis	0.05 mg Hg/l effluent; 0.7 g Hg/kg Hg processed
Manufacture of other organic and inorganic Hg compounds	0.05 mg Hg/l effluent; 0.05 g Hg/kg Hg processed

5.4.5 Fire gilding (gold plating)

5.4.5.1 Sub-category description

836. Items of silver and copper alloys can be gold plated using a fire gilding technique where the gold is applied to the item in the form of a gold-mercury amalgam. The items may be statues, jewellery, figurines and even large temple roofs.

837. Fire gilding was the dominant gilding technique in China from 300 B.C., in Europe from 200 A.D. and in Japan from 700 A.D. until the invention of electroplating in the 19th century (Anheuser, 1997, Giumlia-Mair et al., 2014). Today, fire gilding in most counties is mainly applied only as part of restoration work on antique artwork or by reproduction of such artwork. In Nepal and possibly other counties, however, the traditional technique is still applied to a wider extent.

838. The first step in the process is to make a paste of amalgam by mixing fine-cut gold leaves with mercury. The two metals are put into a stone mortar and ground together. Glass may be added in order to grind down the gold shavings. The mixture is diluted from time to time with some water so the amalgam paste on the rim of the mortar is washed down; excess water is soaked up with a sponge (Furger, 2017). As practiced in Europe, the grinding is done underwater in order to reduce the danger

of exposure to mercury fumes (Brepohl et al., 2001). The grinding process when undertaken manually takes four hours or more (Furger, 2017).

839. According to Brepohl et al. (2001) the process works with a range of gold to mercury ratios. The gold to mercury ratio given in ancient sources in Europe, still applied today, are 1:8 (Brepohl et al., 2001). From Japan it is reported that the ancient gold plating techniques also applied a gold to gold to mercury ratio of 1:5 (Saito, 2022). From Nepal, Joshi et al. (2022) and Furger (2017) report on gold to mercury ratios in the range og 1:4 - 1:5 by weight while the Minamata Initial Assessment indicate an average ratio of 1:15 (MFE, 2017). Devkota (2022) report that the ratio varies from 1:6 to 1:20, depending on the quality of gold.

840. After mixing, the gold amalgam is coated onto the freshly cleaned item by an iron rod or brush. The metal surface coated with the amalgam is heated in a flame of a gas burner until (most of) the mercury has evaporated. In Nepal, the mercury is vaporised over an open gas flame and released into the atmosphere (Furger, 2017, MFE, 2017). From Europe it is reported that the evaporation nowadays takes place in a fume hood (Brepohl et al., 2001).

841. Good-quality gilding requires several layers of gold to achieve a perfect surface. Two or three coats are usual for the technique used in Nepal (Furger, 2017).

842. According to Brepohl et al. (2001) it is normal for some of the mercury to remain on the item permanently bound in the gold, but if more than 5-15% remains, the result is a pale colour. To avoid this the amalgam is heated further, but care must be taken not to go so far that the gold fuses into the surface where it will make an alloy with the silver of the item.

843. After cooling, the entire surface of the item is scratch-brushed by an alkaline soapy solution and cleaned with a "burnishing" stone.

844. The process applied in Japan today in one workshop for the restoration and reproduction of decorative metal details in the field of Cultural Heritage is apparently different. According to Giumlia-Mair et al. (2014), the items to be gilded are made from unalloyed copper. After polishing the item, mercury and nitric acid are applied, and finally three to five gold foils are wrapped around the piece. In this way, the three metals - copper, mercury and gold - form an amalgam. The object is heated in a brazier over 352°C to drive off the mercury in the form of vapour.

845. Another process designated "cold mercury gilding" has been reported to be used in the past to some extent. This process involves the application of mercury on the surface of the item to be gilded, with the formation of a copper-mercury amalgam. Gold leaves are applied on the amalgam and the object is left at room temperature until the mercury has evaporated and the gold leaf is firmly bonded to the surface (Giumlia-Mair, 2020). The process worked on unalloyed copper but not on bronze or other copper-based alloys. No examples of application of this process today have been identified.

5.4.5.2 Main factors determining mercury releases and mercury outputs

Table 5-117 Main releases and receiving media during the life-cycle of fire gilded items

Phase of life cycle	**Air**	**Water**	**Land**	**Products**	**General waste**	**Sector specific treatment/ disposal**
Production ***1**	**X**	x	x	x		
Use					x	
Disposal						x

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

846. Releases mainly take place during production of the fire-gilded products, with releases to the air as the main release pathway. A small part of the mercury is by the production released to waste and soil while a minor part remains amalgamated in the surface film of the products.

847. According to the mercury inventory in Nepal (MFE, 2017) it has been estimated that about 95% of the used mercury is released into air while blowing the items with a hot flame to remove the mercury, 3% of Hg may be released to water used to wash the items after the gilding process, whereas 2% may be released to land in the immediate vicinity of gold plating activities.

848. However, the available information indicates that some of the mercury remains on the item. According to Joshi et al. (2022) with reference to the literature, detection of mercury in the gold is a characteristic of fire-gilding, and a mercury content in the range of 8 – 25% is possible in the fire-gilded films. The contents depend on the sintering conditions by the manufacture

849. A recent study of the gold thin films deposited by the fire-gilding method applied in Nepal have determined the mercury content of newly formed surface film in the range of 5.5 - 6.7% Hg by weight (Joshi et al., 2022). The ratio of mercury to gold by weight is about 0.1. If the gold to mercury ratio in the amalgam used for the gilding has been 1:4 -1:5 (Joshi et al., 2022) and the gold to mercury ratio in the final film is 1:0.1, it can be estimated that 2-2.5 % of the applied mercury remains in the film.

850. Furger (2017) reports on analyses of mercury content of surfaces of newly gilded products from Nepal. The gold to mercury ratios in the surface layers are higher than the ratios reported by Joshi et al., 2022. For three products the following gold to mercury concentrations were measured at the surface: 3.5-19.5 % Au : 15.8 - 26.8 % Hg; 17.2 % Au : 11.4 % Hg; 8.9 % - 4.6 % Hg. If a gold to mercury ratio of 1:5 in the applied amalgam is assumed, then approximately 10% of the mercury would remain on the item. According to Brepohl et al. (2001) it is normal for 5-15% of the mercury to remain behind permanently bound in the gold, and if more than this remains, the result is a pale colour.

851. The analyses of mercury on the items concern the very surface of the items and not the entire surface layer which may explain the significant differences in the results.

852. On the basis of the available information is will initially be assumed that on average 10% of the mercury remains in the items.

Use and disposal

853. Limited information is available on the further fate of mercury in the products. Furger (2017) notes that newly gilded objects in Nepal have mercury levels above 10% in the surface layer, a more that 40-years old buddha figure had a concentration of 4.6%, whereas antique Himalayan bronzes with traces of fire gilding showed levels of 0.2 - 0.5%. The author notes that also the gold content of the objects declines. Singh and Singh (2017) analysed a gilded sample from a 17th century gilded window in Nepal. The Mercury content of the cleaned sample was determined by EDS to be 1.6% (w/w) whereas the content of the sample before cleaning was 0.7%. A study of plating and surface treatment of ancient metalwork from Europe, Egypt and Japan notes that if amalgam gilding was employed some mercury can always be detected on the objects and the gilding layer (Giumlia-Mair, 2020). In one example 5-12% of mercury was found in a silver foil with traces of gilding. This may illustrate that the mercury to some extent form an amalgam with the underlaying layer as also described for the technique used in Japan. The residual mercury content of mercury gilded objects can be between 3% and 25% in the gold layer (Giumlia-Mair, 2020). It is not reported to what extent the total mercury and gold content of the surface layer had declined.

854. No data are available on the releases during use of the gilded products, but it will here be assumed that the main release pathway would be releases as dust by wear and tear which ultimately ends up in soil and general waste. It cannot be excluded that a small part of the mercury is released to air over time (may be hundreds of years), but no data on mercury releases from products have been

available. Mercury is in general tightly bound in amalgams. The product is assumed ultimately to be disposed of for recycling of the materials, but the products may likely be in use for centuries.

5.4.5.3 Discussion of mercury inputs

Table 5-118 Overview of activity rate data and mercury input factor types needed to estimate releases from fire gilded items

Life-cycle phase	Activity rate data needed	Mercury input factor
Production	Total mercury consumption for fire gilding ***1**	Kg of mercury released per kg of mercury used for production
Use	Total number of fire gilded products consumed per year, by type	g mercury per fire gilded products consumed by type
Disposal	Total number of fire gilded products consumed per year, by type	g mercury per fire gilded products consumed by type

Notes: *1 If not available the total amount of mercury may be estimated by use of default factors for mercury per product of each type.

Production

855. As described above, the gold to mercury ratio varies with ratios in the range of 1:4 to 1:20. Calculating the mercury input on the basis of the gold input is thus rather uncertain. However, if the gold consumption is known (due to its high value) but not the mercury consumption, the mercury consumption can be roughly estimated based on the mentioned range.

856. The approach applied in Nepal for estimating the total mercury consumption in the country for this application area has been to collect information on the average mercury input for various sizes of statues and then multiplied with the number of statues of the different sizes manufactured in the reference year (MFE, 2017). The estimated mercury input per item varied from 22 to 217 g, depending on size and other factors. The total weight of the items was estimated at 1,255 tonnes and the total mercury consumption at 12.8 tonnes. As an average for the types of statues produced in Nepal, a total of approximately 1 kg of mercury was used for 1 tonne of items gilded. For items such as juwelleries, for which the surface to weight ratio may be higher, higher input factors could be expected.

857. According to Devkota (personal communication), as applied in Nepal, 10 gram of gold on an average normally covers 0.4 m^2 of the surface. The mercury consumption per m^2 would then depend on the applied gold to mercury ratio, but it would be in the range of 100 to 400 g of mercury per m^2.

Use and disposal

858. As discussed above, it is initially assumed that 10% of the applied mercury remains on the items. Based on the data from Nepal, it can be estimated that on average 1 tonne of items contain 0.1 kg mercury and the items would contain 10 to 40 g of mercury per m^2.

5.4.5.4 Input factors and output distribution factors

859. Based on the so far compiled examples given above, the following preliminary default input and output distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows.

a) Default mercury input factors

860. Actual data on mercury used to produce fire gilded products will lead to the best estimates of releases.

861. If no other indications are available on the total mercury consumption for fire gilding are available, a first estimate can be formed by using the default input factors selected in Table 5-150 below. Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low-end default factors have been set to indicate a low-end estimate for the mercury input to the source category (but not the absolute minimum), and the high-end factor is expected to result in a high-end estimate.

Table 5-119 ***Preliminary*** *default input factors for fire gilded items*

Material	Default input factors; g Hg/metric ton of fire gilded products; (low end - high end)
Manufacture of fire gilded products*1	200 - 2,000 (1,000)
Use and disposal of fire gilded objects	20 - 200 (100)

Note *1: Alternatively, an input factor for production could be 100 – 400 (250) g of mercury per m2 of surface gilded.

b) Default mercury output distribution factors

862. The default mercury output distribution factors for the fire gilding process are based on the Nepal MIA (MFE, 2019), adjusted for newer information on the percentage of mercury remaining in the final products.

Table 5-120 ***Preliminary*** *default mercury output distribution factors for fire gilding*

Phase in life-cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal*1
Fire gilding of products (no fume collection)	0.85	0.03	0.02	0.10		
During use and disposal of fire gilded products			0.2		0.3	0.5

Notes: *1: The dominant sector-specific treatment may be recycling due to the metals content (incl. gold).

c) Links to other mercury sources estimation

863. No links suggested.

5.4.5.5 Source specific main data

864. The most important source specific data would in this case be:

- Mercury consumption per item type.
- Number of fire gilded items produced and used annually.

5.5 Consumer products with intentional use of mercury

Table 5-121 Consumer products with intentional use of mercury: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Chapter	Sub-category	Air	Water	Land	Product	Waste/ residue	Main inventory approach
5.5.1	Thermometers with mercury	X	X	X	X	X	OW
5.5.2	Electrical and electronic switches, contacts and relays with mercury	X	x	X	X	X	OW
5.5.3	Light sources with mercury	X	x	X	X	X	OW
5.5.4	Batteries containing mercury	X	x	X	X	X	OW
5.5.5	Polyurethane with mercury catalyst	X	x	x	X	X	OW
5.5.6	Biocides and pesticides	X	X	X	X	X	OW
5.5.7	Paints	X	x	x	X	x	OW
5.5.8	Pharmaceuticals for human and veterinary uses	X	x	x	x	X	OW
5.5.9	Cosmetics and related products		X		X	x	OW

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

5.5.1 Thermometers with mercury

5.5.1.1 Sub-category description

865. Mercury thermometers have traditionally been used for most medium temperature range measurements. Today they are increasingly substituted by electronic and other thermometer types, but the degree of substitution probably varies among countries. Several European countries have already banned the use of thermometers and other products containing mercury, e.g. Sweden, Denmark, the Netherlands, and France. In the United States, voluntary efforts are underway jointly with appropriate industry and associations to reduce mercury in thermometers through mercury free substitutes. Several USA States have banned the use of mercury fever thermometers, and most major retailers no longer sell them (UNEP, 2002).

866. Major remaining uses may be medical thermometers (body temperature in hospitals, households, etc.), ambient air temperature thermometers, in chemical laboratories, and in controls of some machines (large diesel engines) and industrial equipment. Mercury thermometers may contain between about 0.6 and several 100 grams/unit, depending on the use (COWI, 2002 and US EPA, 1997a).

867. In the production of glass thermometers, tubes are generally filled with mercury in an isolated room. A typical mercury filling process is conducted inside a bell jar. Each batch of tubes is set with open ends down into a pan and the pan set under the bell jar, which is lowered and sealed. Mercury is allowed to flow into the pan from either an enclosed mercury addition system or a manually filled reservoir. A vacuum system is used to pull the mercury into the tubes. After filling, the pan of tubes is manually removed from the bell jar. Excess mercury in the bottom of the pan is purified and transferred back to the mercury addition system or filling reservoir. No specific information on the release of mercury from this step was identified in the reference; however, some mercury vapour may possibly be lost to the atmosphere during this process. Excess mercury in the tube stems is forced out the open ends by heating the bulb ends of the tubes in a hot water or oil bath. The tubes are cut to a length

just above the mercury column, and the ends of the tubes are sealed. These operations are performed manually at various work stations (Reisdorf and D'Orlando, 1984 and US EPA, 1984, as cited in US EPA, 1997a).

5.5.1.2 Main factors determining mercury releases and mercury outputs

Table 5-122 Main releases and receiving media during the life-cycle of thermometers with mercury

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Production	**X**	**X**	x	**X**		x
Use	**X**	**X**	x			
Disposal	**X**		**X**		**X**	x

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

868. Releases may take place:

1) From production of mercury thermometers (to air, water and soil) depending on how closed manufacturing systems are, and on the handling and workplace procedures in the individual production units;
2) By breakage or loss of thermometers (to air, water, soil) during use; and
3) During disposal of the thermometers after their use (directly to soil or landfill and subsequently to water and air), closely depending on types and efficiency of employed waste collection and handling procedures.

869. In some countries parts of the used mercury thermometers are collected for safe handling of the mercury and possibly recycling.

i) Production

870. Based on an analysis by Barr (2001), it seems that the portion of mercury input that is released during production in the USA is likely to be very small (Barr, 2001). Vapour emissions from mercury purification and transfer are typically controlled by containment procedures, local exhaust ventilation, temperature reduction to reduce the vapour pressure, dilution ventilation, or isolation of the operation from other work areas. The tube bore size also can be modified to reduce the use of mercury. The major source of mercury emissions in the production of thermometers may be in the mercury filling step (US EPA, 1997a).

871. Nonetheless, mercury emissions can occur from several sources during the production of thermometers. Many of the procedures used in thermometer production are performed manually, and as a result, emissions from these procedures are more difficult to control. The most significant potential sources of emissions are mercury purification and transfer, mercury filling, and the heating out (burning-off) process. Additional emissions may occur due to mercury spills, broken thermometers, and other accidents that may occur during the production process.

ii) Use

872. Since thermometers are sealed, releases of mercury do not occur during use of thermometers unless the thermometer breaks or cracks. Thermometers often break during use, as indicated by the percentage of breakage estimated later in this chapter. This breakage can lead to elevated mercury ambient air levels in residences, resulting in risks to vulnerable populations such as small children (Carpi and Chen, 2001). Once a thermometer breaks, mercury is released to various media, including air (as

vapours), land and waste water. The broken thermometers may as well be disposed of with solid waste, but in this case it is here regarded as disposal (see below). The extent of releases to each pathway depends on clean-up procedures and other factors.

iii) Disposal

873. Some thermometers containing mercury may be recycled and the mercury recovered for future use. However, a large percent are disposed of in municipal solid waste, medical wastes, hazardous waste, or possibly other types of waste disposal methods (burn barrels, informal dumping, wastewater, etc.) (Barr, 2001). The extent of each of these disposal methods probably varies considerably across countries. In some western countries, the amount being collected separately and recycled has increased over the past several years.

5.5.1.3 Discussion of mercury inputs

Table 5-123 Overview of activity rate data and mercury input factor types needed to estimate releases from thermometers with mercury

Life-cycle phase	Activity rate data needed	Mercury input factor
Production	Total mercury consumption for thermometer production ***1**	Kg of mercury released per kg of mercury used for production, or per kg of mercury in produced thermometers
Use	Number of mercury thermometers consumed per year, by type and sector	g mercury per thermometer supplied, by type and sector
Disposal	Number of mercury thermometers consumed per year, by type and sector	g mercury per thermometer supplied, by type and sector

Notes: *1 If not available the total amount of mercury may be estimated by use of default factors for mercury per thermometer of each type.

i) Production

874. In most countries thermometers are produced only by a few manufactures of thermometers, if any. The amount of mercury used for the production, the number of thermometers produced and the actual releases from the production of thermometers should preferably be obtained by direct contact with the manufactures, if possible. Releases from the production may in some cases be available from national environmental statistics.

875. In case specific information cannot be obtained, the number of thermometers produced per year may be available from national statistics, and the amount of mercury used for the production may be estimated using default factors for mercury per thermometer. In case specific information on production volume exists, but release estimates are not available, a first estimate may be obtained using default distribution factors. See examples of mercury content per unit and distribution factors below.

ii) Use

876. Mercury releases by breakage and loss during use of thermometers can be estimated from the national consumption of mercury with thermometers and the estimated fraction of the used thermometers that break or are lost during use. The number of mercury thermometers in use reflects mercury content and consumption number from earlier years (life-times of a few to many years, depending on type and use). If no historical data are available, input numbers from current consumption combined with expert judgments of supply trends can be used for a first approximation.

877. Consumption numbers of thermometers may be obtained by direct contact with the main suppliers (including manufactures) or from national trade statistics. Preferably the consumption of thermometers should be broken down by the sectors: hospital sector, households, and

industry/laboratories. A breakdown by sectors is most probably not possible on the basis of national trade statistics only, but requires that the necessary information can be obtained from suppliers.

iii) Disposal

878. Mercury input to disposal is the mercury content in the thermometers as supplied, multiplied by the national consumption numbers for the same thermometers. Note that mercury disposal with thermometers reflects mercury content from earlier years (life-times of a few to many years, depending on type and use). This is important as mercury concentrations in thermometers may have decreased over time in many countries. If no historical data are available, input numbers from current consumption combined with expert judgments of supply trends can be used for a first approximation. Preferably the consumption of thermometers should be broken down by the sectors: hospital sector, households, and industry/laboratories as the disposal system for the three sectors are often different.

879. Examples of mercury content by thermometer type are presented in Table 5-124. Medical thermometers contain today from 0.25 - 1.85 g mercury per thermometer depending on type, country and region. There is a trend in the direction of using smaller amounts of mercury per thermometer and thermometers disposed of may contain more mercury than new thermometers. Thermometers for ambient temperature measurement in general contain slightly more mercury, ranging from 2 to 5 g mercury. A large number of different glass thermometers are used in laboratories, industry, and for special applications and the reported mercury content of these thermometers range from 0.3 to 48 g per thermometer.

Table 5-124 Examples of mercury content in thermometers by type and region (g mercury per unit)

Thermometer type	Mercury content (g Hg/item)	Country/region for data	Remarks
Medical thermometers	0.5-1.5	European Union	Floyd *et al.*, 2002
	2	France	AGHTM, 2000
	1.85	Russia	Yanin, 2004
	0.61	USA	US EPA, 1992
	0.7	Canada	Environment Canada, 2003a
	0.25	Denmark	Skårup *et al.*, 2003
Household thermometers	0.5-2.25	European Union	Floyd *et al.*, 2002 The use is not further specified
Ambient air temperature thermometer	2-5	Russia	Yanin, 2004
	2.25	USA	US EPA, 1992
	3	Canada	Environment Canada, 2003a
Industrial and special application thermometers	10	European Union	Floyd *et al.*, 2002
	3.9-7.4	Russia	Yanin, 2004
	5-200	Denmark	Maag *et al.*, 1996; Control of large diesel engines in ships etc.
Laboratory thermometers	1.4-48	Russia	Yanin, 2004
Thermometers for testing petroleum products	0.3-2.2	Russia	Yanin, 2004

5.5.1.4 Examples of mercury in releases and wastes/residues

i) Production

880. Mercury emission data for thermometer production in the USA appear to be very limited. One 1973 report by US EPA presents an atmospheric emission factor for overall instrument manufacture of 9 kg of mercury emitted to the air for each metric ton of mercury used (9 kg lost/metric ton input). This emission factor should be used with extreme caution, however, as it was based on survey responses gathered in the 1960's, not on actual test data, and the emissions factor may not be applicable to thermometer production. In addition, instrument production and the mercury control methods used in instrument production have likely changed considerably since the time of the surveys (US EPA, 1997a).

881. Unilever reports that over an 18 year operation period of their thermometer factory in India, less than 1% (10 kg/metric ton mercury input; based on worst case assumptions) have been released to the atmosphere primarily through vaporization (Unilever, 2003).

882. Little data have been available regarding other releases from production. Toxics Link (2003) reports a breakage rate of 30-40% during production at instrument manufacturing facilities in India, some of which is however reported recovered by the manufacturers. Releases may occur due to mercury spills, broken thermometers, and other accidents that may occur during the production process. These releases may often not be accounted for and can only be estimated from detailed mass balances for the production of the thermometers.

ii) Use and disposal

883. The disposal routes will be different for thermometers used in hospitals, households and laboratories/industry.

884. Mercury thermometers are in general disposed of because of malfunctioning (the recorded temperature is wrong) or because they break. In some countries, e.g. in the USA and Sweden, some thermometers may be disposed of through thermometer-exchange programs where the mercury thermometers are exchanged with electronic thermometers. The breakage rate reported in different studies is very variable and depends on the actual use of the thermometers, with the highest rates for medical thermometers used in households.

885. A breakage rate of 5% was assumed in a 1992 report by US EPA (US EPA, 1992) based on a 1990 telephone survey of US thermometer manufacturers.

886. Contrary to this Barr (2001) assumes that 50% of thermometers in the USA are broken by consumers because there is little reason to discard a thermometer if it is not broken. Of the 50% of thermometers broken, Barr assumes that 20% of the mercury ends up in wastewater after people clean up the spill by washing the area, and 10% is lost to air through volatilization. The remaining mercury is distributed between municipal solid waste, infectious waste and recycling. These percentages are rough estimates by Barr, based on very limited data (Barr, 2001). Since fever thermometers are often used in clinical settings, disposal as infectious waste is included as a potential pathway for thermometers, along with breakage, municipal solid waste disposal, recycling, and wastewater (Barr, 2001). Barr (2001) estimates that 88% of fever thermometers not broken during use in Minnesota in 1996 was disposed of to municipal solid waste, while 12% was collected for recycling.

887. Skårup *et al.* (2003) does not report on the breakage rates but estimate that about 1/3 of the mercury in household medical thermometers is released to waste water by clean up of the spills from broken thermometers. The remaining part is considered roughly equally distributed between disposal to the municipal solid waste and hazardous waste in Denmark. It is estimated that 90% of the mercury in thermometers used by industry/laboratories is disposed of with hazardous waste (for recycling), whereas 5% is disposed of with municipal waste and waste water, respectively. In Denmark mercury from thermometers used in the hospital sector is reported mainly to be disposed of as chemical waste; whether the thermometers are broken or not (Skårup *et al.*, 2003).

888. Floyd *et al.* (2002) assumed that 5% of mercury-containing measuring and control equipment in the European Union break before it complete its useful lifetime. The breakage rate applies to all equipment and the rate for medical thermometers used in households may be significantly higher. It is

estimated that 10% of the mercury in the broken equipment is emitted to the atmosphere, 20% goes to the sewer, 20 % is collected for recovery and 50% is disposed of to general waste. For mercury in all measuring and control equipment in the European Union, Floyd *et al*. (2002) estimate that 15% is collected for recovery, 80% is disposed of to solid waste and 5% break during use.

889. In France about 90% of the mercury thermometer consumption is attributed to the hospital sector (AGHTM, 2000). The average life of the thermometers is estimated at 1-2 months maximum in hospitals and thermometers are reported to be very frequently broken. The authors assume that 100% of the thermometers break and the possibility of recovering the mercury is very low, because the breakage occurs in places where access is difficult. The mercury is consequently to a large extent released to waste water when the rooms are swept.

890. Thermometers collected by thermometer-exchange programs are expected go to mercury recycling facilities or hazardous waste treatment.

5.5.1.5 Input factors and output distribution factors

891. Based on the so far compiled examples given above, the following preliminary default input and output distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows.

a) Default mercury input factors

892. Actual data on mercury levels in the particular thermometers will lead to the best estimates of releases.

893. If no information is available on the mercury content in the actual thermometers used, a first estimate can be formed by using the default input factors selected in Table 5-125 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum).

894. Note that these numbers refer to mercury-filled thermometers only. When quantifying the annual supplies of thermometers, one should be aware that many non-mercury thermometers are sold (glass thermometers with alcohol or liquid metal alloys, and electronic thermometers), so specific information on the supply of mercury-filled thermometers is required.

Table 5-125 ***Preliminary*** *default mercury input factors, by thermometer type*

Thermometer type	**Mercury content (g Hg/item)**
Medical thermometers	0.5-1.5
Ambient air temperature thermometer	2-5
Industrial and special application thermometers (e.g. marine engine control)	5-200
Miscellaneous glass thermometers with Hg, incl. for laboratories	1-40

b) Default mercury output distribution factors

895. The output factor to air from production was based on the Unilever data described above. Mercury releases to wastes and other pathways are not known. The default output distribution factors for production pre-entered in the IL2 spreadsheet were based on limited data available for thermometers and batteries, assuming some similarities in mercury handling, etc.

896. For the disposal, outputs are extremely dependent on the actual waste management practices in each of the sectors where mercury thermometers are used, and the default factor given below are simplifications meant to raise the signal that substantial mercury outputs may follow each of the noted pathways. Quantifications of the actual waste streams in each of the sectors in the country will give a more relevant picture of the mercury outputs from this products group. If no such specific quantitative data are available, the distribution factors given in the table below can be used.

897. Note that the table only distributes outputs on direct releases to the environment and the two waste categories mentioned. The final destiny of mercury in wastes depends highly on the national/regional waste treatment scenario and the emission reduction designs involved. See descriptions of these issues in the sections covering general waste incineration (section 5.8) and landfills/deposition (section 5.9).

898. Note also that in the default mercury output distribution factors mentioned here, informal dumping or incineration of waste is quantified as direct releases to air, land and water, as relevant. Beware of double-counting, if estimates of mercury releases are also made separately for informal dumping or incineration of waste.

Table 5-126 ***Preliminary*** *default mercury output distribution factors for use and disposal of thermometers*

Phase in life cycle	**Default output distribution factors, share of Hg input**				
	Air	**Water**	**Land**	**General waste**	**Sector specific treatment/ disposal *1**
Production *3	0.01	?	0.01	?	?
During use and disposal (actual waste management status in country): *2					
No or very limited separate thermometer collection. All or most general waste is collected and handled in a publicly controlled manner	0.1	0.3		0.6	
No or very limited separate thermometer collection. Missing or informal collection and handling of general waste is widespread	0.2	0.3	0.2	0.3	
Separate thermometer collection with high collection rates. All or most general waste is collected and handled in a publicly controlled manner	0.1	0.3		0.3	0.3

Notes: *1 Mercury recycling or special deposition, for example secured disposal in old mines;

*2 Mercury inputs to disposal are the amounts of mercury in the thermometer types, combined with disposed amounts of the respective thermometer types. If annual supply data for a few years earlier (for the same thermometer types) are available, they can be used as approximations for disposed amounts;

*3 Outputs in share of mercury inputs to production in the country. If mercury amounts supplied to production can not be obtained, an approximation can be the amount of mercury in the produced products.

c) Links to other mercury sources estimation

899. The estimated outputs to separately collected waste and municipal solid waste from this section contribute to the mercury input to landfills/deposits (section 5.9) and waste incineration (section 5.8).

900. The estimated outputs for recycling from this section contributes to the mercury input to mercury recycling (section 5.7.1).

5.5.1.6 Source specific main data

901. The most important source specific data would in this case be:

- Domestic production numbers for mercury-containing thermometers;
- Consumption of mercury-containing thermometers for the hospital sector, households and laboratories/industry, respectively; and
- Setup and efficiency of waste management systems in each of the sectors where mercury thermometers are used.

902. With regard to domestic production, the mercury consumption and production output may be confidential information. Production volumes may be obtained from national production statistics but most probably not broken down by thermometer types.

903. Consumption of mercury-containing thermometers may be available from national trade statistics, but most probably not broken down by thermometers type and sector. Information on breakdown on types must then be obtained from suppliers.

904. See also advise on data gathering in section 4.4.5.

5.5.2 Electrical switches and relays with mercury

5.5.2.1 Sub-category description

905. Mercury has been used (and continues to be used) in a variety of electrical switches and relays. Data from the USA indicate that mercury consumption remains significant for this product group (USA, 2002). In some countries mercury in electrical components have been under substitution during the last two decades and non-mercury substitutes are being used for most or all of these applications in some countries today. However, the status and extent of substitution probably varies considerably between countries. Moreover, regardless of status of substitution, mercury switches and relays will likely be present in the wastes for years to come due to very long service life of these items. This sub-category is a very diverse product group both in terms of differences in applications, mercury content and life spans for the electrical components and it may take a substantial effort to estimate mercury releases the sub-category. Recent studies in the US demonstrate there are non-mercury alternative switches/relays that are comparable or superior to the mercury products with respect to cost and functionality for virtually all applications (Galligan *et al.*, 2003, as cited by NRDC in comments to UNEP, 2005). Consequently, a growing number of States within the USA have enacted legislation prohibiting the sale of new mercury switches and relays.

906. The primary use of elemental mercury in electrical apparatus manufacturing is in tilt switches also designated "silent" switches. A mercury tilt switch is constructed by adding mercury into a glass tube containing metal wire contacts, and then sealing the tube. An out-side mechanical force or gravity activates the switch by moving the switch from a vertical to a horizontal position causing the mercury to flow from one end of the tube to the other, thus providing a conduit for a electrical current. Tilt switches have in the USA mainly been used for silent electric wall switches and electric switches for thermostats used in residential and commercial heating. Barr (2001) reports that mercury switches have been used in thermostats for more than 40 years. Mercury-free thermostats are available; however, they are reported to not last as long or work as well as mercury thermostats. Some countries do

fine without them, however. Studies in the US now indicate non-mercury thermostats are equivalent or superior to the mercury models because of improvements made to the non-mercury models (Lowell Center for Sustainable Production, 2003), (Maine DEP Order, 2003) and Maine Board of Environmental Protection, 2004). Thermostats with mercury switches were still on the market in the USA as of year 2001 (Barr, 2001) and mercury thermostats continue to be sold in the United States as of 2005, although the market is decreasing about 10%/year, and this trend will accelerate as laws in six states (and pending in others) prohibiting the sale of new mercury thermostats become effective (PSI, 2004). Heating, ventilation and air conditioning (HVAC) contractors are the primary consumers of these devices, which are probably still used widely in homes and other buildings throughout the world. In cars, tilt switches have been widely used for "convenience lights" like the ones that operate when a trunk is opened. Also, small tilt switches have been used for antilock braking systems (ABS) and active ride-control systems. In American cars produced in 1996, light switches accounted for 87% of the total 11.2 metric tons use, ABS for 12% and ride-control for 1%. (Griffith *et al*., 2001) In ABS systems mercury was mainly used in 4-wheel drive systems. New cars sold in the US do not contain mercury switches in either convenience lights or ABS systems, as of 2003. In European cars mercury has not been used since the mid 1990-ies (Skårup *et al*., 2003).

907. A specialized type of tilt switch is the "float switch". These have typically been used in sump pumps and bilge pumps to activate or deactivate the equipment. The arm of the float will be attached to a control box, which contains the mercury tilt switch. The movement of the arm turns the switches on or off. In Denmark in 1992, mercury float switches accounted for about 60% of the total mercury use in switches and relays (Skårup *et al*., 2003). The “level" switches used to set an electrical current on or off in response to mechanical movements (traditionally a glass tube with floating mercury) may be the most significant item with regard to quantities of mercury consumed. Mercury tilt switches are also found in numerous other products including chest freezer lids, telephones, theft alarms on boats, clothes washers, some blinking sport shoes, railway control lights and laptop computers.

908. Beside the use of mercury tilt switches in common thermostats, mercury is also used in two other types of thermostats. An "accustat" is a glass thermostat resembling a thermometer with two electrical connections. By the expansion of the mercury it switches on/off an electrical flow.

909. Another type is the mercury thermostat probes, also known as flame sensors or gas safety valves. The metal probe consists of a metal bulb and thin tube attached to a gas-control valve. The mercury is inside the tube and expands or contracts to open and shut the valve. They are most commonly present as part of the safety valve that prevents gas flow if the pilot light is not lit in several types of gas-fired appliances, such as water heaters, furnaces, and space heaters. Mercury thermo fuses have been used in automatic coffee makers and irons (Skårup *et al*., 2003)

910. Relays are electrically controlled switches. Larger plunger or displacement relays are used in high current lighting and heating. The mercury displacement relay uses a metallic plunger device to displace mercury. The plunger is lighter than mercury so it floats on the mercury. When the coil power is off, the mercury level is below the electrode tip and no current path exists between the insulated centre electrode and the mercury pool. When coil power is applied the plunger is drawn down into the mercury pool by the pull of the magnetic field and the plunger centres itself within the current path. Plunger relays contain up to 400 g mercury (Environment Canada, 2003b).

911. Wetted read relays are found in small circuit controls for low voltage electronic devices. A wetted reed relay consists of a glass encapsulated reed with its base immersed in a pool of mercury and the other end capable of moving between two sets of contacts (Galligan *et al*, 2003). The mercury flows up the reed by capillary action and wets the contact surface of the reed and the stationary contacts. Reed relays are primarily used in test, calibration, and measurement equipment - that is: specialist - applications where stable contact resistance over the life of the product is necessary. The mercury content of each relay is typically 1-10 mg (Skårup *et al*., 2003), and though they may be widely used the total mercury consumption with relays of electronics have been relatively small compared to the

mercury switches described above. Mercury contact relays with a switch similar to the tilt switches described above may be used, but the use seems not to be widespread.

5.5.2.2 Main factors determining mercury releases and mercury outputs

912. Similar to other products containing mercury, releases may occur:

1) From production of mercury switches and relays (to air, water and soil) depending on how well closed the manufacturing systems are, and on the workplace procedures in the individual production units;
2) By breakage or loss of switches (to air, water, soil) during use; and
3) During disposal of the products containing the switches (or the switches themselves) after their use (directly to soil or landfill and subsequently to water and air), closely dependent on types and efficiency of the waste handling procedures (COWI, 2002).

Table 5-127 Main releases and receiving media during the life-cycle of switches and relays with mercury

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Production	x	x	x	**X**		x
Use	x	x	x			
Disposal	**X**		**X**		**X**	**X**

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

i) Production

913. During the manufacture of electric switches (wall and thermostat), mercury may be emitted during welding or filling, as a result of spills or breakage, during product testing, and as a result of material transfer (US EPA, 1997a). See US EPA (1997a) for a description of the production processes for these devices.

ii) Use

914. Since the mercury is contained in a sealed glass bulb inside the device, it is not released during normal use (Environment Canada, 1999). Once a switch breaks, the mercury is released to various media, including air (as vapours), land, and waste water. The broken switches may as well be disposed of with solid waste, but in this case it is here regarded as disposal. The extent of releases to each pathway depends on clean-up procedures and other factors.

iii) Disposal

915. Due to the long life-time of the equipment and the significant decrease in the consumption in the recent years in some countries, availability of historical consumption data is crucial for determination of the amount of mercury disposed of with discarded equipment. One study in the USA estimated that 10% of switches are discarded after 10 years, 40% after 30 years and the remaining 50% after 50 years (US EPA, 1992, as cited by US EPA, 1997b). Mercury-containing tilt switches used in buildings (e.g. wall switches and switches in thermostats) usually last 30 to 50 years, and their disposal usually occur when buildings are renovated or demolished (Environment Canada, 1999). Switches and relays in electric/electronic equipment and cars are usually disposed of when the equipment or cars are discarded and the amount disposed of today reflects the consumption 15-20 years ago.

916. Floyd *et al*. (2002) , studying the consumption in the EU, note that in practice the lifetime will be determined by the life of the equipment within which the switches are contained, and estimate that in practice the lifetime is likely to be of the order 5-10 years. This likely applies only for other switches and relays than the types used in houses and cars.

917. As the consumption pattern has changed significantly in recent year in some countries, the amount of mercury disposed of with discarded products can most likely not be estimated reliably on the basis of information on today's consumption, using a steady-state assumption. However, it may sometimes be possible to estimate the number of mercury thermostats discarded annually without using historic sales data by obtaining the quantity of replacement thermostats (all kinds) sold annually (as provided by trade publications) and estimating the percentage of thermostats replaced which are mercury containing (PSI, 2004). This methodology could be used for other mercury products where replacement sales data are available.

918. Based on historical consumption data it may be possible to estimate the amount of equipment accumulated in the society (equipment still in use). The fraction of the discarded equipment collected for safe handling of the mercury will mainly be dependent on the existence and efficiency of specific collection campaigns and the general practice for treatment of waste of electric and electronic equipment. Information on the amounts collected and the estimated collection efficiency may be the best basis for estimates of total mercury in the discarded equipment. In some cases it may be useful to form rough estimates based on corresponding data from countries with similar conditions.

919. In some countries specific campaigns for collection of mercury containing switches exists e.g. "Mercury-free Colorado Campaign - Thermostat Recycling Program" (DPHE, 2003). The campaigns may significantly increase the amount of mercury collected as there is generally no strong economic incentive for recycling of mercury. Unfortunately, notwithstanding the Colorado campaign and other similar efforts elsewhere, voluntary efforts in the USA have produced very limited results thus far (PSI, 2004, as cited by NRDC in comments to UNEP, 2005). Accordingly, a growing number of States are prohibiting new sales.

920. The amount of the discarded switches that is collected for recycling will further depend on the practice and legal requirements regarding treatment of electric and electronic waste. In countries in the European Union specific requirement for removal of mercury containing components, such as switches or backlighting lamps, are to be implemented before August 2004.

921. Even in countries with separate collection, a portion of the switches and relays are disposed of with MSW and waste from scrap dealers and breakers.

922. For switches in wastes that end-up in protected landfills, part of the mercury will be released only slowly as the encapsulation is degraded, by gradual evaporation to the atmosphere, with slow leaching to waste water (or the ground water, if no membrane is used under the landfill), and perhaps ultimately in larger scale if excavation works occur (or even climatic/geological changes). See the description of landfills/deposition in section 5.9.

923. For switches in wastes that end up in waste incineration, most of the mercury will be released to the atmosphere when incinerated, while minor parts will remain in the solid incineration residues - and, if applied - in flue gas cleaning residues, and subsequently deposited in landfills or other deposits, as described in section 5.8.

924. In cases of uncollected, diffusely lost waste, or informal, un-protected waste dumps, the losses occur directly to land.

The market in 2019

925. An extensive research on selected mercury-added products was performed for the 2019 Toolkit update, with a focus on products that had been poorly investigated in Minamata Initial Assessment studies due to difficulties in national data collection. While it has been known for decades that

alternatives to all uses of mercury in switches and relays exist, the research conducted for this the 2019 Toolkit update (in 2018-2019) showed that several types of mercury-added switches and relays are still readily available from suppliers. For example: Indiamart.com (an Internet market showing Indian suppliers) lists examples of mercury wetted switches (for high currents) and tilt switches from many suppliers (for example level switches). (Indiamart.com, accessed October 2018), Newark Element 14 and Gordo Sales Inc. has available mercury displacement relays (for high currents; Newarc.com, 20018; Gordosales.com, accessed October 2018), and Comus International lists mercury tilt switches and read relays (data transfer relays; Testco-inc.com, accessed October 2018). This means that mercury switches and relays continue to be a relevant source sub-category for mercury emissions and releases.

5.5.2.3 Discussion of mercury inputs

Table 5-128 Overview of activity rate data and mercury input factor types needed to estimate releases from switches and relays with mercury

Life-cycle phase	Activity rate data needed	Mercury input factor
Production	Total mercury consumption for production or Number of switches and relays produced per year (in the country) by type	Kg of mercury released per kg of mercury used for production or per kg of mercury in produced switches
Use ***1**	Historical data on number of mercury switches consumed per year	g mercury per switch supplied, by type and sector
Disposal ***1**	Historical data on number of mercury switches consumed per year	g mercury per switch supplied, by type and sector

Notes: *1 If these data are not available, the default input factors presented below can be used; they are based on data on mercury supply per capita with this product type and operate with the activity rate of number of inhabitants in the country.

i) Production

926. In most countries the number of manufactures of mercury-containing switches and relays is probably not more than a few, if any. Information on the amount of mercury used for the production, the number of devices produced and the actual releases from the production should preferably be obtained by direct contact to the manufactures, if feasible. Releases from the production may further be available from national environmental statistics. If case specific information cannot be obtained, the number of switches produced per year may be available from national statistics and the amount of mercury used for the production may be estimated using default factors for mercury per unit. However, such statistics are probably not available in most countries. In case only information on production volume is available, a first estimate of the releases from the production may be obtained using the examples of mercury content per switch and distribution factors below.

927. In the USA in 1996, a total of 49 metric tons mercury were consumed in the production of wiring devices and switches (Sznopek and Goonan, 2000), accounting for about 13% of the total intentional consumption of mercury in the country. As reported in 2004 (Barr, 2004) the estimated annual consumption of mercury in products such as switch/relay use (including thermostats) represented 42% of product use in the US, i.e. a total of 103 short tons (app. 91 metric tons). The Interstate Mercury Education and Reduction Clearinghouse (IMERC) data base indicates switch/relay manufacturers

(including thermostats) notified this consortium of States that they used more than 69 short tons of mercury on products sold in the US in 2001 (NEWMOA, 2001).

ii) Use

928. Contrary to for example thermometers, mercury containing switches and relays usually reach the consumers as components of other equipment, and for this reason it is difficult to obtain a reliable estimate of the actual consumption of mercury with marketed products. It should be noted that this part of the assessment may be quite time consuming. Market information will most probably not be available from national trade statistics. Today consumption of mercury-containing switches may be obtained by direct contact to the main suppliers of the main products in which these devices may be present: thermostats, air conditioning equipment, submerged pumps, cars, etc. In case mercury inventories or assessments exist for neighbouring countries, information from those countries may be used if nothing else is known. By way of example of the methodology, US EPA (1992) estimated the number of thermostats purchased on the basis of the number of new homes constructed annually (US EPA, 1992, as cited in Barr, 2001). This approach may account for some of the actual consumption, but will not cover replacements sales. In any case, information is also needed on number of thermostats/switches per building and percent of thermostats/switches that contain mercury versus non-mercury types (Barr, 2001).

929. An additional difficulty in the estimation is if the use of mercury switches has ceased or decreased heavily in society. In this case current consumption data is of no use, and mercury releases by breakage during use of switches, and by disposal, must be estimated based on old supply data combined with life span estimates for the switches. The accumulated number of mercury switches in use reflects mercury content and consumption number from earlier years. Life-times may of up to 50 years for some application.

930. Another possible approach is to estimate breakage and disposal on the basis of the total amount accumulated in the society, multiplied with the estimated share of the switches in use that break or is discarded per year. The share of switches which break may be negligible, but the total amounts accumulated in society is in any case used for the estimate of the amount disposed of as discussed below.

931. The first step in estimating the amount of mercury in use is to determine whether mercury-containing switches have been used (and is still marketed) in the country. The main application areas to be checked are presented in Table 5-129. When it is confirmed that mercury-containing switches have been used (or are still marketed) for a specific application, the next step is to estimate the amount still in use.

Table 5-129 Examples of mercury content in electrical and electronic switches, contacts and relays in g mercury per kg of the particular items, per type and origin of data.

Type of electrical and electronic switch, contact or relay	**Mercury content (g Hg/item)**	**Country/ region for data**	**Remarks**
Thermostat tilt switches	3	USA	PRF, 1996; Thermostats frequently contain 2-6 tilt switches
Thermostats (accustat)	1.8 – 14.4	Russia	Yanin, 2004
	1	USA	Huber, 1997
Flame sensor	2.5	USA	Huber, 1997; Used in gas ranges
Silent wall switches	3	USA	US EPA, 1997a
	2	USA	PRF, 1996
Freezer light and washing machine switches	2	USA	Huber, 1997
Industrial switches	up to 3.600	USA	PRF, 1996
	3-6	USA	Huber, 1997
Float switches	6.8-13.6	Denmark	Skårup *et al.*, 2003 (for sewer pumps etc.)
Switch in blinking sport shoes	2	Denmark	Skårup *et al.*, 2003
Switches in automobiles	0.7-1.5	USA	Griffith *et al.*, 2001; Mercury switches used in underhood and trunk lighting. 4-wheel drive anti-lock brake systems (ABS), and ride-control systems
Switches	0.9-23	Russia	Yanin, 2004
Plunger or displacement relays	up to 400	Canada	Environment Canada, 2003b
Mercury relays in electronics	0.001-0.01	Denmark	Skårup *et al.*, 2003

iii) Disposal

932. For those applications where historical consumption data exist, the amount disposed of may be estimated assuming an average life-time for the equipment. As an example Barr estimated total disposal of mercury with thermostats in Minnesota from the consumption 20 years earlier assuming an average lifespan of 20 years for a thermostat (Barr, 2001).

933. Information on types of collected equipment and collected amounts of mercury may be obtained by contacting companies or other organizations engaged in treatment of mercury-containing waste. The information gathered may indicate which types of equipment may be disposed of in the country. The total for the country may be estimated by extrapolation of the obtained data from described locations or sectors.

934. Examples of mercury content in electrical and electronic switches and relays are presented in Table 5-129.

5.5.2.4 Examples of mercury in releases and wastes/residues

i) Production

935. Three facilities in the USA that manufacture electric switches and electric components reported emissions of about 2 kg of mercury to air for year 1994, or a total of about 6 kg from the 3 facilities (US EPA, 1997a). These facilities are not known to employ technologies to remove mercury from exhaust streams. However, measures are taken to reduce workplace exposures, including process

modification, containment, ventilated enclosure, local exhaust ventilation, temperature control, dilution ventilation, and isolation (US EPA, 1997a).

936. No mercury emission data have been identified for other manufacturers of electrical switches. In the production of either mercury buttons for wall switches or thermostat switches, the principal sources of mercury emissions occur during filling processes that are conducted in isolated rooms. The isolation rooms are vented to maintain the room at a slight negative pressure and prevent mercury contamination of adjacent work areas. In 1997, US EPA reported that no emission data or results of tests were available to develop an estimate of mercury emissions from the two processes (US EPA, 1997a). However, one report (US EPA, 1973, as cited in US EPA, 1997a), presents an emission factor for the overall electrical apparatus production process of 4 kg of mercury emitted for each metric tons of mercury used. This emission factor should be used with caution because it was based on engineering judgment and not on actual test data (US EPA, 1997a). Electrical switch production and the mercury control methods used in the industry have likely changed considerably since 1973.

ii) Use

937. Minimal releases are expected to occur during use because these switches and similar devices are typically enclosed in a sealed glass container and other casing. Compared to thermometers, for which breakage is one of the main reason for their discard, mercury switches are mainly discarded with the equipment they are incorporated into.

938. However, occasionally these devices can break during use, which will result in releases to air, and possibly to land and water. It has not been possible to identify any studies that estimate that the releases from breakage of these devices, however, mercury releases may possibly be significant for some countries. Although, for the European Union, Floyd *et al.* (2002) estimate that the breakage of switching equipment is negligible. Skårup *et al.* (2003) does not estimate any releases from breakage of switches.

iii) Disposal

939. The disposal of mercury with switches will depend on the presence of collection systems.

940. In Denmark in 2001, the major part of the mercury was collected, primarily through a take-back system for telephones (Skårup *et al*, 2003). In addition, switches were collected as part of the treatment of spent freezers and electronic equipment. About 10-30% of the total discarded mercury was disposed of to MSW (and incinerated). In total 0.9-1.7 metric tons were discarded while the current consumption was estimated at less than 0.024 metric tons/year.

941. Floyd *et al*. (2002) estimated that within the European Union 15% of the mercury in these devices is collected for recovery, 80% disposed with solid waste and 5% disposed of with steel scrap (e.g. switches in cars and refrigerators). One possible explanation to that the relatively low amounts flowing to steel scrap, is that the use of mercury switches in cars has been substituted quite early in the European Union, compared to for example the USA. The total mercury amounts disposed of within the EU was estimated to 13.5 metric ton/year in 2000, while the consumption in 2000 was 9 metric ton/year. The consumption in the mid-1990's was around 28 metric ton/year according to that study.

942. In the USA, the total reported consumption of mercury with wiring devices and switches was estimated at 49 metric tons/year for 1996, while the disposed mercury amount accounted for from this product group was 32 metric tons/year, of which the half was collected for recovery. The consumption of mercury for production of switches in the USA was quite stable within the period 1970-1995 (Sznopek and Goonan, 2000). As reported in 2004 (Barr, 2004) the estimated annual consumption of mercury in products such as switch/relay use (including thermostats) represented 42% of product use in the US, i.e. a total of 103 short tons (app. 91 metric tons).

943. Lassen et al. (2008) estimated the total consumption of mercury in switches in 2008 in the EU27+Norway+Switzerland at 0.6 metric tons. The major application area was tilt switches

accounting for more than half of the total. The study estimated the total amount of mercury accumulated in switches in society in 2008 at 125 metric tons. The total flow to waste management in 2008 was estimated at 14 metric tons; of this, 7 metric tons was recycled, 5.6 metric tons was disposed of with municipal solid waste while 1.4 metric tons was disposed off to other disposal.

944. As of 2017, most uses of mercury-added switches and relays have been restricted in the EU, and the with the Minamata Convention, most uses are restricted in Parties to the Convention, and their use may today be more limited than indicated fot he EU in 2008 above.

945. The disposal and consumption data reported above are summarized in Table 5-130, along with calculated per capita data.

Table 5-130 Reported annual mercury consumption with switches and relays in selected countries and regions, in total and per inhabitant ***1**

	Denmark, 1993	**Denmark, 2001**	**EU 27+2 2008**	**EU 15, 2000**	**EU 15, mid 1990's**	**USA, 1996**	**USA, 2004(?)**
Reported mercury consumption for switches and relays, kg/y	300	24	600	9000	28000	49000	909000
Population, millions	5.4	5.4	500	376	376	281	296
Annual mercury consumption with switches and relays in g per inhabitant	0.06	0.004	0.0012	0.02	0.07	0.17	0.31

Notes: 1* Denmark: Already in 1993, most of the mercury switches and relays sold had been substituted with mercury-free alternatives; most of the consumption was for tilt switches in sewer pumps, a use which had also ceased by 2001;

EU: The use of mercury switches in cars had been abandoned in most cars on the market already by the mid 1990s or earlier;

USA: The reported consumption of mercury for production of switches in the USA was quite stable within the period 1970-1995 (Sznopek and Goonan, 2000); since 1996, the use in cars has likely decreased. According to Barr (2004, as cited by NRDC in comments to UNEP, 2005), a later estimate for the US. consumption is 100 short tons (90.9 metric tons), using this estimate the grams/inhabitant is calculated as 0.31 g per inhabitant for the United States.

5.5.2.5 Input factors and output distribution factors

946. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows.

947. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

948. Due to lack of sufficient data, no default factors were set for the production of mercury switches and relays.

a) Default mercury input factors

949. If no other information is available enabling input estimation as described above, a first estimate can be formed by using the default input factors selected in Table 5-131 below (based on the data sets presented in this section). Because consumption varies so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum).

950. The default input factors are based on the consumption data from the developed countries and regions described above. In developing countries with substantial parts of the population with no access to electricity and thus presumably a lower prevalence of what could be broadly termed "technical installations", the prevalence of the mercury-added product types in question may also be lower, relatively to the developed countries from which the default input factors were derived. Note however, that mercury-added products are in many cases old technology, which are in the process of being substituted for by electronic solutions. In countries dominated by older technology, but with general access to electricity, the prevalence of mercury-added products may be as high as, or even higher than, in developed countries.

951. Lower access to electricity can be adjusted for by multiplying the population number used in the calculations by the electrification rate as assessed by the IEA. IEA estimated electrification rates for selected developing countries from 2009 are shown in Annex 8.4. For countries with no IEA estimates, electrification rates were estimated here, based on the IEA data for neighbouring countries, or based on other knowledge about the regions in question (see details in the annex). This approach is used in the Inventory Level 1 spreadsheet (automatically) and has been implemented as an option in the Inventory Level 2 spreadsheet as well (manually).

952. Note that Annex 8.4 also includes population data for most countries of the World.

Table 5-131 ***Preliminary*** *default input factors for mercury use in switches, contacts and relays(updated in 2022)*

	Default input factors; g mercury consumed per inhabitant per year; low end - high end (intermediate)
Mercury consumed annually with mercury switches and relays	0 - 0.25 (0.0012)

b) Default mercury output distribution factors

953. Note that in the default mercury output distribution factors mentioned here, informal dumping or incineration of waste is quantified as direct releases to air, land and water, as relevant. Beware of double-counting, if estimates of mercury releases are also made separately for informal dumping or incineration of waste.

954. If no local output distribution factors are available, the default output distribution factors pre-entered in the IL2 spreadsheet can be used. They were based on limited data available for thermometers and batteries, assuming some similarities in mercury handling, etc.

Table 5-132 ***Preliminary*** *default mercury output distribution factors for use and disposal of electrical and electronic switches, contacts and relays*

Phase in life cycle	**Default output distribution factors, share of Hg input 2***				
	Air	**Water**	**Land**	**General waste**	**Sector specific treatment/ disposal *1**
Use and disposal (depending on actual waste management status in country):					
No or very limited separate switches collection. All or most general is waste collected and handled in a publicly controlled manner ***4**	0.1		0.1	0.8	
No or very limited separate switches collection. Missing or informal collection and handling of general waste is widespread ***3**	0.3		0.4	0.3	
Separate collection with high switches collection rates. All or most general is waste collected and handled in a publicly controlled manner ***4**	0.1		0.1	0.4	0.4

Notes: *1 Separate collection of mercury-containing switches and relays which may be directed to mercury recycling or special, secure deposition;

*2 Mercury inputs to use and disposal are the amounts of mercury in the component types, combined with disposed amounts of the respective component types. If annual supply data (for the same component types) are available for an estimated component life-time earlier, they can be used as approximations for disposed amounts;

*3 The distribution between air, land and general waste here is artificial, and is meant only to raise a signal that significant mercury releases may follow these pathways in countries with widespread informal waste handling such as diffuse dumping and informal waste incineration. Such waste handling is considered here as direct releases to the environment;

*4 No data were observed on the distribution of mercury not collected separately. The distribution suggested between general waste, air and land is artificial, and is meant to signal that besides general waste, some mercury in switches used in buildings may possibly follow demolition waste which may not be lead to a secure landfill, and some mercury in switches used in freezers and cars may possibly be released through the shredding of recycled iron and steel from these products.

c) Links to other mercury sources estimation

955. The estimated mercury outputs to separately collected waste and general household waste from this sub-category **contributes** to the mercury inputs to landfills/deposits (section 5.9) and household waste incineration (section 5.8).

5.5.2.6 Source specific main data

956. The most important source specific data would in this case be:

- Domestic production of mercury-containing switches and relays;
- Actual and historical data on consumption of mercury-containing switches; and
- Setup and efficiency of waste management systems.

957. Most likely mercury-containing switches are produced in a few production plants, if any, and a point source approach to mercury release estimates is therefore recommended. Mercury consumption for domestic production and production output should be obtained by direct contact to manufactures, as production volumes most probably cannot be obtained from national production statistics.

958. If national historical data are not available, assessments/inventories of neighbouring countries (or countries in the same market region), if available, may be used for a rough estimate.

959. Se also advises on data gathering in section 4.4.5

5.5.3 Light sources with mercury

5.5.3.1 Sub-category description

960. Mercury is used in small amounts per lamp in a number of different types of discharge lamps, with fluorescent tubes and compact fluorescent lamps (CFLs) as the most common examples (COWI, 2002). Approximately 95% of the mercury-containing lamps used in the USA in the late 90ies were linear fluorescent light tubes (NESCAUM, 1998). The remainders are compact fluorescents or specialty lamps (such as metal halide, mercury vapour, high-pressure sodium, and neon lamps) which are produced for commercial or municipal use, such as street lighting (NJ MTF, 2002). Significant progress has been made by some producers to reduce the amount of mercury per lamp, with reductions of about a factor 10 achieved in newer mercury-lamps as compared to traditional types. Lamp types with high mercury content are, however, still reported to be on the market, and may be sold in large quantities as they are generally cheaper than low-mercury lamps (COWI, 2002). Non-mercury alternatives for these lamps, with similar energy saving qualities, are now available on the market in the form of LED lamps, which are available for general lighting purposes with light qualities approaching that of fluorescent lamps. Other light sources reported to contain mercury include: special lamps for photographic purposes, chemical analyses (atomic absorption spectrometry lamps), ultraviolet sterilisation, and back lights for flat-screens for computers (and likely for televisions).

961. Elemental mercury is introduced into the tube when it is manufactured, and it acts as a multi-photon source, producing ultra-violet light when an electrical current is passed through the tube. Mercury in fluorescent lamps has essentially two different chemical compositions: vapour-phase elemental mercury and divalent mercury adsorbed on the phosphor powder, the metal lamp ends, or other components. The amount of mercury required in vapour form in the discharge to energize the lamp is 50 micrograms – about 0.5 to 2.5% of the total placed in the lamp when manufactured (Dunmire *et al.,* 2003). Over time, the mercury in the tube reacts with phosphorus powder which coats the inside surface of the tube, and it loses its efficacy. Therefore, there must be enough initial elemental mercury in the lamp so that at least 50 micrograms is available in vapour form even at the end of the lamp's rated life (typically 5 years of use for linear tubes in commercial service, and about the same for CFLs in residential use). At the end of lamp life, most of the mercury is in divalent form. According to Floyd *et al*., 2002 (citing NEMA, 2000) 99% of the mercury present in lamps when disposed is embedded in the tube coating powder.

962. Historically, manufacturers added mercury in quantities sufficient to ensure an adequate supply of available mercury in the tube throughout its life span. Recent advances in the development of fluorescent tubes have allowed manufacturers to reduce the amount of mercury necessary to account for an adequate lifespan of the tube (Bleasby, 1998, as cited in Environment Canada, 1999).

5.5.3.2 Main factors determining mercury releases and mercury outputs

963. In North America (USA, Canada, and Mexico), mercury releases from improper fluorescent light tube disposal have declined substantially over the last decade as a result of recycling programs and changes in design technology (Environment Canada, 1999).

Table 5-125 Main releases and receiving media during the life-cycle of light sources with mercury

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Production	**X**	x	x	**X**		**X**
Use	x	x	x			
Disposal	**X**		**X**		**X**	**X**

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

964. Mercury emissions from fluorescent lamp manufacturing may occur during mercury handling operations and during lamp production. Handling operations that may result in mercury vapour emissions include mercury purification, mercury transfer, and parts repair. During lamp production, mercury may be emitted from the mercury injection operation and from broken lamps, spills, and waste material. (US EPA, 1997a).

965. Since the mercury is contained is a sealed glass tube, it is not considered released during normal use. No release estimates were found. Lamps may break during use, but more likely the lamps break after they have been replaced, during temporary storage before they are properly disposed of. When these lamps break, elemental mercury, liquid mercury and phosphor powder with adsorbed mercury can be released. In addition, mercury can be released from small pieces of glass and other lamp components, which are contaminated with mercury if they are not properly managed (NJ MTF, 2002).

966. The releases of mercury by disposal of the lamps depend of the disposal method. In many countries systems for collection of used mercury lamps for recycling exist. The collected lamps may be processed for recycling of the mercury-containing phosphorous powder for production of new lamps or the collected lamps may be processed for recovery of the mercury contained in powder. In some countries the collected powder may be disposed of on landfills without recovery of the mercury. During recycling, mercury may be released from the cutting/crushing of lamps or from the recovery of mercury from the powder. Lamps disposed of to landfills will to a large extent break by the disposal and the mercury vapour will be released immediately to the atmosphere. The major part of the mercury in the lamps is bound to the phosphorous powder and will only slowly be released. By incineration of lamps the majority of the mercury will evaporate and be captured by the pollution abatement controls or emitted to the atmosphere.

5.5.3.3 Discussion of mercury inputs

Table 5-133 Overview of activity rate data and mercury input factor types needed to estimate releases from light sources with mercury

Life-cycle phase	Activity rate data needed	Mercury input factor
Production	Total annual mercury consumption for lamp production. or Number of mercury lamps produced per year, by lamp type	(not relevant) or mg of mercury per lamp, by lamp type
Use	Number of mercury lamps supplied per year, by lamp type	mg of mercury per lamp, by lamp type
Disposal	Number of mercury lamps supplied per year (5-10 years ago), by lamp type	mg of mercury per lamp (5-10 years ago), by lamp type

967. The mercury content of the lamps by type is used as input factor for all life-cycle phases. Examples of mercury content in lamps are shown in Table 5-134. In general the amount of mercury in fluorescent light tubes has been reduced in the western world, and today the mercury content of fluorescent tubes (double end) there range from 3 mg to 46 per tube.

968. It has been reported by industry in the USA that the average mercury content of 4-feet lamps has been reduced from about 48 mg in 1985 to 42 mg in 1990, to 23 mg in 1994, and to 12 mg in 1999 (NEMA, as cited in NJ MTF, 2002). The majority of fluorescent lamps in service in the USA in recent years are T12 lamps (about 3.3 cm in diameter), which contain an average of 22 mg (NJ MTF, 2002). T8 lamps (about 2.2 cm diameter), which are designed to be more energy efficient, also contain less mercury (about 14 mg) (MTF, 2002). However, since 1995 the mercury content in these T12 and T8 lamps has been reduced due to the introduction of "low mercury" bulbs, with less than 10 mg mercury (NJ MTF, 2002). In Canada, the average mercury content in fluorescent lamps has fallen from 48.2 mg in 1985 to 27.0 mg in 1995, with an industry target to further reduce mercury content to 15.0 mg by 2000 (Environment Canada, 1999).

969. In the European Union the average for fluorescent tubes has been reduced from 15 mg in 1997 to 10 in 2001 (Floyd *et al*., 2002). The average content of compact fluorescent tubes is reported to be 5 mg in both 1997 and 2001.

The market in 2019

970. Since the early 2000's, much work has been done to lower the mercury contents of lamps sold to general consumers globally. Major drivers have been eco-labels and regulation in the EU and elsewhere. This is also reflected in Table 5-134 below. On the other hand, some companies have (in 2018) stated higher mercury contents than were observed earlier, for some specialty lamp types, perhaps due to the rapid move towards mercury-free LED lamps in the late 2010s and the resulting changes in the market.

i) Production

971. In 1995 in the USA, 30 tons of mercury was purchased for the manufacture of electric lighting, including fluorescent, mercury vapour, metal halide, and high-pressure sodium lamps (Plachy, 1996, as cited in US EPA, 1997a). Lamps do not contain all of the mercury purchased for the manufacture; most of the mercury not retained in the lamps is returned to mercury recyclers for purification and reuse. However, a small amount of the mercury input is loss to the environment during the production process. In 1994, 15.7 metric tons of the 27 metric tons of mercury were actually contained in the lamps (NEMA 1996, as cited in US EPA, 1997a).

972. In the European Union 5.9 tons mercury was used for production of mercury lamps, of this 4.0 tons was use for production of double end fluorescent tubes, the remaining part for production of other lamp types (Floyd *et al*., 2003).

ii) Use

973. Mercury releases by breakage of lamps before it is disposed of can be estimated from the national consumption of mercury lamps and the estimated fraction of the lamps that break before disposal. Consumption numbers of lamps may be obtained by direct contact to the main suppliers or from national trade statistics. See estimates on breakage rates below.

iii) Disposal

974. Mercury input to disposal is the mercury content in the light sources as supplied multiplied by the number of such items consumed a few years earlier (life-times of a few years, depending on type and use). This is important as mercury concentrations in the light sources may have changed in the past years in many countries. If no historical data are available, input data from current production can be used as an estimate for previous years. NJ MTF (2002) expects lamps discarded today to be about 5

years old (NJ MTF, 2002). Skårup *et al.* (2003) estimate the life span of fluorescent light sources at 8-10 years under Danish conditions.

975. Examples of mercury content in light sources by type and region (for data) are presented in Table 5-134 below.

5.5.3.4 Examples of mercury in releases and wastes/residues

i) Production

976. Based on data for 1994 in USA, a total of 27 metric tons of mercury were purchased for the manufacture of lamps at 4 facilities. About 15.7 metric tons of this mercury was contained in the product lamps. Most of the remaining mercury was returned to recyclers. One production facility reported emissions of 0.21 tons for 1994, and the total emissions in 1994 for all 4 facilities during production were estimated to be 0.4 tons mercury (US EPA, 1997a). Emissions in 1995 were probably quite similar in magnitude (about 0.4 tons).

977. No add-on controls have been identified for these production facilities. However, methods to maintain low mercury levels are employed and include containment, air ventilation, temperature control, and isolation. Mercury releases may occur during handling operations such as mercury purification, mercury transfer, and repair of various parts. During the production process, mercury may be emitted from injection operation and from broken lamps, accidental spills, and from various waste materials (US EPA, 1997a).

ii) Use

978. Floyd *et al.* (2002) estimate that 5% of the lamps break before they are disposed of. Based on the information that 99% of the mercury present in lamps is embedded in the tube coating, they estimate that as a maximum 5% of the mercury in the broken lamps is released to the atmosphere while the remaining 95%, present in the phosphorous powder, is collected and disposed of with municipal solid waste.

979. US EPA (1997c) discusses different estimates of overall atmospheric emissions rates from broken lamps. The estimates range from about 1.2-6.8 % of total mercury content and US EPA assume a central estimate of 3% of total mercury. The question of migration of mercury from the phosphorus powder is also discussed. Studies has demonstrated that for the uncovered broken lamp, emissions over a 20-day period totalled 1.28 mg out of the estimated total lamp content of 42 mg, or about 3% of the total mercury content of the lamp.

980. Barr (2001) assumes that 5% of the mercury supplied with lamps is emitted to the air from breakage by the users.

iii) Disposal

981. The fate of the mercury used in lamps is dependent on many factors, especially the disposal methods of the country. For example, in the USA, it is estimated that 13-15% of disposed lamps are recycled or disposed of as hazardous waste, and 85 to 87% are disposed in regular municipal solid waste (MSW) (NEMA, 2000 and US EPA, 1997a, as cited in NJMTF, 2002). In the early 1990s, only about 2% of lamps were recycled in the USA (US EPA, 1994). However, since that time, the percent recycled has probably increased significantly in the USA.

982. The US inventory of mercury releases estimates, based on a model from 1993, that 8% of the total mercury content of waste lamps is releases to the atmosphere from lamps breakage by transport of the waste. The estimate is based on the assumption that all lamps break by collection and transport of the waste.

Table 5-134 Examples of mercury content in light sources in mg mercury per item, by type and origin of data (overleaf)

Type of light source	**Mercury content in light source (mg Hg/item)**	**Country/region for data**	**Remarks**
Fluorescent tubes (double end)	15 (1997) 10 (2002) 1,4 – 10 (2015)	European Union	Floyd et al., 2002 COWI/ICF, 2018
	15-45	Russia	Yanin, 2004
	10-22	USA	DiFrancesco and Shinn, 2002
	23-46	Canada	Environment Canada, 2003a
	40	China	UNEP, 2008
	3-4 1,4-10 1.8 – 15	Global	Lowest content on the marked, based on information from manufactures Philips, 2018 Ledvance (form.Osram Sylvania, 2018)
Compact fluorescent lamp (CFL single end)	5 1,4 – 4 (2015)	European Union	Floyd et al., 2002 COWI/ICF, 2018
	10	Canada	Environment Canada, 2003a
	12- 30	Russia	Yanin, 2004
	8	China	UNEP, 2008
	1,4-3,5 1,3-4	Global	Philips, 2018 Ledvance, 2018
High pressure mercury vapour	30 38-39 (2015) 13.7 – 72 11 – 165	European Union Global Global Global	Floyd et al., 2002 COWI/ICF, 2018 Philips, 2018 Ledvance, 2018
High pressure discharge lamps	38	Russia	Yanin, 2004
High-pressure sodium lamps	30 13-20 (2015)	European Union	Floyd et al., 2002 COWI/ICF, 2018
	9 11 – 34 1 – 29	Russia Global Global	Yanin, 2004 Philips, 2018 Ledvance, 2018
UV light for tanning	25	Denmark	Maag et al. 1996
	5	Russia	Yanin, 2004
Metal halide lamps	25 2-32 (2015)	European Union	Floyd et al., 2002 COWI/ICF, 2018

	24	Russia	Yanin, 2004
	< 15	Global	Philips, 2018
	2,5-145	Global	Ledvance, 2018
	15-281	Global	Metal halide dble end, Ledvance, 2018

983. Floyd *et al.* (2002) estimate correspondingly that 6% of the mercury in lamps disposed of to landfills will be emitted when the lamps break. In the European Union 75% of the lamps *disposed with solid waste* is landfilled, while the remaining 25% is incineration.

984. For lamps that are recycled in effective, closed loop systems, most of the mercury is captured. Very little is expected to be released directly to the environment during the recycling process.

985. About 700 million lamps were discarded in the USA in 1999. Since these lamps were about 5 years old, and probably contained an average of about 20 mg mercury, one can estimate that roughly 14 metric tons of mercury were discarded in the USA in 1999. Barr (2001) has estimated that about 26 - 42% of this mercury is emitted to air, and that the remainder ends up on land (Barr, 2001). NJMTF estimates that 15 - 45% of the mercury in disposed lamps goes to air.

986. Skårup *et al.* (2003) estimate the life span of fluorescent light sources at 8-10 years under Danish conditions.

987. The long-term emission from the landfilled phosphorus powder is in general poorly understood, but this source likely contribute to observed mercury emissions from landfills (see section 5.9).

5.5.3.5 Input factors and output distribution factors

988. Based on the so far compiled examples given above, the following preliminary default input and output distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows.

a) Default mercury input factors

Table 5-135 ***Preliminary*** *default mercury input factors, by type of light source*

Type of light source	**2017 Toolkit version (and earlier)** **Mercury content in light source, mg Hg/item, low – high (intermediate)**	**2019 Toolkit update** **Mercury content in light source, mg Hg/item, low – high (intermediate)**
Fluorescent tubes (LFL double end)	10 – 40 (25)	2 – 15 (8)
Compact fluorescent lamp (CFL single end)	5 – 15 (10)	1.4 – 4 (2.7)
High pressure mercury vapour	30 (30)	15 – 70 (40)
High-pressure sodium lamps	10 – 30 (20)	10 – 30 (20)
UV light for tanning	5 – 25 (15)	5 – 25 (15)
Metal halide lamps	25 (25)	5 – 150 (25)

b) Default mercury output distribution factors

989. No output distribution factors were defined for light source production due to lack of data. If no local output distribution factors are available, the default output distribution factors for production

pre-entered in the IL2 spreadsheet can be used. They were based on limited data available for thermometers and batteries, assuming some similarities in mercury handling, etc.

990. As only very small amounts of mercury is emitted to the atmosphere from lamp breakage at the users, while most the mercury in broken lamps are discarded with wastes, no separate default output distribution factors are defined for the use phase.

991. For the disposal, outputs are extremely dependent on the actual waste management practices in each of the sectors where mercury thermometers are used, and the default factor given below are simplifications meant to raise the signal that substantial mercury outputs may follow each of the noted pathways. Quantifications of the actual waste streams in each of the sectors in the country will give a more relevant picture of the mercury outputs from this products group. If no such specific quantitative data are available, the distribution factors given in the table below can be used.

992. Note that the table only distributes outputs on direct releases to the environment and the two waste categories mentioned. The final destiny of mercury in wastes depends highly on the national/regional waste treatment scenario and the emission reduction designs involved. See descriptions of these issues in the sections covering general waste incineration (5.8) and landfills/deposition (5.9).

993. Note also that in the default mercury output distribution factors mentioned here, informal dumping or incineration of waste is quantified as direct releases to air, land and water, as relevant. Beware of double-counting, if estimates of mercury releases are also made separately for informal dumping or incineration of waste.

*Table 5-136 **Preliminary** default mercury output distribution factors for production, consumption and disposal of light sources*

Phase in life cycle	Default output distribution factors, share of Hg input 2*				
	Air	**Water**	**Land**	**General waste**	**Sector specific treatment/ disposal *1**
Use and disposal (depending on actual waste management status in country):					
No or very limited separate lamps collection. All or most general is waste collected and handled in a publicly controlled manner	0.05			0.95	
No or very limited separate lamps collection. Missing or informal collection and handling of general waste is widespread ***3**	0.3		0.3	0.4	
Separate lamps collection with high collection rates. All or most general is waste collected and handled in a publicly controlled manner	0.05			0.8	0.15

Notes: *1 Recycling of light powder containing mercury for new lamps, or recycling of the mercury;
*2 Mercury inputs to use and disposal are the amounts of mercury in the lamp types, combined with disposed amounts of the respective lamp types. If annual supply data for 5-10 years earlier (for the same lamp types) are available, they can be used as approximations for disposed amounts;
*3 The distribution between air, land and general waste here is artificial, and is meant only to raise a signal that significant mercury releases may follow these pathways in countries with widespread informal waste handling such as diffuse dumping and informal waste incineration. Such waste handling is considered here as direct releases to the environment.

c) Links to other mercury sources estimation

994. The estimated mercury outputs to separately collected waste and general household waste from this sub-category **contributes** to the mercury inputs to landfills/deposits (section 5.9) and household waste incineration (section 5.8).

5.5.3.6 Source specific main data

995. The most important source specific data would in this case be:

- Consumption of mercury-containing lamps, including imports;
- National or regional trends in mercury concentrations in the various lamp types;
- Estimated share of the supplied lamps that break during use; and
- Setup end efficiency of waste management systems.

996. Mercury-containing light sources are mainly produced in relatively few, larger production plants, and a point source approach to mercury release estimates from production is therefore recommended, where possible.

997. See also advice on data gathering in section 4.4.5.

5.5.4 Batteries with mercury

5.5.4.1 Sub-category description

998. The use of mercury in various types of batteries has been extensive and it has been among the largest product uses of mercury. Mercury has mainly - or perhaps solely - been used in primary (that is non-rechargeable) batteries.

999. Mercury is used in high concentrations (about 30-32% w/w) in mercury oxide batteries (sometimes called zinc-mercury batteries), where mercury oxide serves as the positive electrode in the battery. These have probably mainly been sold as button shape cells in the west, but also in larger cylindrical and other shapes. Marketing of mercury oxide batteries is now severely restricted in several countries, while some specific uses may still be exempted (for instance military uses in some countries). In the USA, for example, mercury-oxide batteries are now prohibited, but were previously used in transistorized equipment, hearing aids, watches, calculators, computers, smoke detectors, tape recorders, regulated power supplies, radiation detection meters, scientific equipment, pagers, oxygen and metal monitors, and portable electrocardiogram monitors (US EPA, 1997a).

1000. In the following other battery types, mercury has served as reaction modifier, preventing gas development (and thus breakage) during use of the battery, and a corrosion inhibitor (US EPA, 1997a).

1001. Earlier, alkaline cylindrical cells on the European market had mercury concentrations of up to around 1%. Due to environmental restrictions on large western markets, mercury consumption with cylindrical alkaline batteries decreased, however, and most global battery brands are now produced without intentionally added mercury content. However, some nationally or regionally traded brands of alkaline batteries with mercury added, still exist.

1002. Button cell shaped batteries of alkaline, silver oxide and zinc/air types still contain mercury in most cases (at concentrations up to around 1% w/w).

1003. Other battery types are not considered to contain mercury today. Note that besides plain battery sales, batteries may be imported and exported in substantial amounts in the package of other products like electronics, toys, greeting cards with sounds etc.

5.5.4.2 Main factors determining mercury releases and mercury outputs

Table 5-137 Main releases and receiving media throughout the life-cycle of batteries with mercury

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Production	**X**	x	x	**X**		x
Use						
Disposal	**X**		**X**		**X**	**X *1**

Notes: ***1** Separately collected batteries containing mercury (or categorized under sorting as such) may be disposed of in specially secured landfills;

X - Release pathway expected to be predominant for the sub-category;

x - Additional release pathways to be considered, depending on specific source and national situation.

i) Production

1004. The workplace procedures in battery manufacture, particularly for mercury oxide batteries, and product reject rates, may be an important factor determining the extent of releases.

1005. Note that many countries do not have domestic battery production, but rely on imports.

ii) Disposal

1006. The actual mercury concentrations in the batteries supplied is of major importance for the tonnage of mercury released from this product category.

1007. For the category as such, the consumption of mercury oxide batteries is of particular importance, because of the relatively high mercury content.

1008. Besides the mercury content, however, the existence and efficiency of battery collection schemes, as well as the general waste management pattern, are the most important factors influencing mercury releases from batteries. The distribution of the mercury in disposed batteries to receiving pathways is highly dependent of the waste management practice in the country in question.

1009. In some countries parts of the used batteries are collected for safe handling of the mercury (and cadmium in other types) and possibly recycling. From North European experiences collection rates of about 50% are considered high, and in many cases less is collected, even when considerable information and collection efforts are made. Generally, separately collected batteries are expected to be deposited with a higher degree of safety than household waste. Recycling of batteries with mercury is probably not a widespread procedure today, though more extensive recycling of battery materials is under consideration in some countries.

1010. Even in countries with separate battery collection, major parts of the consumed batteries are disposed of with general household waste. For batteries in wastes lead to protected landfills, parts of the mercury will be released only slowly as the encapsulation is degraded, by gradual evaporation to the atmosphere, with slow leaching to waste water (or the ground water, if no membrane is used under the landfill), and perhaps ultimately in larger scale if excavation works occur (or even climatic/geological changes). See the description of landfills/deposition in section 5.9. In cases of uncollected, diffusely lost waste, or informal, un-protected waste dumps, the losses occur directly to land. The actual evaporation or bio-availability of the contained mercury may be delayed several years or even decades, because the degradation of the battery encapsulation is expected to happen slowly.

1011. For batteries in wastes that end up in waste incineration, some of the mercury will be released to the atmosphere when incinerated, while other parts will remain in the solid incineration residues, and if applied, in flue gas cleaning residues, and subsequently deposited in landfills or other deposits, as described in section 5.8. In case of informal waste incineration, parts of the mercury will evaporate and be released to the atmosphere, while other parts will stay in solid residues and be lost to land.

iii) The market in 2019

1012. Mercury oxide batteries were among the products for which an extensive research was conducted for the 2019 Toolkit update, and in addition, selected trade associations were contacted. The production of mercury oxide batteries was considered terminated globally and both the European Portable Battery Association (EBPA, 2018) and the National Electrical Manufacturing Association (NEMA, USA, 2018) replied to contacts made for the 2019 Toolkit update that they are not aware of manufacturing of mercury oxide batteries globally. However, the research conducted for the 2019 update of the Toolkit, at least two Russian websites selling mercury oxide batteries were found. One of these claims that a specific mercury oxide button cell battery, PX625[1], commonly used in older cameras (probably for light measurement) is today only produced in Russia (www.px625.ru, accessed Oct 2018). The website of the Russian company JSC Energia (2019) produces several types of "mercury-zinc" batteries (another name for mercury oxide batteries); both specialty battery packs (see Figures xx below), and standard mercury oxide button cells. However, they only produce based on individual orders, and do not themselves market these batteries to consumers.

Figure 5-14 *Specialty battery pack from JSC Energia (2019). Product text: "Where voltage stability is required, miniature autonomous sources, high discharge currents, reliable operation in a wide temperature range (from minus 30 - plus 60 °C), the RC system current sources meet all the above requirements".*

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[1] According to www.px625.ru the battery type is also known as: PX625 / PX13 / EPX625 / V625PX / MR09 / MR9 / H-D / HD / RPX625 / RM625 /KX625 / HD1560 / 1124MP / Mallory RM-625R / Eveready E625N / Burgess HG-625R / 4370 / 4371 / V13PX / EPX13 / V625PX / HD625 / PN625 / RM625 / 4625 / 625 / H1560 / HD-D / M01 / M20 / 8930 / Varta 7002 / Pertrix 7002

Figure 5-15 Specialty battery from JSC Energia (2019). According to the company, "they are used in instrumentation equipment, radio stations, scientific and military equipment, geophysical devices" (JSC Energia, 2019).

1013. Mercury oxide battery import is often observed in small and irregular quantities when making UN Comtrade import/export data extracts for developing countries. Based on quite many observations of unexpectedly high imports in Minamata Initial Assessment inventory development work, it is not unlikely that some of these import/export registrations are errors in reporting of other potentially mercury-containing battery cells (for example zinc-air, silver oxide of alkaline button cells). This was also observed by Maxson (2017), and inventory developers are recommended to report such possible irregularities and check it with importers, if possible. However, the high frequency of mercury oxide battery registrations confirms the continued trade of these batteries.

1014. As regards other mercury-added battery types, the 2006/66/EC Directive prohibits the placing on market of all batteries or accumulators, whether or not incorporated into appliances, that contain more than 0,0005 % of mercury by weight. In button cells however, mercury concentrations up to 2 % by weight were allowed until 1 October 2015. The EU Regulation 2017/852 on mercury, implementing the Minamata Convention in the EU, similarly prohibits export, import and manufacturing of batteries or accumulators that contain more than 0,0005 % of mercury by weight after 31.12.2018.

1015. The research on the producers and associations from different parts of the world revealed the following as regards the status of mercury-added versus mercury-free batteries other than mercury oxide batteries.

1016. The document "Product Information Primary and Rechargeable Batteries", prepared by European Portable Battery Association (EPBA, 2015), describes the indicative chemical composition of the batteries produced by the members of the association, including the following mercury concentrations:

- Silver oxide button cells – 0,4 %
- Alkaline manganese dioxide button – 0,6 %
- Zinc air button – 1%.

1017. The Battery Association of Japan (2019) mentions on its website that in 1995 - mercury battery production stopped, in 2005 - silver oxide zinc batteries using no mercury was achieved, and in 2009 - alkaline button batteries using no mercury was achieved.

1018. The Chinese online market of batteries (www.made-in-china.com) provides the list of products and the list names of companies that produce batteries. Most of batteries are mentioned to be mercury free.

1019. A Special Policy Study on Mercury Management in China, prepared in 2011 (CCICED, 2011), mentions that while mercury use in Chinese batteries was confirmed to have been high before 2000, most Chinese manufacturers have reportedly now shifted to lower-mercury technologies, following both domestic and international legislative trends and customer demands.

1020. On the other hand, in China from 1 January 2021, mercury-containing batteries will be prohibited in manufacturing and importing, exempting zinc-silver oxide and zinc air battery with mercury concentrations below 2%. Mercury oxygen batteries and battery packs, zinc mercury batteries (= mercury oxide), cylindrical alkaline manganese batteries with mercury concentration more than 0.0001% and keto alkaline manganese batteries with mercury concentration more than 0.0005% are required to be eliminated, in accordance with the Guidance on Industrial Structure Adjustment. (http://www.cirs-reach.com/news-and-articles/China-Enforcing-Mercury-Convention.html, Article China Enforcing Mercury Convention)

1021. As regards the US, the factsheet provided by Northeast Waste Management Officials' Association (NEWMOA, 2018) indicates that mercuric oxide button-cell batteries are no longer sold in the U.S. for personal or commercial use in accordance with the Mercury Containing and Rechargeable Battery Management Act of 1996, except of some limited applications. As regards other mercury-added button cells, many companies have ceased manufacturing mercury button-cell batteries and/or stopped selling products in which mercury button-cell batteries are a component. As of the 2016 reporting period, 51 companies have confirmed to IMERC (NEWMOA, 2018) a complete phase-out of these products with additional companies actively working towards phase-out. Some of the large battery manufacturers, including Sony Corporation, New Leader, and Energizer, manufacture non-mercury zinc air, silver oxide, and/or alkaline manganese button-cell batteries. However, many of these models are reported as more expensive than their mercury counterparts and some may not be commercially available in the U.S.

1022. The research of the biggest companies revealed that as of June 2019, the following major suppliers only supply mercury-free batteries, including micro alkaline batteries, silver oxide batteries and zinc air batteries: Duracell (2019), Energizer, Varta (2019), Panasonic. As regards the Russian companies, no information was available except on mercury oxide batteries (see above), and they did not respond to personal communication for the 2019 Toolkit update.

1023. According to NEMA (2019) on the US market, mercury is a non-issue as all makers have been mercury free for cylindrical batteries since the early 90’s and button types (alkaline, silver oxide and zinc air) since at least 2012. Globally, NEMA reports that there are examples of mercury use in cylindrical batteries (China) and zinc air batteries (Japan) but with low sales volumes, roughly estimated less than 5% for cylindrical (China) and less than 10% for zinc air (Japan). It is NEMA’s understanding that all other types are globally mercury free.

1024. The EPBA (2019) provided the following information about silver oxide, zinc air and alkaline button cell batteries in some countries and regions:

1025. “Japan: 1) Silver oxide batteries of BAJ (Battery Association of Japan) members are all mercury-free with the estimated market share of 90%. 2) Alkaline button cells likewise, however, BAJ market share is estimated less than 50%. They don’t know the situations of the non-BAJ brands. 3) Zinc air batteries of BAJ members are almost mercury-free with a slight exception. BAJ market share is estimated 90%.

1026. We do not have specific information about other Asian countries, but there is an assumption that China and India have considerable markets of mercury-added button cells.

1027. Australia: Feedback from the association is that its members hadn't seen batteries containing Mercury on the Australian market for a number of years...however, legacy batteries are available on eBay.

1028. Latin America: Mercury -free batteries are now dominating (>~90%) over mercury containing versions of the same battery type."

5.5.4.3 Discussion of mercury inputs

Table 5-138 Overview of activity rate data and mercury input factor types needed to estimate releases from batteries with mercury

Life-cycle phase	Activity rate data needed	Mercury input factor
Production	Mercury used for production, kg/y*2	Not relevant (factor is 1)
Use	Not needed (Releases negligible)	Not needed (Releases negligible)
Disposal	Metric tons of batteries supplied per year a battery lifetime ago ***1**, of each battery type	Kg mercury per metric ton of batteries supplied of each type

Notes: *1: As a substitute for metric tons disposed of per year. If good estimates of amounts of batteries disposed of annually exist, these should preferably be used. In times of changing consumption or substitution with mercury-free batteries, the current supply and current disposal will differ from each other. *2: If the amount of mercury used per year in production is not available, the amount can be estimated from data on the number of batteries of each relevant type produced in combination with data on the mercury contents of each type, as given in this report.

Production

1029. Input data on mercury to production of the different mercury containing batteries may not be generally available (except by direct contact to manufacturers). Estimating releases from production as a percentage of the expected mercury content in the battery type in question may be an easier approach for a first estimate. See examples of mercury content and releases from production below.

Disposal

1030. Mercury input to disposal is the mercury content in the batteries as supplied, multiplied by the number of batteries (of the same type) that are disposed of. Note that mercury disposal with batteries reflects battery mercury content from earlier years (life-times of a few years, depending on type and use). This is important, as mercury concentrations in batteries have changed in the last few years in many countries. If no historical data are available, input numbers from current supply can be used as an estimate.

1031. Examples of mercury content in batteries per type and region (for data) are presented in Table 5-139 below.

Table 5-139 Examples of mercury content in batteries in g mercury per kg of batteries, per type and origin of data

Battery type	**Mercury content in battery (kg Hg/metric ton batteries)**	**Country/region for data**	**Remarks**
Mercury oxide (all sizes); also called zinc-mercury cells	320	European Union	Floyd *et al.* (2002). The sale of mercury oxide batteries is prohibited in the EU since 2000.
Zinc-air button cells	12.4	European Union	EBPA (industry) data as cited by Floyd *et al.* (2002). Probably mean values, as mercury concentrations may vary somewhat. Mercury content in button cells above 20 kg/metric ton battery are prohibited in the EU since 2000.
	10	European Union	EBPA (2015)
Alkaline button cells	4.5 - 10 ***1**	European Union	Remarks identical as for zinc-air. 10 kg/metric ton is an older value from Scandinavia (early 1980's).
	6	European Union	EBPA (2015)
Silver oxide button cells	3.4 - 10 ***1**	European Union	Remarks identical as for zinc-air. 10 kg/metric ton is an older value from Scandinavia (early 1980's).
	4	European Union	EBPA (2015)
Alkaline, other than button cell shapes	"0" - 10 ***1**	European Union	Most internal brands are mercury free today, but some nationally or regionally traded brands of alkaline batteries with mercury added, still exist. Non-button alkaline cells with mercury content above 0.25 kg/metric ton battery were prohibited in the EU since 1993, while content above 0.005 kg/metric ton are prohibited since 2000.

Notes: ***1**: 10 kg/metric ton is an older value from Scandinavia (early 1980's). Used here to illustrate potential maximum values in battery brands produced with older technology.

5.5.4.4 Examples of mercury in releases and wastes/residues

Production

1032. US EPA (1997a) reports an example of one mercury oxide production facility where ventilation air from the production rooms was filtered with particle retaining fabric filters and a charcoal filter, where only 0.1% (1 g/kg) of the mercury used in the production was released to the atmosphere. Presumable, additional amounts of mercury were disposed with used filter material, but this is not reported. US EPA states that this example should be used with caution, because of questionable data quality, and because other battery manufacturers may not have similar emission reduction equipment.

1033. Another example have been reported from Russia where up to about 27% of the mercury used for mercury oxide battery production was lost during the production, with rejected products and other solid waste (24%), with releases to waste water (2%) and the atmosphere (1%); (Lassen *et al.*, 2004).

1034. Regarding production of other battery types with much lower mercury content, release percentages could be similar to mercury oxide battery production.

ii) Disposal

1035. In Denmark an estimated 20-30% of the button cell consumption was collected separately in 2001, while the number was higher - an estimated 30-60% - for larger alkali batteries (Hansen and Hansen, 2003). The remaining parts of the batteries were expected to be disposed of with household waste, of which most ended up in waste incineration. Diffuse, informal waste dumping or incineration is deemed negligible in Denmark. Mercury disposal with batteries reflects battery mercury content from earlier years, therefore mercury oxide still represented the majority of the mercury releases/wastes from batteries in Denmark in 2001 (after mercury oxide sales were prohibited in 2000; Skårup *et al.*, 2003). In the Netherlands collection efficiency across all battery types can be estimated at about 50-70% of the potential, depending on how the collection efficiency is calculated. Collection rates at or slightly below this level were also reported for the (large) municipality of Göteborg in Sweden (based on Hansen and Hansen, 2003). These examples are likely to be among the highest collection rates among current battery collection schemes.

5.5.4.5 Input factors and output distribution factors

1036. Based on the so far compiled examples given above, the following preliminary default input and output distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows.

a) Default mercury input factors

Table 5-140 ***Preliminary*** *default mercury input factors, by battery type*

Battery type	Mercury content in battery (kg Hg/metric ton batteries)
Mercury oxide (all sizes); also called mercury-zinc cells	320
Zinc-air button cells	12
Alkaline button cells	5
Silver oxide button cells	4
Alkaline, other than button cell shapes	0.25 ***1**

Notes: *1 In EU countries an input factor of 0.005 kg/metric ton should likely be used.

b) Default mercury output distribution factors

1037. Note that the output factors for battery production are only relevant for countries with domestic production. Inputs to production are actually the purchases of mercury for the production (of which some is lost during production), but they can be estimated from concentrations in the batteries combined with data on production volumes. The default output distribution factors for production pre-entered in the IL2 spreadsheet (slightly different than those listed here) were based on limited data available for thermometers and batteries, assuming some similarities in mercury handling, etc.

1038.

1039. As regards disposal, quantifications of the actual waste streams in the country will give a more relevant picture of the mercury outputs from this products group. If no such specific quantitative data are available, the distribution factors given in the table below can be used. They are simplifications indicating main trends only, set with the aim of raising the signal that substantial releases may occur to these pathways.

1040. Note that the table only distributes outputs on direct releases to the environment and the two waste categories mentioned. The final destiny of mercury in wastes depends highly on the national/regional waste treatment scenario and the emission reduction designs involved. See descriptions of these issues in the sections covering general waste incineration (section 5.8) and landfills/deposition (section 5.9).

1041. Note also that in the default mercury output distribution factors mentioned here, informal dumping or incineration of waste is quantified as direct releases to air, land and water, as relevant. Beware of double-counting, if estimates of mercury releases are also made separately for informal dumping or incineration of waste.

c) Links to other mercury sources estimation

1042. The estimated mercury outputs to separately collected waste and general household waste from this sub-category **contributes** to the mercury inputs to landfills/deposits (section 5.9) and household waste incineration (section 5.8).

Table 5-141 ***<u>Preliminary</u>*** *default mercury output distribution factors for battery production and disposal*

Phase in life cycle	**Default output distribution factors, share of Hg input**				
	Air	**Water**	**Land**	**General waste**	**Sector specific treatment/ disposal**
Production *2	0.005	0.005	?	?	0.01
Disposal (Actual waste management status in country) *4:					
No or very limited separate battery collection. All or most general is waste collected and handled in a publicly controlled manner				1	
No or very limited separate battery collection. Missing or informal collection and handling of general waste is widespread *3	0.25		0.25	0.5	
Separate battery collection with high collection rates. All or most general is waste collected and handled in a publicly controlled manner				0.6	0.4 ***1**

Notes: *1 For button cell batteries, this category will often be special deposits with higher safety guards against mercury releases;

*2 Outputs in share of mercury amounts in produced batteries. Note that output factors for battery production are only relevant for countries with domestic production;

*3 High separate collection rates for batteries combined with a high degree of informal general waste handling is not deemed a relevant combination, as separate collection is often an advanced step following high general standards;

*4 Mercury inputs to disposal are the concentrations of mercury in the battery types, combined with disposed amounts of the respective battery types. If annual supply data for a few years earlier (for the same battery types) are available, they can be used as approximations for disposed amounts.

5.5.4.6 Source specific main data

1043. The most important source specific data would in this case be:

- Consumption of mercury oxide batteries; including imports (also imports incorporated in other products such as toys, greeting cards etc.)
- National or regional trends in mercury concentrations in other batteries (local brands, national/regional regulation etc.); and
- Setup end efficiency of waste management systems.

1044. Regarding mercury oxide batteries, it is an often encountered problem that national trade statistics are often severely inaccurate, because these batteries are normally sold in small quantities and are therefore very vulnerable to miss-categorization of other batteries in traders' reports to the statistics bureaus. This has consequences, because even moderate reported sales of mercury-oxide batteries may represent mercury turnover exceeding by far the total mercury consumption with other battery types.

1045. Most likely, batteries are mainly produced in relatively few, larger production plants, and a point source approach to mercury release estimates from production is therefore recommended, where possible.

1046. See also advice on data gathering in section 4.4.5.

5.5.5 Polyurethane with mercury catalysts

5.5.5.1 Sub-category description

1047. In two-components polyurethanes, for many applications, the catalysts of choice for catalysing the reaction between a polyol and an isocyanate composition, i.e., for hardening or curing the polyurethane (PU) materials, have long been organic mercury compounds (Lassen et al., 2008). Please note that the use of the catalysts for polyurethanes differs from the use of catalysts in the production of monomers (e.g. VCM) in the way that the catalyst in the polyurethanes is incorporated into the final product.

1048. In past years mercury was extensively used as a catalyst to promote a large range of polymer reactions. Mercury compounds have remained important catalyst in the production of polyurethane elastomers, coatings, sealants and adhesives (so-called CASE applications). The mercury compounds are in particular used for polyurethane elastomers (flexible plastics) that are cast into sometimes complex shapes, or sprayed onto a surface as insulation, corrosion protection, etc. Alternative, mercury-free catalysts are however available and widely used today (Lassen *et al.*, 2008).

1049. The polyurethane products are used for a wide range of end-products including rollers, flooring, gaskets, encapsulation of electronic components, shoe soles, shock absorption and repair of industrial installations.

1050. The main mercury compounds used are phenyl mercury compounds, first of all phenylmercury neodecanoate. The content of the phenylmercury compounds in the catalysts is typically in the range of 60-70% by weight corresponding to 25-30% mercury by weight.

1051. Like any catalyst used in polyurethane systems, the mercury catalyst is incorporated into the polymer structure and remains in the final product. The catalyst is added to the polyurethane at levels of 0.2-1%, depending on the other components and the desired properties of the polymer. Consequently, the phenylmercury neodecanoate concentration in the polyurethane product is on the order of 0.1-0.6% and the mercury content in the range of 0.05-0.3 % (Lassen *et al.*, 2008).

1052. It is estimated that 300-350 metric tons/year of mercury catalyst may be used globally in polyurethane applications (Lassen et al., 2008).

5.5.5.2 Main factors determining mercury releases and mercury outputs

Table 5-142 Main releases and receiving media throughout the life-cycle of polyurethane with mercury catalyst

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Production	x	x		X		x
Use	X	X				
Disposal	X		X		X	

Notes: ***1** **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

1053. The main releases of mercury are from the use of products with polyurethane parts and by the disposal of discarded products.

1054. Mercury may be released from products during use. The mercury may be released both in the form of the phenylmercury compounds and as elemental mercury from the brake down of the mercury catalysts in the products. The release rates are dependent on wear and tear of the products.

1055. The polyurethane parts typically end up in the general household waste or in general waste from construction and industry. Systems for separate collection of polyurethanes with mercury catalyst are not known from any country. For polyurethane wastes that end up in waste incineration, some of the mercury will be released to the atmosphere when incinerated, while other parts will remain in the solid incineration residues, and if applied, in flue gas cleaning residues, and subsequently deposited in landfills or other deposits, as described in section 5.8. In case of informal waste incineration, parts of the mercury will evaporate and be released to the atmosphere, while other parts will stay in solid residues and be lost to land.

5.5.5.3 Discussion of mercury inputs

Table 5-143 Overview of activity rate data and mercury input factor types needed to estimate releases from polyurethane with mercury

Life-cycle phase	Activity rate data needed	Mercury input factor
Production	Metric tons of mercury catalysed polyurethane produced per year (in the country)	Kg of mercury released per kg of mercury used in manufacturing of polyurethanes
Use	National population	g mercury in polyurethane consumed per inhabitant per year
Disposal	National population	g mercury in polyurethane consumed per inhabitant per year

Production

1056. In most countries mercury catalysts for polyurethane production are produced only by one manufacturer, if any. The amount of mercury used for the production, the quantities of catalyst produced and the actual releases from the production of the catalysts should preferably be obtained by direct contact with the manufactures, if possible. Releases from the production may in some cases be available from national environmental statistics.

1057. The mercury catalysts are used for production of two-component polyurethane systems where the catalyst is mixed with one of the two components. The releases from this operation are estimated to be insignificant.

1058. The two-component polyurethane systems are used by manufacturers of polyurethane end-products or by users of sealants and adhesives. Input data on mercury for production of the different mercury containing polyurethane products may not be generally available (except by direct contact to manufacturers).

Use

1059. Mercury releases by evaporation of phenylmercury compounds and elemental mercury may in principle be estimated on the basis of information on the amount of mercury catalysed polyurethane accumulated in products in the society. The accumulated amounts reflect the mercury content and consumption of mercury containing polyurethanes from earlier years. A significant part of the polyurethane may be imported in finished products. In most countries neither data on the actual consumption figures nor historical data will be available, and it will be necessary to base the estimates on general information on the global use of mercury for this application.

1060. Very limited information is available on the use of mercury in polyurethanes in different countries and until recently the total mercury use for this application was generally assumed to be very small.

1061. In a detailed study for the European Commission Lassen et al. (2008) estimated on the basis of industry communications that 300-350 metric tons of mercury catalyst may be used globally in polyurethane applications, of which some 60-105 metric tons in the European Union. It corresponds to more than 100 metric tons of mercury consumption worldwide, and 20-35 metric tons of mercury consumption with polyurethanes in the European Union. Mercury catalysts seems not to be essential as alternatives exists and according to Kometani *et al*. (year not indicated) mercury catalysts are not used in Japan. Although the mercury catalysts may not be used in some countries, imported products most likely still contain mercury catalyzed polyurethanes.

1062. If the 100 tons mercury per year is equally distributed on the global population of 6.2 billion inhabitants the mercury consumption per person (capita) can be estimated at 0.02 g Hg/year. The consumption in the European Union corresponds to a mercury consumption per person of 0.05 g Hg/year.

Disposal

1063. In most countries no data will be available on mercury containing polyurethane in the waste stream and it will be nearly impossible to obtain reliable data for estimating the total quantities.

1064. Assuming a steady state situation the total quantities disposed off corresponds to the total input with products subtracted the releases during use of the products.

The market in 2019

1065. An extensive research was conducted for selected mercury-added products for the 2019 Toolkit update, with a focus on products that had been poorly investigated in Minamata Initial Assessment studies due to difficulties in national data collection. Polyurethanes (PU) were among these products, as recently mercury catalysts have only been applied in a narrow array of final products. And even the product types, where mercury catalysts have been applied recently, are also widely produced with mercury-free catalysts. Furthermore, in many countries such products may rather be imported than manufactured nationally. It can therefore be very complex to undertake a detailed national assessment of mercury catalysts use in polyurethane products.

1066. The use of mercury compounds as catalysts in polyurethane has been restricted in the EU through the September 2012 EU Commission Regulation No.848/2012 amending the REACH regulation's Annex XVII by adding the following five phenylmercury compounds used as catalysts in polyurethane (PU) elastomer production to a list of restricted substances:

- Phenylmercury neodecanoate (CAS # 26545-49-3)
- Phenylmercury acetate (CAS # 62-38-2)
- Phenylmercury 2-ethylhexanoate (13302-00-6)
- Phenylmercuric octanoate (CAS # 13864-38-5)
- Phenylmercury propionate (CAS # 103-27-5)

1067. After October 10, 2017, these five compounds can no longer be manufactured in the EU, placed on the market or used as a substance or in mixtures, in articles (= final products) or parts of articles in EU-based manufacturing, if the concentration of mercury is equal to or greater than 0.01% by weight.

1068. Many other organomercury compounds can be used as catalysts in polyurethane production. Currently, at least two additional mercury compounds are marketed for use as a catalyst in PU systems: [µ -[(oxydiethylene phthalato)2-)]] diphenylmercury (CAS No 94070-93-6) and bis(phenylmercury) dodecenylsuccinate (CAS No. 27236-65-3) (ECHA, 2011). The research conducted for the 2019 Toolkit update showed that these compounds are available for sale globally, but to a lesser extent then the five compounds restricted in the EU.

1069. Some polyurethane products are marketed as mercury-free and those are in most cases polyurethanes for insulating windows (not known as a major area for use of mercury compounds).

1070. The research conducted for the 2019 toolkit update showed that mercury compounds usable as catalysts for polyurethane production are still available for sale from different companies and laboratories. Several companies sell Phenylmercury neodecanoate, mentioning that it is intended for use as a catalyst for polyurethane synthesis, including a company from Canada (Toronto Research Chemicals) and several companies from China (Suzhou Health Chemicals Co., Ltd., Hangzhou DayangChem Co., Ltd, Skyrun Industrial Co.Limited, Molbase) and India (IndiaMart, Advanced Technocracy Inc). Companies from China and Canada did not reply to the emails requesting more information for this study.

1071. The only reply offering mercury catalysts in quantities ranging from 25 mg to 500 mg was received from a seller via Indiamart[2], but it is not clear which company (the initial request was probably forwarded to potential sellers). These small sales amounts may indicate use for chemical research and analysis, rather than industrial scale supplies. But it signals that the chemicals may still be produced, and orders of significant amounts would anyhow always be negotiated individually and not as Internet batch sales. Fhu Tradex from Poland offered for sale pure mercury, as well as mercury catalysts.

1072. Thor Specialties (2019, UK), formerly a major supplier of mercury compounds for polyurethane production, informed that they have not supplied mercurial polyurethane catalysts since 2013-2014, but they recall that also companies in China and India supplied these chemicals (they could not name the companies however). This is consistent with other findings in the 2019 toolkit update, as mentioned above.

1073. Indian Polyurethane Association (IPUA, 2019) states that according to discussions with the IPUA members from the elastomer section, no members are using mercury-based catalysts today.

1074. The Polyurethane Manufacturing Association (PMA, 2019) provided the following information: "Traditionally, mercury catalysts were used in room temperature processable and curable systems, particularly those that are used outdoors where there is potential water exposure. Mercury catalyst is unique in that it is active down to about 40 F and it does not promote the water reaction which

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[2] In response to the data request, Indiamart asked for more details in order to prepare an offer of mercury catalyst.

can cause bubbles or foaming. To our knowledge, most of this industry has switch away from mercury."

1075. An assessment of data from the Rotterdam Convention's PIC notifications, revealed import and export from EU countries of various mercury compounds, including diphenyl[mu-[(tetrapropenyl)succinato(2-)-O:O']]dimercury (alternative), (neodecanoato-O)phenylmercury and phenylmercury acetate in the period 2014-2016, but not in 2017 (no data available after 2017). The individual quantities cannot be distinguished, as they are reported as a whole group of mercury compounds. The reporting import countries from the EU (UK, Spain, Italy, Belgium, France, Germany) also reported export of mercury compounds in 2014 and 2015 (before the EU restrictions mentioned above).

1076. As a conclusion, based on the extensive research done in 2019, the use of mercury compounds for catalyzing polyurethane elastomers may likely be continuing in 2019, while with some restrictions applying for EU-based industry.

5.5.5.4 Examples of mercury in releases and wastes/residues

Production

1077. US EPA (1997a) reports that during the production of mercury compounds, emissions of mercury vapour and particulate mercury compounds may occur at the following sources: reactors, driers, filters, grinders, and transfer operations.

1078. No data on actual releases from the production of phenylmercury compounds are available, but the releases are assumed to be small compared to releases later in the life cycle of the products.

1079. Releases from the manufacturing of polyurethane systems and final polyurethane parts may be significant, but no data has been available for estimating the releases.

ii) Use and Disposal

1080. Actual investigations of mercury releases from articles have been reported for polyurethane elastomer flooring in the U.S.A. Polyurethane flooring with mercury catalysts has previously been widely used in school gyms and sport arenas in the U.S.A. and probably also in other parts of the world.

1081. According to an investigation by the Minnesota Department of Health (U.S.A.), some polyurethane elastomer flooring manufactured from about 1960 through at least 1980 contained up to 0.1% mercury in phenylmercuric acetate or other organo-mercuric salts that were used as catalysts (Reiner, 2005, as cited by ATSDR, 2006). This concentration is similar to the concentration in polyurethane elastomers applied in many places of the world today.

1082. Ambient mercury concentrations in school gyms ranged from 0.13 to 2.9 µg/m3, and in 5 of 6 gyms was above the RfC level of 0.3 µg/m3 established by US EPA as the exposure level below which no adverse health effect is expected (MDH, 2006). A separate investigation in Ohio (USA) showed that PU elastomer floors in schools also emitted mercury is excess of the 0.3 µg/m3 RfC level (Newhouse 2003). Similar results have been obtained from other schools in the U.S.A., but no reports from other places of the world have been identified.

1083. According to ATSDR (2008) the chemical literature is not clear about whether the mercury vapor from phenylmercury acetate or other mercury compounds found in floorings is elemental mercury vapor, or if it is the vapor form of the mercuric compound in the flooring. However, it is not known if phenylmercury acetate in the floor is converted to elemental mercury prior to volatilizing, or if it is converted to elemental mercury in the air. Environmental Health Information from Minnesota Department of Health states that when new, these floors contained up to 0.1% mercury, but as the floors age, the mercury content slowly decreases, so levels in floors that are decades old can be considerably less than 0.1% (MDH, 2008a). No documentation on the decrease in the mercury content is provided.

1084. In an investigation in Ohio, tests showed that five out of nine 3M Tartan Brand flooring should be considered hazardous waste as a material leaching test showed a concentration above 0.2 mg Hg/l. (ATSDR, 2003). The results indicate that exposure by skin contact may take place, but this exposure is considered insignificant compared to the exposure by inhalation.

1085. Wear and tear of surfaces may lead to increased emissions as mercury may be released from the particles and from the part of the surface which is exposed by the abrasion. High levels of abrasion may in particular be expected for some out-door uses e.g. shoe soles and roller skates rollers.

1086. Besides releases to the air, the leaching and abrasion may lead to releases to waste water.

1087. No actual data for estimating average releases from the polyurethane products are available, but as indicated by Minnesota Department of Health above the releases may be so significant that the concentration in the polyurethane material significantly decrease over time. In the absence of actual data it will be roughly assumed that on average 5% of the mercury in the polyurethane is released to waste water and 10% to the air over the entire service life of the products.

5.5.5.5 Input factors and output distribution factors

1088. Based on the so far compiled examples given above, the following preliminary default input and output distribution factors are suggested for use in cases where source specific data are not available.

a) Default mercury input factors

1089. If no other information is available enabling input estimation as described above, a first estimate can be formed by using the default input factors selected in Table 5-144 below (based on the data sets presented in this section). Because of the high uncertainty on the estimate, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum).

Table 5-144 ***Preliminary*** *default input factors for mercury use in mercury containing polyurethanes*

	Default input factors; g mercury consumed per inhabitant per year; (low end - high end)
Mercury consumed annually with mercury containing polyurethanes	0.01-0.05

1090. The default input factors are based on the consumption data from the developed countries and regions described above. In developing countries with substantial parts of the population with no access to electricity and thus presumably a lower prevalence of what could be broadly termed "technical installations", the prevalence of the mercury-added product types in question may also be lower, relatively to the developed countries from which the default input factors were derived. While polyurethane products are not only used in "technical installations", the electrification rate is suggested as a possible indicative factor for the level of development in the country.

1091. Lower level of technical development can thus be adjusted for by multiplying the population number used in the calculations by the electrification rate as assessed by the IEA (multiply by electrification rate in percent and divide by 100 percent). IEA estimated electrification rates for selected developing countries from 2009 are shown in Annex 8.4. For countries with no IEA estimates, electrification rates were estimated based on other sources (see details in the annex). This approach is used in the

Inventory Level 1 spreadsheet (automatically) and has been implemented as an option in the Inventory Level 2 spreadsheet as well (manually).

Note that Annex 8.4 also includes population data for most countries of the World.

b) Default mercury output distribution factors

1092. Table 5-145 below provides default mercury output factors for production, use and disposal of mercury in polyurethanes. Note that output factors for mercury catalyst production are only relevant for countries with domestic production. Inputs to production are the actual purchases of mercury for the production (of which a small part is lost during production).

1093. I most countries data on mercury releases from polyurethane products and data on mercury-catalysed polyurethanes in the waste streams will not be available, and the distribution factors given in the table below can be used.

1094. Note that the table only distributes outputs on direct releases to the environment and the two waste categories mentioned. The final destiny of mercury in wastes depends highly on the national/regional waste treatment scenario and the emission reduction designs involved. See descriptions of these issues in the sections covering general waste incineration (section 5.8) and landfills/deposition (section 5.9).

1095. Note also that in the default mercury output distribution factors mentioned here, informal dumping or incineration of waste is quantified as direct releases to air, land and water, as relevant. Beware of double-counting, if estimates of mercury releases are also made separately for informal dumping or incineration of waste.

c) Links to other mercury sources estimation

1096. The estimated mercury outputs to municipal solid waste from this sub-category contributes to the mercury inputs to landfills/deposits (section 5.9) and municipal solid waste incineration (section 5.8).

*Table 5-145 **Preliminary** default mercury output distribution factors for use and disposal of mercury catalysed polyurethane wastes*

Phase in life cycle	Default output distribution factors, share of Hg input				
	Air	**Water**	**Land**	**General waste**	**Sector specific treatment/ disposal**
Manufacturing of polyurethane products	n.d.	n.d.	n.d.	n.d.	n.d.
Use and disposal (Actual waste management status in country) *1					
All or most general waste is collected and handled in a publicly controlled manner	0.1	0.05	?	0.85	
Missing or informal collection and handling of general waste is widespread.	0.2	0.1	0.4	0.3	

Notes: *1 Mercury inputs to disposal are the concentrations of mercury in polyurethane parts in the waste disposed. If annual supply data for a few years earlier are available, they can be used as approximations for disposed amounts, otherwise a steady state is assumed using the per inhabitant estimates

5.5.5.6 Source specific main data

1097. The most important source specific data would in this case be:

- Amounts of mercury used annually in domestic production of mercury catalysts for polyurethane production;
- Quantified releases of mercury from domestic production of mercury catalysts for polyurethane production; and
- Information on share of mercury-catalysed polyurethane products in national consumption of relevant product categories.

1098. Mercury catalysts are produced in a few production plants, if any in the country, and a point source approach to mercury release estimates from production is therefore recommended. Mercury consumption for domestic production and production output should be obtained by direct contact to manufactures, as production volumes most probably cannot be obtained from national production statistics.

5.5.6 Biocides and pesticides

5.5.6.1 Sub-category description

1099. Many mercury compounds are toxic to microorganisms, and mercury compounds have been used in biocides in paper industry (slimicides in the production - see section 5.3.2), in paints (discussed separately in section 5.5.6), and on seed grain and other agricultural applications. These uses have been discontinued or banned in many countries (UNEP, 2002).

1100. A major biocide use of mercury compounds have been seed dressing. The use of sow seed with mercury based seed dressing for bread baking was the cause of two severe mercury intoxication incidents in Iraq some decades ago (UNEP, 2002).

1101. In the former Soviet Union the production of the organomercuric pesticides was initiated in 1955 with a production of 5 metric ton/year reaching a maximum of 200 metric ton/year by 1960

(Lassen *et al*. 2004) The production in the Russian Federation has ceased, but it is estimated that in recent years 20-40 metric tons has annually been used from stocks (Lassen *et al.*, 2004). The main compound is ethyl mercury chloride with a mercury content of 1.9-2.3 % in the pesticide, but 14 different compounds have been applied as pesticides in the country.

1102. In Australia, a liquid fungicide product contains 120 g/l of mercury as methoxy-ethyl mercuric chloride to control pineapple disease in sugarcane sett. (UNEP, 2002)

1103. In India the use of organo-mercurial pesticides in 1999-2000 reported by the Directorate of plant protection was 85 metric tons (Wankhade, 2003). During the period from 1995 to 2000 no production, import or export was reported indicating that the consumed pesticides originate from stockpiles (Wankhade, 2003). Formerly a number of mercury-based pesticides were used in India, but today most are banned.

5.5.6.2 Main factors determining mercury releases and mercury outputs

Table 5-146 Main releases and receiving media during the life-cycle of biocides and pesticides with mercury

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Production	?	?	?	**X**	?	?
Use (pesticides)	**X**	**X**	**X**		x	x
Disposal		x	**X**		x	**X**

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation;
? - Releases may occur, but no data are available on this aspect.

1104. No data are available as regards the possible mercury releases from production of mercury based biocides.

1105. For the biocide/pesticide use, the most important factors deciding the releases are the mercury concentration in the used products, and the way these products are applied. As pesticides may have been a domination use (besides paints - see section 5.5.6), the indications of release pathways inTable 5-146 refer to this use. While the majority of the product in use will end up on land, some will likely end up in water through disposal of unused amounts, washing of the equipment used, leaching to ground water and runoff with surface water. Unused product, including stocks of obsolete pesticides, may be lost diffusely or disposed of with normal waste or through special disposal programs.

5.5.6.3 Discussion of mercury inputs

Table 5-147 Overview of activity rate data and mercury input factor types needed to estimate releases from biocides and pesticides

Life-cycle phase	Activity rate data needed	Mercury input factor
Pesticide use	Amount of pesticides used	Mercury concentration in the used pesticides

1106. Besides the data given above, no data were found on mercury concentrations in pesticides and other biocide uses than paints and pharmaceuticals (see sections 5.5.6 and 5.5.7, respectively).

5.5.6.4 Examples of mercury in releases and wastes/residues

1107. In some countries significant amounts of obsolete pesticides are stored in farm house and warehouses under inadequate conditions.

1108. In the Russian Federation, the amount of mercury containing pesticides stored in warehouses (except landfills) and requiring destruction or storage at the special landfills is supposed to exceed 1,000 metric tons containing about 20 metric tons of mercury (Lassen *et al.,* 2004).

5.5.6.5 Default input factors and output distribution factors

1109. Due to lack of data, no default factors were defined for this source category. Collection of specific data is recommended in countries where pesticide/biocide use takes place. The default output distribution factors pre-entered in the IL2 spreadsheet for production were based on limited data available for thermometers and batteries, assuming some similarities in mercury handling, etc.

5.5.7 Paints

5.5.7.1 Sub-category description

1110. Phenyl mercuric acetate (PMA) and similar mercury compounds were formerly widely added as biocide to water based paints and may still be used in some countries. These compounds were used to extend shelf-life by controlling bacterial fermentation in the can (in-can preservatives) and to retard fungus attacks upon painted surfaces under damp conditions (fungicides).

1111. In the USA the use of mercury biocides in paint ended in 1991. In the USA before the ban in 1991, mercury compounds were used in 25 to 30 % of all interior latex paint (it was not used in oil based paint), and in 20 to 35 % of outdoor latex paint (Heier, 1990).

1112. For the Global Mercury Assessment (UNEP (2002) Thailand reports that less than 25% of the paint factories in Thailand still use mercury as an additive in the process and in quantities of not more than 0.5 % of total weight. It is probable that mercury is used as preservative in paint in other countries, but the status of mercury-based paint manufacture and use in other countries is uncertain.

1113. Also, inorganic mercury compounds of very low solubility were formerly used as additives in marine coatings and paints to prevent fouling of boat hulls by bacteria and other marine organisms. This use had largely been discontinued by the mid-1970s (US DOC, as cited in NJ MTF, 2002).

5.5.7.2 Main factors determining mercury releases and mercury outputs

Table 5-148 Main releases and receiving media during the life-cycle of paints with mercury

Phase of life cycle	**Air**	**Water**	**Land**	**Products**	**General waste**	**Sector specific treatment/ disposal**
Production ***1**	x	x	x	**X**	x	x
Use	**X**	x			x	
Disposal					x	x

Notes: *1 Mercury releases from production of paints and their ingredients may likely take place, but no data are available to describe such releases. The releases in the use phase are likely much higher, because most of the mercury compounds used is expected to follow the produced paints;

X - Release pathway expected to be predominant for the sub-category;

x - Additional release pathways to be considered, depending on specific source and national situation.

1114. No data are available to describe the potential mercury releases from production of paints.

1115. Some studies suggest that when mercury-containing paints were applied, the painted surfaces released elemental mercury to the air (US EPA, 1992 and Agos *et al*., 1990). NJ MTF (2002) reports that air is the major receiving media of these releases (NJ MTF, 2002). The half-life of mercury in these paints has been estimated to be about 1 year i.e. that half of the mercury content is released each year (NJMTF, 2002). Releases from paints in the USA (and possibly other countries) were significant until recent years. About 227 metric tons of PMA and other mercury compounds were used per year in paints in the USA between the mid 1960s and 1991. Assuming that all of the mercury used in these paints is eventually released to the environment, and that the half-life is roughly 1 year, one can estimate that from the late 1960s to early 1990s, roughly 227 metric tons of mercury were released per year in the USA to the environment from these paints. However, given the relatively short half life of these paints and since the use was stopped in 1991, today releases from this source in the USA are expected to be rather low. (See NJ MTF, 2002 for more discussion and analysis on this issue).

5.5.7.3 Discussion of mercury inputs

Table 5-149 Overview of activity rate data and mercury input factor types needed to estimate releases from paints with mercury

Life-cycle phase	Activity rate data needed	Mercury input factor
Use and disposal	Consumption of mercury containing paint in metric tons per year	Mercury concentration in the used paints; g mercury per metric tons of paint

1116. The most important data needed to estimate releases from paints would be data on concentration of mercury in the paints used, amount of paints used, time (what years) these paints were used, and an indication of how quickly mercury is released from the applied paints (for example the half-life of mercury in the paints). Also, it is very useful to know what year the use of these paints ended, if so, in the country under study.

1117. The information on actual concentration of mercury in paints is scarce. Before the ban in 1991 the US EPA permitted interior latex paint to contain less than or equal to 300 ppm (0.03%) elemental mercury and exterior latex paint to contain less than or equal to 2000 ppm (0.2%; MMMW, 1990) The actual concentration varied. Husar and Husar quote an assessment reporting interior latex paint mercury concentration of 45 ppm, and exterior paint concentrations of 1,050 ppm based on interviews of US paint companies in 1990s (Husar and Husar, 2001).

1118. In a reported incidence of mercury poisoning in 1989 in the US, the walls were painted with latex paint containing 930-955 ppm mercury. (MMWR, 1990).

1119. From Australia Alphen (1998) reports about a paint additive containing 37 g Hg/L; added to paint at the recommended rate of it would result in 460 mg Hg/L (Alphen, 1998). Alphen further report that paints having in excess of 300 ppm mercury had been encountered in a limited survey of South Australian paints. As mentioned above, Thailand reports that less than 25% of the paint factories in Thailand still use mercury as an additive in the process and in quantities of not more than 5000 ppm (0.5%) by total weigh. In Costa Rica, the regulation on the content of lead and mercury in paints sets a maximum limit of mercury in paints to 50 ppm (0.005 %) (UNEP, 2002).

The market in 2019

1120. Phenylmercury acetate is a well-known pesticide/biocide and the use of the compound is by COWI and Concorde East/West (2008) indicated as "bactericide, fungicide in paints". According to the questionnaire response from Italy for that study, 4.4 tonnes phenylmercury 2-ethylhexanoate was used as biocide in the production of paint in Italy in 2006 (COWI and Concorde East/West, 2008). As the mercury containing biocides are not included in the Review Programme under the Biocide Directive, they should have been phased out by September 2006 and the mercury containing biocides are no longer allowed on the European market.

1121. A company from India, Indian Platinum Private Limited (2019) is selling phenyl mercuric acetate that can be used as preservative in paints, as disinfectant and in other applications.

1122. The Modern Technology of Paints, Varnishes & Lacquers (2nd Edition, 2007) (Asia Pacific Business Press Inc.) is describing in the chapter "Metallic soaps as fungicides" the use of mercury naphtalenate as fungicide and very efficient even in solutions containing only 0.1-0.25% of mercury. However, it is mentioned that due to high toxicity and consumer resistance, neither elemental mercury nor mercury naphtalenate has been widely used. The same publication mentions in the chapter marine coatings that toxins like oxide of mercury are used to retard the growth of marine flora in antifouling paints. The proportion of toxic ingredients are 1 lb to a gallon of material.

1123. Thailand's Thai Industrial Standard for Alkyd Enamel Paints (TIS 2625-2557), issued on January 29, 2016, requires that all enamel paints manufactured or sold in Thailand and used for construction and decorative purposes must contain no more than 0.01% (100 ppm) lead, mercury and cadmium (dry weight) and must not exceed 0.1% (1,000 ppm) hexavalent chromium (dry weight). The regulation took effect in January 2017.

5.5.7.4 Examples of mercury in releases and wastes/residues

1124. By the application of the paints a minor part of the paint will be discharged with waste water by cleaning of the equipment and a part remaining in the cans will be disposed of with solid waste. Bass (2001) estimate that about 5 % is discharged with waste water, 3% ends up in municipal solid waste while the remaining 92% is emitted to air from the paint after application.

1125. With a reported half-life of one year almost all mercury will be emitted from the paint.

5.5.7.5 Input factors and output distribution factors

1126. Due to lack of data, no default factors were established for production of paints and their ingredients. If no local output distribution data are available, the default output distribution factors pre-entered in the IL2 spreadsheet for production can be used. They were based on limited data available for thermometers and batteries, assuming some similarities in mercury handling, etc.

1127. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default input and distribution factors are suggested for paint use, in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows.

1128. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

a) Default mercury input factors

1129. Actual data on mercury levels in the paints used will lead to the best estimates of releases.

1130. If no other indications are available on the mercury concentration in the paints, a first estimate can be formed by using the default input factors selected in Table 5-150 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor is expected to result in a high end estimate.

Table 5-150 ***Preliminary*** *default input factors for mercury in paints*

Material	Default input factors; g Hg/metric ton paint; (low end - high end)
Paints with mercury based biocides	300 - 5000

b) Default mercury output distribution factors

1131. The default mercury output distribution factors for paint use are based on the estimates of Bass (2001) as described above.

Table 5-151 ***Preliminary*** *default mercury output distribution factors for use of paints*

Phase in life-cycle	Default output distribution factors, share of Hg input				
	Air	Water	Land	General waste	Sector specific treatment/ disposal *1
Use of paint (application and when applied)	0.92	0.05		0.03	

c) Links to other mercury sources estimation

1132. No links suggested.

5.5.7.6 Source specific main data

1133. The most important source specific data would in this case be:

- Mercury concentrations in mercury-containing paints used; and
- Amounts of mercury-containing paints used annually.

5.5.8 Pharmaceuticals for human and veterinary uses

5.5.8.1 Sub-category description

1134. Mercury has been used in various pharmaceuticals such as vaccines, eye drops, some herbal medicines and other products, functioning mainly as preservatives (COWI, 2002). For example, thimerosal/thiomersal (ethyl thiosalicylate) has been used for decades in vaccines to prevent growth of various pathogens. The use of mercury in vaccines and eye drops and some other pharmaceuticals has decreased significantly in recent years (UNEP, 2002). However, the production and use still occurs, also in Western countries. Releases may occur during production, use and disposal of these products (UNEP, 2002 and COWI, 2002).

1135. According to information submitted from the Australian government for the preparations for the 23rd session of the UN Environment Governing Council and the use in the Global Mercury Assessment (UNEP, 2002), there are a number of veterinary chemicals containing mercuric chloride (one product), phenyl mercuric nitrate (five products) and sodium ethlymercurithiosalicylate (97 products). In many of these products the mercuric compound is not the active ingredient (e.g. some vaccines contain small amounts of thiomersal – sodium ethylmercurithiosalicylate), and a "counter irritant" for horses contains mercuric chloride at 3 g/L and is used topically to treat leg injuries, soreness and musculoskeletal conditions.

1136. According to Skårup *et al.* (2003), mercury is still used as a preservative in certain vaccines used in Denmark; in about half of the influenza vaccines consumed, and in vaccine for "Japanese Encephalitis". The influenza vaccines contain 50 µg thimerosal per dose (vaccines are supplied as single dose units in Denmark, contrary to many developing countries). With this very small amount per dose, the total consumption of thimerosal (mercury compound), the total consumption with influenza vaccines in Denmark (ca. 5 million inhabitants) is below 20g mercury/year.

1137. The use of mercury compounds in vaccines may be much more prevalent in other countries, perhaps especially in developing countries and other countries where vaccines are supplied in multiple-dose units, and demands for preservatives may therefore be higher. Most likely, the mercury amounts used are, however, minimal compared to other mercury uses such as dental fillings, thermometers, blood pressure gauges, batteries, etc.

Table 5-152 Other examples of pharmaceuticals containing mercury.

Pharmaceutical/ mercury compound	**Reported use**	**Reference**
Thimerosal, $C_9H_9HgNaO_2S$	Preservative widely used in pharmaceuticals and vaccines	NIH, 2004
Phenylmercuric acetate, $C_8H_8HgO_2$	Preservative in pharmaceuticals	NIH, 2004
Phenylmercuric nitrate, $C_6H_5HgNO_3$	Preservative in pharmaceuticals	NIH, 2004
Mercurochrome	Treatment of cuts	SH, 2004

1138. Another major ancient use of mercury in pharmaceuticals was in medicals against syphilis. No records of present use for this purpose have, however, been encountered.

1139. Mercury in pharmaceuticals will be released through the body to waste water or land, and unused products may be disposed of as general or hazardous waste depending on prevalent waste management practices.

1140. No attempt was made to establish default input factors and output distribution factors for this sub-category.

5.5.9 Cosmetics and related products

5.5.9.1 Sub-category description

1141. Mercury has been used in skin lightening creams, soaps, and as preservatives in some eye cosmetics. These products are rare or non existent in some countries. The production and use has decreased significantly in the West over the past decades. However, in other countries production and use continue. Releases may occur during production, use and disposal of these products (UNEP, 2002 and COWI, 2002).

5.5.9.2 Main factors determining mercury releases and mercury outputs

Table 5-153 Main releases and receiving media during the life-cycle of cosmetics and related products with mercury

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Production	?	?		X	?	
Use		X				
Disposal					x	

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation;
? - Releases may occur, but no data are available on this aspect.

5.5.9.3 Discussion of mercury inputs

Table 5-154 Overview of activity rate data and mercury input factor types needed to estimate releases from cosmetics and related products with mercury

Life-cycle phase	Activity rate data needed	Mercury input factor
Use	Metric tons of mercury-containing cosmetics used	g mercury per metric tons cosmetics used

1142. The soap and cream is meant to be applied to the skin, then left to dry and left on overnight. The soaps contain up to 3% of mercury iodide (HgI_2) and the creams contain up to 10% ammoniated mercury (OECD, 1994).

1143. The use of skin lightening cosmetics is widespread in many African countries. Approximately 25% of 210 questioned women in Bamako, Mali, used skin bleaching agents (Mahe *et al*., 1993). Among these, 11% used mercury-added products; whereas 16% used agents of unknown composition. In Dakar, Senegal, 53% of 425 questioned women were current users of skin bleaching agent. Ten% of the product contained mercury iodide and 13% was of unknown composition (Guidice and Yve, 2002). In Lagos, Nigeria, 77% of 440 interviewed traders (women and men) used skin lightening cosmetics (Adebajo, 2002). Hydroquinolone based products were the most commonly used products, but cortico-steroids and mercury-based products were also widely used.

1144. In a survey of 536 women in Lome, Togo, mercury derivatives were the active ingredient in 31% of the used cosmetics. (Pitche *et al*., 1997). In Kenya fourteen types of toilet soap were collected in Kisumu and analysed (Harada *et al*., 2001). The analysed European-made soaps contained 0.47-1.7 % mercury (as mercury iodide) whereas the mercury content of the domestically made soaps was at trace content level. Glahder *et al*. (1999) report the analysis of mercury in three brands of soaps purchased in Tanzania. According to the declaration the soaps contained 2% mercury iodide. The analysed mercury content was 0.69% (as mercury); about 78% of the declared content.

1145. The use of mercury-containing cosmetics has in recent year been banned in many African countries and the widespread use of mercury containing cosmetics may today not take place in some of the countries mentioned above.

1146. The use if mercury containing skin-lightening soap may also take place in European countries, despite an EU wide ban of their use. The Danish EPA found in 2000 through a survey, 7 types of mercury-containing soaps marketed in Denmark (Danish EPA, 2000). The soaps contained 1-3 % mercury iodide.

1147. Formerly a significant amount of mercury was used in Europe for production of mercury containing cosmetics which was exported to other parts of the world. For example, Ireland imported 17 metric tons of mercury in 1999 for use in soaps, which were subsequently exported from the EU (Maxson, 2004). The production of mercury containing cosmetics was banned in 2003 under Annex 5 of EU Regulation implementing the Rotterdam Convention.

1148. Mercury biocides may be used in some eye cosmetics at very low concentrations.

1149. It has not been possible to identify estimates of the total consumption of mercury with cosmetics from any country. The use of mercury containing cosmetics is a health issue for people using these cosmetics. Accordingly, while release data for this use may be difficult to obtain, and will likely be small if estimated, the health implications for this use may warrant priority attention.

5.5.9.4 Examples of mercury in releases and wastes/residues

1150. It has not been possible to identify any assessments of the fate of mercury used in cosmetics. The main pathway is assumed to be releases to water when the cosmetics are removed by washing. A small part left in the tubes and containers may be disposed of with general waste.

5.5.9.5 Input factors and output distribution factors

1151. Due to lack of data, no default factors were established for production of cosmetics and their ingredients. For similar reasons, no default factors were established for other cosmetics than skin lightening products. If no local output distribution data are available, the default output distribution factors pre-entered in the IL2 spreadsheet for production can be used. They were based on limited data available for thermometers and batteries, assuming some similarities in mercury handling, etc.

1152. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default input and distribution factors are suggested for use of skin lightening creams and soaps, in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows.

1153. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

a) Default mercury input factors

1154. Actual data on mercury levels in the creams and soaps used will lead to the best estimates of releases.

1155. If no other indications are available on the mercury concentration in these cosmetics, a first estimate can be formed by using the default input factors selected in Table 5-155 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor is expected to result in a high end estimate (but not the absolute maximum).

Table 5-155 ***Preliminary*** *default input factors for cosmetics and related products containing mercury*

Material	**Default input factors; g Hg/metric ton cream/soap; (low end - high end)**
Skin lightening creams and soaps with mercury	10,000 - 50,000

b) Default mercury output distribution factors

1156. The following default mercury output distribution factors for skin lightening soap and creams are based on assumptions regarding use and disposal.

Table 5-156 ***Preliminary*** *default mercury output distribution factors for use and disposal of cosmetics containing mercury*

Phase in life-cycle	**Default output distribution factors, share of Hg input**				
	Air	**Water**	**Land**	**General waste**	**Sector specific treatment/ disposal**
Use and disposal of cosmetics with mercury		0.95	0.05		

c) Links to other mercury sources estimation

1157. No links suggested.

5.5.9.6 Source specific main data

1158. The most important source specific data would in this case be:

- Mercury concentrations in mercury-containing cosmetics used; and
- Amounts of mercury-containing cosmetics used annually.

5.6 Other intentional product/process uses

Table 5-157 Other intentional products/process uses: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Chapter	Sub-category	Air	Water	Land	Product	Waste/ residue	Main inventory approach
5.6.1	Dental mercury-amalgam fillings	x	**X**		**X**	**X**	OW
5.6.2	Manometers and gauges	x	**X**	x	**X**	**X**	OW
5.6.3	Laboratory chemicals and equipment	x	**X**		**X**	**X**	OW
5.6.4	Mercury metal use in religious rituals and folklore medicine	**X**	**X**	**X**	**X**	**X**	OW
5.6.5	Miscellaneous product uses, mercury metal uses and other sources	**X**	**X**	**X**	**X**	**X**	OW

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

5.6.1 Dental mercury-amalgam fillings

5.6.1.1 Sub-category description

1159. Dental amalgam fillings consist of an alloy of mercury, silver, copper and tin (typically about 44-51% mercury by weight). The alloy is typically supplied to the dentists either: 1) as pure mercury along with a powder mix of the other metals, which are weighed and mixed in an agitator in the clinic; or 2) as small capsules where mercury and the metal powder are present in the right formula and only need to be mixed (in the capsule before opening) in the clinic, prior to filling the cavity in the tooth (COWI, 2002). Other variants of the same principles may occur.

1160. Mercury is released to air, water, and wastes during the production, use and disposal of the amalgam fillings (such as following the removal of fillings or teeth containing fillings during medical/dental procedures, or through lost teeth). Also, releases can occur at the end of life of a person with fillings. For example, dental amalgams are a major factor determining mercury releases to air from crematoria (see section 5.10.1).

1161. In the dental clinic parts of the mixed amalgam filling is filled into the cavity, but there is always an unused rest, which is often collected for waste disposal or recycling (especially due to the silver value). Often the filling is adjusted in the surface which releases a little amalgam particles to the waste water system. Also at the routine renewal of amalgam fillings, the old filling is drilled out, and amalgam particles are lead to the waste water system. Often larger amalgam particles from such operations will be withheld in a mesh filter in the water suction system, from where they can be retrieved for waste disposal of recycling. In countries with strict waste water regulations for dental clinics, the clinics may have an additional central filter which is much more effective than the coarse mesh filter in retaining mercury amalgam from the waste water. In addition, teeth with amalgam fillings may be removed in the clinic, and disposed of as general waste or separately collected hazardous waste, or sent for recycling. In Denmark, and perhaps also in other countries, a substantial number of extracted teeth are sent to dental schools for the use in practical dentist teaching (Maag *et al.*, 1996; Skårup *et al.*, 2003).

5.6.1.2 Main factors determining mercury releases and mercury outputs

Table 5-158 Main releases and receiving media during the life-cycle of dental mercury-amalgam fillings

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal *1
Production/supply of materials for fillings				**X**		
Dental preparations and procedures at dental offices	x	**X**			**X**	**X**
Use (while in peoples mouths)		X				
Disposal		**X**			**X**	**X**

Notes: *1: Separate collection for treatment as hazardous/medical waste or for recycling;

X - Release pathway expected to be predominant for the sub-category;

x - Additional release pathways to be considered, depending on specific source and national situation.

1162. Releases of mercury could take place during processing/packaging of mercury and capsules at the producers/suppliers, but the releases may be minimal due to the simple processing. No emissions controls are known to be used in production in USA. Small fractions of mercury are released to air in the dentist clinic.

1163. The most important aspects influencing mercury releases from dental amalgam are as follows:

- The amounts of dental amalgam used per person (capita) in the country, reflecting both the general dental care standard in the population, and the extent of use of alternative dental filling materials (plastic composites, ceramics or cast gold crowns);

- The presence of modern high-efficiency amalgam filters in the dental clinics waste water system. If present, they may collect 90 - 99.9 % of the amalgam input to the waste water in the clinic. If only the coarse mesh filters (strainers) are used, most of the amalgam - perhaps 80 - 90% based on the Danish studies - is lost to the public waste water system (or released to the environment if no such system exists);

- The fate of amalgam waste (excess amalgam from new fillings, in collected filter material and in extracted or lost teeth). It may be collected separately for recycling or other treatment as hazardous/medical waste, or it may be disposed of with general waste to landfills, incineration or other waste treatment as prevailing in the country.

1164. Losses of mercury from fillings during use (while still in the mouth) are taking place continuously at very low rates. Until recently, these mercury outputs have been deemed negligible by some researchers, but a 2001 study from the capital of Sweden, Stockholm, indicated that about 44% of the total mercury inputs to waste water treatment originated from amalgam fillings in the mouth, while only about 21% of the total mercury inputs to waste water treatment originated from dental clinics (Sörme and Lagerkvist, 2002; Sörme *et al.*, 2003). The mercury release estimates from amalgam in the mouth of inhabitants were based on excretion rates of 60 µg/ (day*person) with faeces and urine (citing Skare and Engquist, 1994), and did not include contributions from food intake (Sörme and Lagerkvist, 2002; Sörme *et al.*, 2003). These results should be seen in the context that other mercury input sources to waste water are likely minimal in Sweden compared to many other places in the world (Sweden is perhaps one of the countries where mercury has been regulated most strictly for several decades).

5.6.1.3 Discussion of mercury inputs

Table 5-159 Overview of activity rate data and mercury input factor types needed to estimate releases from dental mercury-amalgam fillings

Life-cycle phase	**Activity rate data needed**	**Mercury input factor**
Production of ingredients	Mercury purchased for the production per year	Mercury loss per Kg mercury purchased for production
Preparations of fillings in the teeth at dentist clinics	Number of amalgam fillings made per year or National population	g mercury used for preparation of one amalgam filling or Estimated mercury consumption for amalgam fillings per capita
Use (while in peoples mouths)	National population	Estimated mercury excretion per capita per year
Disposal	Number of amalgam fillings made per year 10-20 years ago or National population	g mercury used for preparation of one amalgam filling or Estimated mercury consumption for amalgam fillings per capita 10-20 years ago

1165. Based on data from Denmark, depending on size and type of filling, about 0.4-1.2 g of mercury is used per filling on average, including excess amalgam; about 0.4 g mercury for a one surface filling and about 1.2 g for a filling on three surfaces of the tooth. Based on detailed Danish data on the types of fillings actually made, the average mercury consumption per filling is about 0.8 g Hg/filling (based on Maag *et al.*, 1996, and Skårup *et al.*, 2003). Similar quantities per filling may be used in other countries.

Table 5-135 Reported annual mercury consumption for dental fillings in selected countries, in total and per inhabitant ***1**

	Denmark, 1983	Denmark, 1993	Denmark, 2001	Sweden, 1991	Sweden, 2003	Norway, 1995	Norway, 1999	USA, 1996
Reported mercury consumption with amalgam fillings, Kg/year	3100	1800	1200	1700	103	840	510	31000
Population, millions ***2**	5.4	5.4	5.4	8.9	8.9	4.5	4.5	281
Annual mercury consumption with dental amalgam, g per inhabitant	0.57	0.33	0.22	0.19	0.01	0.19	0.11	0.11

Notes: *1 Denmark: Mercury amalgam has been gradually substituted for by other filling materials. Since 1994, amalgam fillings have been banned except for adult's molar teeth on surfaces with tough wear (Skårup *et al*., 2003). Sweden: In the early 1990's a quick shift towards alternatives made the amalgam consumption drop, since then the consumption has dropped more slowly (Kemi, 1998). Dental amalgam in Sweden and the reduction of the used amounts has declined significantly the last 5-6 years. In 1997 the sold amounts of mercury to dental amalgam was 980 kg and in 2003 it was 103 kg (Kemi, 2004). Norway: Norwegian Pollution Control Authority, as cited by Maag *et al*. (2001). USA: Mercury consumption for amalgam fillings reported as almost constant between 1980 and 1996 (Sznopek and Goonan, 2000);

*2 CIA'a World Fact Book (accessed 2003 at http://www.odci.gov/cia/publications/factbook/index.html).

1166. Rothenburg and Katz (2011) suggested that basing estimation of mercury inputs with dental amalgam on input factors as shown above in combination with population numbers only, might produce too high estimates for countries with lower dental restoration frequency than the developed countries mentioned above. They suggested to further adjust such mercury input estimates with a factor describing the number of dental personnel present in the country of interest, as compared to the number of dental personnel in the countries from which the mercury consumption per capita were derived. This adjustment was applied in Inventory Level 1 and can also be used in Inventory Level 2 if desired; see also Section 5.6.1.5 below. The latest available aggregated estimates of the number of dental personnel in most countries of the world are reported by the WHO (2006). Annex 8.4 to this Reference Report shows the WHO's estimates of the density of dental personnel per 1000 inhabitants. For a few countries, such estimates were missing, and approximations were made here as described in the Appendix notes. Some dental personnel data, in combination with WHO's description of the background for the estimates, indicate that reported dental personnel data for some countries may be vulnerable to reporting errors and estimation principles (in the context of this Toolkit). Reported dental personnel densities below the 20% percentile for non-OECD countries (i.e. some developing countries) were therefore replaced by the same 20% percentile in the appendix (see the appendix).

1167. Amalgam fillings typically have a lifetime of 10-20 years (for adult's teeth), which means that current mercury outputs due to disposal of “spent" fillings typically reflect consumption at about 10-20 years ago. NJ MTF assumed a half-life of about 15 years per filling (NJ MTF, 2002).

5.6.1.4 Examples of mercury in releases and wastes/residues

1168. In detailed Danish studies (Skårup *et al.*, 2003; Maag *et al.*, 1996) it was estimated that in Denmark about 60% of the consumed (new) amalgam is built into fillings, while about 25% is excess amalgam (a little more is mixed than used), and about 15% is sucked out of the mouth and goes to waste water (or to a filter) during the filling and shaping process. In the same study it was estimated, based on a mass balance approach, that about 70% of the mercury in old fillings were drilled out and went to waste water (or to waste via filters), while about 20% was extracted (mainly from adults) or lost (mainly from children) and went to waste, and about 10% remained with deceased people and was released to soil (cemeteries) or to the atmosphere (from cremation) (COWI, 2002). Regarding amalgam wastes following the waste water produced in the dental clinics, an estimated 80% of the dental clinics in Denmark have high efficiency central filters which can retain about 95% of the amalgam waste in the waste water, while the remaining 20% or so of the clinics are not assumed to have these filters (Skårup *et al.*, 2003). For the clinics which have coarse mesh filters only, and do not have high efficiency filters, it is roughly estimated that only 20 - 50% of the mercury in the waste water is retained in the filters and disposed of to hazardous waste, municipal waste or recycling (based on Skårup *et al.*, 2003, and their citations from Arenholt-Bindslev and Larsen, 1996).

1169. NJ MTF reports that tests of wastewater from dental offices in 6 US cities and one European city suggest that an average of about 0.1 g of mercury per dentist is released per day from dental offices (Bill Johnson, 1999, as cited in NJ MTF, 2002). However, the data indicate that the amount released by each dentist varies considerably (NJ MTF, 2002). A study in Massachusetts USA (MWRA, 1997) estimated that 0.06 - 0.34 g mercury is released per facility per day to wastewater (MWRA, 1997, as cited in NJ MTF, 2002).

1170. Some dental clinics have filters collecting varying fractions of the mercury in the clinic's waste water (up to about 95%). Excess amalgam and sometimes the filter fraction may be collected and processed to recover the silver. The amount of mercury discharged by a dentist office is dependent on various factors, including whether filters (or “chairside traps”) are used. One study reports that an average of 2 g mercury per dentist per day is discharged if no filtration is used (Drummond *et al.*, 1995, as cited in NJ MTF, 2002). If chairside traps are used, about 60 - 70% of the mercury is captured and does not get released to waste water (NJ MTF, 2002). Some facilities also use additional filter systems such as vacuum filters or air/water separators which collect additional, smaller mercury particles (NJ MTF, 2002).

1171. In NJ, the mercury-contaminated material captured by traps and other control devices is typically released in MSW or recycled (NJ MTF, 2002).

1172. The total amount of mercury used in the dental industry in the USA in 1995 was 32 metric tons (Plachy, 1996, as cited in US EPA, 1997a). A report by Perwak, *et al*. (1981) estimated that 2% of the mercury used in dental applications is emitted to the atmosphere (from the clinics). Using the 2% figure, 1995 mercury emissions were estimated to be 0.64 metric tons in the USA (US EPA, 1997a).

1173. There are slow releases of elemental mercury vapours throughout the lifetime of the filling, which can be released directly to air or wind up in human wastes (such as in urine and faeces) (Barr, 2001).

1174. In addition to the above mentioned, the mercury amalgams also lead to significant releases during crematoria (described in section 5.10.1) and in cemeteries (see section 5.10.2).

5.6.1.5 Input factors and output distribution factors

1175. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows.

1176. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

1177. Due to lack of data, no default factors can be set for the production and supply of the amalgam ingredients.

a) Default mercury input factors

1178. Actual data on number of amalgam fillings prepared annually will lead to the best estimates of releases. This number can be multiplied with average mercury amount used per filling: 0.8 g Hg/filling, as described above for the Danish situation.

1179. If no information is available on the number of amalgam fillings prepared annually, a first estimate can be formed by using the default input factors selected in Table 5-160 below (based on the data sets presented in this section). Because consumption vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum).

Table 5-160 ***Preliminary*** *default input factors for mercury use in preparation of dental amalgam fillings*

	Default input factors; g mercury consumed per inhabitant per year; (low end - high end)
Mercury used annually for dental amalgam preparations	0.05 - 0.2

1180. Note that if it is desired to use the default factors above in combination with adjustment for number of dental personnel in the country as described above in Section 5.6.1.3, it is recommended to use the high end default input factor (0.2 g mercury consumed per inhabitant per year), multiplied with the countries' estimated dental personnel density (as shown in Annex 8.4) and divided by the dental personnel density of Denmark. This approach is used in the Inventory Level 1 spreadsheet (automatically) and has been implemented as an option in the Inventory Level 2 spreadsheet as well (manually). Note that Annex 8.4 also includes population data for most countries of the World.

b) Default mercury output distribution factors

1181. The default output factors defined below are primarily based on the Danish data above, as they provide correlated input and output data sets and are based on detailed investigations.

1182. Note that the mercury outputs should calculated based on mercury inputs with dental fillings at different times (as shown in the table below) for the different life cycle phases of the amalgam fillings, due to the long lifetime of amalgam fillings. If the supply of mercury for preparation of dental amalgam fillings is known to have been relatively constant over the last 20 years, current supply data can be used as an input approximation.

1183. Because the waste disposal routines will vary much between countries, an artificial, even distribution among the waste types was chosen to raise the signal that significant mercury outputs may take place through both of these outputs. If more specific information is available regarding the waste management practices, individual adjustments can be made to the calculations. In countries with a general lack of special management practices for hazardous or medical wastes, the full output to waste should likely be allocated to "general waste".

Table 5-161 ***Preliminary*** *default mercury output distribution factors for dental amalgam*

Phase in life-cycle	Default output distribution factors, share of Hg input					
	Air	**Water**	**Land *1**	**Products 2***	**General waste *1**	**Sector specific treatment/ disposal *1**
Preparations of fillings in the teeth at dentist clinics (share of current mercury supply for amalgam fillings)	0.02	0.14		0.6	0.12	0.12
Use - from fillings in the mouth (share of mercury supply for *fillings* 5-15 years ago) ***3**		0.02				
Disposal - via clinics and households and death (share of mercury supply for fillings 10-20 years ago) ***4**:						
- in countries where most dental clinics are equipped with high efficiency amalgam filters (95% retention rate)		0.02		0.06	0.26	0.26
- in countries where only dental chair filters/strainers are used in most clinics		0.3	0.08	0.06	0.08	0.08

Notes:

*1 Because the waste disposal routines will vary much between countries, an artificial, even distribution among the waste types was chosen to raise the signal that significant mercury outputs may take place through both of these outputs. Sector specific treatment may be recycling, disposal as hazardous waste, or disposal as medical waste;

*2 For preparation of fillings: The actual fillings when in the teeth. For the disposal phase, the mercury re leased with "products" is the mercury remaining in fillings by the time of the persons death; this mercury will be released to cemeteries of via cremation.

*3 This is a very rough estimate of mercury release from dental fillings in the mouth based on the data from Sweden described above (based on Sörme and Lagerkvist, 2002; Sörme et al., 2003; and their citation of Skare and Engquist, 1994); the conversion from amounts in the mouth to Hg supply is based on the data from Denmark (see above) indicating that 60% of the supply of Hg for dental fill ings end up in the mounted fillings, while 40% is lost during the preparation of the fillings.

*4 The factors here reflect that only about 60% of the original supplies were built into the fillings when they were made.

c) Links to other mercury sources estimation

1184. No links suggested.

5.6.1.6 Source specific main data

1185. The most important source specific data would in this case could be some or all of the following:

- Data on total amount of mercury used in dental sector in the country, or
- Data on average amount of mercury used by each dentist per year;
- Data on percent of dentist clinics that use high efficiency amalgam filters;
- Average number of fillings per person in a country (as an indication of the general dental care standards; and
- Data on the distribution of dental amalgam wastes from dental clinics between general waste, and recycling, hazardous waste, or medical waste.

5.6.2 Manometers and gauges

5.6.2.1 Sub-category description

1186. Mercury is used in some blood pressure gauges, industrial and meteorological manometers, and pressure valves (UNEP, 2002). Blood pressure gauges are probably mainly supplied with mercury in the product. For pressure valves in district heating and educational uses the metallic mercury used is often supplied separately and not as integrated in the product. Mercury may be supplemented during the use period for all types mentioned. The mercury may be disposed of with the apparatus or separately. Non-mercury alternatives exist for all uses and are gradually substituting for the mercury-using equivalents in some countries (Maag *et al.*, 1996, as cited in COWI, 2002). It should be noted that quantification of mercury supplied separately for these uses may be difficult to distinguish from other metallic mercury consumption (COWI, 2002).

5.6.2.2 Main factors determining mercury releases and mercury outputs

Table 5-162 Main releases and receiving media during the life-cycle of manometers and gauges with mercury

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Production	x	x		**X**	x	x
Use	x	**X**	x			
Disposal					**X**	**X**

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

1187. Like for other products containing mercury, releases may take place: 1) from production of gauges/manometers supplied with mercury (to air, water and soil) depending on how closed manufacturing systems are, and on the workplace practices of mercury in the individual production facilities; 2) by breakage or loss of mercury from gauges/manometers (to air, water/waste water, soil) during use, and; 3) during disposal of the mercury with or without manometers/gauges/valves after their use (directly to soil or landfill and subsequently to water and air), depending on types and efficiency of the waste handling procedures (COWI, 2002).

5.6.2.3 Discussion of mercury inputs

Table 5-163 Overview of activity rate data and mercury input factor types needed to estimate releases from manometers and gauges

Life-cycle phase	Activity rate data needed	Mercury input factor
Production	Mercury supplied to production annually	Not relevant (= 1)
Use	Number of devices supplied annually	Amount of mercury in each type of device
Disposal	Number of devices disposed of annually	Amount of mercury in each type of device

1188. The product group is very diverse and a large number of different equipment exists. However, only scarce information has been available on the actual mercury content of the equipment. Examples of mercury content in manometer and gauges from different countries/regions are shown in the table below. The mercury content ranges from about 70 g in medical blood pressure gauges to several hundred kilos mercury in pressure valves for district heating plants.

Table 5-164 Examples of mercury content in manometer and gauges in g mercury per item by type and origin of data

Type of equipment	Mercury content in equipment (g Hg/item)	Country/region for data	Remarks
Medical blood pressure gauges	85	European Union	Floyd *et al.*, 2002
	70	Denmark	Skårup *et al.*, 2003
Manometers	up to 150	European Union	Floyd *et al.*, 2002
U-shaped manometers	70-140	Denmark	Maag *et al.*, 1996
Manometers for milking systems	354	Minnesota	MTAP, 2003
Manometers and barometers used for measuring air pressure	100 - 500	USA	US EPA, 2003c
Barometers	40-1,000	European Union	Floyd *et al.*, 2002
	590-2,200	Russia	Yanin, 2004
Environmental manometers	3,000	European Union	Floyd *et al.*, 2002
Pressure valves in district heating plants	100,000-600,000	Denmark	Maag *et al.*, 1996
Pressure gauges	211; 1683	Russia	Yanin, 2004

1189. **Other** manometers **and gauges with mercury:** Includes the remaining manometers and gauges within the category. A default input factor can be based on Floyd et al. (2001) assuming that approximately 2 metric tons of the quantity included in that report’s product group “other measuring equipment” would be “other manometers and gauges with mercury”. This corresponds to approximately 0.005 g Hg per inhabitant per year in the included European countries. Examples of mercury in releases and wastes/residues

1190. Mercury may be released from manometers and valves during use and it is often necessary to top up mercury. Mercury released from mercury valves, with several hundred kg mercury in each, in district heating plants is demonstrated to be significant sources of mercury to many municipal waste treatment plants in Denmark (Markmann *et al*., 2001).

The market in 2019

1191. An extensive research was conducted for selected mercury-added products for the 2019 Toolkit update, with a focus on products that had been poorly investigated in Minamata Initial Assessment studies due to difficulties in national data collection, including manometers, showed that mercury-filled manometers are readily available. A deeper analysis of the applications for the offered mercury manometers have not been performed for this update. Examples of marketed products are: Various U-shape manometers (and mercury to be used in them) marketed by Midland Scientific Inc., USA (2018). The same product types were marketed by Flowtech Measuring Instruments Private Limited, India (Indiamart.com, accessed 2018).

1192. It should be noted that marketing of mercury-added products for research purposes, as well as non-electronic measuring devices installed in large-scale equipment and for high precision measurements (with no suitable alternatives), are exempted from the restrictions of the Minamata Convention. This means that these products may likely continue to be available after the 2020 phaseout-date for the selected mercury added products in the Minamata Convention, and that the mercury-containing waste from such products needs to be collected and handled in an environmentally sound manner continually.

5.6.2.4 Input factors and output distribution factors

Medical blood pressure gauges (mercury sphygmomanometers): These manometers are suggested quantified separately as data on the sale of blood pressure gauges may be more readily available. Outputs are assumed distributed as for medical thermometers.

1193. If no information is available on the mercury content in the actual manometers and gauges used, a first estimate can be formed by using the default input factors selected in the table below (based on the data sets presented in this section).

1194. Note that these numbers refer to mercury-filled products only. When quantifying the annual supplies of pressure gauges, one should be aware that many non-mercury gauges are sold (electronic pressure gauges), so specific information on the supply of mercury-filled gauges is required.

Table 5-165 ***Preliminary*** *default mercury input factors for medical blood pressure gauges*

Product type	Mercury content (g Hg/item)
Medical blood pressure gauges	70-85

Table 5-166 ***Preliminary*** *default mercury input factors for other manometers and gauges*

Product type	Mercury consumption per inhabitant (g Hg/inhabitant)
Other manometers and gauges	0.005

Other manometers and gauges with mercury: Includes the remaining equipment within the category. A default input factor is derived from European experience as described in the Reference report to be approximately 0.005 g Hg per inhabitant per year. Outputs are assumed distributed as for medical thermometers.

1195. The default input factors are based on the consumption data from the developed countries and regions described above. In developing countries with substantial parts of the population with no access to electricity and thus presumably a lower prevalence of what could be broadly termed "technical installations", the prevalence of the mercury-added product types in question may also be lower, relatively to the developed countries from which the default input factors were derived. Note however, that mercury-added products are in many cases old technology, which are in the process of being substituted for by electronic solutions. In countries dominated by older technology, but with general access to electricity, the prevalence of mercury-added products may be as high as, or even higher than, in developed countries.

1196. Lower level of technical development can thus be adjusted for by multiplying the population number used in the calculations by the electrification rate as assessed by the IEA (multiply by electrification rate in percent and divide by 100 percent). IEA estimated electrification rates for selected developing countries from 2009 are shown in Annex 8.4. For countries with no IEA estimates, electrification rates were estimated here, based on the IEA data for neighbouring countries, or based on other knowledge about the regions in question (see details in the annex). This approach is used in the Inventory Level 1 spreadsheet (automatically) and has been implemented as an option in the Inventory Level 2 spreadsheet as well (manually).

1197. Note that Annex 8.4 also includes population data for most countries of the World.

b) Default mercury output distribution factors

1198. For both product sub-groups outputs are assumed distributed as for medical thermometers, in lack of more specific information.

1199. For the disposal, outputs are extremely dependent on the actual waste management practices in each of the sectors where mercury thermometers are used, and the default factor given below are simplifications meant to raise the signal that substantial mercury outputs may follow each of the noted pathways. Quantifications of the actual waste streams in each of the sectors in the country will give a more relevant picture of the mercury outputs from this products group. If no such specific quantitative data are available, the distribution factors given in the table below can be used.

1200. Note also that in the default mercury output distribution factors mentioned here, informal dumping or incineration of waste is quantified as direct releases to air, land and water, as relevant. Beware of double-counting, if estimates of mercury releases are also made separately for informal dumping or incineration of waste.

*Table 5-167 **Preliminary** default mercury output distribution factors for use and disposal of manometers and gauges*

Phase in life cycle	**Default output distribution factors, share of Hg input**				
	Air	**Water**	**Land**	**General waste**	**Sector specific treatment/ disposal *1**
Production *3	0.01	?	0.01	?	?
During use and disposal (actual waste management status in country): *2					
No or very limited separate mercury manometer collection. All or most general waste is collected and handled in a publicly controlled manner	0.1	0.3		0.6	
No or very limited separate mercury manometer collection. Missing or informal collection and handling of general waste is widespread	0.2	0.3	0.2	0.3	
Separate mercury manometer collection with high collection rates. All or most general waste is collected and handled in a publicly controlled manner	0.1	0.3		0.3	0.3

Notes: *1 Mercury recycling or special deposition, for example secured disposal in old mines;

*2 Mercury inputs to disposal are the amounts of mercury in the product types, combined with disposed amounts of the respective product types. If annual supply data for a few years earlier (for the same product types) are available, they can be used as approximations for disposed amounts;

*3 Outputs in share of mercury inputs to production in the country. If mercury amounts supplied to production can not be obtained, an approximation can be the amount of mercury in the produced products.

c) Links to other mercury sources estimation

1201. The estimated outputs to separately collected waste and municipal solid waste from this section contribute to the mercury input to landfills/deposits (section 5.9) and waste incineration (section 5.8).

1202. The estimated outputs for recycling from this section contributes to the mercury input to mercury recycling (section 5.7.1).

5.6.2.5 Source specific main data

1203. The most important source specific data would in this case be:

- Domestic production numbers for mercury-containing blood pressure gauges;
- Consumption of mercury-containing blood pressure gauges for the hospital sector, and medical doctors;
- Information on the prevalence of mercury containing manometers and pressure controls in industry, etc.; and
- Setup and efficiency of waste management systems in each of the sectors where mercury containing blood pressure gauges are used.

1204. See also advise on data gathering in section 4.4.5.

c) Links to other mercury sources estimation

1205. Mercury used in this sub-category may contribute to the mercury inputs to the waste water system, to general waste treatment, and to treatment of hazardous/medical waste.

5.6.3 Laboratory chemicals and equipment

5.6.3.1 Sub-category description

1206. Mercury is used in laboratories in instruments, reagents, preservatives, and catalysts. Some of this mercury is released to air, primarily through lab vents. However, most of the mercury may be released in wastewater or disposed of as hazardous waste or municipal waste.

1207. Examples of mercury containing laboratory equipment and laboratory chemicals are listed in the two following tables. For many of the chemicals the total use of mercury is most probably very low. Mercury may have been substituted in some of the equipment and for some of the mentioned analytical methods. Some standard analyses seem, however, difficult to substitute in practice - even though substitutes are in many cases available - because standards are there to improve reproducability of the analysis practices and therefore favour the well-known, and they are often also required in public regulation.

Table 5-168 Mercury containing laboratory equipment

Equipment	Reported use	Reference
Blood gas analyser	Mercury in reference electrode in Radiometer (brand) blood gas analyser	Floyd *et al*., 2001
Mercury electrodes (calomel)	Reference electrode in electrochemistry e.g. for pH measuring	Bjørnstad, 1992
Blood lead analyser	ESA (brand) Model 2020B lead analyser electrode	Floyd *et al*., 2001
Mercury drop electrode	Potentiometry	Bjørnstad, 1992
Coulter counter	Counting and measuring the size of microscopic particles. The mercury may be in a pressure gauge, on-off switch, timing count gauge, vacuum gauge, and possibly other gauges, depending on the model.	Bjørnstad, 1992; SH, 2004
Sample collector for oil offshore		Bjørnstad, 1992
Centrifuges	Older models may use mercury in balance cups	NIH, 2004
Electron microscope	Mercury used as vibration damper	NIH, 2004
Thermostats	Variety of applications	See section XX
Thermometers, manometers, and other measuring equipment	Variety of applications	See section XX, XX
Mercury lamps for atomic absorption spectrophotometers and other equipment	Variety of applications	See section XX

Table 5-169 Mercury containing laboratory chemicals

Reagent/ mercury compound	Reported use	Reference
Mercuric sulphate, $HgSO_4$	Chemical oxygen demand (COD) analyses In laboratory electrochemistry for creation of electrochemical chains. Flame photometer	Skårup *et al*., 2003 Lassen *et al*., 2004 NIH, 2004
Mercuric chloride, $HgCl_2$	Ingredient of Zenker's solution (72 g Hg/L) and B5 (37 g Hg/L); tissue fixative for pathology, histology Ingredient of Hayem's solution for red blood cell count For identification of tyrrol, for nephelometric determination of dimethyl sulphide, for quantitative determination of cysteine by potentiometer titration, and as catalyst for hydro halogenation	Floyd *et al*, 2002 Lassen *et al*., 2004
Mercury chloride, Hg_2Cl_2, calomel	For preparation of reference electrodes	Lassen *et al*., 2004
Mercuric oxide, HgO	Catalyst for detection of nitrogen in organic compounds using Kjeldahl method (other catalysts may be used as well) Harris hematoxylin	Skårup *et al*., 2003 NIH, 2004
Mercury sulphate, $HgSO_4$ or its mixture with $CuS0_4$ or $Se0_2$	Catalyst for detection of nitrogen in organic compounds using Kjeldahl method	Lassen *et al*., 2004

Reagent/ mercury compound	Reported use	Reference
Mercury oxides	Oxidizers in preparatory chemistry; for determination of acids titers; in laboratory organic synthesis; for obtaining of some nitrose compounds, hypochlorides, organic siloxanes; for preparation of reference electrodes.	Lassen *et al.*, 2004
Metallic mercury	In polarography based on the use of mercury or amalgam dropping or jet indicator electrodes; masking agent for quantitative determination of organic nitrates; determining fluoride purity and its concentration in gases; creation of new superconducting materials; development of new gas-discharge devices; mercury porometry (determination of porosity of various materials and substances); laboratory electrochemistry (mercury coulometry and electrochemical data converters); for preparation of reference electrodes.	Lassen *et al.*, 2004
Organic compounds of Hg	For determination of organic disulphide; in laboratory organic synthesis; in preparative chemistry	Lassen *et al.*, 2004
Nessler's reagent (alkaline solution $K_2[HgI_4]$	Bun Test Enzyme, non-protein nitrogen For detection and photometric determination of ammonia (NH3), for detection of alcohols and aldehydes, for identification (in paper and thin-layer chromatography) of hydro amino acids	NIH, 2004; Lassen *et al.*, 2004
Mercury iodide, HgI_2	Histology stain Masking agent for quantitative determination of organic nitrates; component of heavy liquids used in mineralogical analysis for distinction of minerals by density, - Tule fluid (water solution of HgI_2 + 2KI) and Shoushin-Rorbach fluid (BaI_2HgI_2 x nH_2O). For preparation of reference electrodes	SH, 2004; Lassen *et al.*, 2004
Mercury fluoride, Hg_2F_2	For preparation of reference electrodes	Lassen *et al.*, 2004
Mercury bromide, Hg_2Br_2	For preparation of electrolytes	Lassen *et al.*, 2004
Mercury dibromide. HgBr+	In laboratory electrochemistry for preparation of cathodes for concentrate current conversion	Lassen *et al.*, 2004
Water solutions $Hg(NO_3)_2$ or $Hg(ClO_4)_2$	As titrants for mercurimetry (titrimetric method of analysis of anions Cl^-, Br-, SCN^-, CN^-).	Lassen *et al.*, 2004
Water solutions, $Hg(NO_3)_2$	As a titrant in mercurometry (titrimetric method halogenides detection).	Lassen *et al.*, 2004
Mercuric nitrate, $Hg(NO_3)_2$	Determination of chlorides in blood Catalyst for synthesis of tetra-nitro-methane Parasitology Trichrome stain	Lassen *et al.*, 2004 NIH, 2004
Mercuric thiocyanate, $Hg(SCN)_2$	Analytical reagent in rodanometry and mercurimetry (also for determination of halogenides, sulphides, tiosulphides and cyanides)	Lassen *et al.*, 2004
Mercury fulminate, $Hg(ONC)_2$	Synthesis of aromatic ketones using Hoesh's reaction	Lassen *et al.*, 2004
Millon's reagent (solution $HgNO_3$ and $Hg(NO_3)_2$ in diluted HNO_3, containing admixture HNO_2)	Protein test (containing hydroxyl phenol group) Colour reaction for proteins and phenols	NIH, 2004; Lassen *et al.*, 2004

Reagent/ mercury compound	Reported use	Reference
Mercury acetate, $(CH_3COO_2)Hg$	Used in chinolisidine chemistry	Lassen *et al.*, 2004
$Hg(COOCH_3)_2$, $Hg(CN)_2$, HgO, $HgBr_2$	Catalysts in Koenigs-Knorr reaction (synthesis of glycosides and oligosarides)	Lassen *et al.*, 2004
Phenolic mercuric acetate	Ion selective electrode	SH, 2004
Methyl mercury hydroxide, CH_4HgO	Denaturant in single-strand conformation polymorphism (SSCP) analysis of PCR products, Gel electrophoresis, Protein precipitation	NIH, 2004
Takata's reagent	Takata-Ara	NIH, 2004

1208. The OECD mercury monograph (OECD, 1994) provides information on the use of mercury by category in 13 countries around 1990. Laboratory use accounted in total for all countries for 2.7% of the total mercury use. For the individual countries the share represented by laboratory use ranged from 0.2% in Belgium (in 1990) to 14% in Germany (in 1985).

1209. In the USA, mercury used for laboratory chemicals (reagents and catalysts) and laboratory equipment decreased from about 32 metric tons in 1990 to 20 metric tons in 1996 (Sznopek and Goonan, 2000). It is in the report roughly estimated that one third of total was used in laboratory instruments.

1210. In Denmark the use of mercury with laboratory chemicals has decreased from about 510 kg/year in 1982/83 (Hansen, 1985) to 20-40 kg/year in 2001 (Skårup *et al.*, 2003). The main reason for the decrease is the substitution of mercury for nitrogen analysis in organics using the Kjeldahl method which formerly accounted for the main part of the total. In 2001 mercury sulphate used for chemical oxygen demand (COD) analyses accounted for the major part of the mercury used with laboratory chemicals.

1211. COD analysis represented as well in France the major laboratory chemical use and it is reported that about 900 kg mercury was annually used for this analysis method only (AGHTM, 2000)

1212. Floyd *et al*. (2002) roughly estimate that 100-200 kg of mercury is used in chemical agents and hospital laboratory reagents in the EU (15) around year 2000. Considering 20-40 kg is used in Denmark alone the estimate seems, however, to be very low.

1213. According to Lassen et al. (2008) the EU27 consumption of mercury with laboratory chemicals and for product control in, the pharmaceutical industry in 2008 in the European Union was 3-10 tonnes corresponding to 0.006-0.02 g Hg/inhabitant. On this basis a default input factor of 0.01 g Hg/inhabitant can be calculated. This default factor can be used where no other data are available.

1214. In the European Union the main mercury use for other laboratory equipment is mercury in analysis of pose size characteristics (porosimetry and pycnometry) and hanging drop electrodes. Lassen et al. (2008) estimated the EU27 use of mercury in laboratories for porosimetry and pycnometry in 2008 at 10-100 tonnes while the use of for hanging drop electrodes was estimated at 0.1-0.5 tonnes. Later information indicated that the actual consumption for porosimetry and pycnometry is most likely in the lower end, and 20 tonnes will be used as best estimate. On this basis a default value for other laboratory equipment is estimated at 0.04 g Hg/inhabitant.

5.6.3.2 Main factors determining mercury releases and mercury outputs

Table 5-170 Main releases and receiving media from mercury use in laboratories

Phase of life cycle	Air	Water	Land	General waste	Sector specific treatment/ disposal
Mercury use in laboratories	x	**X**		**X**	**X**

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

1215. A small part of the mercury may be emitted to the air during use in the laboratories and released to the surroundings though air exhausters from fume hoods. The major part of the mercury will be disposed of with used agents. The fate of mercury depends on the systems for management of laboratory waste in the country. The waste may be disposed of for sector specific treatment, landfills or discharged though the drain to the sewer.

5.6.3.3 Discussion of mercury inputs

Table 5-171 Overview of activity rate data and mercury input factor types needed to estimate releases from laboratory chemicals and equipment

Activity rate data needed	Mercury input factor
Number/amount of mercury-containing devices or chemical reagents supplied per year	Amount of mercury in each type of devices or chemical reagents

5.6.3.4 Examples of mercury in releases and wastes/residues

1216. In 1994, an estimated 1.0 metric tons of mercury was emitted into the atmosphere in the USA from general laboratory use (US EPA, 1997b). An emission factor of 40 kg of mercury emitted to the atmosphere for each metric ton of mercury used in laboratories was used for the estimate. The emission factor was based on a relatively old assessment using engineering judgment and not actual test data. The factor is therefore considered quite uncertain.

1217. In the Russian Federation, laboratories are obligated to neutralize the mercury-containing wastes. In general the waste is then transported to landfills, but small laboratories may after neutralization discharge the reagent wastes in strongly diluted solution to the sewerage system (Lassen *et al.*, 2004).

5.6.3.5 Input factors and output distribution factors

1218. No ordinary default factors were defined for this source sub-category.

1219. However, for laboratory chemicals a preliminary default input factor can be based on current consumption in the European Union as described above. On this basis a default input factor of 0.01 g Hg/inhabitant can be calculated. This default factor can be used where no other data are available.

1220. For other laboratory equipment a preliminary default input factor can be based on current consumption in the European Union as described above. On this basis a default value for other laboratory equipment is estimated at 0.04 g Hg/inhabitant.

1221. The default input factors are based on the consumption data from the developed countries and regions described above. In developing countries with substantial parts of the population with no access to electricity and thus presumably a lower prevalence of what could be broadly termed "technical installations", the prevalence of the mercury-added product types in question may also be lower, relatively to the developed countries from which the default input factors were derived. Note however, that mercury-added products are in many cases old technology, which are in the process of being substituted for by electronic solutions. In countries dominated by older technology, but with general access to electricity, the prevalence of mercury-added products may be as high as, or even higher than, in developed countries.

1222. Lower level of technical development can thus be adjusted for by multiplying the population number used in the calculations by the electrification rate as assessed by the IEA (multiply by electrification rate in percent and divide by 100 percent). IEA estimated electrification rates for selected developing countries from 2009 are shown in Annex 8.4. For countries with no IEA estimates, electrification rates were estimated here, based on the IEA data for neighbouring countries, or based on other knowledge about the regions in question (see details in the annex). This approach is used in the Inventory Level 1 spreadsheet (automatically) and has been implemented as an option in the Inventory Level 2 spreadsheet as well (manually).

1223. As regards default output distribution factors, an equal distribution between output to water, general/municipal waste and sector-specific waste (hazardous waste and recycling) is set as default. This is because laboratories may often have stricter and more informed waste management protocols than in the general society. However, local data on the management of laboratory waste should be used, if possible, to reflect the actual distribution in the country in question.

1224. **Links to other mercury sources estimation** - It should be noted that mercury used in this sub-category may contribute to the mercury inputs to the waste water system, to general waste treatment, and to treatment of hazardous/medical waste.

5.6.4 Mercury metal use in religious rituals and traditional medicines

5.6.4.1 Mercury metal in traditional Asian medicines

Sub-category description

1225. Mercury-containing compounds are intentionally used in certain traditional Asian medicines, such as traditional Chinese and Tibetan medicines, Indian Ayurvedic and Siddha medicines and in Unani medicine practiced in Middle East and South Asian countries.

1226. Ayurvedic formulations are based on herbal products but often include intentionally added heavy metals as part of the *Rasa-shastra* practice. *Rasa-shastra* literally means the “Science of Mercury”. It is a specialized branch of Ayurveda dealing mainly with materials which are known as "*Rasa dravyaas*". The products dealt with under this discipline are an important component of Ayurvedic therapeutics. Mercury is mainly used in Ayurvedic medicines in the form of mercury sulphide (HgS) designated *Rasa-Sindoor*, an inorganic compound of mercury. More rarely, other inorganic compounds of mercury such as mercury(II) chloride are used. According to Saper et al. (2004) approximately 80% of the Indian population use ayurvedic medicine and the use in Western countries has increased.

1227. Mercury is also used extensively in Siddha medicine originating in Southern India (Gnanashanmugam et al., 2018). Metals and minerals are used more predominantly in Siddha medicines than in other systems such as Ayurveda (Gnanashanmugam et al., 2018). In Siddha medicines, mercury is used in five forms such as *rasam* (mercury), *lingam* (mercury sulphide), *veram* (mercury(II) chloride), *pooram* (mercury(1) chloride), and *rasa-chinduram* (mercuric oxide) (Gnanashanmugam et al., 2018).

1228. Unani (or yunani) medicine is a traditional medicine of Graeco-Arabic origin practiced in Middle East and South Asian countries (NIHFW, 2022). Mercury plays an important role in Unani medicine (Prechel, 2015).

1229. The Tibetan medical system is based upon Indian Buddhist literature and has some similarity with the other systems. It continues to be practiced in Tibet and other parts of China, Northern India, Nepal, Bhutan, Ladakh, Siberia, and Mongolia. Mercury sulphide is the dominant form of mercury in the preparations, but other mercury compounds could be present in substantial quantities, ranging from 2 to 52% of the total mercury content (Liu et al. 2018). Mercury is used in three distinct types of preparations (*Tsothel, Karthul,* and *Chokla*) that vary in their use and therapeutic range (Sallon et al., 2016).

1230. A list of Traditional Chinese Patent medicines in the 'Pharmacopoeia of the People's Republic of China' (English Edition, 1997) lists 43 different products containing one or more of these ingredients; these products are used for a wide variety of indications, including ulcers, insomnia, and epilepsy (as cited in UNEP 2007). Mercury in the form of mercury sulphide (e.g. in *Angong Niuhuang* pills), mercury chloride (e.g. in *Baijiang Dan pills* and *Shengji Yuhong Gao* paste) or mercury oxide (e.g. in *Zhuhong Gao* paste) is included in some traditional Chinese herbal preparations (Zhao and Wang, 2022). Most preparations are for ingestion, but some are for cutaneous application. Traditional Chinese medicine (TCM) is popular in Chinese and East Asian societies as well as some other Western countries and plays an active role in the modern healthcare system including patients with cancer (Wang et al., 2018).

Main factors determining mercury releases and mercury outputs

Table 5-172 Main releases and receiving media during the life-cycle of traditional Asian medicines.

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Production ***1**	X	?	?	X	x	
Use		X			x	
Disposal			?		x	

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

Production

1231. No detailed information is available on the releases from the production of traditional Asian medicines as practiced today.

1232. The traditional process of production of Ayurvedic preparations with mercury is described in detail by Pradash (2013). The applied methods would certainly result in very significant releases of mercury to the air and waste, but no mass balance for the entire process is provided. Repeating distillation of the mercury is an important step, and the mercury is as reported distilled 7 times with copper and 7 times with different herbs. It is reported that the traditional method using a simple open bowl (*Kanduk Yantra*) gave 10 g of mercury from initial 1 kg. With an improved method using a *shivalingam*-shaped mercury distillation plant less than 10 g of mercury was lost per kg of mercury used (1% lost) (Pradash, 2013).

Use and disposal

1233. According to Liu et al. (2018) more than 99% of the ingested mercury in traditional Tibetan medicine is excreted to wastewater with less than 0.5% present, partly as methyl mercury, is accumulated in the human body. As the chemical form of mercury is quite similar in the different forms of traditional medicines is will here be assumed that 100% of the ingested mercury in all the types of medicines is excreted to wastewater.

1234. Likely a small part of medicines are not used but disposed of with general waste.

Discussion of mercury inputs

Table 5-173 Overview of activity rate data and mercury input factor types needed to estimate releases from production and use of traditional Asian medicines

Life-cycle phase	Activity rate data needed	Mercury input factor
Production	Total quantity of traditional medicines produced by type	Kg of mercury used per tonne of traditional medicines produced by type
Use	Total quantity of traditional medicines used	kg mercury per tons traditional medicines consumed by type
Disposal	Total quantity of traditional medicines used	kg mercury per tons traditional medicines consumed by type

Notes: *1 If not available the total amount of mercury may be estimated by use of default factors for mercury per product of each type or an average for all types.

Production

1235. Mercury levels in various types of traditional Asian medicines is reviewed below for development of default input factor for the use phase. The input for production would need to further take into account the released to the environment and waste from the production processes. Using traditional techniques, these releases could be quite significant, but no data have been available regarding the techniques used at modern production sites. It is however assumed similar to the abovementioned, indicating a possible loss of about 1% to the air and, assuming economic handling of mercury, 0,04% loss to general waste (mostly produced in countries with minimal hazardous waste collection systems).

Use and disposal

1236. Mercury is intentionally added to certain types of traditional Asian medicines, but the available studies of mercury content of the medicines typically have analysed more randomly sampled medicines.

1237. Balla and Pannu (2022) found detectable levels of mercury in 29 of 42 ayurvedic preparations from the local market of Chandigarh, India. The median mercury concentration was 14 mg/kg with a range from 0.00 to 61,095 mg/kg (average not reported). A study of 230 randomly selected US-manufactured and Indian ayurvedic preparations purchased via the Internet found significantly higher prevalence of heavy metals and mercury concentrations in *Rasa-shastra* medicines compared to other ayurvedic preparations (Saber et al., 2010). *Rasa-shastra* compared with *non-rasa-shastra* medicines had a greater prevalence of mercury (9.4% vs 3.2%) and higher median concentrations of mercury (20,800 mg/kg vs 35 mg/kg in medicines with detectable Hg concentration). The median value of all preparations with detectable mercury (4.1% of all products) was 103.8 mg/kg (Saber et al., 2010). Saber et al. (2004) detected mercury in 6 out of 70 ayurvedic medicines from Asia sold in the USA. The median concentration of the 6 medicines with mercury was 20,225 mg/kg. Mikulski et al. (2017) found mercury in 97 of 252 samples of ayurvedic medicines from India with a median value of 50 mg/kg and a range of 0.8 - 279,000 mg/kg (average not reported).

1238. Martena et al. (2009) analysed 292 traditional medicines used in Ayurveda, traditional Chinese and traditional Tibetan medicine sold on the Dutch market. Mercury was found in 131 of the products (45%) in levels from 0.2 up to 171,000 mg/kg (17%) and the highest concentration was found in the Ayurvedic medicine *yogendra ras*. The average mercury level in the positive samples was 11,800 mg/kg, the median level was 50 mg/kg and the 95th percentile was 86,000 mg/kg. The prevalence of medicines with detectable mercury was higher in the traditional Tibetan medicines (75% of samples) as compared with the ayurvedic (48%) and the traditional Chinese (19%). The average concentration of all analysed samples can be estimated at 5,300 mg/kg (0.53%), but the data do now allow for estimating the average for each type of medicines.

1239. A quite similar average concentration has been demonstrated in a study of traditional Tibetan medicine. According to (Liu el al., 2018a), there are seven commonly used types of traditional Tibetan medicine, which are produced by 8 major factories. Liu el al. (2018) analysed three pills from each type in triplicate. The average concentration in the products was 5,600 ± 3,900 mg/kg (s.d.). The range was 24 - 12,000 mg/kg and the authors note that the range was within the ranges reported by other studies of traditional Tibetan medicines. Approximately 96 % of the mercury in the medicines was in the form of α–HgS. The concentration of methyl mercury was in the range of 0.022 to 37 mg/g and accounted on average for 0.29% of the mercury in the medicines. Liu et al. (2018a) estimate the total intake of mercury in the population of Tibet Autonomous Region, China at 4.5 tonnes primarily with traditional medicines, but indicate that the number is uncertain as no statistics on the market volume for the medicines is available. Another study by Liu el al. (2018b) found that HgS was not the exclusive form of mercury in the analysed medicines and that other forms could take up from 2 to 52% of the total mercury in the medicines.

1240. Mino and Yamada (2005) analysed 45 traditional Chinese medicines purchased at Chinese and Japanese markets. A high mercury concentration in the range of 1.2 - 15% was detected in 14 of 34 samples from the Chinese markets while it was not detected in 11 samples from Japanese markets. The average of all 45 samples can be estimated at 2,100 mg/kg (2.1%). High concentrations of up to 13% mercury in some types of traditional Chinese medicines has also been reported from the UK (GPW, 2005).

1241. Nepal reports in its Minamata Initial Assessment (MFE, 2019) that 11 manufactures in the country produce ayurvedic medicine, and that one of these manufacturers store 30 kg of liquid mercury and 110 kg mercury sulphide. It is further indicated that 3,515 tons of "homoeopathic medicaments, including pure Ayurvedic and Yunani" was imported during the reference year but no data on mercury content is available. If these medicines on average contained 0.5% mercury (as estimated above for three types of traditional medicines) it would correspond to 18 tonnes; illustrating the potential significance of this application even it may possibly be overestimated here.

Input factors and output distribution factors

1242. Actual data on mercury used to produce traditional medicines and knowledge on the mercury content of produced medicines will lead to the best estimates of inputs and releases.

a) Default mercury input factors

1243. If no other indications on the total mercury consumption for production of traditional medicines are available, a first estimate can be formed by using the default input factors selected in Table 5-150 below. Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor is expected to result in a high end estimate.

Table 5-174 ***Preliminary*** *default input factors for use of traditional Asian medicine*

Material	Default input factors; kg Hg/metric ton of traditional medicine; (low end - high end)
Traditional medicine types of Asian origin (all types)*1	0.2 - 2.0 (0.5)

Note *1: Note carefully that the activity rates for use and disposal refer to ALL MEDICINES of the following types, and not only those known to contain mercury or its compounds: Traditional Chinese medicines; traditional Tibetan medicines, Indian Ayurvedic and Siddha medicines, Unani medicines (Middle East and South Asia).

The input factor is derived based on averages of mercury concentrations in all medicines of the relevant types, mercury-containing or not (this is an exception to the general principle of the Toolkit).

b) Default mercury output distribution factors

1244. The default mercury output distribution factors for traditional Asian medicines.

Table 5-175 ***Preliminary*** *default mercury output distribution factors for traditional Asian medicines*

Phase in life-cycle						
	Air	**Water**	**Land**	**Products**	**General waste**	**Sector specific treatment/ disposal**
Manufacture of traditional Asian medicine*	0.01	?	?	x	0.04	?
During use and disposal		0.95			0.05	

c) Links to other mercury sources estimation

1245. No links suggested.

5.6.4.2 Source specific main data

1246. The most important source specific data would in this case be:

- Mercury content (preferably by type) of traditional Asian medicines
- Quantity of traditional Asian medicines (preferably by type) produced and used annually.

5.6.4.1 Mercury use in homeopathic medicines

1247. The overall principle behind homeopathic remedies is, that their effects are perceived to occur on a “vibrational” (sensing) basis, rather than the chemical interaction basis that is used in allopathic medicine. In homeopathy, toxics with well known symptoms are administered at very low concentrations to patients experiencing similar symptoms due to various somatic (physical) or psychological disorders; the principle being that the human body and mind will react positively to ease or cure those underlying disorders.

1248. It is evident from descriptions of homeopathic remedies based on metal mercury and mercury compounds that the homeopathic medicine producers and practitioners a fully aware of the toxic effects of mercury, and this is described explicitly on their websites.

1249. Several of the internet sources consulted claim that in the remedies, the classic (chemical) hazardous characteristics of mercury are not present. Some mention that no trace of the actual mercury is left (or similar wording) due to dilution. The mercury used does however remain in the remedies (Allergica, 2022).

1250. The toxics used, including mercury and some of its compounds (see below) are diluted, using very specific procedures, with water or other media to concentrations levels typically from 10-5 (10 ppm = g/metric ton level, called “D5”) to 10-12 (“D12”) or higher.

1251. Classic homeopathic remedies are internationally traded commodities, but they may in principle also be prepared locally with simple means, yet very specific procedures.

1252. Many homeopathic remedies prepared on the basis of mercury are in use (Hahnemann (1869), NativeRemedies (2022), Homeo book (2002), Elma Skin Care (2022), International Academy of Classical homeopathy (2022), Materia Medica by John Henry Clarke (2022). Some often mentioned examples are listed below. The remedies shown in italic font below are mentioned as much used:

- *Mercurius solubilis, based on metal mercury dissolved in nitric acid ("Merc. Sol")*
- *Mercurius vivus, based on metallic mercury diluted with lactose powder ("Merc. Viv.")*
- Mercurius corrosivus, based on mercury chloride ("Merc. Cor.")
- Mercurius dulcis, mercurous chloride (calomel; "Merc. Dulc.")
- Cinnabaris, (cinnabar, HgS)

Main factors determining mercury releases and mercury outputs

Table 5-176 Main releases and receiving media during the life-cycle of mercury use in homeopathic medicine

Phase of life cycle	**Air**	**Water**	**Land**	**Products**	**General waste**	**Sector specific treatment/ disposal**
Production		**?**		**x**	**?**	**x**
Use		**x**	**?**		**x**	

Discussion of mercury inputs

1253. The mercury concentrations can be determined on the basis of the level of dilution of the remedies in questions, as shown in Table 5-177.

1254. As mercury's toxicity is well known to producers of homeopathic remedies, it is assumed that the mercury losses during production will be marginal, and likely only related to accidents. With the lack of actual data, all mercury used is here assumed to end up in the products. However, inventory developers may wish to request data on production losses from any national producers.

Table 5-177 Examples of mercury concentrations in homeopathic remedies – examples D6. Input factors for other dilution levels: D5, D7, D8, D9, D10, D11, D!2, etc. can be deduced from these data as every D step equals a factor 10 dilution (based on Allergica (2022) and stoichiometric formulas)..*

Product type	**Mercury content (mg Hg/kg)**
Mercurius solubilis, diluted with water (and nitric acid in 1st step and alcohol in last step) ("Merc. Sol"):	
D6	1
Mercurius vivus, diluted in lactose powder ("Merc. Viv."):	
D6	1
Mercurius corrosivus, mercury chloride diluted with water and alcohol in last step ("Merc. Cor.")	

D6	0.74
Mercurius dulcis, mercurous chloride/calomel diluted in water and alcohol in last step (“Merc. Dulc.”):	
D6	0.85
Cinnabaris, diluted in water and alcohol in last step	
D6	0.86

Notes, *: So, as D6 is 1ppm (or 1mg/kg), D5 would be 10 mg/kg, and D7 would be 0.1 mg/kg, and similarly.

Examples of mercury in releases and wastes/residues

1255. No data have been found on mercury releases from production of homeopathic remedies based on mercury or its compounds.

1256. Losses from use of the remedies are assumed to be primarily to water releases through urination.

Input factors and output distribution factors

1257. If no other indications on the total mercury consumption for production of homeopathic medicines are available, a first estimate can be formed by using the default input factors selected in Table 5-150 below. Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category.

1258. Input factors by dilution step (D) can be deduced from the values in Table 5-177.

b) Default mercury output distribution factors

1259. The default mercury output distribution factors for homeopathic medicines.

Table 5-178 ***Preliminary*** *default mercury output distribution factors for homeopathic medicines*

Phase in life-cycle						
	Air	**Water**	**Land**	**Products*1**	**General waste**	**Sector specific treatment/ disposal**
Manufacture of homeopathic medicine	?	?	?	x	?	0.05
During use and disposal		0.95			0.05	

5.6.4.2 Mercury use in religious rituals and other traditional medicines

1260. Mercury is used in certain cultural and religious practices and folklore medicine in many countries. A number of practices exist that use mercury, including: *Santería* (an Afro-Hispanic belief system), *Palo Mayombé* (Caribbean), *Candomblé* (Afro-Brazilian), *Voodoo* (Afro-Haitian), *Espiritismo* (Puerto Rican), and *Yoruba Orisha* (Afro-Hispanic). Most of these uses are associated with African roots, and many of them are related the Roman Catholic teachings of Spaniards (UNEP, 2007). Mercury use in religious practice is also reported from India, South Africa, Lesotho and Romania. Very limited information on quantities used for the practices are available.

1261. *Santeria* is an Afro-Hispanic belief system. The use of mercury for *Santeria* and other spiritual practices has been reported in the Dominican Republic, Cuba and other Caribbean islands, Suriname, Belize, Trinidad, Jamaica, Peru, Ecuador, Argentina, Brazil, Colombia, Mexico, Venezuela, Guyana, France, the Netherlands, and Puerto Rico (Wendroff, 1991 as cited by UNEP 2007). Furthermore, the number of followers of *Santeria* and similar religions in the United States, was estimated to be 0.5-5 million (Mazur, 2011). In a study in one community in Massachusetts, 38% of 898 respondents said they or someone they knew had used mercury for religious, spiritual, or health purposes (Mazur, 2011). Mercury is used in a variety of ways that pose a poisoning risk to users. Examples of uses identified in *Santeria* are: Swallow a capsule of mercury mixed with holy water, take mercury with beer to increase virility; burn mercury in a candle, wash the house with water containing mercury to purify it, rub a mixture of mercury and alcohol on an area affected by arthritis or apply mercury to the skin during massages. In communities and regions where these practices are prevalent, mercury is typically sold in capsules from "*botanicas*" or "*yerberias*," which are small, privately owned shops that sell popular religious articles, as well as a variety of products believed to have medicinal or healing properties. Mercury is sometimes sold in gelatin capsules which typically contain 8-9 g mercury (Riley et al., 2001 as cited by UNEP 2007). Small glass jars or plastic bottles or even plastic bags are sometimes used as well, and these may contain as much as 65 grams of mercury (UNEP 2007).

1262. Quite similar uses are described for other of the mentioned religious practices in the Caribbean and Latin America.

1263. Mercury capsules known as *Azogue*, sold in religious stores, are sometimes used as a Mexican folk remedy for indigestion or gastroenteritis blockages (*empacho*). Ingestion of the heavy, mobile liquid mercury is believed by practitioners to dislodge gastrointestinal blockages, particularly in children (Geffner and Sandler, 1980 as cited by UNEP, 2007).

1264. *Parad* is an amalgamation of mercury and other metals used in India to make relics for worship of Shiva in the Hindu tradition. Solidifying mercury is an ancient Vedic science. "*Dharnidhar Samhita*" (scripture) has prescribed sixteen steps through which elemental mercury has to pass to purify it and bring out its beneficial qualities before it is alloyed (mixed with other metals) to make *parad*, which can be moulded into any solid form. To people who practice this, the benefits of parad are said to be many and varied and may include: Removes bad luck from the workplace or home, curing a range of diseases, warding off evil spirits, establishing an inner spiritual balance, increasing willpower, stopping nightmares and resolving marriage problems. Sales of *parad* statues, jewellery and other artifacts through websites and television are widespread in India (UNEP, 2008). Parad is traditionally made of silver and mercury. The exact ratio of mercury to silver varies - some websites state that *parad* is made of 90 percent mercury and 10 percent silver, some it is pure solidified mercury while others claim only 25-30 percent is mercury. A study by the Indian non-governmental organization Toxics Link revealed that the primary chemical composition of the analysed Parad items was 74.8% tin and 24.9% mercury, with other metals at low percentages (including silver at 0.04%) (UNEP, 2008). Kiefer et al. (2019) found that 14 analysed items contained 21-23% mercury by mass, 10–55% lead and up to 0.3% arsenic. The remaining part consisted mainly of tin whereas silver was not detectable in any of the items. Considering the sample sizes of the studies it cannot be excluded that some items of *parad* with 90 percent mercury and 10 percent silver as declared actually are marketed.

1265. The use of mercury is widespread among South African traditional health practitioners (Street et al. 2015). Of a total of 198 traditional health practitioners from two main metropolitan areas of KwaZulu-Natal province in South Africa participating in a study by Street et al. (2015), 78 (39 %) used metallic mercury for healing purposes. Of the mercury users, 95 % stated that they were taught to use it by other traditional health practitioners. The two main routes of administration were oral and sub-cutaneous implantations used by 85% and 59% of the practitioners using mercury, respectively. The most common reason for mercury administration were for childbirth (90 % of practitioners using mercury) and protection against guns (50 % practitioners using mercury). Other reported reasons included sterility, protection ritual on house, gynaecological complaints, aphrodisiac, for pregnant women, sexually transmitted infections and gastrointestinal aches and cramp. Approximately 25 million South Africans use traditional medicines (Street et al. 2015). Similar practices have been witnessed in Lesotho, including for securing an easy childbirth.

1266. In Romania, ritual practices involving elemental mercury imply mostly drinking liquids with mercury in order to protect marriage or to have good luck and money (Ţincu et al., 2016). Traditional Romanian witchcraft which implies putting mercury in hidden places of the house is used to curse one's enemies and this type of practice using mercury is reported to be highly popular. Approximately 200 cases of poisoning are admitted per year to the Toxicology Unit Department, Clinical Emergency Hospital, Bucharest, Romania (Ţincu et al., 2016).

Main factors determining mercury releases and mercury outputs

Table 5-179 Main releases and receiving media during the life-cycle of mercury metal use in religious rituals and folklore medicine

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Preparation and distribution at botanicas or other shops	X	X	X	X	X	
Use	X	X	X		X	
Disposal	X	X	X		X	

Notes: **X**- Release pathway expected to be predominant for the sub-category;
x- Additional release pathways to be considered, depending on specific source and national situation.

1267. Mercury used in these practices could ultimately be released to air, wastewater, or to MSW. Mercury vapours are released if the mercury is not contained in sealed containers. Some practices such as sprinkling it in homes and automobiles, and especially burning it in candles, increase the rate of vaporization.

Discussion of mercury inputs

1268. Mercury is usually sold in capsules that contain on average about 8 - 9 grams of mercury.

Examples of mercury in releases and wastes/residues

1269. With regard to disposal methods, one study (Johnson, 1999, as cited in NJ MTF, 2002) found that 64% of mercury users reported throwing mercury in the garbage, 27% flushed it down the toilet, and 9% threw it outdoors.

Input factors and output distribution factors

1270. No default factors were defined for this source sub-category, so inventory developers have to collect specific national data for the sub-category.

1271. **Links to other mercury sources estimation** - It should be noted that mercury used in this sub-category may contribute to the mercury inputs to the waste water system, to general waste treatment, and to direct releases to the environment.

5.6.5 Miscellaneous product uses, mercury metal uses, and other sources

1272. The sources discussed below are mentioned because they are known to be possible sources of mercury use and releases. However, in this Toolkit, we have not attempted to provide source descriptions, example data, or other information about these sources because of limited data available and because of limited resources to search for data. If these sources are identified in the country, specific investigations must be made to collect data on consumption, use, releases pathways and disposal enabling quantification of releases to the environment:

- Infra red detection semiconductors, where mercury is part of the crystal structure of infra read detection semiconductors. These devices are used for various infrared (IR) uses for example night vision and IR spectroscopic analysis;
- Bougie tubes and Cantor tubes;
- Educational uses;
- Gyroscopes with mercury;
- Vacuum pumps with mercury;
- Use of mercury as a refrigerant in certain cooling systems;
- Light houses (Marine navigation lights; lens/lamp unit float on mercury in some types);
- Mercury in large bearings of rotating mechanic parts in for example older waste water treatment plants;
- Tanning;
- Pigments;
- Browning and etching steel;
- Certain colour photograph paper types;
- Recoil softeners in rifles;
- Explosives (mercury-fulminate a.o.);
- Fireworks;
- Executive toys.

1273. Significant amounts of mercury may be found in Bougie tubes and Cantor tubes used by medical practitioners in hospitals. (Floyd *et al.*, 2002) The Bougie tube is a mercury-weighted instrument that is used to ‘pound’ an opening in the oesophagus when there are cancerous growths or other obstructions. Buogies may contain up to 1361 g mercury (SH, 2004). The Conter tube is a tube almost 2 meters long which is filled with mercury and is inserted down the patient’s gastrointestinal tract. It is reported to contain 54 - 136 g (SH, 2004).

5.7 Production of recycled metals ("secondary" metal production)

Table 5-180 Production of recycled metals: sub-categories with main pathways of releases of mercury and recommended inventory approach

Chapter	Sub-category	Air	Water	Land	Product	Waste/ residue	Main inventory approach
5.7.1	Production of recycled mercury ("secondary production)	**X**	**X**	**X**	**X**	**X**	PS
5.7.2	Production of recycled ferrous metals (iron and steel)	**X**	x	x		x	PS
5.7.3	Production of other recycled metals	**X**	x	x		x	PS

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

5.7.1 Production of recycled mercury ("secondary production”)

5.7.1.1 Sub-category description

1274. There are two basic types of secondary mercury production: recovery of liquid mercury from dismantled equipment and mercury recovery from scrap products using extractive processes. In the USA (and probably many other countries), the total quantity of mercury recovered as liquid mercury is much greater than that recovered by extractive processes. Three areas that comprise a large proportion of the liquid mercury recovery globally are: 1) dismantling of chlor-alkali facilities; 2) recovery from mercury meters used in natural gas pipelines; and 3) recovery from manometers, thermometers, and other equipment. In each of these processes, the liquid mercury is drained from the dismantled equipment into containers. The second type of production involves the processing of scrapped mercury-added products and industrial wastes and sludges using thermal or chemical extractive processes (US EPA, 1997a and COWI, 2002). (For a description of the processes, see US EPA, 1997a).

1275. The same recycling plants described in above paragraph may also be engaged in recovering of mercury from mineral residuals from mining and primary processing of zinc or other metals, and sludge from pre-distribution cleaning of natural gas. These activities are often called by-product mercury recovery, as opposed to post consumer recycling. When quantifying national mercury cycling, this distinction is useful, and if data exist on this split this information could be reported in the inventory documentation.

1276. Note that mercury recycling may be an import source of mercury to the economy of countries where such facilities exist. Received and refined mercury from these sources is brought back into the global mercury trade cycle. Mercury recycling activities are often economically favoured by governments to encourage collection and treatment of this type of hazardous waste (COWI, 2002)

1277. In some countries mercury recycling activities contribute substantially to mercury market supplies, while other countries do not currently have domestic recycling plants. Some of these countries without recycling programs may export parts of their waste with high mercury concentrations to recycling facilities abroad (COWI, 2002).

5.7.1.2 Main factors determining mercury releases and mercury outputs

Table 5-181 Main releases and receiving media from production of recycled mercury (secondary production)

Phase of life cycle	Air	Water	Land	General waste	Sector specific treatment/ disposal
Recovery of liquid mercury	X	X	X	x	X
Extraction of mercury from scrap products	X	X	X	x	X
By-product mercury recovery	X	X	X	x	X

Notes: **X**- Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

1278. Mercury recycling/recovery activities may lead to substantial releases of mercury to the atmosphere, to aquatic and terrestrial environments. The amounts lost depend very much on how carefully the process releases are managed. Processing facilities may be equipped with release reduction devices with the potential to reduce direct releases of pollutants to the atmosphere as well as to aquatic and terrestrial environments. As in other sectors, release reduction technology yields additional solid or fluid residues, which also have to be managed to prevent or reduce additional releases (COWI, 2002).

1279. In the USA (and probably many other countries) information on the performance of specific emission control measures is very limited and site specific. If a scrubber is used mercury vapour or droplets in the exhaust gas may be captured in the spray. Concentrations in the workroom air due to mercury vapour emissions (such as from the hot retort process) may be reduced by the following methods: containment, local exhaust ventilation, dilution ventilation, isolation, and/or personal protective equipment. Vapour emissions due to mercury transfer during the distillation or filling stages may be reduced by containment, ventilation (local exhaust or ventilation), or temperature control (US EPA, 1997a).

5.7.1.3 Discussion of mercury inputs

Table 5-182 Overview of activity rate data and mercury input factor types needed to estimate releases from production of recycled mercury ("secondary production")

Process type	Activity rate data needed	Mercury input factor
Recovery of post-consumer mercury	Amounts of produced mercury	kg Hg input/kg total Hg output

5.7.1.4 Examples of mercury in releases and wastes/residues

1280. During extraction of mercury from waste materials, emissions may vary considerably from one type of process to another. Emissions may potentially occur from the following sources: retort or furnace operations, distillation, and discharge to the atmosphere from the charcoal filters. The major mercury emission sources are due to condenser exhaust and vapour emissions that occur during unloading of the retort chamber. Mercury emissions also can occur in the filling area when the flask overflows and during the bottling process. One company in the USA (Mercury Refining Company) reported results from two emission test studies conducted in 1994 and 1995 that showed average mercury emissions of 0.85 kg per metric tons of mercury recovered (MRC, 1997, as cited in US EPA, 1997a). In 1973, emission factors were estimated to be 20 kg per metric tons of mercury processed due to uncontrolled emissions over the entire process (Anderson, 1973, as cited in US EPA, 1997a).

1281. In the USA, mercury release data were reported in the 1994 Toxics Release Inventory (TRI) for 2 facilities (which use extractive processes). One facility reported mercury emissions to the atmosphere of 116 kg for 1994, and the other facility reported 9 kg mercury emitted to atmosphere for 1994. Plants that focus mainly on obtaining liquid mercury from old equipment (and that do not use the extractive process) are expected to have lower emissions.

1282. In the USA in 1996, an estimated 446 metric tons of mercury was recycled from industrial scrap. The recycling is estimated to have accounted for approximately 0.4 metric tons of mercury emissions in 1995 (US EPA, 1997b). Major sources of recycled mercury include dental amalgams, scrap mercury from instrument and electrical manufacturers (lamps and switches), wastes and sludges from research laboratories and electrolytic refining plants, and mercury batteries.

1283. Weight of processed mercury containing waste and weight of the commercial mercury recovered from the waste in a Russian mercury recycling facility is shown in the table below. The facility employs a tubular rotary oven for the recovery. The oven is a metal cylinder body with the diameter 1.6 m and the length 14 m, installed at a gradient of 3-4° and lined with refractory bricks. The total reported mercury release from the process was 120 kg broken down into 52 kg with off-gas, 65 kg with waste water, 3 kg with cinders, and 0.5 kg unaccounted losses. The average emission to air from the process was 2 kg/metric ton mercury processed whereas the release to wastewater corresponds to and 2.5 kg per metric tons mercury processed. The previous years the releases were significantly higher and the mercury emission to air decreased from 1999 to 2001 for 20 g/metric ton processed mercury to 2 g/metric ton. During the same period the releases to water increased from 0.5 - 2.5 g/metric ton processed mercury.

Table 5-183 Processing of mercury-containing waste at a recycling facility in Russia in 2001 (Lassen et al., 2004)

Type of waste	**Weight of waste, kg**	**Commercial Hg, kg**
Catalyst, sorbent, sludge (from VCM production)	244,312	9,793
Unconditioned mercury	16,113	16,097
Mercury lamps	20,610	7
Mercury-containing devices	1,784	131
Luminophor concentrate	23,700	78
Other (galvanic elements, mercury-contaminated construction waste and soils, proper production waste, etc.)	54,800	343
Total	361,319	26,449

5.7.1.5 Input factors and output distribution factors

1284. Based on the information compiled above by Lassen *et al.* (2004) describing one facility in Russia, the following preliminary default mercury release factors are suggested for use in cases where source specific data are not available (they are pre-entered in the IL2 calculation spreadsheet). It is emphasized that use of these data on other facilities is of course associated with substantial uncertainty, and must be considered indicative only. Because these default factors are based on a very limited data base, they should be considered preliminary and subject to revisions.

1285. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

Table 5-184 Specific reported outputs and output distribution factors for a recycling facility in Russia (Lassen et al., *2004)*

	Specific reported outputs *1	Output distribution factors - Share of outputs	Specific release factors
	Kg/year	**Unit less**	**Kg Hg release/metric ton Hg totally released (as reported)**
Hg produced	26449	0.995	-
Air releases	52	0.002	2,0
Waste water releases	65	0.002	2,4
Sector specific waste disposal (Cinders - solid residues)	3	0.0001	0.1
Sector specific treatment/disposal (unaccounted losses)	0,5	0.00002	0.02
Sum of reported outputs	26569,5	1	-

Notes: *1 Data from Lassen *et al.* (2004) describing one facility in Russia. The use of these data on other facilities is associated with substantial uncertainty, and must be considered indicative only.

1286. **Links to other mercury sources estimation** - The mercury inputs to waste treatment sub-categories can be qualified through the quantification of mercury inputs to society with products and materials, as described in sections 5.1 to 5.6. Beware of double-counting of mercury outputs when developing the mercury inventory. Note that mercury inputs to recycling facilities may include mercury waste imported from abroad.

5.7.1.6 Source specific main data

1287. The most important source specific data would in this case be:

- Specifically measured mercury amounts to all output streams.

5.7.2 Production of recycled ferrous metals (iron and steel)

5.7.2.1 Sub-category description

1288. Iron and steel are produced from scrap metal, using various high temperature processes. Mercury may be present in recycled metals/materials as a result of presence of natural mercury impurities in the original materials, as well as presence of mercury contamination originating from anthropogenic use of mercury (e.g. mercury switches in cars going to iron/steel recycling). The latter soruce is considered to be the predominant source.

5.7.2.2 Main factors determining mercury releases and mercury outputs

Table 5-185 Main releases and receiving media from production of recycled ferrous metals (iron and steel)

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Shredding, storage and smelting	X	x	x		x	x

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

1289. Ferrous scrap is processed by different industries and types of facilities and involves various process steps. For example, some automobiles are sent to dismantlers initially and valuable components are removed. The remaining automobile is usually crushed then shipped to a shredder. Some older automobiles are sent directly to the shredders. Other discarded items enter the scrap process at various stages of the processing system. Mercury may be released to air, water or land during various points in the process, including shredding (NJ MTF, 2002) and smelting.

5.7.2.3 Discussion of mercury inputs

Table 5-186 Overview of activity rate data and mercury input factor types needed to estimate releases from production of recycled ferrous metals (iron and steel)

Life-cycle phase	Activity rate data needed	Mercury input factor
Shredding, storage and smelting	Numbers of vehicles/appliances recycled annually	Mercury content per vehicle/appliance recycled

1290. The scrap includes recycled metals from discarded motor vehicles and home appliances, and waste metals from demolished building structures. Mercury is present in many items that are included in this scrap. For example, in the USA in the 1990s, about 9 metric tons mercury per year were used in tilt switches (such as trunk lights) and in anti-lock breaking systems (ABS) in automobiles. One study (ECGLU, 2001) estimated that between 155 - 222 metric tons of mercury were in automobiles on the road in the USA in year 2001. Since, the average age of automobiles on the road is about 9 years, and since the vast majority of discarded automobiles become scrap metal, one can estimate that about 10% (or 15 - 22 metric tons) of the mercury in automobiles enters the scrap processing system each year (NJMTF, 2002).

1291. Mercury use in switches has declined roughly about 60 - 80% from the period 1996 to 2000 in the USA. However, the use of mercury in ABS systems has increased by about 130 - 180% over the same period (NJMTF, 2002).

1292. Mercury switches in cars have been substituted earlier in European cars than described for the USA above.

1293. Mercury is also found extensively in gas pressure regulators, switches and flame sensors in appliances that become part of the scrap for iron and steel production (Cain, 2000, as cited in NJ MTF, 2002).

1294. In its 2006 report to the Legislature, the Agency estimated that 43,000 vehicles are discarded annually in Vermont, USA, with the potential of 25,000 individual mercury switches. Each switch contains about one gram of mercury (Vermont ANR, 2008), equalling about 2 grams of mercury per vehicle on average, including vehicles which do not contain mercury switches.

1295. According to Vermont ANR (2008) mercury switches were discontinued from use as follows (presumably for the US market, but may have general relevance): Ford and General Motors, 2003 model year; DaimlerChrysler, late 1990s; and European manufacturers, 1993 model year. Toyota and Honda reportedly never used mercury auto switches in convenience lights or braking systems. Subaru, Nissan, and Mitsubishi had limited use of mercury switches in anti-lock brake sensors.

5.7.2.4 Examples of mercury in releases and wastes/residues

1296. In New Jersey, USA, there are 3 facilities that produce steel by melting scrap in electric arc furnaces and 3 facilities that produce cast iron from melting scrap in furnaces called "cupolas." The total estimated mercury emissions to air from these six facilities is about 0.46 metric tons/year (NJ MTF, 2002), or an average of about 0.076 metric tons/year from each facility. Total mercury emissions to air in the USA for this sub-category was estimated to be about 15.6 metric tons/year based on a study by the Ecology Center (Ecology Center, 2001, as cited in NJ MTF, 2002).

1297. The major pathway of releases is expected to be to air, via stack emissions from the iron and steel facility furnaces (NJ MTF, 2002). Mercury releases to air, land and water may also occur at other points during process, such as during storage, shredding and dismantling activities (NJ MTF, 2002).

1298. However, a mass balance study at one facility estimated that only 31% was released through stack emissions, 49% was in furnace silo dust, 18% was in shredder fluff residues, and 2% emitted during shredding (Cain, 2000, as cited in NJ MTF, 2002).

5.7.2.5 Input factors and output distribution factors

1299. No attempt was made to define default factors for production of recycled iron and steel.

1300. If no specific data are available on the prevalence of mercury switches, etc., in recycled ferrous metal, a first estimate can be formed by using the default input factors selected in Table 5-187 below (based on the data sets presented in this section). The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum possible). The low end input factor is expected to be relevant in countries where switches with mercury has not been used cars and house appliances within the last 10 years, or where switches are generally removed before metal recycling.

1301. Note that the default input factor given only includes mercury switches in vehicles. If mercury components (electric switches, gas thermostats, etc.) have been used in other recycled metal appliances nationally, these must be quantified separately to be included in the inventory.

*Table 5-187 **Preliminary** default input factors for mercury in ferrous metals recycling*

Material	Default input factors; g Hg/vehicle; (low end - high end) *1
Per vehicle recycled	0,2 - 2

Notes: *1 Relevance - see text above.

b) Default mercury output distribution factors

*Table 5-188: **Preliminary** default mercury output distribution factors for recycling of ferrous metals*

	Default output distribution factors, share of Hg input*1					
	Air	Water	Land *2	Products	General waste *2	Sector specific treatment/ disposal
None	0.33		0.34		0.33	?

Notes: *1 These default factors are derived from one example from the USA. Air emissions are likely to be higher in facilities without dust retention filters on the furnace air outlets.

*2 The distribution on land deposition and general waste may likely vary with local conditions and the distribution here is artificial, meant to signal that these may be important output pathways.

c) Links to other mercury sources estimation

1302. For the waste treatment sub-categories it is very important to keep in mind that the mercury content in the waste originates from 1) intentionally used mercury in discarded products and process waste; 2) natural mercury impurities in high volume materials (plastics, paper, etc.) and minerals; and 3) mercury as a human-generated trace pollutant in high volume materials. Note that parts of these mercury inputs may be directed to municipal, hazardous and medical waste.

1303. The mercury releases to the environment and waste deposits from these sub-categories should therefore be seen as a consequence of mercury being present in the products used in society.

1304. Similarly, the estimated mercury inputs to waste treatment sub-categories can be qualified through the quantification of mercury inputs to society with products and materials, as described in sections 5.4 - 5.6. Beware of double-counting of such mercury inputs when developing the mercury inventory.

1305. Note that mercury inputs to incineration from mercury trace concentrations in high volume materials (plastics, metals, etc.) are not quantified individually in this Toolkit.

5.7.2.6 Source specific main data

1306. The most important source specific data would in this case be:

- Inputs are extremely dependent on the national or regional history of mercury-containing components in especially cars and home appliances. National information on the prevalence/existence of mercury switches in cars (and housing) over the last 10-20 years is a key issue for inventory refinement.
- Amount of each type of scrap metal processed; and,
- Measured data on emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

5.7.3 Production of other recycled metals

5.7.3.1 Sub-category description

1307. In principle aluminium, copper, zinc and other metals which are recycled in most countries, may contain mercury. Mercury inputs to production of recycled non-ferrous metal are largely un-described in the literature. For most metals, the processes involved in their original manufacture indicate that natural mercury impurities in the feed materials do not follow the produced metals to any major degree. Most of the mercury input to non-ferrous metal recycling, if any, would therefore originate from mercury use in other mercury-containing materials or products/components. As for production of recycled steel, the most obvious contributions may likely come from mercury switches, relays, thermostats and similar. Based on background knowledge on mercury use in components and products, non-ferrous metals fed to recycling activities may perhaps generally be less contaminated with mercury than recycled steel.

1308. Aluminum is one recycled metal among others with potential for mercury emissions. Contamination of recycled aluminium and other metals are suspected. Mercury tends to preferentially amalgamate with aluminium rather than ferrous metals, therefore, in the recycled metals stream, mercury contamination may be more associated with aluminium versus ferrous metals. It is possible that facilities that process recycled aluminium using heat release some mercury to air and other media.

5.7.3.2 Main factors determining mercury releases and mercury outputs

Table 5-189 Main releases and receiving media during the life-cycle of production of other recycled metals

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Production	**X**	x	x		x	x

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

5.7.3.3 Discussion of mercury inputs

Table 5-190 Overview of activity rate data and mercury input factor types needed to estimate releases from production of other recycled metals

Life-cycle phase	Activity rate data needed	Mercury input factor
Shredding, storage and smelting	Amounts of recycled metal produced	Mercury content per metric ton of metal produced

5.7.3.4 Examples of mercury in releases and wastes/residues

1309. The NJ MTF assumed that releases from recycled aluminium production facilities would be similar in amount to the releases from facilities that produce recycled ferrous metals (iron and steel) described above, and that the primary receiving medium is air. Therefore, NJ MTF assumed that about 455 kg are emitted to the air from each recycled aluminium-producing facility in New Jersey (NJ MTF, 2002).

5.7.3.5 Input factors and output distribution factors

1310. No attempt was made to define default factors for production of other recycled metals. Inputs are extremely dependent on the national or regional history of mercury-containing components in scrapped metal products.

5.7.3.6 Source specific main data

1311. The most important source specific data would in this case be:

- Measured data or literature data on the mercury concentrations in various types of scrap metal processed at the source;
- Amount of each type of scrap metal processed; and,
- Measured data on emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

5.8 Waste incineration

Table 5-191 Waste incineration: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Chapter	Sub-category	Air	Water	Land	Product	Waste/ residue	Main inventory approach
5.8.1	Incineration of municipal/ general waste	**X**	x	x	x	**X**	PS
5.8.2	Incineration of hazardous waste	**X**	x			**X**	PS
5.8.3	Incineration of medical waste	**X**	x			**X**	PS
5.8.4	Sewage sludge incineration	**X**	**X**			**X**	PS
5.8.5	Open waste burning on landfills and informally	**X**	**X**	**X**			OW

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

5.8.1 Incineration of municipal solid waste (MSW)

5.8.1.1 Sub-category and process description

1312. The mercury content in the general waste stream originates from three main groups of inputs: 1) intentionally used mercury in discarded products and process waste; 2) natural mercury impurities in high volume materials (plastics, paper, etc.) and minerals; and 3) mercury as a human-generated trace pollutant in high volume materials. The mercury concentrations are directly dependent on the inputs of mercury to the waste, and will therefore likely vary much between different countries and circumstances.

1313. Refuse or municipal solid waste (MSW) consists primarily of household garbage and other non-hazardous commercial, institutional, and non-manufacturing industrial solid waste. In some countries, sewage sludge and pathogenic medical waste is incinerated along with municipal waste.

1314. MSW is sometimes incinerated (under controlled conditions as described here), while waste fractions dominated by mineral materials is generally deposited in landfills. The quantitative split between incineration and other treatments of combustible waste vary between countries.

1315. The MSW may be burned without pre-treatment or may be treated for production of so-called 'refuse-derived fuel'. In the USA, refuse-derived fuel incinerators burn MSW that has been processed to varying degrees, from only removal of large, bulky and non-combustible items, to extensive processing to produce a well separated fuel suitable for co-firing in pulverized coal-fired boilers. Processing MSW to refuse-derived fuel generally raises the heating value of the waste because many of the non-combustible items are removed (US EPA, 1997a). In countries with well established schemes for recycling of glass and metals from households, and separate deposition of construction waste (typically in developed countries), such pre-treatment of waste before incineration is common.

1316. In some types of incinerators, a part of the mercury may remain in the fraction of the waste not fully incinerated and leave the incinerator with the grate ash. Generally, however, virtually all of the mercury present in the waste is converted to a vapour because of the high temperatures of the combustion process. The major part of the mercury leaves with the exhaust gas and the share of mercury input that is released as air emissions through the stack will be largely dependent on the control devices present. Poorly controlled facilities will have most releases going out through the stack in the form of mercury air emissions whereas in well controlled facilities, most mercury input will end up in the flue gas cleaning residues. The effectiveness of various controls is discussed below.

5.8.1.2 Main factors determining mercury releases and mercury outputs

Table 5-192 Main releases and receiving media from incineration of municipal/general waste

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/disposal
Controlled waste incineration	**X**	x	x	x	**X**	**X**

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

1317. Important factors determining releases of mercury from this sub-category are the concentration of mercury in the wastes and the efficiency of the control devices (if present) to reduce mercury emissions.

1318. The incineration technology, and particularly the flue gas cleaning systems applied, determine the distribution of the output of mercury between air emissions, accumulation in solid incineration residues (grate ash) and flue gas cleaning residues, and releases to water (only indirectly to water via wet flue gas cleaning technology types). Post-combustion equipment for flue gas cleaning, applied widely in many countries today, retains parts of the otherwise released mercury. The flue gas cleaning systems used are similar to those described for large coal combustions plants (mentioned in section 5.1.1), except for a possible additional (integrated) step involving injection and subsequent capturing of activated carbon (which adsorbs/absorbs some mercury). The activated carbon technology is used in some countries, for example the USA, Germany, Sweden, Denmark and Austria.

5.8.1.3 Discussion of mercury inputs

Table 5-193 Overview of activity rate data and mercury input factor types needed to estimate releases from incineration of municipal/general waste

Activity rate data needed	Mercury input factor
Amount of waste burned	Concentration of mercury in the waste

1319. The mercury content of the MSW will depend on the use of mercury-added products in the country and the presence of specific collection systems for mercury containing waste products. Known sources of mercury in MSW include, among others, batteries, discarded electrical equipment, fluorescent lamps, teeth and other dental amalgam waste, some paint residues, and some plastics. Depending on the life-time of the products, the sources of mercury in the waste will reflect the use of mercury for the different products a number of years before the assessment of mercury in the waste.

1320. In the USA the sources of mercury to the waste stream have changed over time as a consequence of the changes in the mercury use pattern. Mercury batteries have, during the period from 1980 to 2000, accounted for the major part of mercury in products in the MSW in the USA (Table 5-194). In 1989, it was estimated that about 88% of the total discard of mercury was from batteries. Of the 88%, about 28% was from mercuric oxide batteries and the remainder from alkaline and other batteries (US EPA, 1997a). However, the number of mercury-containing batteries consumed since the late 1980s has decreased significantly in the USA and probably many other countries, but as the total mercury content of the waste has decreased significantly, batteries in 2000 still accounted for more than 50% of the mercury in products in the waste stream (Table 5-194).

1321. As of 1989, 644 metric tons of mercury was reported discarded in the municipal solid waste stream in the USA, and the concentration of mercury in solid waste is reported to be in the range of less than 1 to 6 ppm by weight with a typical value of 4 ppm by weight (ppm = g mercury per metric tons waste). However, because of changes in mercury consumption, the quantity of mercury discarded in the municipal solid waste stream has decreased dramatically since 1989 to a level of about 157 metric tons in 2000 (Table 5-194).

1322. Mercury concentration in MSW in New Jersey in 2001 has been estimated to be in the range of 1.5 - 2.5 ppm (NJ MTF, 2002).

Table 5-194 Mercury in products in the MSW stream in the USA *in 1980, 1989 and 2000 projected (based on Franklin Associates, Ltd. (1989), as cited by Yep* et al., *2002)*

Waste type	**Percentage of total, except***		
	1980	**1989**	**2000 (projected)**
Household batteries	78.4	87.6	57
Electric lighting	4.4	3.8	23.7
Paint residues	4.9	2.6	0.3
Fever thermometers	4.7	2.3	9.7
Thermostats	1.3	1.6	6.0
Pigments	4.2	1.4	0.9
Dental uses	1.3	0.6	1.3
Special paper coating	0.2	0.2	0.0
Mercury light switched	0.1	0.1	1.1
Film pack batteries	0.5	0.0	0.0
Total discards	100	100	100
*Total discards in USA (in metric tons)	497	644	157

1323. The sources of mercury in MSW in Denmark in 1992/93 and 2001, respectively, are shown in Table 5-195. In 1992/93 batteries accounted for more than half of the total content, similar to the results from the USA shown above. In 2001 the batteries accounted for only 27%, mainly due to a decrease in the content of mercury in alkaline and 'other' batteries. In 2001 mercury present as a natural impurity of the waste (natural trace element) accounted for 28% of the total mercury content in the waste. Please note that this contribution is not included in the sources of mercury in MSW in the USA shown in (Table 5-194). As illustrated, the uncertainty of the estimates for each waste group is quite high even though the estimates are based on detailed substance flow analyses. The total mercury content of the waste decreased in the period from 0.4 - 1.2 ppm to 0.1 - 0.6 ppm (the actual mercury content is according to the studies most probably in the high end of the estimated ranges).

Table 5-195 Sources of mercury in MSW disposed of for incineration in Denmark 1992/93 and 2001 (Maag et al.*, 1996; Skårup* et al.*, 2003)*

Waste type	**1992/93**		**2001**	
	kg Hg/year	**% of total**	**kg Hg/year**	**% of total**
Teeth and miscellaneous dental waste	200 - 310	18	64 - 180	12
Light sources	4 - 20	1	19 - 110	6
Switches and relays	0 - 120	4	75 - 380	22
Thermometers	80 - 200	10	19 - 38	3
Monitoring equipment	0 - 40	1	19 - 47	3
Batteries	420 - 1,100	53	52 - 510	27
Mercury as impurity (trace element)	20 - 370	14	28 - 560	28
Total (rounded)	700 - 2,200	100	280 - 1,800	100

1324. Data on concentration of mercury in waste in developing countries have only been found relatively recently (2006 and onwards), and only for a few Asian countries. A review of literature in English, Spanish and Russian on mercury concentrations in waste in developing countries performed for the 2019 Toolkit update is summarised in Table 5-196.

Table 5-196 Summary of a literature review on mercury concentrations in municipal solid waste in developing countries.

Country	**Reference and place**	**Min gHg/t MSW**	**Max gHg/t MSW**	**Average g Hg/t waste**	**Remarks**
China	Yan Lin et al (2013), in combination with waste amount estimates from Wiedinmeyr et al (2014), China			**~0.5**	National estimate calculated here, based on partial national consumption numbers and MSW amount estimates
China	Chen et al (2013), 8 incineration plants in Pearl River delta			**0.208** +/- 0.13	Air emission factor only, no data on other outlets (ash, flyash, etc.)
China	Zhu et al (2013), Shanghai, as cited by Tao et al (2017)	0.19	1.68	**0.63**	
China	Li et al (2010), Guiyang	0.17	46.22	**1.769** +/- STD 7.072	42 samples from 3 landfill sites in Guiyang, China
China	Li et al (2010), Wuhan	0.24	1.27	**0.606** +/- STD 0.349	8 samples from 2 landfill sites in Wuhan, China
China	Duan et al (2016), Chongqing			**3.74** +/- 0.321	Derived here from data on emission factor and Hg fraction emitted
India	Chakraborty et al (2013), consumption derived (partial), India			**0.2**	Calculated based on mercury input estimates. Not all intentional uses included, waste definition unclear, may be all landfilled material (not only MSW), so may be an underestimate
India	Raman and narayanan (2008), Chennai, landfill	0.10	0.37	**0.25**	4 landfill waste samples only
Thailand	Muenhor et al (2009), Koh Samui incineration plant	0.15	0.56		"Untreated waste in an industrial area" (actually it is a tourist island), waste from 2006
Thailand	Prechthai et al (2006), MSW			**0.4** +/-0.1	Measured, but in small air-dried samples (Hg and H2O loss?) of 3-7 years old MSW, meaning waste was from 1999-2003
	Simple range from data in this table	0.1	46		
	Simple range from data in table, excluding possible outlier	0.1	4.1	**~1**	

1325. Maxson (2017) estimated the distribution of mercury supply on applications and regions for UN Environment. For Sub-Saharan Africa, he estimated the consumption of the types of mercury applications that could end up in municipal solid waste (batteries, dental amalgam, measuring devises, lamps, electronic/electrical devices, compounds and other) at 37-123 tonnes Hg/y (mid-range 81t/y). Hoornweg and Bhada-Tata (2012) estimated, for the World Bank, the total municipal solid waste production in Sub-Saharan Africa at around 62 million tonnes/year (associated with substantial uncertainty). Note that this includes also waste that is dumped informally and burned openly. Combining these two sets of numbers indicates a mercury concentration in municipal solid waste in Sub-Saharan Africa of 0.6-2.0 gHg/t waste (mid-range 1.3), meaning at a level similar to the data presented in Table 5-196.

1326. Data on concentration of mercury in waste in developed countries in the literature review performed for this Toolkit in 2018 is summarised in Table 5-197; developed countries were not the main focus of the literature review, so other data may exist.

Table 5-197 Other examples of mercury concentrations in municipal solid waste in developed countries (from review done for the 2019 Toolkit update).

1327.

Reference, country	**Min gHg/t MSW**	**Max gHg/t MSW**	**Average, if available**	**Remarks**
Kyoto Municipal Government (1999), 1998 data, Kyoto, Japan			0.4	In 1983 it was 2 gHg/t MSW.
Akiko Kida (2011), citing Tanigawa and Urano (1998), Japan	0.034	0.078		The surprisingly low values appear to be from an investigation of RDF possibilities and may as such be only a sorted fraction of municipal waste. Data are from 1999 or before.
Riber at el (2005), Denmark	Not detected	1.1	0.6+/-16%	Combustible household, institution and industry waste, where significant parts of Hg-added products have been separated from the MSW.
Reimann (2002), Germany			1.4	MSW
Belevi (1998), Switzerland1			4.2	Household waste
Belevi (1998), Switzerland2			2.9	MSW
Below Babineau (undated slide presentation) 2013 data, 4 MSW incinerators, Minnesota, USA:				Note observed differences between facilities in the same US state; the reference gives no explanation for diffeences, but separation of Hg-added waste products could be a reason
-Olmsted (n=16)	0	1.7	0.61	Measured in solid residues, air emissions omitted (small, they say, has AC filter). Slight decline 2005-2013 (except for outliers in2009 -high- and 2013 -low.
-HERC (n=12)	0.45	1.6	0.83	Selected by reference as most representative of Minnesota state, USA (large facility, no "pre-sorter"). Measured in solid residues, air emissions omitted (small, they say, has AC filter). Steady trend over time observed.
-Perham (n=21)	0.8	1.6	1.16	Measured in solid residues, air emissions omitted (small, they say, has AC filter). Steady trend.
-Polk (n=9)	0.15	0.32	0.22	Measured in solid residues, air emissions omitted (small, they say, has AC filter). Steady trend.

1328. Data on mercury trace concentrations in large volume waste can give an indication of the mercury input to waste treatment that is not originating in mercury-added products; examples from the literature as summarised by NPI (2010) are given below.

	Hg, concentration g/t, dry weight basis	**Reference**
Paper/cardboard	0.1	A
Paper/cardboard	<0.1	B
Paper/cardboard	0.2	C
Wood	1	B

	Hg, concentration g/t, dry weight basis	Reference
Wood	<0.1	C
Total plastics	<0.1	B
Dense plastics	0.1	A
Film plastics	0.1	A
PVC	0.2	D
Textiles	0.1	A
Textiles	<0.1	B
Textiles	<0.1	C
Stone/ceramics	<0.1	B
Glass	0.1	A
Glass	<0.1	B
Organic waste	0.1	A
Organic waste	<0.1	B
Organic waste	0.5	C

References: a) Burnley (2007); b) Otte (1995); c) Herring et al. (1999); d) Dimambro et al. (2006);

5.8.1.4 Examples of mercury in releases and wastes/residues

1329. Atmospheric mercury emissions from municipal waste combustors (MWCs) can to some extent be reduced by removing mercury adsorbed to particles from the flue gas by electrostatic precipitators (ESPs) and fabric filters (FFs). The mercury removal efficiency of the filters depends on the filter's capability for removal of small size particles. Acid gas reduction in the flue gas may also contribute to the mercury retention.

1330. The removal efficiency of the controls may be enhanced by adsorbing the mercury vapours from the combustion chamber onto acid gas adsorbent material or other adsorbents and then removing the particle-phase mercury. The PM control devices most frequently used in the USA are electrostatic precipitators (ESPs). To achieve high mercury control, reducing flue gas temperature at the inlet to the control device to 175 ºC (or lower) is beneficial. Typically, newer MWC systems use a combination of gas cooling and duct sorbent injection (DSI) or spray dryer (SD) systems upstream of the particle removal device to reduce temperatures and provide a mechanism for acid gas control (US EPA, 1997a).

1331. Under incineration conditions at temperatures above 850ºC and O_2 content of 8-10% vol., the prevailing mercury species will be mercury chlorides (I and II) and elemental mercury (Velzen *et al.* 2002). The thermodynamically calculated chemical equilibrium for mercury in a typical flue gas containing HCL and SO_2 shows that the major product between 300 and 700ºC is $HgCl_2$, whereas above 700ºC elemental mercury is the dominant species. A summery of mercury removal efficiencies for different flue gas cleaning equipment in incinerators is shown in Table 5-198 (Velzen *et al.*, 2002). For the estimation it is assumed that the $HgCl_2$/Hg(0) ratio is between 70/30 and 80/20. 'Special absorbents' (or adsorbents) added may be absorbents impregnated with sulphur or sulphur compounds or active carbon based adsorbents, which increase the sorption of mercury on particles.

Table 5-198 Mercury removal efficiencies of flue gas cleaning systems for waste incinerators

Equipment	Temperature (ºC)	$HgCl_2$	Hg(0)	Overall	Reference
Electrostatic precipitators (ESP)	180	0 - 10%	0 - 4%	0-8%	Velzen *et al.*, 2002
Electrostatic precipitators (ESP)				10%	Pirrone *et al.*, 2001
Fabric filters (FF)				29%	Pirrone *et al.*, 2001
Wet scrubbers	65-70	70 - 80%	0 - 10%	55 - 65%	Velzen *et al.*, 2002
Wet scrubbers with conditioning agent		90 - 95%	20 - 30%	76 - 82%	Velzen *et al.*, 2002
Spray absorbers + FF (limestone)	130	50 - 60%	30 - 35%	44 - 52%	Velzen *et al.*, 2002
Spray absorbers + FF (special absorbents added) ***1**		90 - 95%	80 - 90%	87 - 94%	Velzen *et al.*, 2002
Entrained flow absorbers + fabric filter (special absorbents added) ***1**	130	90 - 95%	80 - 90%	87 - 94%	Velzen *et al.*, 2002
Circulating fluidized bed + fabric filter (special absorbents added) ***1**	130	90 - 99%	80 - 95%	87 - 98%	Velzen *et al.*, 2002
ESP or FF + carbon filter beads				99%	Pirrone *et al.*, 2001
ESP or FF + carbon injection				50 - >90%	Pirrone *et al.*, 2001
ESP or FF + polishing wet scrubber				85%	Pirrone *et al.*, 2001

Notes - *1 Special absorbents may be absorbents impregnated with sulphur or sulphur compounds or active carbon based absorbents, which increase the sorption of mercury on particles.

1332. As shown in the table, simple electrostatic precipitators sometimes only have very low mercury removal efficiencies. Wet scrubbers or spray absorbents using limestone for acid gas removal has efficiencies of 55-65% and 44-52%, respectively. For obtaining high removal efficiency, >90%, the addition of special absorbents/adsorbents, most often activated carbon, is a requisite.

1333. According to compliance tests recently conducted at 115 of the 167 large municipal solid waste incinerators in the USA, the average mercury control efficiencies for large municipal incineration plants was 91.5%. The average control efficiency at each site was based on a 3-test average determined by measuring the total flue gas concentration of mercury both before and after the control system at each site (injection of powdered activated carbon upstream of either a spray dryer and fabric filter baghouse, or a spray dryer and electrostatic precipitator) (UNEP, 2002).

1334. The mercury eliminated from exhaust gases is retained in incineration residues and, for some types of filtering technology, in solid residues from wastewater treatment (from the scrubbing process). These residues are generally sent to landfills or – depending upon their content of hazardous materials and other characteristics – used for special construction purposes (gypsum wallboard, roadbeds or similar). In some cases such solid residues are stored in special deposits for hazardous waste, which are additionally secured with a membrane or other cover that eliminates or reduces releases by evaporation and leaching.

1335. Some examples of the distribution of mercury in the different outflows from municipal waste incinerators are shown inTable 5-199. Compared to the typical removal efficiencies shown in Table 5-198, the ESPs of these incinerators have relatively high removal efficiency, through the retention of a larger part of the small-size particles.

Table 5-199 Examples of mercury removal efficiencies of flue gas cleaning systems for waste incinerators

	Percentage of total outlet to:						
	Emission to air	**Grate ash**	**ESP/FF dust**	**Acid gas cleaning filter cake**	**Carbon adsorber residue**	**Waste water**	**Flue gas cleaning system**
Schachermayer *et al.*, 1995 (Austria)	<1	5	30	65		<1	ESP, wet scrubber, denox
Amagerforbrænding, 2000 (Denmark)	7	1	92			<0.01	ESP, semi-dry flue gas cleaning process
Acthenbosch and Richers, 2002, (Germany)	0.4	-	44.3	54.6	0.7		ESP, spray dryer ESP, wet scrubbers, scr, carbon adsorber
Shin Chan-Ki *et al.*, 2000 (Korea)	7.3	1.8	13.9			77 *1	ESP, wet scrubber

Notes - *1 Indicated in the reference as "gas cleaning water"; it is not mentioned if the waste water is filtered, and if the filter cake disposed of separately.

1336. Atmospheric mercury emissions from MWCs in the USA have declined significantly over the past decade. These reductions were partly due to reduction of mercury in the wastes, but also partly due to improvement/enhancement of control technologies. In the early 1990s about 40 metric tons were released from MWCs, and by 2001 the atmospheric emission had declined to about 4 metric tons mercury (US EPA, 2001).

1337. Current emission controls on New Jersey (USA) solid waste incinerators, which primarily consist of the injection of carbon into the particulate control device, remove an estimated 95% or more of the mercury from the exhaust gas. The carbon is eventually mixed with the ash. Based on information from the New Jersey task force, mercury remains adsorbed on the injected carbon and mercury releases from this residue are likely to be low (NJ MTF, 2002).

1338. The US EPA developed atmospheric emission factors (EFs) for MWCs for the year 1994, as shown in Table 5-200. The EFs for early years would likely be higher, and EFs for more recent years would likely be lower due to the decreased concentrations of mercury in the wastes.

Table 5-200 Average emission factors for municipal solid waste incinerators in the USA for 1994-1995 (based on US EPA, 1997a)

Combustor Type	**Mercury concentration µg/dry m^3 at standard conditions, at 7% O_2**	**Average emission factors in g/metric ton waste**
MSW without acid gas control	340	1.4
MSW with acid gas control	205	0.83
MSW with acid gas control + carbon	19	0.077
Refuse-derived fuel without acid gas control	260	2.6
Refuse-derived fuel with acid gas control	35	0.34

Notes: Acid gas control includes SD, DSI/FF, SD/ESP, DSI/ESP, SD/FF, and SD/ESP configurations); SD = spray dryer; DSI = duct sorbent injection; ESP = electrostatic precipitator.

5.8.1.5 Input factors and output distribution factors

1339. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows. Also, the presented default factors are expert judgments based on summarized data only. In many cases calculating releases intervals will give a more appropriate estimate of the actual releases.

1340. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far-reaching action is taken based on the release estimates.

a) Default mercury input factors

1341. Actual data on mercury levels in the waste - for example established through the procedures of this Toolkit - will lead to the best estimates of releases.

1342. If no indications are available on the mercury concentration in the municipal waste in the country, a first estimate can be formed by using the default input factors selected in Table 5-201 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low- end default factor has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate. The low-end input factor is expected to be relevant for a situation where substantial parts of the waste products with high mercury concentration (thermometers, batteries, dental amalgam wastes, switches etc.) have been sorted out of the waste for separate treatment, and will therefore be present in lower numbers in the municipal waste. The high-end input factor is expected to be relevant for situations where no such sorting takes place and most of the product waste with high mercury concentrations is therefore present in the municipal waste. As mentioned, the mercury levels in waste are of course also directly dependent on the consumption of mercury-containing products and materials in the country investigated.

1343. In previous versions of the Toolkit, default input factors of 1-10 (intermediate 5) g/Hg/t MSW were suggested, focusing on developing countries. This was done as a conservative estimate as no measured data were available from developing countries, as substitution with mercury-free products was expected to be less prevalent in these regions, and because separate collection of mercury-added products is generally absent in developing countries. However, for the 2019 update of the Toolkit, limited data from developing countries have become available as described above. At the same time, mercury-free products such as for example digital thermometers have been observed frequently in developing countries over the last years. Based on the data collected for the 2019 Toolkit update, revised default input factors of 0.2 – 4 (intermediate 1) gHg/t MSW are suggested as shown below.

1344. A simple test, based on your Inventory Level 2 results, will indicate if the default factors may over-estimate the mercury releases from this activity in the country. See Annex 8.5 for more details.

Table 5-201 ***Preliminary*** *default input factors for mercury in municipal solid waste*

Material	Default input factors; g Hg/metric ton waste; low end - high end (intermediate) *1
Municipal solid waste (general "household" waste) *1	0.2 – 4 (1)

Notes: *1 The low end input factor is expected to be relevant for a situation where substantial parts of the waste products with high mercury concentration (thermometers, batteries, dental amalgam wastes, switches etc.) have been sorted out of the waste for separate treatment, and will therefore be present in lower numbers in the municipal waste. The high end input factor is expected to be relevant for situations where no such sorting takes place and most of the product waste with high mercury concentrations is therefore present in the municipal waste. As mentioned, the mercury levels in waste are of course also directly dependent on the consumption of mercury-containing products and materials in the country investigated; the default factors were derived primarily from data from developed countries.

b) Default mercury output distribution factors

Table 5-202 ***Preliminary*** *default mercury output distribution factors for municipal solid waste incineration*

Emission reduction devices *1	**Default output distribution factors, share of Hg input**					
	Air	**Water**	**Land**	**Products *2**	**General waste**	**Sector specific treatment/ disposal *4**
None	1			?	?	
PM reduction with simple ESP, or similar	0.9		***3**	?	?	0.1
Acid gas control with limestone (or similar acid gas absorbent) and downstream high efficiency FF or ESP PM retention	0.5		***3**	?	?	0.5
Mercury specific absorbents and downstream FF	0.1		***3**	?	?	0.9

Notes: *1 PM = particulate material; FF = fabric filter; ESP = electrostatic precipitator;

*2 Depending on the specific flue gas cleaning systems applied, parts of the mercury otherwise deposited as residue may follow marketed by-products (for example road bed slags/ashes and fly-ash for cement production);

*3 In case residues are not deposited carefully, mercury in residues could be considered released to land;

*4 May be landfilled at general waste landfill or at specially secured hazardous waste landfills.

c) Links to other mercury sources estimation

1345. For the waste treatment sub-categories it is very important to keep in mind that the mercury content in the waste originates from 1) intentionally used mercury in discarded products and process waste; 2) natural mercury impurities in high volume materials (plastics, paper, etc.) and minerals; and 3) mercury as a human-generated trace pollutant in high volume materials. Note that parts of these mercury inputs may be directed to municipal, hazardous and medical waste.

1346. The mercury releases to the environment and waste deposits from these sub-categories should therefore be seen as a consequence of mercury being present in the products used in society.

1347. Similarly, the estimated mercury inputs to waste treatment sub-categories can be qualified through the quantification of mercury inputs to society with products and materials, as described in sections 5.4 - 5.6.

1348. Calculated input totals from waste related mercury sources: To avoid double counting of mercury inputs with waste products in the input total in the Inventory Level 2 spreadsheet, only 10% of the mercury input to waste incineration sources, general waste deposition and informal dumping is included in the total for mercury inputs. These 10% represent approximately the mercury input to waste from materials which were not quantified individually in this Toolkit. These materials include such things as food wastes, paper, plastic, etc. which generally have very low mercury concentrations but very high volumes. The actual fraction of mercury from such materials, of the total inputs of mercury to waste, will vary between regions and very little data on this issue is available in the literature. Limited data from a Danish substance flow analysis (Skårup *et al.*, 2003) for mercury indicate however, that this mercury fraction is small, in the range of some 2-20% of total mercury inputs to general waste.

5.8.1.6 Source specific main data

1349. The most important source specific data would in this case be:

- In case mercury inputs to waste (through products etc.) can be estimated quite accurately, these input data can be used in the quantification of mercury releases from waste incineration. Note, however, that mercury inputs to incineration from mercury trace concentrations in high volume materials (plastics, paper, etc.) are not quantified individually in this Toolkit, and quantification of total inputs would therefore tend to be underestimated when using this approach.

1350. As mercury inputs in waste are typically difficult to measure, or otherwise quantify accurately, the following data may likely give the best estimates of mercury releases/outputs from waste incineration:

- Atmospheric releases: Measurements of average mercury concentrations in the flue gas combined with measurements of flue gas produced (per year) at average conditions;

- Outputs to solid residues: Measurements of average mercury concentrations and amounts of residues produced per year for each relevant residue output stream (ashes/slags, flue gas cleaning residues, gypsum boards etc.);

- Aquatic releases (if any): Measurements of average mercury concentrations in the aquatic discharges combined with measurements of the amounts discharged (per year) at average conditions.

1351. See also advice on data gathering in section 4.4.5.

5.8.2 Incineration of hazardous waste

5.8.2.1 Sub-category description

1352. The mercury content in the hazardous waste stream originates primarily from intentionally used mercury in discarded products and process waste. Some hazardous waste is incinerated as part of the treatment/disposal management. The mercury concentrations are directly dependent on the inputs of mercury to the waste, and will therefore likely vary much between different countries and circumstances.

1353. Hazardous waste refers to residues and wastes which contain hazardous materials in significant quantities. Generally spoken, all materials including consumer goods, which require special precautions and restrictions during handling and use, belong to this group. Any consumer goods, which are labelled to such an extent and have entered the waste stream, must be considered hazardous waste. These include solvents and other volatile hydrocarbons, paints and dyes, chemicals including pesticides and herbicides, pharmaceutical products, batteries, fuels, oils and other lubricants, as well as goods containing heavy metals. Also, all materials contaminated with these materials such as soaked rags or paper, treated wood, production residues, *etc.,* are considered hazardous waste (UNEP, 2003).

1354. Waste with high concentrations of mercury would generally not be suitable for incineration, and would preferably be sorted out of the hazardous waste before incineration and treated separately. In practice this may, however, not always be fully attained.

1355. Typically hazardous waste is burned either in special technology incinerators or in rotary kiln type furnaces. Special technology incinerators include very low technology drum type, grate type, or muffle type furnaces. Also, other technologies (such as supercritical water oxidation, and electric arc vitrification) which treat hazardous waste, can be included in this group (although they are not necessarily classified as "incineration"). Hazardous waste is in some countries incinerated at cement plants and light weight aggregate kilns, which are described in sections 5.3.1 and 5.3.3.

1356. Incinerators are equipped with a wide variety of air pollution control devices that range in complexity from no control to complex, state-of-the-art systems that provide control for several pollutants. Generally speaking, the control techniques employed resemble the ones described for municipal waste incineration (see section 5.8).

5.8.2.2 Main factors determining mercury releases and mercury outputs

Table 5-203 Main releases and receiving media from incineration of hazardous waste

Phase of life cycle	**Air**	**Water**	**Land**	**Products**	**General waste**	**Sector specific treatment/ disposal**
Incineration	**X**	x			x	**X**

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

1357. The mercury content in the waste determines the mercury inputs. The incineration technology and particularly the flue gas cleaning systems applied, determine the distribution of the output of mercury between air emissions, accumulation in solid incineration and gas cleaning residues, and releases to water (only indirectly to water via some flue gas cleaning technology types).

5.8.2.3 Discussion of mercury inputs

1358. Mercury inputs to hazardous waste may vary extensively between countries due to differences in waste sorting and waste handling/treatment practices. General data on mercury inputs to this sector can most likely not be defined, and consequently a detailed data search and/or measurements on individual hazardous waste facility could be necessary.

1359. In cases where reliable mercury release estimates exist from very similar conditions (may apply within the same country or local region), an extrapolation based on waste amounts may is a possible approach to form preliminary estimates.

5.8.2.4 Examples of mercury in releases and wastes/residues

1360. The US EPA estimated atmospheric emissions of mercury from hazardous waste incinerators for the year 1996. Using similar calculations, an average mercury baseline emission rate for cement kilns and light-weight aggregate kilns was also calculated (US EPA, 1997a). Total 1996 atmospheric mercury emissions from hazardous waste combustion in the USA were estimated to be 6.3 metric tons (US EPA, 1997a). No data were given for mercury outputs to solid residues or waste water.

1361. Incinerators are equipped with a wide variety of air pollution control devices that range in complexity from no control to complex, state-of-the-art systems that provide control for several pollutants. Generally speaking, the control techniques employed resemble the ones described for municipal waste incineration (see section 5.8).

5.8.2.5 Input factors and output distribution factors

1362. Due to lack of data, it is not deemed reasonable to define default factors specifically for hazardous waste incineration. Note, however, that hazardous waste incineration may be a significant mercury release source, and it should therefore not be neglected in the inventory. If possible, site specific data should be obtained. In cases where no site specific data can be obtained, a first very rough estimate can be formed by combining data for amounts of hazardous waste incinerated with the default input factors set for medical waste (section 5.8.3); most of the possible mercury input sources are the same. For the mercury outputs, the default output distribution factors set for municipal waste incineration may be used as defaults (section 5.8.1).

1363. In cases where reliable site specific mercury release estimates exist from very similar conditions (may apply within the same country or local region), an extrapolation based on waste amounts may be a better approach to form preliminary estimates.

1364. **Links to other mercury sources estimation** - For the waste treatment sub-categories it is very important to keep in mind that the mercury content in the waste originates from 1) intentionally used mercury in discarded products and process waste; 2) natural mercury impurities in high volume materials (plastics, paper, etc.) and minerals; and 3) mercury as a human-generated trace pollutant in high volume materials. Note that parts of these mercury inputs may be directed to municipal, hazardous and medical waste.

1365. The mercury releases to the environment and waste deposits from these sub-categories can therefore be seen as a consequence of mercury being present in the products used in society.

1366. Similarly, the estimated mercury inputs to waste treatment sub-categories can be qualified through the quantification of mercury inputs to society with products and materials, as described in sections 5.4 - 5.6. Beware of double-counting of such mercury inputs when developing the mercury inventory.

1367. Calculated input totals from waste related mercury sources: To avoid double counting of mercury inputs with waste products in the input total in the Inventory Level 2 spreadsheet, only 10% of the mercury input to waste incineration sources, general waste deposition and informal dumping is included in the total for mercury inputs. These 10% represent approximately the mercury input to waste from materials which were not quantified individually in this Toolkit. These materials include such things as food wastes, paper, plastic, etc. which generally have very low mercury concentrations but very high volumes. The actual fraction of mercury from such materials, of the total inputs of mercury to waste, will vary between regions and very little data on this issue is available in the literature. Limited data from a Danish substance flow analysis (Skårup *et al.*, 2003) for mercury indicate however, that this mercury fraction is small, in the range of some 2-20% of total mercury inputs to general waste.

5.8.2.6 Source specific main data

1368. The most important source specific data would in this case be:

- In case mercury inputs to waste (through products etc.) can be estimated quite accurately, these input data can be used in the quantification of mercury releases from waste incineration. Note, however, that mercury inputs to incineration from mercury trace concentrations in high volume materials (plastics, paper, etc.) are not quantified individually in this Toolkit, and quantification of total inputs would therefore tend to be underestimated when using this approach.

1369. As mercury inputs in waste are typically difficult to measure, or otherwise quantify accurately, the following data may likely give the best estimates of mercury releases/outputs from waste incineration:

- Atmospheric releases: Measurements of average mercury concentrations in the flue gas combined with measurements of flue gas produced (per year) at average conditions;

- Outputs to solid residues: Measurements of average mercury concentrations and amounts of residues produced per year for each relevant residue output stream (ashes/slags, flue gas cleaning residues, gypsum boards etc.);

- Aquatic releases (if any): Measurements of average mercury concentrations in the aquatic discharges combined with measurements of the amounts discharged (per year) at average conditions.

5.8.3 Incineration of medical waste

5.8.3.1 Sub-category description

1370. Medical waste includes infectious and non-infectious wastes generated by a variety of facilities engaged in medical care, veterinary care, or research activities such as hospitals, clinics, doctors' and dentists’ offices, nursing homes, veterinary clinics and hospitals, medical laboratories, and medical and veterinary schools and research units. The mercury content in the medical waste stream originates primarily from intentionally used mercury in discarded products and process waste. The mercury concentrations are directly dependent on the inputs of mercury to the waste, and will therefore likely vary much between different countries and circumstances.

1371. Medical waste is considered to be every waste generated from medical activities regardless if these activities take place in a hospital or are performed by a medical doctor, dentist or any other physician. The waste generated during these activities includes secretes, blood, pharmaceuticals and packaging materials and/or tools used for the medical treatment of people or animals. To reliably destroy viruses, bacteria, and pathogens this waste is often thermally treated by incineration (UNEP, 2003). A medical waste incinerator (MWI) is any device that burns such medical waste.

1372. In some countries medical waste - as defined above - is incinerated in hazardous waste incinerators or in municipal waste incinerators suited for the purpose.

1373. Available information indicates that MWI systems can be significant sources of mercury emissions. Mercury emissions result from mercury-bearing materials contained in the waste. Known mercury sources include thermometers, dental material with mercury amalgam, blood pressure gauges, batteries, laboratory chemicals (in tissue samples etc.), fluorescent lamps, high-intensity discharge lamps (mercury vapour, metal halide, and high-pressure sodium); special paper and film coatings, and pigments; most of which should preferably be sorted out the waste stream before incineration, if possible. Note that this composition overlaps with possible mercury inputs to hazardous waste, and in many cases it may be difficult to determine this distribution of mercury inputs, if both kinds of waste incineration take place in a country.

1374. Incinerators are equipped with a wide variety of air pollution control devices. Generally speaking, the control techniques employed resemble the ones described for municipal waste incineration (see section 5.8.1).

1375. A number of air pollution control system configurations have been used to control particulate material (PM) and gaseous emissions from the medical waste incinerators combustion stacks. Most of these configurations fall within the general classes of wet systems and dry systems. Wet systems typically comprise a wet scrubber designed for PM control (venturi scrubber or rotary atomizing scrubber) in series with a packed-bed scrubber for acid gas removal and a high-efficiency mist elimination system. Most dry systems use a fabric filter for PM removal, but ESP's have been installed on some larger medical waste incinerators. These dry systems may use sorbent injection via either dry injection or spray dryers upstream from the PM device to enhance acid gas control. Additionally, some systems incorporate a combination dry/wet system that comprises a dry sorbent injection/fabric filter system followed by a venturi scrubber. Because the systems described above are designed primarily for PM and acid gas control, they have limitations relative to mercury control. However, recent EPA studies indicate that sorbent injection/fabric filtration systems can achieve improved mercury control by adding activated carbon to the sorbent material (US EPA, 1997a).

5.8.3.2 Main factors determining mercury releases and mercury outputs

Table 5-204 Main releases and receiving media from incineration of medical waste

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Incineration	X	x			x	X

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

1376. The mercury content in the waste determines the mercury inputs. The incineration technology and particularly the flue gas cleaning systems applied, determine the distribution of the output of mercury between air emissions, accumulation in solid incineration and gas cleaning residues, and releases to water (only indirectly to water via some flue gas cleaning technology types).

5.8.3.3 Discussion of mercury inputs

Table 5-205 Overview of activity rate data and mercury input factor types needed to estimate releases from incineration of medical waste

Activity rate data needed	Mercury input factor
Amount of waste incinerated	Concentration of mercury in the waste

1377. According to US EPA (2004) there is up to 50 times more mercury in medical waste than in general municipal waste in the USA, and the amount of mercury emitted from general medical incinerators averages more than 60 times that from pathological waste incinerators

5.8.3.4 Examples of mercury in releases and wastes/residues

1378. In Canada in 1995, in total 580 kg mercury was emitted to the air from 218 biomedical incinerators, accounting for 28 % of the total waste incinerator emission in the country (Environment Canada, 2000). Sources of mercury in waste products included batteries, fluorescent and high intensity lighting, fixtures, thermometers, specialty papers and films, and pharmaceutical materials and pigmented materials. Based on a 1990 emissions sampling program involving six hospitals in Ontario, it was estimated that, on average, 14 grams of mercury were emitted for each metric ton of waste incinerated (Environment Canada, 2000).

1379. In the USA in 1996, 14.6 metric tons mercury was emitted to the atmosphere from incinerating 204,000 metric tons of pathological waste and 1,410,000 metric tons general medical waste (US EPA, 1997b). This corresponds to an average atmospheric emission of 8.9 g/metric ton of waste.

1380. The general medical waste contain significantly more mercury than the pathological waste and the average for the general medical waste will thus be slightly higher that 8.2 g mercury per metric ton (US EPA, 2004)

1381. The primary outlet of atmospheric emissions to air from medical waste incineration is the combustion gas exhaust stack. However, small quantities of mercury may be contained in the fugitive PM emissions from ash handling operations, particularly if the fly ash is collected in a dry air pollution control system with high mercury removal efficiencies. During the 1980s and 1990s, mercury emissions have been measured at least 47 medical waste incinerators (MWI's) in the USA. About 40 of these tests were considered by the US EPA to be adequate for emission factor development (US EPA, 1997a).

1382. Emission factors for MWI's with combustion controls, wet scrubbers, fabric filter/packed bed systems, and dry scrubbers (with and without activated carbon injection) were developed by US EPA.

1383. Table 5-206 presents the atmospheric emission factors for MWI's with each control technology developed by US EPA (1997a). The emission factors presented in the table are average emission factors that represent emissions from continuous and intermittent MWI's that burn a mixture of non-infectious waste and infectious waste. While the procedure used to calculate the MWI emission factors provides average emission factors that represent the industry cross section, it should not be used to determine emission factors for individual facilities. The numbers seam to indicate that the mercury inputs in the incinerated medical waste would in this case be close to - a little higher than – 37 g mercury per metric ton of waste. This situation may have changed towards lower values since 1997.

Table 5-206 Atmospheric mercury emission factors for medical waste incinerators (MWIs), developed by US EPA (1997a)

Air Pollution Control	g/metric ton waste
Combustion control	37
Wet scrubber	1.3
Dry scrubber without carbon	37
Dry scrubber with carbon	1.7
Fabric Filter/packed bed	1.3

5.8.3.5 Input factors and output distribution factors

1384. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows.

1385. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

a) Default mercury input factors

1386. Actual data on mercury levels in the waste - for example established through the procedures of this Toolkit - will lead to the best estimates of releases.

1387. If no indications is available on the mercury concentration in the waste, a first estimate can be formed by using the default input factors selected in Table 5-207 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate.

Table 5-207 ***Preliminary*** *default input factors for mercury in medical waste*

Material	Default input factors; g Hg/metric ton waste; low end - high end (intermediate) *1
Medical waste ***1**	8 – 40 (24)

Notes: *1 The low end input factor is expected to be relevant for a situation where substantial parts of the waste products with high mercury concentration (thermometers, batteries, dental amalgam wastes, fluorescent lamps etc.) have been sorted out of the waste for separate treatment, and will therefore be present in lower amounts in the waste. The high end factor is expected to reflect a situation where mercury-added products are still used in the medical sectors and the separation of these products from the waste stream is more moderate.

b) Default mercury output distribution factors

1388. In case no site specific data on distribution of mercury outputs are available, the default mercury output distribution factors set for municipal waste incineration can be applied to form a first rough estimate (see section 5.8.1).

c) Links to other mercury sources estimation

1389. For the waste treatment sub-categories it is very important to keep in mind that the mercury content in the waste originates from 1) intentionally used mercury in discarded products and process waste; 2) natural mercury impurities in high volume materials (plastics, paper, etc.) and minerals; and 3) mercury as a human-generated trace pollutant in high volume materials. Note that parts of these mercury inputs may be directed to municipal, hazardous and medical waste.

1390. The mercury releases to the environment and waste deposits from these sub-categories should therefore be seen as a consequence of mercury being present in the products used in society.

1391. Similarly, the estimated mercury inputs to waste treatment sub-categories can be qualified through the quantification of mercury inputs to society with products and materials, as described in sections 5.4 - 5.6. Beware of double-counting of such mercury inputs when developing the mercury inventory.

1392. Calculated input totals from waste related mercury sources: To avoid double counting of mercury inputs with waste products in the input total in the Inventory Level 2 spreadsheet, only 10% of the mercury input to waste incineration sources, general waste deposition and informal dumping is included in the total for mercury inputs. These 10% represent approximately the mercury input to waste from materials which were not quantified individually in this Toolkit. These materials include such things as food wastes, paper, plastic, etc. which generally have very low mercury concentrations but very high volumes. The actual fraction of mercury from such materials, of the total inputs of mercury to waste, will vary between regions and very little data on this issue is available in the literature. Limited data from a Danish substance flow analysis (Skårup *et al.*, 2003) for mercury indicate however, that this mercury fraction is small, in the range of some 2-20% of total mercury inputs to general waste.

5.8.3.6 Source specific main data

1393. The most important source specific data would in this case be:

- In case mercury inputs to waste (through products etc.) can be estimated quite accurately, these input data can be used in the quantification of mercury releases from waste incineration. Note, however, that mercury inputs to incineration from mercury trace concentrations in high volume materials (plastics, paper, etc.) are not quantified individually in this Toolkit, and quantification of total inputs would therefore tend to be underestimated when using this approach.

1394. As mercury inputs in waste are typically difficult to measure, or otherwise quantify accurately, the following data may likely give the best estimates of mercury releases/outputs from waste incineration:

- Atmospheric releases: Measurements of average mercury concentrations in the flue gas combined with measurements of flue gas produced (per year) at average conditions;

- Outputs to solid residues: Measurements of average mercury concentrations and amounts of residues produced per year for each relevant residue output stream (ashes/slags, flue gas cleaning residues, gypsum boards etc.);

- Aquatic releases (if any): Measurements of average mercury concentrations in the aquatic discharges combined with measurements of the amounts discharged (per year) at average conditions.

5.8.4 Sewage sludge incineration

5.8.4.1 Sub-category description

1395. Sewage sludge is the product of any wastewater treatment processes regardless of its origin (e.g., wastewater from municipal, agricultural or industrial activities). The mercury concentrations are directly dependent on the inputs of mercury to the waste water, and will therefore likely vary much between different countries and circumstances.

1396. If the concentrations of hazardous substances are low enough, the sludge may be spread on farmland as fertilizer in some countries. Otherwise, the sludge can either be incinerated (separately or by co-combustion in power plants, municipal waste incinerators, cement kilns etc.), be landfilled, or undergo other treatment like wet oxidation, pyrolysis, gasification, etc.

1397. In some countries, sewage sludge is commonly sent for incineration as final disposal. In the USA for example, about 785,000 metric tons of sewage sludge (dry weight) are estimated to be incinerated annually (B. Southworth, 1996, as cited in US EPA, 1997a).

Process Description

1398. The sewage sludge incineration process involves two primary steps. The first step is the dewatering of the sludge (or vaporization of moisture from the sludge). Sludge is generally dewatered until it is about 20 - 35% solids. Systems using Thermal Conditioning Processes regularly obtain dewatered sludge that contains in excess of 40% solids. Sludge will usually burn without auxiliary fuel if it is greater than 25% solids. After dewatering, the sludge is sent to the incinerator, and thermal oxidation occurs. The following description is for sludge incineration in separate incinerators, often placed as an integrated part of larger waste water treatment plants: The unburned residual ash is removed from the incinerator, usually in a continuous basis, and is disposed in a landfill or reused (i.e., bricks, concrete, asphalt, etc.). A portion of the non-combustible waste, as well as unburned volatile organic compounds, exits the combustor through the exhaust gas stream. Air pollution control devices, primarily wet scrubbers, are used to remove pollutants from the exhaust gas stream. The gas stream is then exhausted, and the pollutants collected by the control device are sent back to the head of the wastewater treatment plant with the scrubber effluent (and thereby re-introduced in the waste water treatment system). Because mercury and mercury compounds are relatively volatile, most mercury will leave the combustion chamber in the exhaust gas; concentrations in the ash residue are expected to be negligible (US EPA, 1997a).

1399. If such a system is not purged deliberately through any other material outputs (for example by landfilling ashes or some of the flue gas cleaning residues), the only mercury output paths will in principle be atmospheric releases from the incineration, and releases with the treated waste water at the outlet of the waste water treatment plant.

5.8.4.2 Main factors determining mercury releases and mercury outputs

Table 5-208 Main releases and receiving media from sewage sludge incineration

Process	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Sludge incineration	**X**	**X**			x	X

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

1400. The most important factors determining releases of mercury from this sub-category are the concentration of mercury in the sludges that are incinerated, the type of control measures present at the source, and the fate of the incineration residues. If all incineration residues are fed back into the waste water treatment plant, no mercury retention is attained; a steady state situation will build up and all mercury inputs will be released to the atmosphere or to aquatic environments via the outlet of the waste water plant.

5.8.4.3 Discussion of mercury inputs

Table 5-209 Overview of activity rate data and mercury input factor type needed to estimate releases from sewage sludge incineration

Activity rate data needed	Mercury input factor
Amount of sewage sludge incinerated (preferably on ad dry matter basis)	Concentration of mercury in sewage sludge incinerated (preferably on ad dry matter basis) ***1**

Notes: *1 For the same sludge (and with the same actual mercury content), dry matter based concentration will always be higher than wet matter concentrations. Always use the same basis (wet or dry) for the amounts of sludge, and the mercury concentration in sludges, when calculating mercury inputs.

1401. The most recent data on the mercury content of sewage sludge in the USA obtained from the 1988 National Sewage Sludge Survey showed a mean mercury concentration of 5.2 ppmwt (parts per million by weight = g Hg/metric ton). Earlier data obtained in the mid 1970's indicate that mercury concentrations in municipal sewage sludge ranged from 0.1 - 89 ppmwt with a mean value of 7 ppmwt and a median value of 4 ppmwt. Other early data collected by US EPA from 42 municipal sewage treatment plants in the early 1970's showed a range of 0.6 - 43 ppmwt, with a mean value of 4.9 ppmwt on a dry solids basis (US EPA, 1997a).

1402. In Denmark in 1999, average mercury concentrations in sludge samples representing about 95% of the total sewage sludge production in Denmark were 1.2 g Hg/metric ton of dry sludge (dry matter basis). Of this, about 41% was applied on agricultural or forest land, about 28% was incinerated, and the remainder was landfilled or otherwise stored or treated. (Skårup *et al.*, 2003, based on Danish EPA, 2001).

1403. In Finland, the average mercury concentration in sewage sludge is 0.5 g/metric ton (dry matter basis; Finnish Environment Institute, 2004).

1404. Lassen *et al.* (2004) presents examples of reported mercury concentrations in municipal sewage sludge in the Russian Federation. In major cities represented (Moscow, St. Petersburg), the concentrations are about 1-2 g Hg/metric ton (dry matter basis). In smaller cities represented concentrations vary more; most results are in the range of 0.1-1 g Hg/metric ton (dry matter basis), while 4 out of 14 smaller cities have results in the range of 2.4-10 g Hg/metric ton (dry matter basis).

5.8.4.4 Examples of mercury in releases and wastes/residues

1405. Various wet scrubbers are used to control pollutant emissions from sludge incinerators, including low pressure drop spray towers, wet cyclones, higher pressure drop venturi scrubbers, and venturi/impingement tray scrubber combinations (US EPA, 1997a).

1406. Emissions factors from US EPA, which have been developed for various controls scenarios, are presented in Table 5-210. However, mercury concentration in sludge and effectiveness of the control technologies vary widely, therefore these emissions factors have limitations and uncertainty.

1407. If such a system is not purged deliberately through any other material outputs (for example by landfilling ashes or some of the flue gas cleaning residues), the only mercury output paths will in principle be atmospheric releases from the incineration, and releases with the treated waste water at the outlet of the waste water treatment plant.

Table 5-210 Atmospheric mercury emissions factors for sewage sludge incinerators in the USA

Incinerator type	**Control status**	**Atmospheric Mercury Emission factor in g per metric tons dry sludge (g/metric tons)**
Multiple Hearth	Cyclone	2.3
Multiple Hearth	Cyclone and venturi scrubber	1.6
Multiple Hearth	Impingement scrubber	0.97
Multiple Hearth	Venturi scrubber and impingement scrubber	0.005
Fluidized Bed	Venturi scrubber and impingement scrubber	0.03

1408. In Germany studies have demonstrated that only 1-6 % of the mercury supplied with the sludge is found in the fly ash separated with electrostatic precipitators (Saenger *et al.*, 1999a).

1409. The distribution of mercury by incineration of sewage sludge in a fluidized bed sludge incinerator in Hamburg, Germany, is shown in Figure 5-16. The mercury concentration of the raw flue gas ranged between 500 and 950 μg/m^3 whereas is in the cleaned gas was below 40 μg/m^3 (Saenger *et al.*, 1999b). The incinerator is equipped with an adsorber with injection of a mixture of activated carbon and lime hydrate. The adsorbent is removed in a fibrous filter, which is fed into the incinerator.

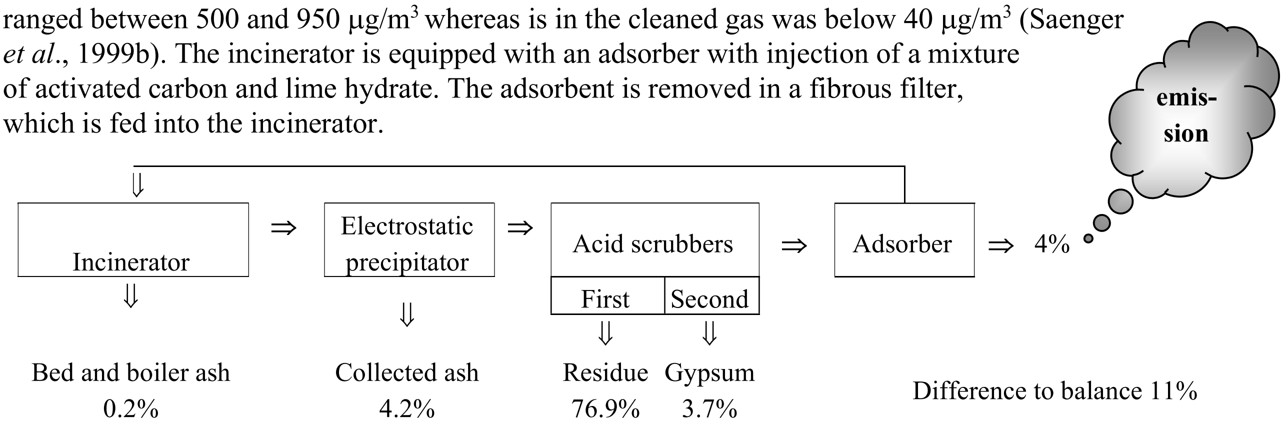

Figure 5-16 Balance of mercury in a sewage sludge incineration plant of Hamburg, Germany (Saenger et al., 1999b)

5.8.4.5 Input factors and output distribution factors

1410. No attempt was made to establish default factors for this sub-category. Mercury inputs to and releases from sludge incineration is highly dependent on the amounts of mercury discharged to the waste water treatment system.

1411. **Links to other mercury sources estimation -** Mercury in sludge led to sludge incineration may also be calculated in the section on waste water treatment. Beware of double counting.

5.8.4.6 Source specific main data

1412. The most important source specific data would in this case be:

- Measured data or literature data on the mercury concentrations in the sludges combusted at the source;
- Amount of sludge burned; and
- Measured data on emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

1413. See also advice on data gathering in section 4.4.5.

5.8.5 Open waste burning on landfills and informally

5.8.5.1 Sub-category description

1414. Open waste burning is defined here as waste incineration undertaken at informal conditions, in barrels, containers, in landfills (of any kind) or on bare land, with no flue gas controls and diffuse spreading of incineration residues on land/landfill. If mercury is present in the waste, part of it will be released to air, and part of it will remain in incineration residues (including unburned and semi-degraded waste) with a potential for additional subsequent mercury releases to air, ground water and surface waters. Given the volatility of mercury, it is expected that most of the mercury is released into the air (considered as 100% in default factors in the IL2 spreadsheet) as a result of open waste burning. This waste disposal method will contribute to the global emissions of mercury (and several other hazardous pollutants) and may pose an immediate risk for the local community in which it takes place, because air emissions are not controlled and residues may cause contamination of the local ground water.

1415. If this is a widespread waste disposal method in the country or region examined, the potential mercury releases can be indicated through 1) quantification of mercury inputs with individual products and materials as described in this Toolkit, or 2) by applying the mercury input default factors (mercury concentrations in municipal solid waste) described in section 5.8.1 (municipal waste incineration), in combination with rough estimates of amounts of waste incinerated informally per year. The resulting estimates are of course very uncertain, but may give a rough indication of the order of magnitude of mercury releases from informal waste burning.

c) Links to other mercury sources estimation

1416. It should be noted, that mercury inputs to incineration from mercury trace concentrations in high volume materials (plastics, paper, etc.) are not quantified individually elsewhere in this Toolkit.

5.9 Waste deposition/landfilling and waste water treatment

Table 5-211 Waste deposition/landfilling and waste water treatment: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Chapter	Sub-category	Air	Water	Land	Product	Waste/ residue	Main inventory approach
5.9.1	Controlled landfills/deposits	x	x	**X**		**X**	OW
5.9.2	Diffuse deposition under some control	x	**X**	**X**		**X**	OW
5.9.3	Informal local disposal of industrial production waste	**X**	**X**	**X**			PS
5.9.4	Informal dumping of general waste	**X**	**X**	**X**			OW
5.9.5	Waste water system/treatment		**X**	**X**		x	OW/PS

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

5.9.1 Controlled landfills/deposits

5.9.1.1 Sub-category description

1417. Mercury content in the general waste stream originates from three main groups: 1) intentionally used mercury in spent products and process waste; 2) natural mercury impurities in bulk materials (plastics, tin cans, etc.) and minerals, and; 3) mercury as an anthropogenic trace pollutant in bulk materials. The quantitative split between deposition, incineration and other treatments of waste vary between countries. Informal, uncontrolled waste dumping may be significant in some countries. Types of waste (and thereby mercury content) allowed at landfills/deposits may vary between countries, and deposits receiving more hazardous waste fractions - for instance chemicals or solid residues from waste incineration - is sometimes designed to give better protection of the groundwater and other environmental media.

1418. Throughout the history of any deposit/landfill, relatively small amounts of mercury are released annually from the deposit with outputs of water (leaching water and surface run-off), and with air to the atmosphere, because part of the mercury is slowly evaporating from the waste. The fate of the mercury released with water depends greatly on the presence and efficacy of protective lining under the deposit and associated waste water management. If the water is not collected and sent to waste water cleaning, the mercury (and other substances) may contaminate soil and groundwater under and around the deposit. If the water is sent to waste water cleaning, the mercury will mainly follow the sludge fraction and go to land use or other fate, while the rest will follow the water discharge from the waste water treatment (COWI, 2002).

1419. The largest "release" of mercury, in terms of mercury quantities associated with deposition of waste, is of course the actual accumulation of waste - and thereby mercury - on the site, possibly giving rise to long term environmental impacts through excavation, urbanisation and other impacts.

1420. For "average composition" municipal waste, it may be useful in the quantification of releases to consider the split of waste amounts between the different waste treatment streams applied in the country; quantifications from waste incineration may give some impression of the general content of mercury in municipal waste.

1421. According to Lindberg *et al.* (2001), landfills are the only measured anthropogenic sources of dimethyl-mercury, along with monomethyl-mercury the main mercury species responsible for mercury effects in the broad public through seafood digestion. Methyl-mercury is also formed from elemental mercury (from anthropogenic and natural sources) by biological processes in nature (see UNEP, 2002).

1422. Shunlin Tang *et al.* (2004) indicated a clear trend that mercury releases to the atmosphere (total gaseous mercury) from relatively new waste were higher at daytime than during the night. This finding could indicate - as could perhaps be expected - that mercury releases to the atmosphere from landfills is influenced by ambient temperatures. Other factors which could change in the time span of a day - like atmospheric pressure - could perhaps also have influenced the mercury concentrations in the landfill venting gases. In the general situation, one would expect the releases of mercury with landfill gas to be higher in regions with higher ambient temperatures, due to the temperature dependence of the volatility of mercury and methyl-mercury, and perhaps also the temperature dependence of microbial activity. Besides the concentration and physical availability of the mercury in the waste, regional ambient temperatures could perhaps be an important factor in the magnitude of atmospheric mercury releases from landfills.

5.9.1.2 Main factors determining mercury releases and mercury outputs

Table 5-212 Main releases and receiving media from controlled landfills/deposits

Phase of life cycle	Air	Water	Land	Product	General waste	Sector specific treatment/ disposal
Landfills	x	x	**X**		**X**	

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

5.9.1.3 Discussion of mercury inputs

Table 5-213 Overview of activity rate data and mercury input factor types needed to estimate releases from controlled landfills/deposits

Activity rate data needed	Mercury input factor
Amounts of waste landfilled	Mercury concentration in the waste

1423. For discussion of mercury content in municipal waste, see section 5.8.1 on municipal waste incineration.

5.9.1.4 Examples of mercury in releases

1424. Examples of mercury concentrations in land fill gas and leachate are shown in Table 5-214 below.

1425. Lindberg *et al.* (2004) note that mercury fluxes from landfills are dominated not by landfill gas, but by releases during routine waste handling operations at the working face of the landfill; direct emissions are according to Lindberg *et al.* (2004) typically below 10% of the total mercury release from landfills.

1426. Oak Ridge National Laboratory (USA) researchers estimate that the amount of mercury lost during collection, storage, compacting and transfer activities may be comparable to what’s lost at the working face of the landfill. They base this conclusion on amounts of mercury measured in dumpsters and open pits at transfer stations (NEWMOA, 2003).

1427. Based on measurements of mercury releases via landfill gas flares, landfill cover and the working face where the new waste is worked on and not yet covered, Lindberg (2004) estimated the total atmospheric releases from municipal landfill operations in the state of Florida, USA, to be in the order of 10-50 kg mercury per year. Mercury releases from the working face of the landfills were more than tenfold higher than the mercury releases with flared land fill gas.

Table 5-214 Examples of mercury concentrations in landfill gas and leachate

Country (location)	**Landfill gas (ng/m3) *1**	**Leachate (µg Hg/l)**	**Reference and remarks**
Mexico (Mexico City)	Range in 4 landfills: TGM 20-50; range in a 5th landfill: TGM 1100-1500	Range in same 4 landfills: 0.3-5; same 5th landfill: 9	De la Rosa *et al.,* 2004; 5 land fills, municipal waste from Mexico City area
Korea	Average: TGM 420		Kim and Kim, 2002, as cited by De la Rosa *et al.,* 2004
USA (Florida)	8 active landfills: Range of site averages: TGM 340 - 12000 (6 sites with TGM above 1390, 4 sites with TGM above 6900) 4 closed landfills: Range of site averages:TGM 10 - 140		Lindberg *et al.,* 2004; includes also measured concentrations of DMHg and MMHg
USA (Minnesota)	Average from one closed landfill: TGM 8600		Lindberg *et al.,* 2004
USA (Delaware)	Average from one active landfill: TGM 410		Lindberg *et al.,* 2004
USA (California)	Average from one closed landfill: TGM 4700		Lindberg *et al.,* 2004
China (Guiyang, capital of Guizhou province)	Vent gas from 6 months old municipal waste: TGM: 666 Vent gas from 12 months old waste: TGM: 25.6 Vent gas from 24 months old waste: TGM: 14.5		Shunlin Tang *et al.,* 2004. In municipal waste.
Denmark		0.5	Maag *et al.,* 1996; used in reference as roughly estimated DK average

Notes: *1 TGM = total gaseous mercury (this includes all gaseous mercury species present);
MMHg: Mono-methyl-mercury (organics species), DMHg. Dimethyl-mercury (organic species).

5.9.1.5 Input factors and output distribution factors

a) Default mercury input factors

1428. Actual data on mercury levels in the waste - for example established through the procedures of this Toolkit - will lead to the best estimates of mercury inputs to landfills.

1429. If no indications are available on the mercury concentration in municipal waste, a first estimate can be formed by using the default input factors selected in Table 5-215 below (based on the data sets presented in section 5.8.1 on municipal waste incineration). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate. The low end input factor is expected to be relevant for a situation where substantial parts of the waste products with high mercury concentration (thermometers, batteries, dental amalgam wastes, switches etc.) have been sorted out of the waste for separate treatment, and will therefore be present in lower numbers in the municipal waste. The high end input factor is expected to be relevant for situations where no such sorting takes place and most of the product waste with high mercury concentrations is therefore present in the municipal waste. As mentioned, the mercury levels in waste are of course also directly dependent on the consumption of mercury-containing products and materials in the country investigated.

1430. The default input factors here were derived from data from developed countries only. A simple test, based on your Inventory Level 2 results, will indicate if the default factors may over-estimate the mercury releases from this activity in the country. See Annex 8.5 for more details.

1431. No default input factors could be established for hazardous waste landfill, due to lack of data.

Table 5-215 ***Preliminary*** *default input factors for mercury in municipal waste*

Material	**Default input factors; g Hg/metric ton waste; low end - high end (intermediate) *1**
Municipal solid waste (general "household" waste) ***1**	0.2 – 4 (1)

Notes: *1 The low end input factor is expected to be relevant for a situation where substantial parts of the waste products with high mercury concentration (thermometers, batteries, dental amalgam wastes, switches etc.) have been sorted out of the waste for separate treatment, and will therefore be present in lower numbers in the municipal waste. The high end input factor is expected to be relevant for situations where no such sorting takes place and most of the product waste with high mercury concentrations is therefore present in the municipal waste. As mentioned, the mercury levels in waste are of course also directly dependent on the consumption of mercury-containing products and materials in the country investigated.

b) Default mercury output distribution factors

1432. Available data are not sufficient to form input-correlated output distribution factors as generally used in this Toolkit. The Reference Report provides a summary of data on emissions to air and via leachate water. The limited data available indicate that mercury air emissions from landfills may be relatively modest compared to major mercury sources such as coal fired power plants, etc. To signal that landfills are however a relevant mercury release source, artificial output factors were set as signal values as follows: To air: 0.01 of mercury in waste landfilled annually (meaning that 1 percent of the mercury landfilled is calculated as released to air during the entire life of the landfill; a realistic yet maybe underestimated fraction). To water (via leachate): 0.0001 of mercury in waste landfilled annually. See the table below.

Table 5-216 ***Preliminary*** *default emission factors suggested for landfilling of municipal waste*

	Default output distribution factors, share of Hg input					
	Air	**Water**	**Land**	**Products**	**General waste**	**Sector specific treatment/ disposal**
Landfilling of municipal waste	0.01	0.0001	-	-	-	-

c) Links to other mercury sources estimation

1433. For the waste treatment sub-categories it is very important to keep in mind that the mercury content in the waste originates from 1) intentionally used mercury in discarded products and process waste; 2) natural mercury impurities in high volume materials (plastics, paper, etc.) and minerals; and 3) mercury as a human-generated trace pollutant in high volume materials. Note that parts of these mercury inputs may be directed to municipal, hazardous and medical waste.

1434. The mercury releases to the environment and waste deposits from these sub-categories should therefore be seen as a consequence of mercury being present in the products used in society.

1435. Similarly, the estimated mercury inputs to waste treatment sub-categories can be qualified through the quantification of mercury inputs to society with products and materials, as described in sections 5.4 - 5.6. Beware of double-counting of such mercury inputs when developing the mercury inventory.

1436. Note that mercury inputs to incineration from mercury trace concentrations in high volume materials (plastics, paper, etc.) are not quantified individually in this Toolkit.

5.9.1.6 Source specific main data

1437. The most important source specific data would in this case be:

- Amount of waste sent to landfills; and
- Concentration of mercury in the waste sent to landfills.

5.9.2 Diffuse deposition under some control

5.9.2.1 Sub-category description

1438. This sub-category covers deposition of special types of waste under roads, in constructions, etc. under controlled procedures (based on risk assessment) and with some retention of pollutants from wash-out, etc.; for example incineration residues, fly ash from coal combustion and other solid residues. Such deposition may in the long run lead to mercury releases to soil, groundwater, surface water and the atmosphere, and may therefore be of interest as a potential mercury source under individual circumstances. The sub-category covers wastes which are often produced in very large quantities.

1439. The sub-category is not attempted quantified separately here, but is covered under the sub-categories where the waste is generated, where it is generally designated as outputs to "sector specific treatment/disposal" accompanied by a descriptive table note.

5.9.3 Informal local disposal of industrial production waste

5.9.3.1 Sub-category description

1440. In many countries, historical production activities involving the use and release of mercury have been proven to have caused local deposition - often on-site - of production waste with elevated mercury content. No attempt was made here to collect evidence of similar ongoing activities, but they cannot be ruled out, especially in countries with less strict regulation or enforcement of regulation on such industrial activities.

1441. Incidents of informal or illegal disposal of industrial waste with elevated mercury content are of a local or national character, and it is difficult to give any general description of the phenomenon except that potential candidates may most likely be among the industrial activities listed in the section on "potential hot-spots" (section 5.11).

1442. Informal disposal of mercury waste may cause severe local mercury contamination and is therefore a potentially important mercury release source which must be identified and investigated on an individual basis.

5.9.4 Informal dumping of general waste

5.9.4.1 Sub-category description

1443. Informal dumping of waste is defined here as waste dumping undertaken under informal conditions with no safeguards to minimise releases of pollutants to the surroundings. If mercury is present in the waste, it represents a potential for mercury releases to soil, air, ground water and surface waters. This waste disposal method may pose an immediate risk for the local community in which it takes place, because mercury (and other contaminants) may cause contamination of the local ground water.

1444. If this is a widespread waste disposal method in the country or region examined, the potential mercury releases can be indicated through 1) quantification of mercury inputs with individual products and materials as described in this Toolkit, or 2) by applying the mercury input default factors (mercury concentrations in municipal waste) described in section 5.8.1 (municipal waste incineration), in combination with rough estimates of amounts of waste dumped informally per year. The resulting estimates are of course very uncertain, but may give a rough indication of the order of magnitude of mercury releases from informal waste dumping.

5.9.4.2 Input factors and output distribution factors

a) Default mercury input factors

1445. Actual data on mercury levels in the waste - for example established through the procedures of this Toolkit - will lead to the best estimates of mercury inputs to informal dumping.

1446. If no indications are available on the mercury concentration in general waste, a first estimate can be formed by using the default input factors selected in Table 5-217 below (based on the data sets presented in section 5.8.1 on municipal waste incineration). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate. The low end input factor is expected to be relevant for a situation where substantial parts of the waste products with high mercury concentration (thermometers, batteries, dental amalgam wastes, switches etc.) have been sorted out of the waste for separate treatment, and will therefore be present in lower numbers in the municipal waste. The high end input factor is expected to be relevant for situations where no such sorting takes place and most of the product waste with high mercury concentrations is therefore present in the municipal waste. As mentioned, the mercury levels in waste are of course also directly dependent on the consumption of mercury-containing products and materials in the country investigated.

1447. The default input factors here were derived from data from developed countries only. A simple test, based on your Inventory Level 2 results, will indicate if the default factors may over-estimate the mercury releases from this activity in the country. See Annex 8.5 for more details.

*Table 5-217 **Preliminary** default input factors for mercury in general waste*

Material	Default input factors; g Hg/metric ton waste; low end - high end (intermediate) *1
Municipal solid waste (general "household" waste) ***1**	0.2 – 4 (1)

Notes: *1 The low end input factor is expected to be relevant for a situation where substantial parts of the waste products with high mercury concentration (thermometers, batteries, dental amalgam wastes, switches etc.) have been sorted out of the waste for separate treatment, and will therefore be present in lower numbers in the municipal waste. The high end input factor is expected to be relevant for situations where no such sorting takes place and most of the product waste with high mercury concentrations is therefore present in the municipal waste. As mentioned, the mercury levels in waste are of course also directly dependent on the consumption of mercury-containing products and materials in the country investigated.

b) Default mercury output distribution factors

1448. The default output distribution factors below can be used if specific knowledge is not available. These default factors are formed on a basic assumption that most of the mercury is released to land, while minor fractions may be lost to air via evaporation, and to water via surface run-off of precipitation. These default factors are only meant to signal that these releases may be significant.

*Table 5-218 **Preliminary** default mercury output distribution factors for informal dumping of general waste*

	Default output distribution factors, share of Hg input					
	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Informal dumping of general waste	0.1	0.1	0.8	-	-	-

1449.

1450. **Links to other mercury sources estimation** - It should be noted that mercury releases to informal waste incineration and waste dumping under the individual product and materials sub-categories are quantified in these sub-sections as direct releases to land, air and water. Beware of double-counting. Note, however, that mercury inputs to dumping from mercury trace concentrations in high volume materials (plastics, paper, etc.) are not quantified individually elsewhere in this Toolkit.

5.9.5 Waste water system/treatment

5.9.5.1 Sub-category description

1451. The most important factors determining releases of mercury from waste water are the amount of mercury-containing wastes that are discharged to the system and the concentration of mercury in those wastes. Mercury content in waste water mainly originates from the two source groups: 1) intentionally used mercury in products and processes (such as from dental amalgams, spillage from thermometers and other devices, and industrial discharges); and 2) atmospheric mercury washed out by precipitation that goes to waste water systems (originating from both anthropogenic and natural sources). As such, waste water treatment is an intermediate mercury release source where mercury inputs from original mercury contamination is distributed on the output pathways water (with treated water), land (through the application of sludge as fertiliser) and air (through sludge incineration and sludge application). In addition some sludge is disposed of in landfills.

1452. The quantitative split between the parts of waste water that go to public waste water (treatment) systems and waste water discharged directly to aquatic environments varies between countries, and possibly also among local regions within a country. The same may be the case for the degree of mercury removal attained in treatment systems before the water is discharged to the environment (efficiency for mercury retention may vary considerably depending on individual plant configurations). This sub-category also includes waste water piping systems that lead the collected waste water directly to the sea, ocean or water ways without any waste water cleaning activities involved.

1453. Waste water treatment systems are facilities that receive waste water from domestic and industrial sources and then clean it, filter it and treat it in various ways to remove harmful materials and to produce water clean enough to be discharged into local waterways, such as rivers or oceans. A typical waste water treatment plant consists of a collection system, a series of processes that remove solids, organics and other pollutants from wastewater, and a series of processes for managing and treating sludge. In addition to these treatment processes, these systems can also include intercepting sewers, outfall sewers, sewage collection systems, pumping, power and other equipment (US EPA, 1998).

5.9.5.2 Main factors determining mercury releases and mercury outputs

Table 5-219 Main releases and receiving media from waste water system/treatment

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Waste water system/treatment		**X**	**X**		x	x

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

1454. Some larger industries have individual waste water cleaning facilities. Direct discharges of untreated waste water may take place in some cases both from industry and municipal waste water systems in some countries. Waste water piping systems receiving both actual waste water, rain water from roads, and other water runoff, are more prone to periodic direct release incidents due to heavy rainfall (due to wastewater bypassing treatment systems due to large volumes) (COWI, 2002).

1455. In activated sludge treatment systems, or other systems with a high retention of particulate material, notable parts of the mercury in the waste water will follow the sludge (f. ex. roughly 50% in Denmark), meaning that mercury concentrations in the water outlets will be reduced as compared to inlet concentrations. In some countries the spreading of waste water sludge on farmland as fertiliser is preferred, and threshold limits on allowable mercury concentrations may be applied. Other sludge fractions (particularly those with concentrations of pollutants exceeding the thresholds) are deposited on landfills or incinerated (see section 5.8.4). Some waste water treatment facilities have their own sludge incineration plant, while other sludge incineration takes place in municipal waste incineration plants.

1456. Releases of mercury with wastewater appear to be underestimated in many cases. A regional assessment for the Baltic Sea indicated f. ex. that only a minor fraction of the mercury inputs to this marine area came from atmospheric deposition (COWI, 2002).

5.9.5.3 Discussion of mercury inputs

Table 5-220 Overview of activity rate data and mercury input factor types needed to estimate releases from waste water system/treatment

Activity rate data needed	Mercury input factor
Amounts of treated or conveyed waste water	Average mercury concentrations in input waste water.

1457. If comprehensive mercury release inventories are made (for example based on this Toolkit), this may form an approach to crosscheck quantification of mercury inputs to the waste water system, see f. ex. Skårup *et al.* (2003).

Table 5-221 Averages and percentiles for mercury concentrations in inflows to and outflows from waste water treatment plants in Denmark in 2001 (Danish EPA, 2002, as cited by Skårup et al.*, 2003)*

Inflow to waste water plant (µg Hg/l)			**Discharge from waste water plant (µg Hg/l)**		
Average	5th percentile	95th percentile	Average	5th percentile	95th percentile
0.5	0.1	1.6	0.17	0.02	0.39

1458. Table 5-221 shows mercury concentrations in inflows to and outflows from municipal waste water treatment plants. In Denmark, most mercury release sources had been reduced very significantly by 2001; in around 1993, average concentrations in inflows to a few major waste water treatment plants were in the range of 1.1-3.4 µg mercury/l (Maag *et al.*, 1996). Based on the numbers in Table 5-221 in combination with comprehensive data on mercury concentrations in municipal sewage sludge, it can be calculated that about 50-70% of the mercury inflow to municipal waste water treatment plants in Denmark in 2001 was withheld in the sludge (based on Skårup *et al.*, 2003). Waste water treatment plant designs in Denmark favour long retention times and very efficient activated sludge production and retention (due to abatement of other pollutants), and mercury retention with sludge in Denmark should therefore likely be considered as in the high end in the global perspective.

5.9.5.4 Examples of mercury in releases and wastes/residues

Mercury in output water from waste water treatment plants

1459. See data from Denmark above.

Mercury in sewage sludge

1460. The most recent data on the mercury content of sewage sludge in the USA obtained from the 1988 National Sewage Sludge Survey showed a mean mercury concentration of 5.2 ppm (parts per million by weight = g mercury/metric ton). Earlier data obtained in the mid 1970's indicate that mercury concentrations in municipal sewage sludge ranged from 0.1 - 89 ppm with a mean value of 7 ppm and a median value of 4 ppm. Other early data collected by US EPA from 42 municipal sewage treatment plants in the early 1970's showed a range of 0.6 - 43 ppm, with a mean value of 4.9 ppm on a dry solids basis (US EPA, 1997a).

1461. In Denmark in 1999, average mercury concentrations in sludge samples representing about 95% of the total sewage sludge production in Denmark were 1.2 g mercury/metric ton of dry sludge (dry matter basis). Of this, about 41% was applied on agricultural or forest land, about 28% was incinerated and the remainder (about 31%) was landfilled or otherwise stored or treated. (Skårup *et al.*, 2003, based on Danish EPA, 2001).

1462. In Finland, the average mercury concentration in sewage sludge is 0.5 g/metric ton (dry matter basis). 94% of the sludge was spread on land/used in soil works in parks, gardens and agricultural land, while 6% was landfilled (Finnish Environment Institute, 2004).

1463. Lassen *et al.* (2004) present examples of reported mercury concentrations in municipal sewage sludge in the Russian Federation. In the major cities represented (Moscow, St. Petersburg), the concentrations are about 1-2 g mercury/metric ton (dry matter basis). In the smaller cities represented, concentrations vary more; most results are in the range of 0.1-1 g mercury/metric ton (dry matter basis), while 4 out of 14 smaller cities have results in the range of 2.4-10 g mercury/metric ton (dry matter basis). Only a fraction of the produced sewage sludge in Russia is used as fertiliser (probably below 15%). After long-time dewatering and settling in sludge beds the majority is landfilled or dumped in quarries (Lassen *et al.*, 2004).

5.9.5.5 Input factors and output distribution factors

a) Default mercury input factors

1464. Currently, sufficient data to define default factors, which reflect actual conditions for waste water treatment plants, have not been collected. In many countries relevant specific data may, however, likely exist locally or nationally. With the aim of enabling the development of roughly indicative release estimates from this source, default input estimates were, however, developed based on the available data on mercury concentrations in sewage sludge and mercury retention efficiencies. These defaults might be used where no national or source specific data exist.

1465. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

1466. Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will likely result in a high end estimate.

1467. The mercury levels in waste water are of course also directly dependent on the consumption of mercury-containing products and materials in the country investigated. The low end input factor is expected to be relevant for a situation where the economical activity is so low that the consumption of mercury with commodity products is low, and industrial use of mercury is negligible, or for countries where most of the mercury use has been substituted for by mercury-free products and processes.

1468. The default input factors here were derived from data from developed countries only. A simple test, based on your Inventory Level 2 results, will indicate if the default factors may over-estimate the mercury releases from this activity in the country. See Annex 8.5 for more details.

Table 5-222 ***Preliminary*** *default input factors for mercury in wastewater system/treatment*

Material	Default input factors; µg Hg/l waste water; low end - high end (intermediate)
Municipal waste water	0.5 – 10 (5.25)

b) Default mercury output distribution factors

Table 5-223 ***<u>Preliminary</u>*** *default mercury output distribution factors for wastewater system/treatment*

Type of waste water treatment plant	**Default output distribution factors, share of Hg input**					
	Air	**Water**	**Land**	**Products**	**General waste**	**Sector specific treatment/ disposal*1**
No treatment; direct release from sewage pipe		1				
Mechanical treatment only		0.9			0.1	
Mechanical and biological (activated sludge) treatment; no land application of sludge		0.5			0.3	0.2
Mechanical and biological (activated sludge) treatment; 40% of sludge used for land application		0.5	0.2		0.15	0.15

Notes: *1 Sludge incineration. The shown distribution between general waste and incineration is arbitrary. Use estimates of actual distribution, if available.

c) Links to other mercury sources estimation

1469. For the waste treatment sub-categories it is very important to keep in mind that the mercury content in the waste originates from 1) intentionally used mercury in discarded products and process waste; 2) natural mercury impurities in high volume materials (plastics, paper, etc.) and minerals; and 3) mercury as a human-generated trace pollutant in high volume materials. The mercury releases to the environment and waste deposits from these sub-categories should therefore be seen as a consequence of mercury being present in the products used in society.

1470. Similarly, the estimated mercury inputs to waste treatment sub-categories can be qualified through the quantification of mercury inputs to society with products and materials, as described in sections 5.4 - 5.6. Beware of double-counting of such mercury inputs when developing the mercury inventory.

1471. Mercury in sludge led to sludge incineration may also be calculated in the section on sludge incineration. Beware of double counting.

5.9.5.6 Source specific main data

1472. The most important source specific data would in this case be:

- Measurements of mercury concentrations in water in inlets and outlets of representative waste water treatment plants, and in sewage sludge produced;
- Amount of waste water treated and amount of sewage sludge produced; and
- Estimates of the actual distribution of produced sewage sludges on land, landfills and incineration.

5.10 Crematoria and cemeteries

Table 5-224 Crematoria and cemeteries: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Chapter	Sub-category	Air	Water	Land	Product	Waste/ residue	Main inventory approach
5.10.1	Crematoria	**X**				x	OW
5.10.2	Cemeteries			**X**			OW

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

5.10.1 Crematoria

5.10.1.1 Sub-category description

1473. Cremation is a common practice in many societies to incinerate human corpses. Mercury is released during such cremation. Most of the mercury released is due to the presence of dental amalgam fillings that contain mercury. However, smaller amounts of mercury present in body tissues are also released during cremation.

1474. Most crematoria furnaces are fired using oil or natural gas; some run on electricity. Crematoria are usually located within cities and close to residential areas and normally, stacks are relatively low (UNEP, 2003). Some crematoria are equipped with dust filters or even mercury-specific filters to reduce releases of mercury and other pollutants.

1475. A large number of cremations occur throughout the world each year. For example, in 1995 in the USA, approximately 488,224 cremations were performed at the 1,155 crematories.

1476. Air is reported as the primary “receiving medium” of the mercury released by cremation (NJ MTF, 2002). Since cremations involve high temperatures, in crematories without specific mercury abatement , the vast majority of the mercury in a corpse that is cremated is expected to be released to the air through the stack.

1477. Various techniques are available for reducing mercury emission from crematoria and in some countries, reduction of mercury emission from this source category below certain limits is obligatory. In the EU it is estimated that about half of the crematoria in 2018 were equipped with emission abatement technologies (Deloitte at al., 2020).

1478. The described techniques that may be applied include various techniques with use of activated carbon, catalytic adsorbers, amalgator technique, selenium or gold filters (UNEP, 2006; Schleicher and Gram, 2008). According to Schleicher and Gram (2008), analyzing the costs of installation of mercury filters on Danish crematoria, activated carbon scrubbing is by far the most widely used technology for reducing Hg, and is generally considered to be best available technique (BAT). Several methods with activated carbon exists, but according to Schleicher and Gram (2008), the efficiency of the filters are in general better that 97%.

1479. The average efficiency of abatement techniques applied on crematoria in Sweden is reported to be at 95%. All large Swedish crematoria have installed mercury control techniques and devices. Mercury emissions are reduced by adding injections of activated carbon to control devices such as bag filters or by using bag filters followed by activated carbon filters (Deloitte et al., 2020).

1480. The average efficiency of abatement techniques applied in Germany is reported to be 96.6%. In 2018 about 92% of all crematoria in Germany was equipped with abatement technique (Deloitte et al., 2020).

1481. The efficiency reported for crematoria in Sweden of 95% will be used in the determination of default output distribution factors.

1482. The mercury is mainly captured in the activated carbon. In crematoria where the flue gas pass a bag filter before the activated carbon, a part of the mercury will be captured in the bag filter. In all cases, the mercury captured is considered ultimately to be disposed of as hazardous waste for sector specific treatment.

5.10.1.2 Main factors determining mercury releases and mercury outputs

Table 5-225 Main releases and receiving media from crematoria

Phase of life cycle	Air	Water	Land	Products	General waste	Sector specific treatment/ disposal
Crematoria	X					X

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

1483. Air is reported as the primary “receiving medium” of the mercury released by cremation (NJ MTF, 2002). Since cremations involve high temperatures and since most crematories have limited emission controls that would reduce mercury releases, the vast majority of the mercury in a corpse that is cremated is expected to be released to the air through the stack. In some crematoria, however, that apply efficient emission controls, a significant part of the mercury may end up in fly ash and other residues. Besides, a small percent of mercury may collect on the brick material of the crematoria, and a very small percent may be found in the ash (based on study by Dr. T. Thomassen, as cited by Reindl, 2003).

5.10.1.3 Discussion of mercury inputs

Table 5-226 Overview of activity rate data and mercury input factor types needed to estimate releases from crematoria

Activity rate data needed	Mercury input factor
Number of corpses cremated	Average amount of mercury contained in each corpse

1484. The amount of mercury in each corpse varies considerably and largely depends on the number of dental amalgam fillings, and to a lesser extent on the size of the fillings. In Denmark, the typical filling (as found in the mouth) contains from about 0.2 - 0.6 g of mercury; on average about 0.4g mercury/filling. The average mercury content of fillings of corpses in Denmark in 2001 was estimated at 4.1 g mercury per corpse (Skårup *et al*., 2003). The total mercury content of 41,000 cremated corpses in 2001 was 170 kg and it is in the report estimated that out of this amount nearly 100% was released to the atmosphere, as the crematoria are not equipped with emission controls.

1485. Based on information in NJ MTF (2002), each corpse in New Jersey, USA, contains between 0.8 and 5.6 grams of mercury, with a mean of 2.9 g per corpse due to the presence of fillings. The amount of additional mercury in each corpse due to the presence of mercury in other body tissues (blood, hair, etc.), which is largely due to fish consumption and other exposures, has been estimated to be in range of 1 x 10^{-5} - 0.1 g mercury (Reindl, 2003).

1486. In the Netherlands, research indicates that due to differences in the number of fillings in people of different age groups, the average amount of fillings will increase from 3.2 to 5.1 during the period 1995-2020 (OSPAR, 2002). This means that the emissions from cremations in the Netherlands will double between 2002 and 2020, unless abatement measures are introduced.

1487. In a review of mercury emitted from cremations in the United Kingdom, it is estimated that amalgam fillings on average contain 0.6 g mercury, but alternative estimates mentioned in the review range from 0.36 - 1 g per filling (Passant, 2004). The author estimates that the mercury emission per cremation has steadily increased from 0.49 g/cremation in 1968 to 1.92 g/cremation in 2003, due to an increased number of amalgam fillings and a decreased number of toothless people (Passant, 2004). In 1969, 73% of deceased people were toothless compared to only 44% in 2003. The tendency of increased amounts of mercury per cremation is expected to continue and it is estimated that the total emissions from crematoria in the United Kingdom (unless better emission controls are implemented) will increase from 0.78 metric tons in 1999 to 1.3 metric tons in 2020 (DEFRA, 2004).

5.10.1.4 Examples of mercury in releases and wastes/residues

1488. The total 1995 mercury emissions from all cremations in the USA (total of about 488,224 cremations) were estimated to be 0.73 metric tons (US EPA, 1997a). However, these estimates were based on one set of data (reported in US EPA, 1997a) from tests conducted for a propane-fired incinerator at a crematorium in California (by the California Air Resources Board). Results of this testing of mercury emissions from crematoria without emission controls ranged from 0.626 - 2.26 g mercury/corpse cremated; the average mercury emission factor was 1.5 g/corpse cremated (US EPA, 1997a).

1489. According to an OSPAR survey of mercury emissions from crematoria in European countries, the reported emission per cremation ranged from 0.1 g (in Belgium) to 2.3 g per cremation (in France), see Table 5-227. Note the somewhat different figures for Denmark and the United Kingdom quoted in the previous section.

Table 5-227 Emission of mercury from crematoria in some European countries (based on OSPAR, 2002)

Country	Estimated Hg emission per year (kilos)	Number of crematoria	Number of cremations	Average emission per cremation (g)
Norway	70	42		
Sweden	122	71	65,002	1.9
Germany	42-168	130	333,800	0.1 - 0.5
Netherlands	80			
Belgium	3.7		35,793	0.1
Iceland		1		
Ireland		2		
Switzerland	45	26	40,000	1.1
France	200	80	87,000	2.3
Portugal		4	2,311	

1490. In a review presented by Hylander and Meili (2005), mercury emissions to the air from cremation are estimated to 0.28 metric tons per year in Sweden (Munthe *et al.*, 2001) or 0.03 g per capita per year from a population of 8.5 million with 40–100 metric tons of mercury accumulated in dental fillings and a cremation rate around 65% (Munthe *et al.*, 2001; Rein and Hylander, 2000; SCB, 2002; all as cited by Hylander and Meili, 2005).

5.10.1.5 Input factors and output distribution factors

1491. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows.

1492. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

a) Default mercury input factors

1493. National data on grams of amalgam fillings per corpse cremated annually will lead to the best estimates of releases.

1494. If no information is available on the number of amalgam fillings prepared annually, a first estimate can be formed by using the default input factors selected in Table 5-228 below (based on the data sets presented in this section). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum).

1495. In the 2019 Toolkit update, the default calculation in both the Inventory Level 1 and Level 2 spreadsheets was changed to reflect the level of dental care, as dental amalgam is for most people the key source of mercury in corpses. The methodology and background data used are identical to those used for dental amalgam. In both spreadsheets, the pre-entered default input factor was changed to the maximum of the range (4g Hg/corpse), as this corresponds approximately to the reference dental care level used in the calculations. In Level 2, the pre-entered input factor should not be changed if the suggested method is applied (the method normalises the mercury input to the national dental care level already).

*Table 5-228 **Preliminary** default input factors for mercury inputs to cremation*

	Default input factors; g mercury per corpse; (low end - high end)
Cremation	1 - 4

b) Default mercury output distribution factors

*Table 5-229 **Preliminary** default mercury output distribution factors for cremation*

Phase in life-cycle	**Default output distribution factors, share of Hg input**					
	Air	**Water**	**Land**	**Products**	**General waste**	**Sector specific treatment/ disposal**
Cremation without mercury filter	1					
Cremation with mercury filter	0.05					0.95

c) Links to other mercury sources estimation

1496. The mercury releases from cremation are closely linked to the usage of dental amalgam, and cremation is one of the output pathways from amalgam use.

5.10.1.6 Source specific main data

1497. The most important source specific data would in this case be some (or all) of the following:

- Data on average amount of mercury per corpse;
- Data on the average number of mercury amalgam fillings in the human subpopulation that is expected to be cremated at the source;
- Average amount of mercury per filling;
- Number of human bodies cremated; and
- Measured data on emission reduction equipment applied on the source (or similar sources with very similar equipment and operating conditions).

1498. See also advice on data gathering in section 4.4.5.

5.10.2 Cemeteries

5.10.2.1 Sub-category description

1499. A cemetery – also called a burial ground – is an area where human corpses are buried.

1500. Mercury in the human body, primarily from dental amalgam fillings, will be released to the soil at the cemetery.

5.10.2.2 Main factors determining mercury releases and mercury outputs

Table 5-230 Main releases and receiving media from cemeteries

Phase of life cycle	Air	Water	Land	General waste	Sector specific treatment/ disposal
Burial			X		

Notes: **X** - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

5.10.2.3 Discussion of mercury inputs

Table 5-231 Overview of activity rate data and mercury input factor types needed to estimate releases from cemeteries

Activity rate data needed	Mercury input factor
Number of corpses buried	Average amount of mercury contained in each corpse

1501. For data on mercury amounts per corpse, see section 5.10.1.3 above on cremation.

5.10.2.4 Input factors and output distribution factors

1502. Based on the information compiled above on inputs and outputs and major factors determining releases, the following preliminary default input and distribution factors are suggested for use in cases where source specific data are not available. It is emphasized that the default factors suggested in this Toolkit are based on a limited data base, and as such, they should be considered subject to revisions as the data base grows.

1503. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

a) Default mercury input factors

1504. National data on grams of mercury (in amalgam fillings) per corpse buried will lead to the best estimates of releases.

1505. If no information is available on the number of amalgam fillings prepared annually, a first estimate can be formed by using the default input factors selected in Table 5-232 below (based on the data sets presented in the section on cremation). Because concentrations vary so much, it is recommended to calculate and report intervals for the mercury inputs to this source category. The low end default factors has been set to indicate a low end estimate for the mercury input to the source category (but not the absolute minimum), and the high end factor will result in a high end estimate (but not the absolute maximum).

*Table 5-232 **Preliminary** default input factors for mercury inputs to cemeteries*

	Default input factors; g mercury per corpse; (low end - high end)
Burial	1 – 4

b) Default mercury output distribution factors

Table 5-233 ***<u>Preliminary</u>*** *default mercury output distribution factors for cemeteries*

Phase in life-cycle	**Default output distribution factors, share of Hg input**					
	Air	**Water**	**Land**	**Products**	**General waste**	**Sector specific treatment/ disposal**
Burial			1			

c) Links to other mercury sources estimation

1506. The mercury releases from cremation are closely linked to the usage of dental amalgam, and cremation is one of the output pathways from amalgam use. See section 5.6.1.

5.10.2.5 Source specific main data

1507. The most important source specific data would in this case be some (or all) of the following:

- Data on average amount of mercury per corpse;
- Data on the average number of mercury amalgam fillings in the human subpopulation that are expected to be cremated at the source;
- Average amount of mercury per filling; and
- Number of human bodies buried.

1508. See also advice on data gathering in section 4.4.5.

5.11 Potential hot-spots (contaminated sites)

1509. As described in section 4.3.11, hot-spots of mercury contamination exist as the direct result of disposal practices as described in sections 5.9.3 and 5.9.4 or of inadequate disposal of mercury-contaminated materials. Release from these sites may already be ongoing or can be expected to begin if no remedial action is taken. Table 5-218 below describes an indicative list of locations where hot-spots for mercury can potentially be found. Site-specific evaluation of each hot-spot should determine its current status: immediate threat or potential for releases in the future. In either case the site should be registered in your inventory report as described in the Inventory Level 2 reporting template.

1510. The main pathways of releases of mercury and the recommended inventory approach for each of these potential hot-spots is indicated in the table below.

Table 5-234 Potential hot-spots: sub-categories with primary pathways of releases of mercury and recommended inventory approach

Chapter	Sub-category	Air	Water	Land	Product	Waste/ residue	Main inventory approach
	Closed/abandoned chlor-alkali production sites	x	**X**	**X**		**X**	PS
	Other sites of former chemical production where mercury compounds were produced (pesticides, biocides, pigments etc.), or mercury or compounds were used as catalysts (VCM/PVC etc.)	x	**X**	**X**	x	**X**	PS
	Closed production sites for manufacturing of thermometers, switches, batteries and other products	x	**X**	**X**	**X**	x	PS
	Closed pulp and paper manufacturing sites (with internal chlor-alkali production or former use of mercury-based slimicides)	x	**X**	**X**		**X**	PS
	Tailings/residue deposits from mercury mining	x	**X**	**X**	**X**	**X**	PS
	Tailings/residue deposits from artisanal and large scale gold mining	x	**X**	**X**		**X**	PS
	Tailings/residue deposits from other non-ferrous metal extraction	x	**X**	**X**	**X**	**X**	PS
	Sites of relevant accidents	x	**X**	**X**		**X**	PS
	Dredging of sediments	x	**X**	**X**		**X**	PS
	Sites of discarded district heating controls (and other fluid controls) using mercury pressure valves		**X**	**X**			PS
	Sites of previous recycling of mercury ("secondary" mercury production)	x	**X**	**X**	**X**	**X**	PS

Notes: PS = Point source by point source approach; OW = National/overview approach;
X - Release pathway expected to be predominant for the sub-category;
x - Additional release pathways to be considered, depending on specific source and national situation.

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7 Glossary, acronyms and abbreviations

< - less than;

> - greater than;

°C - degree Celsius (centigrade);

/ - divided by;

* - multiplied by;

% - percent;

µg – microgram (10^{-6} gram);

APC devices - air pollution control (APC) devices;

ATSDR – US Agency for Toxic Substances and Disease Registry;

CIS countries – Countries of the Commonwealth of Independent States (Armenia, Azerbaijan, Belarus, Kazakstan, Kyrgyzstan, Republic of Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine and Uzbekistan).

DS – Dry scrubber, filter type used for acid flue gasses, etc.;

DSI – duct sorbent injection;

EC – European Community (Starting May 1st, 2004, 25 member states (Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malta, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, The Netherlands, United Kingdom)); later expanded with two additional member states to 27;

EU (15) – European Community before expansion 1 May, 2004, when it had 15 Member States (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and the United Kingdom).

EMEP – Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (under the LRTAP Convention);

ESP – Electrostatic precipitator; equipment used to reduce emissions of certain pollutants from combustion flue gases;

EU – European Union. Starting May 1st, 2004, the European Union has 25 member states (Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malta, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, The Netherlands, United Kingdom), establishing an area of more than 4 million square kms with a population of approximately 460 million inhabitants; later expanded with two additional member states to 27;

FAO – Food and Agriculture Organization;

FF - Fabric filter; filter type used to capture particulate matter (here: from combustion flue gases);

FGD – Flue gas desulfurization; process of/equipment for primarily minimizing emissions of sulfur from combustion flue gases;

g – gram;

g/l or g/L – grams per litre;

Hg^0 or Hg(0) - elemental mercury;

Hg^{2+} or Hg(II) - divalent mercury - the dominating mercury form in organic and inorganic mercury compounds. In the atmosphere, mercury species with divalent mercury are more easily washed out of the air with precipitation and deposited than elemental mercury;

Hg_p - particulate mercury - mercury bound in, or adsorbed on, particulate material. In the atmosphere, particulate mercury is deposited much faster than elemental mercury;

IARC - International Agency for Research on Cancer;

ILO - International Labor Organization;

IPCS – International Programme on Chemical Safety;

kg – kilogram;

l or L – litre;

Lifetime - In descriptions of life-cycles of products: The time span from when the product is put into use (usually time of purchase) until it is discarded;

LRTAP Convention – Convention on Long-Range Transboundary Air Pollution;

m – meter;

MethylHg or **MeHg** – methylmercury;

metric ton – 1000 kg;

mg – milligram (10^{-3} gram);

MSC-E – Meteorological Synthesizing Centre – East (associated with the LRTAP Convention);

MSW – municipal solid waste;

MW – Megawatt;

MWC – municipal waste combustor;

MWI – medical waste incinerator;

NEMA – National Electrical Manufacturers Association (in the USA);

ng – nanogram (10^{-9} gram);

OECD - Organization for Economic Cooperation and Development;

ppb – parts per billion;

ppm - parts per million;

PM – Particlate material; particulate matter;

PS - Particle scrubber; equipment designed to reduce emissions of particles from combustion flue gases

SCR - Selective catalytic reduction; equipment designed to reduce emissions of certain pollutants from combustion flue gases;

SD - Spray dryer;

SDA - Spray dryer adsorber system; equipment designed to reduce emissions of certain pollutants from combustion flue gases;

Slag - waste material produced when coal is dug from the earth, or a substance produced by mixing chemicals with metal that has been heated until it is liquid in order to remove unwanted substances from it.

SNCR - Selective non-catalytic reduction; equipment designed to reduce emissions of certain pollutants from combustion flue gases;

t or ton - metric ton = 1000 kg;

UN - United Nations;

UN Environment - United Nations Environment Programme;

UNEP - United Nations Environment Programme (used here in historical references from the time when the agronym "UNEP" was used;

US – United States of America;

US EPA – Environmental Protection Agency of the United States of America;

USA – United States of America;

wFGD – Wet flue gas desulfurization; process of/equipment for primarily minimizing emissions of sulfur from combustion flue gases;

WHO - World Health Organization;

8 Technical annexes

8.1 Harmonised Commodity Description and Coding System (HS) custom codes relevant for mercury

The following lists developed by UNITAR for the Toolkit lists HS custom codes for commodities which may be relevant for mercury inventories. The lists are arranged according to source categories in the Toolkits Inventory Level 2 (the level presented in this report). As HS codes develop over time, and as some countries and regions may have more detailed codes (with more HS digits), please consider the lists here as informative only, and check current codes at you customs data suppliers, for example the UN Comtrade at https://comtrade.un.org/db/mr/rfCommoditiesList.aspx or directly in their data extraction tool at https://comtrade.un.org/data/.

Toolkit references

5.1 Extraction and use of fuels/energy sources
  5.1.1 Coal combustion in large power plants
  5.1.2 Other coal use
  5.1.3 Mineral oils - extraction, refining and use
  5.1.4 Natural gas - extraction, refining and use
  5.1.5 Other fossil fuels - extraction and use

27	CHAPTER 27 - MINERAL FUELS, MINERAL OILS AND PRODUCTS OF THEIR DISTILLATION; BITUMINOUS SUBSTANCES; MINERAL WAXES
2701	Coal; briquettes, ovoids and similar solid fuels manufactured from coal
2701 11	Anthracite
2701 11 10	Having a volatile matter limit (on a dry, mineral-matter-free basis) not exceeding 10 %
2701 11 90	Other
2701 12	Bituminous coal
2701 12 10	Coking coal
2701 12 90	Other
2701 19 00	Other coal
2701 20 00	Briquettes, ovoids and similar solid fuels manufactured from coal
2702	Lignite, whether or not agglomerated, excluding jet
2702 10 00	Lignite, whether or not pulverised, but not agglomerated
2702 20 00	Agglomerated lignite
2703 00 00	Peat (including peat litter), whether or not agglomerated
2704 00	Coke and semi-coke of coal, of lignite or of peat, whether or not agglomerated; retort carbon
2704 00 11	For the manufacture of electrodes
2704 00 19	Other
2704 00 30	Coke and semi-coke of lignite
2704 00 90	Other
2705 00 00	Coal gas, water gas, producer gas and similar gases, other than petroleum gases and other gaseous hydrocarbons
2706 00 00	Tar distilled from coal, from lignite or from peat, and other mineral tars, whether or not dehydrated or partially distilled, including reconstituted tars
2707	Oils and other products of the distillation of high temperature coal tar; similar products in which the weight of the aromatic constituents exceeds that of the non-aromatic constituents
2707 10	Benzol (benzene)

2707 10 10	For use as a power or heating fuel
2707 10 90	For other purposes
2707 20	Toluol (toluene)
2707 20 10	For use as a power or heating fuel
2707 20 90	For other purposes
2707 30	Xylol (xylenes)
2707 30 10	For use as a power or heating fuel
2707 30 90	For other purposes
2707 40 00	Naphthalene
2707 50	Other aromatic hydrocarbon mixtures of which 65 % or more by volume (including losses) distils at 250 °C by the ASTM D 86 method
2707 50 10	For use as power or heating fuels
2707 50 90	For other purposes
2707 91 00	Creosote oils
2707 99	Other
2707 99 11	Crude light oils of which 90 % or more by volume distils at temperatures of up to 200 °C
2707 99 19	Other
2707 99 30	Sulphuretted toppings
2707 99 50	Basic products
2707 99 70	Anthracene
2707 99 80	Phenols
2707 99 91	For the manufacture of the products of heading 2803
2707 99 99	Other
2708	Pitch and pitch coke, obtained from coal tar or from other mineral tars
2708 10 00	Pitch
2708 20 00	Pitch coke
2709 00	Petroleum oils and oils obtained from bituminous minerals, crude
2709 00 10	Natural gas condensates
2709 00 90	Other
2710	Petroleum oils and oils obtained from bituminous minerals, other than crude; preparations not elsewhere specified or included, containing by weight 70 % or more of petroleum oils or of oils obtained from bituminous minerals, these oils being the basic constituents of the preparations; waste oils
2710 11	Light oils and preparations
2710 11 11	For undergoing a specific process
2710 11 15	For undergoing chemical transformation by a process other than those specified in respect of subheading 2710 11 11
2710 11 21	White spirit
2710 11 25	Other
2710 11 31	Aviation spirit
2710 11 41	With an octane number (RON) of less than 95
2710 11 45	With an octane number (RON) of 95 or more but less than 98
2710 11 49	With an octane number (RON) of 98 or more
2710 11 51	With an octane number (RON) of less than 98
2710 11 59	With an octane number (RON) of 98 or more
2710 11 70	Spirit type jet fuel
2710 11 90	Other light oils
2710 19	Other
2710 19 11	For undergoing a specific process

2710 19 15	For undergoing chemical transformation by a process other than those specified in respect of subheading 2710 19 11
2710 19 21	Jet fuel
2710 19 25	Other
2710 19 29	Other
2710 19 31	For undergoing a specific process
2710 19 35	For undergoing chemical transformation by a process other than those specified in respect of subheading 2710 19 31
2710 19 41	With a sulphur content not exceeding 0,05 % by weight
2710 19 45	With a sulphur content exceeding 0,05 % by weight but not exceeding 0,2 % by weight
2710 19 49	With a sulphur content exceeding 0,2 % by weight
2710 19 51	For undergoing a specific process
2710 19 55	For undergoing chemical transformation by a process other than those specified in respect of subheading 2710 19 51
2710 19 61	With a sulphur content not exceeding 1 % by weight
2710 19 63	With a sulphur content exceeding 1 % by weight but not exceeding 2 % by weight
2710 19 65	With a sulphur content exceeding 2 % by weight but not exceeding 2,8 % by weight
2710 19 69	With a sulphur content exceeding 2,8 % by weight
2710 19 71	For undergoing a specific process
2710 19 75	For undergoing chemical transformation by a process other than those specified in respect of subheading 2710 19 71
2710 19 81	Motor oils, compressor lube oils, turbine lube oils
2710 19 83	Liquids for hydraulic purposes
2710 19 85	White oils, liquid paraffin
2710 19 87	Gear oils and reductor oils
2710 19 91	Metalworking compounds, mould-release oils, anti-corrosion oils
2710 19 93	Electrical insulating oils
2710 19 99	Other lubricating oils and other oils
2710 91 00	Containing polychlorinated biphenyls (PCBs), polychlorinated terphenyls (PCTs) or polybrominated biphenyls (PBBs)
2710 99 00	Other
2711	Petroleum gases and other gaseous hydrocarbons
2711 11 00	Natural gas
2711 12	Propane
2711 12 11	For use as a power or heating fuel
2711 12 19	For other purposes
2711 12 91	For undergoing a specific process
2711 12 93	For undergoing chemical transformation by a process other than those specified in respect of subheading 2711 12 91
2711 12 94	Of a purity exceeding 90 % but less than 99 %
2711 12 97	Other
2711 13	Butanes
2711 13 10	For undergoing a specific process
2711 13 30	For undergoing chemical transformation by a process other than those specified in respect of subheading 2711 13 10
2711 13 91	Of a purity exceeding 90 % but less than 95 %
2711 13 97	Other
2711 14 00	Ethylene, propylene, butylene and butadiene
2711 19 00	Other
2711 21 00	Natural gas

2711 29 00	Other
2712	Petroleum jelly; paraffin wax, microcrystalline petroleum wax, slack wax, ozokerite, lignite wax, peat wax, other mineral waxes, and similar products obtained by synthesis or by other processes, whether or not coloured
2712 10	Petroleum jelly
2712 10 10	Crude
2712 10 90	Other
2712 20	Paraffin wax containing by weight less than 0,75 % of oil
2712 20 10	Synthetic paraffin wax of a molecular weight of 460 or more but not exceeding 1 560
2712 20 90	Other
2712 90	Other
2712 90 11	Crude
2712 90 19	Other
2712 90 31	For undergoing a specific process
2712 90 33	For undergoing chemical transformation by a process other than those specified in respect of subheading 2712 90 31
2712 90 39	For other purposes
2712 90 91	Blend of 1-alkenes containing by weight 80 % or more of 1-alkenes of a chain-length of 24 carbon atoms or more but not exceeding 28 carbon atoms
2712 90 99	Other
2713	Petroleum coke, petroleum bitumen and other residues of petroleum oils or of oils obtained from bituminous minerals
2713 11 00	Not calcined
2713 12 00	Calcined
2713 20 00	Petroleum bitumen
2713 90	Other residues of petroleum oils or of oils obtained from bituminous minerals
2713 90 10	For the manufacture of the products of heading 2803
2713 90 90	Other
2714	Bitumen and asphalt, natural; bituminous or oil-shale and tar sands; asphaltites and asphaltic rocks
2714 10 00	Bituminous or oil-shale and tar sands
2714 90 00	Other
2715 00 00	Bituminous mixtures based on natural asphalt, on natural bitumen, on petroleum bitumen, on mineral tar or on mineral tar pitch (for example, bituminous mastics, cut-backs)
2716 00 00	Electrical energy

Toolkit references

5.3 Production of other minerals and materials with mercury impurities

5.3.1 Cement production

5.3.2 Pulp and paper production

Custom code	**Designation**
2521 00 00	Limestone flux; limestone and other calcareous stone, of a kind used for the manufacture of lime or cement
2523	Portland cement, aluminous cement, slag cement, supersulphate cement and similar hydraulic cements, whether or not coloured or in the form of clinkers
2523 10 00	Cement clinkers
	Portland cement
2523 21 00	White cement, whether or not artificially coloured
2523 30 00	Aluminous cement

2523 90	Other hydraulic cements
2523 90 10	Blast furnace cement
3214	Glaziers' putty, grafting putty, resin cements, caulking compounds and other mastics; painters' fillings; non-refractory surfacing preparations for façades, indoor walls, floors, ceilings or the like
3214 10	Glaziers' putty, grafting putty, resin cements, caulking compounds and other mastics; painters' fillings
3214 10 10	Glaziers' putty, grafting putty, resin cements, caulking compounds and other mastics
3816 00 00	Refractory cements, mortars, concretes and similar compositions, other than products of heading 3801

Metal mercury

2805 40 10	Mercury in flasks of a net content of 34,5 kg "standard weight", of a fob value per flask of <= € 224
2805 40 90	Mercury (excl. in flasks of a net content of 34,5 kg "standard weight", of a fob value per flask of <= € 224)
2843 90 10	Amalgams of precious metals
2852 00 00	Compounds, inorganic or organic, of mercury (excl. amalgams)
2853 00 90	Inorganic compounds, n.e.s.; amalgams (excl. of precious metals)

Toolkit references
5.5 Consumer products with intentional use of mercury
5.5.4 Batteries with mercury

The articles which do not contain mercury (mentioned in the custom tariff) should be analysed .

8506 10 11	Manganese dioxide cells and batteries, alkaline, in the form of cylindrical cells (excl. spent)
8506 10 15	Manganese dioxide cells and batteries, alkaline, in the form of button cells (excl. spent)
8506 10 19	Manganese dioxide cells and batteries, alkaline (excl. spent, and in the form of cylindrical cells and button cells)
8506 10 91	Manganese dioxide cells and batteries, non-alkaline, in the form of cylindrical cells (excl. spent)
8506 10 95	Manganese dioxide cells and batteries, non-alkaline, in the form of button cells (excl. spent)
8506 10 99	Manganese dioxide cells and batteries, non-alkaline (excl. spent, and in the form of cylindrical or button cells)
8506 30 10	Mercuric oxide cells and batteries, in the form of cylindrical cells (excl. spent)
8506 30 30	Mercuric oxide cells and batteries, in the form of button cells (excl. spent)
8506 30 90	Mercuric oxide cells and batteries (excl. spent, and in the form of cylindrical or button cells)
8506 40 10	Silver oxide cells and batteries, in the form of cylindrical cells (excl. spent)
8506 40 30	Silver oxide cells and batteries, in the form of button cells (excl. spent)
8506 40 90	Silver oxide cells and batteries (excl. spent, and in the form of cylindrical or button cells)
8506 50 10	Lithium cells and batteries, in the form of cylindrical cells (excl. spent)
8506 50 30	Lithium cells and batteries, in the form of button cells (excl. spent)
8506 50 90	Lithium cells and batteries (excl. spent, and in the form of cylindrical or button cells)
8506 60 10	Air-zinc cells and batteries, in the form of cylindrical cells (excl. spent)
8506 60 30	Air-zinc cells and batteries, in the form of button cells (excl. spent)
8506 60 90	Air-zinc cells and batteries (excl. spent, and in the form of cylindrical or button cells)
8506 80 05	Dry zinc-carbon batteries of a voltage of >= 5,5 V but <= 6,5 V (excl. spent)

8506 90 00	Parts of primary cells and primary batteries, n.e.s.

Toolkit references
5.5 Consumer products with intentional use of mercury
5.5.3 Light sources with mercury

8539 31 10	Discharge lamps, fluorescent, hot cathode, with double ended cap
8539 31 90	Discharge lamps, fluorescent, hot cathode (excl. with double ended cap)
8539 32 10	Mercury vapour lamps
8539 39 00	Discharge lamps (excl. flourescent, hot cathode lamps, mercury or sodium vapour lamps, metal halide lamps and ultraviolet lamps)
8539 49 10	Ultraviolet lamps
8539 49 30	Infra-red lamps

Toolkit references
5.5 Consumer products with intentional use of mercury
5.5.1 Thermometers with mercury
5.5.2 Electrical switches and relays with mercury

9025 11 20	Clinical or veterinary thermometers, liquid-filled, for direct reading
9025 11 80	Thermometers, liquid-filled, for direct reading, not combined with other instruments (excl. clinical or veterinary thermometers)
9025 19 20	Thermometers and pyrometers, not combined with other instruments, electronic
9025 19 80	Thermometers and pyrometers, not combined with other instruments, non-electronic (excl. liquid-filled thermometers for direct reading)
9025 80 20	Barometers, not combined with other instruments
9025 80 40	Hydrometers, areometers and similar floating instruments, hygrometers and psychrometers, whether or not combined with each other or with thermometers or barometers, electronic
9025 80 40	Hydrometers, areometers and similar floating instruments, hygrometers and psychrometers, whether or not combined with each other or with thermometers or barometers, electronic
9025 80 80	Hydrometers, areometers and similar floating instruments, hygrometers and psychrometers, whether or not combined with each other or with thermometers or barometers, non-electronic
9025 80 80	Hydrometers, areometers and similar floating instruments, hygrometers and psychrometers, whether or not combined with each other or with thermometers or barometers, non-electronic
9026 20 40	Spiral or metal diaphragm type pressure gauges
9026 20 80	Instruments and apparatus for measuring or checking pressure of liquids or gases, non-electronic (excl. spiral or metal diaphragm type pressure gauges, and regulators)
9027 30 00	Spectrometers, spectrophotometers and spectrographs using optical radiations, such as UV, visible, IR
9027 50 00	Instruments and apparatus for physical or chemical analysis, using UV, visible or IR optical radiations (excl. spectrometers, spectrophotometers, spectrographs, and gas or smoke analysis apparatus)
9032 10 20	Electronic thermostats
9032 10 81	Non-electronic thermostats, automatic regulating or controlling, with electrical triggering device
9032 10 81	Non-electronic thermostats, automatic regulating or controlling, with electrical triggering device
9032 10 89	Non-electronic thermostats, without electrical triggering device
9032 20 00	Manostats (excl. taps, cocks and valves of heading 8481)

9032 89 00	Regulating or controlling instruments and apparatus (excl. hydraulic or pneumatic, manostats, thermostats, and taps, cocks and valves of heading 8481)
9032 89 00	Regulating or controlling instruments and apparatus (excl. hydraulic or pneumatic, manostats, thermostats, and taps, cocks and valves of heading 8481)

8.2 CAS numbers for mercury substances

1511. The following list developed by UNITAR for the Toolkit shows chemical substances containing mercury and their CAS numbers. Note that other mercury containing substances may exist.

CAS.	**Chemical Name**	**Substance Category**
10045-94-0	Nitric acid, mercury(2++) salt	Inorganics
10112-91-1	Mercury chloride (Hg2Cl2)	Inorganics
10415-75-5	Nitric acid, mercury(1++) salt	Inorganics
104923-33-3	Mercurous chloride	Inorganics
12068-90-5	Mercury telluride (HgTe)	Inorganics
1344-48-5	Mercury sulfide (HgS)	Inorganics
15829-53-5	Mercury oxide (Hg2O)	Inorganics
19122-79-3	Mercuric sulfide red	Inorganics
21908-53-2	Mercury oxide (HgO)	Inorganics
29870-72-2	Cadmium mercury telluride ((Cd,Hg)Te)	Inorganics
592-85-8	Thiocyanic acid, mercury(2++) salt	Inorganics
7439-97-6	Mercury	Inorganics
7487-94-7	Mercury chloride (HgCl2)	Inorganics
7546-30-7	Mercury chloride (HgCl)	Inorganics
7774-29-0	Mercury iodide (HgI2)	Inorganics
7783-33-7	Mercurate(2-), tetraiodo-, dipotassium, (T-4)-	Inorganics
7783-35-9	Sulfuric acid, mercury(2++) salt (1:1)	Inorganics
7783-36-0	Sulfuric acid, dimercury(1++) salt	Inorganics
7789-47-1	Mercury bromide (HgBr2)	Inorganics
1600-27-7	Acetic acid, mercury(2++) salt	Organic-metal salt
27685-51-4	Cobaltate(2-), tetrakis(thiocyanato-N)-, mercury(2++) (1:1), (T-4)-	Organic-metal salt
62638-02-2	Cyclohexanebutanoic acid, mercury(2++) salt	Organic-metal salt
63325-16-6	Mercury, diiodobis(5-iodo-2-pyridinamine)-, dihydriodide	Organic-metal salt
103-27-5	Mercury, phenyl(propanoato-O)-	Organometallics
104-60-9	Mercury, (9-octadecenoato-O)phenyl-, (Z)-	Organometallics
129-16-8	Mercury, (2',7'-dibromo-3',6'-dihydroxy- 3-oxospiro[isobenzofuran-1(3H),9'-[9H]xanthen]-4'-yl)hydroxy-, disodium salt	Organometallics
138-85-2	Mercurate(1-), (4-carboxylatophenyl)hydroxy-, sodium	Organometallics
24806-32-4	Mercury, [μ-[dodecylbutanedioato(2-)-O:O']]diphenyldi-	Organometallics
26545-49-3	Mercury, (neodecanoato-O)phenyl-	Organometallics
33770-60-4	Mercury, [2,5-dichloro-3,6-dihydroxy- 2,5-cyclohexadiene-1,4-dionato(2-)-O1,O6]-	Organometallics
54-64-8	Mercurate(1-), ethyl[2-mercaptobenzoato(2-)-O,S]-, sodium	Organometallics
5954-14-3	Mercury, (acetato-O)[3-(chloromethoxy)propyl-C,O]-	Organometallics
62-38-4	Mercury, (acetato-O)phenyl-	Organometallics
94070-93-6	Mercury, [μ-[(oxydi-2,1-ethanediyl 1,2-benzenedicarboxylato)(2-)]]diphenyl-	Organometallics
91082-69-8	Turpentine, Venice, sulfurized, reaction products with hydrogen tetrachloroaurate(1-), sulfurized turpentine oil and mercurous nitrate, mixed with mercurous oxide	UVCBs-biological
1345-09-1	Cadmium mercury sulfide	UVCBs-inorganic
152923-45-0	Slimes and Sludges, mercury conc. roasting off gas condensate	UVCBs-inorganic

8.3 Mercury concentrations in sphalerit in concentrates and ores for zinc extraction

1512. Below find, with reference to section 5.2.3 on zinc extraction and initial processing, data on mercury concentrations in sphalerit (Hg_{sp}) in concentrates and ores for zinc extraction (Schwartz, 1997).

Mercury concentrations in sphalerit (Hg_{sp}) in concentrates and ores for zinc extraction (Schwartz, 1997)

Country	Number of deposits	Deposit name (district)	Average Hg_{sp} concentration, ppm *1	Analysed material *2	Number of samples	References for analyses and deposit classification	Additional references for deposit classification
Archean VOLCEX deposits (up to greenschist facies)							
Canada	19	Cdn.-Jamieson, Coniagas, Delbridge, Hacket R., High L., Indian Mountain L., Kam-Kotia, Kidd Creek, Lac Dufault, Manitou-Barvue, Mattabi, Mattagami L., N. Slave, Orchan, Poirier, South Bay, Spi L., Sturgeon L., Zenmac	37	M	66	Jonasson and Sangster (1975)	Pye (1964), Wright (1967), Franklin *et al.* (1981), Laznika (1981), Sangster (1986)
Canada	1		123	C	1	(confidential)	
Archean VOLCEX deposits (amphibolite facies)							
Canada	3	Geco, Normetal, Willecho	10	M	13	Jonasson and Sangster (1975)	Franklin *et al.* (1981)
Proterozoic VOLCEX deposits (up to greenschist facies)							
Canada	4	Errington, Flin Flon, Ruttan L., Schist L.	95	M	10	Jonasson and Sangster (1975)	CIM (1957), Franklin *et al.* (1981), Laznicka (1981)
Sweden	11	Boliden, Kristineberg, Langdal, Langsele, Näsliden, Rävliden ABC, Rävliden Cu, Ravlidmyran, Renström, Sturemalmen, Udden	998	C	11	Widenfalk (1979)	
Proterozoic VOLCEX deposits (amphibolite facies)							
Canada	9	Chisel L., Fox L., New Calumet, N. Contact L., Osborne L., Sherridon, Sulphide L., Tetrault, Western Nuclear	97	M	22	Jonasson and Sangster (1975)	Franklin *et al.* (1981), Laznicka (1981)
Finland	1	Vihanti	550	C	1	Kleinevoss (1971)	Isokangas (1978)
Sweden	1	Rudtjebäcken	582	C	1	Widenfalk (1979)	
Phanerozoic VOLCEX deposits (up to greenschist facies)							
Australia	1		50	C	1	(confidential)	
Australia	1		4	M	2	(confidential)	
Australia	1	Woodlawn	6	M	8	Ryall (1979b)	Laznicka (1981)
Canada	1		11	C	1	(confidential)	
Canada	11	Big Bull, Brunswick No. 6, 12, Buchans, Heath Steele, Key Anacon, Seneca, Sturgeon R. Wedge, Weedon, Western	35	M	14	Jonasson and Sangster (1975)	CIM (1957), Douglas (1970). Thurlow *et al.* (1975), Armbrust and Gannicott (1980), Seraphim (1980), Franklin *et al.* (1981)
Japan	1	Shakanai	14	M	12	Nishiyama (1974)	
Japan	3	Furutobe, Hanaoka, Uchinotai	29	M	6	Ozerova (1986)	Ozerova *et al.* (1975)
Kazakstan	1	Ridder-Sokol'noye	1	M	4	Kovrigo *et al.* (1976)	
Norway	4	Bjorkasen, Lokken, Rostvangen Vigsnes	55	M	5	Oftedal (1941)	Rui (1973), Vokes (1976), Bugge (1978)
Russia	6	Mauk, (South Urals), Valentina	64	M	15	Ozerova (1986)	Ozerova *et al.* (1975), Smirnov (1977)

Country	Number of deposits	Deposit name (district)	Average Hg_{sp} concentration, ppm *1	Analysed material *2	Number of samples	References for analyses and deposit classification	Additional references for deposit classification
Spain	1		548	C	1	(confidential)	
Spain	1	Santa Ana	43	C	1	Marcoux *et al.* (1996)	
Spain	1	San Telmo	116	C	1	Marcoux *et al.* (1996)	
United States	4	(East Maine)	17	M	6	Jolly and Heyl (1968)	Bouley and Hodder (1984)
	3	East Pacific Rise, Galapagos Rift, Juan de Fuca Ridge (seafloor)	2	C	5	Bischoff *et al.* (1983)	

Country	Number of deposits	Deposit name (district)	Average Hg_{sp} concentration, ppm *1	Analysed material *2	Number of samples	References for analyses and deposit classification	Additional references for deposit classification
Phanerozoic VOLCEX deposit. (amphibolite facies)							
Norway	1	Hestekletten	30	M	1	Oftedal (1941)	Vokes (1976), Bugge (1978)
Norway	1	Storvarts	100	M	1	Oftedal (1941)	Vokes (1976), Bugge (1978)
Norway	1	Jakobsbakken	42	M	1	Kleinevoss (1971)	Vokes (1976), Bugge (1978)
Proterozoic SEDEX deposits (amphibolite/granulite facies)							
Australia	1	Broken Hill	27	M	24	Ryall (1979a)	
United States	1	Balmat	1198	M	2	Jonasson and Sangster (1975)	deLoraine and Dill (1982), Sangster (1990)
Phanerozoic SEDEX deposits (up to greenschist facies)							
Australia	1		48	C	1	(confidential)	
Australia	1		89	C	1	(confidential)	
Canada	1		109	C	1	(confidential)	
Canada	1	Faro	114	M	2	Jonasson and Sangster (1975)	Tempelman-Kluit (1972), Sangster (1990)
Germany	1	Rammelsberg	164	C	8	Kraume (1955)	
Germany	1	Meggen	6	C	1	Hilmer (1972)	
Phanerozoic SEDEX deposits (amphibolite facies)							
Norway	1	Mofjell	60	C	1	Borsch (1970; quoted by Kleinevoss (1971)	Vokes (1976), Sangster (1990)
Pre-Tertiary veins in low-carbonate rocks							
Canada	20	Arctic Silver, Berens R., Box, (Cobalt) Dor-chester, Frontenac Lead, Homer L., (Keno Hill), Keymet, Kingdon Lead, Ramah, Severn R., Smithers, Thubin L., (Thunder Bay) Turnback L.	32	M	46	Jonasson and Sangster (1975)	Alcock (1930), CIM (1957), Douglas (1970), Thorpe (1972), Sangster (1986), Kissin and Sherlock (1989), Beaudoin and Sangster (1992)
Czech Rep.	1	Pribram	65	M	2	Schroll (1953)	Beaudoin and Sangster (1992)
Germany	1	Clausthal	283	M	3	Kleinevoss (1971)	Beaudoin and Sangster (1992)
Germany	1	Bad Grund	293	M	1	Kleinevoss (1971)	Beaudoin and Sangster (1992)

Country	Number of deposits	Deposit name (district)	Average Hg_{sp} concentration, ppm *1	Analysed material *2	Number of samples	References for analyses and deposit classification	Additional references for deposit classification
Germany	1	Freiberg	30	M	2	Schroll (1953)	Beaudoin and Sangster (1992)
Spain	1	Osor	0.4	M	5	Schwartz (1972)	
Kazakstan	4	Bezymyannoye Kizyl-bel', Kok-tyube, Peraval'noye	86	M	8	Ozerova (1959)	
Ukraine	1	Nagol'no-Tarasovskoye	6	M	1	Saukov (1946; quoted by Dvornikov, 1962)	
Ukraine	1	Gruzskaya	73	M	1	Dvornikov, 1962)	
United States	1	Coeur d'Alene	95	M	14	Fryklund and Fletcher (1956)	
United States	5	Armenius, Madison. (Shawangunk), Valzinco, Wheatley	23	M	5	Jolly and Heyl (1968)	Ingham (1940), Luttrell (1966), Smith (1977)
Pre-Tertiary veins in limestone/dolomite							
Canada	2	Blue Bell, Silver L.	18	M	3	Jonasson and Sangster (1975)	CIM (1957), Franklin and Mitchell (1977)
United States	11	(Central Kentucky), (Central Tennessee vein district)	48	M	27	Jolly and Heyl (1968)	Jewell (1947), Jolly and Heyl (1964), Kyle (1976)
United States	1	Dove Creek	13	C	1	Maher and Fagan (1970)	Jolly and Heyl (1964)
Vein (and carbonate-replacement) deposits linked to Tertiary magmatism							
Bulgaria	1	Madzharovo	0.5	M	2	Ozerova (1983)	Breskovska and Tarkian (1993)
Peru	20	Alianza, Atacocha, Austria Duvaz, Casapalca-Centromin, Casapalca-Gubbins, Cerro de Pasco, Colquirrumi, El Brocal, Huaron, Morococha, Pachapaqui, Perubar, Raura, San Cristobal, Santa Rita, Santander, Uchucchacua, Volcan, Yauli, Yauricocha	31	C	20	Cavanagh and Glover (1991)	Vasquez (1974), Soler (1982, 1986)
Peru	1		31	C	1	(confidential)	
Peru	1		76	C	1	(confidential)	
Peru	1		147	C	1	(confidential)	
Serbia	1	Trepca	33	M	1	Kleinevoss (1971)	Jankovic (1982)
Proterozoic MVT							
Canada	3	Long L., Strathcona, Thirty Islands L.	14	M	9	Jonasson and Sangster (1975)	
Phanerozoic MVT							
Austria	1	Lafatsch	1	C	15	Cerny (1989)	
Austria	1	Bleiberg	2	C	100	Schroll (1983)	Zeeh and Bechstädt (1994)

Country	Number of deposits	Deposit name (district)	Average Hg_{sp} concentration, ppm *1	Analysed material *2	Number of samples	References for analyses and deposit classification	Additional references for deposit classification
Canada	14	Bankeno, Ferndale, Gays R., H.B., Kaladar Road, Kicking Horse, Little Pike Day, Monarch, Newfoundland Zinc, Pine Point, Schoolhouse, Tobermory, Walton, Wiarton	5	M	83	Jonasson and Sangster (1975)	
Germany	1	Stolberg	0.2	M	8	Krahn *et al.* (1986)	
Peru	1	San Vicente	4	C	1	Cavanagh and Glover (1991)	Fontboté and Gorzawski (1990)
Slovenia	1	Mezica	0.4	M	4	Terzic (1972)	Cerny (1989)
United States	20	Almedia, Bamford, (East Tennessee), Friedensville, (Southwest Virginia), (Timberville), (Tri-State), (Upper Mississippi Valley)	3	M	29	Jolly and Heyl (1968)	Hoagland (1971), Smith (1977), Sangster (1990)
United States	1	Nashville Prospect	0.05	M	1	Jones (1988)	
United States	18	(East Tennessee), (Southwest Virginia)	21	C	19	Maher and Fagan (1970)	
Sandstone lead-zinc							
Germany	1	Maubach	10	M	1	Kulms (1970)	
Unclassified deposits in limestone/dolomite							
Canada	1	Prairie Creek	933	M	2	Jonasson and Sangster (1975)	
Ireland	1	Keel	227	M	113	Watling (1974)	
Italy	1	Gorno	55	M	20	Fruth and Maucher (1966)	
Kazakhstan	1	Achisai	6	M	3	Fursov (1958)	
Spain	1	Rubiales	2054	M	76	Arias *et al.* (1992)	
United States	3	Linville Falls, Serpent Mount, Smith	102	M	3	Jolly and Heyl (1968)	
United States	1	East Fork Cabin Creek	10	C	1	Maher and Fagan (1970)	

Notes: *1 The Hg_{sp} concentrations refer to the mercury content of sphalerite (mineral analysis) or the theoretical mercury content of sphalerite in ore (see text).

*2 M = mineral analysis; C = concentrate analysis.

8.4 Country data for certain default calculations

1513. For the sub-categories listed below, default mercury input and release estimations are based on population data in combination with other country-specific activity level indicators:

Sub-category	**Data types used as activity rates**
Dental amalgam fillings ("silver" fillings)	Population, density of dental personnel
Electrical switches and relays with mercury	Population, electrification rate (percent of population with access to electricity)
Polyurethane (PU, PUR) produced with mercury catalyst	Population, electrification rate (percent of population with access to electricity)
Other manometers and gauges with mercury	Population, electrification rate (percent of population with access to electricity)
Laboratory chemicals	Population, electrification rate (percent of population with access to electricity)
Other laboratory equipment with mercury	Population, electrification rate (percent of population with access to electricity)

1514. The country-specific data on population, density of dental personnel and electrification rate needed in the calculations are listed below. UN Environment may update these data as newer revisions become available, and as feasible. The sources of the data are listed in the table notes below. These data are used automatically in the calculations in the Inventory Level 1 spreadsheet and are also suggested for use in Inventory level 2 calculations, as described in the relevant sub-category sections in chapter 5.

Country	**Number of inhabitants 2015*3**	**Electrification rate *2**	**Dental personnel per 1000 inhabitants (adjusted)*1**	**Dental personnel per 1000 inhabitants (original WHO data)**	**Year for dental personnel data*1**
1-Click here to select country	0	100	0.8292		
Afghanistan	33,736,494	16	0.0285	0.0285	2001
Albania*8	2,923,352	100	0.4452	0.4452	1998
Algeria	39,871,528	99	0.3055	0.3055	2002
Andorra*7	78,014	100	0.6667	0.6667	2003
Angola	27,859,305	26	0.0169	0.0002	1997
Antigua and Barbuda*8	99,923	100	0.1884	0.1884	1997
Argentina	43,417,765	97	0.7994	0.7994	1998
Armenia	2,916,950	100	0.2620	0.2620	2003
Australia*8	23,799,556	100	1.1005	1.1005	2001
Austria	8,678,657	100	0.4974	0.4974	2003
Azerbaijan*8	9,617,484	100	0.2714	0.2714	2003
Bahamas*8	386,838	100	0.0709	0.0709	1998
Bahrain	1,371,855	99	0.4628	0.4628	2004
Bangladesh	161,200,886	41	0.0170	0.0170	2004
Barbados*8	284,217	100	0.2360	0.2360	1999
Belarus*9	9,485,772	78	0.4361	0.4361	2003

Belgium	11,287,940	100	0.8083	0.8083	2002
Belize*8	359,288	85	0.1333	0.1333	2000
Benin	10,575,952	25	0.0169	0.0017	2004
Bhutan*6	787,386	72	0.0249	0.0249	2004
Bolivia	10,724,705	78	0.7071	0.7071	2001
Bosnia and Herzegovina*6	3,535,961	99	0.1658	0.1658	2003
Botswana	2,209,197	45	0.0212	0.0212	2004
Brazil	205,962,108	98	1.1086	1.1086	2000
Brunei Darussalam	417,542	100	0.1437	0.1437	2000
Bulgaria*8	7,177,396	99	0.8199	0.8199	2003
Burkina Faso	18,110,624	15	0.0169	0.0043	2004
Burundi*6	10,199,270	4	0.0169	0.0020	2004
Cambodia	15,517,635	24	0.0169	0.0159	2000
Cameroon	22,834,522	49	0.0169	0.0090	2004
Canada*9	35,949,709	97	0.5868	0.5868	2003
Cape Verde*6	532,913	67	0.0233	0.0233	2004
Central African Republic*6	4,546,100	6	0.0169	0.0033	2004
Chad*6	14,009,413	4	0.0169	0.0017	2004
Chile	17,762,681	99	0.4271	0.4271	2003
China	1,397,028,553	99	0.1056	0.1056	2001
Chinese Taipei/Taiwan*10	23,485,755	99	0.4078	0.4078	
Colombia	48,228,697	94	0.7800	0.7800	2002
Comoros*6	777,424	45	0.0367	0.0367	2004
Cook Islands*8	17,449	99	0.5556	0.5556	2001
Costa Rica	4,807,852	99	0.4849	0.4849	2000
Côte d'Ivoire	23,108,472	47	0.0201	0.0201	2004
Croatia*8	4,236,016	99	0.6967	0.6967	2003
Cuba	11,461,432	97	0.8731	0.8731	2002
Cyprus*9	1,160,985	100	0.8166	0.8166	2002
Czech Republic*8	10,603,762	99	0.6582	0.6582	2003
Democratic People's Republic of Korea	25,243,917	26	0.3669	0.3669	2003
Democratic Republic of the Congo	76,196,619	11	0.0169	0.0029	2004
Denmark	5,688,695	100	0.8292	0.8292	2002
Djibouti*6	927,414	62	0.0169	0.0140	2004
Dominica*6	73,162	88	0.0526	0.0526	1997
Dominican Republic	10,528,394	96	0.8380	0.8380	2000
Ecuador	16,144,368	92	0.1660	0.1660	2000
Egypt	93,778,172	100	0.1351	0.1351	2004
El Salvador	6,312,478	86	0.5401	0.5401	2002
Equatorial Guinea*11	1,175,389	34	0.0296	0.0296	2004
Eritrea	4,846,976	32	0.0169	0.0037	2004
Estonia*8	1,315,321	99	1.2780	1.2780	2000
Eswatini (Swaziland)	1,319,011	27	0.0295	0.0295	2004
Ethiopia*8*13	99,873,033	41	0.0169	0.0028	
Fiji	892,149	87	0.0398	0.0398	1999
Finland	5,481,966	100	1.2842	1.2842	2002
France	64,457,201	100	0.6768	0.6768	2004
Gabon	1,930,175	37	0.0489	0.0489	2004
Gambia*6	1,977,590	34	0.0302	0.0302	2003
Georgia*6	3,951,524	100	0.2805	0.2805	2003
Germany	81,707,789	100	0.7834	0.7834	2003
Ghana	27,582,821	61	0.0184	0.0184	2004
Greece	11,217,800	100	1.1322	1.1322	2001
Grenada*8	106,823	100	0.0854	0.0854	1997
Guatemala	16,252,429	81	0.1840	0.1840	1999
Guinea*6	12,091,533	20	0.0169	0.0070	2004
Guinea-Bissau*6	1,770,526	54	0.0169	0.0143	2004
Guyana*6	768,514	78	0.0395	0.0395	2000
Haiti	10,711,061	39	0.0169	0.0121	1998
Honduras	8,960,829	70	0.2123	0.2123	2000
Hungary*8	9,783,925	99	0.5431	0.5431	2003
Iceland	330,243	100	1.0035	1.0035	2000
India	1,309,053,980	75	0.0568	0.0568	2004
Indonesia	258,162,113	65	0.0314	0.0314	2003
Iran, Islamic Republic of	79,360,487	98	0.0944	0.0944	2004
Iraq	36,115,649	86	0.4443	0.4443	2004
Ireland	4,700,107	100	0.5594	0.5594	2004
Israel	8,064,547	100	1.1674	1.1674	2003
Italy	59,504,212	100	0.5755	0.5755	2004
Jamaica	2,871,934	92	0.0800	0.0800	2003
Japan*8	127,974,958	100	0.7100	0.7100	2002

Jordan	9,159,302	100	1.2950	1.2950	2004
Kazakhstan*9	17,749,648	73	0.3379	0.3379	2003
Kenya	47,236,259	16	0.0413	0.0413	2004
Kiribati*12	112,407	95	0.0494	0.0494	1998
Kuwait	3,935,794	100	0.2860	0.2860	2001
Kyrgyzstan	5,865,401	100	0.1931	0.1931	2003
Lao People's Democratic Republic	6,663,967	55	0.0408	0.0408	1996
Latvia*8	1,992,663	98	0.5579	0.5579	2003
Lebanon	5,851,479	100	1.2109	1.2109	2001
Lesotho	2,174,645	16	0.0169	0.0089	2003
Liberia*6	4,499,621	2	0.0169	0.0037	2004
Libyan Arab Jamahiriya	6,234,955	100	0.1403	0.1403	1997
Lithuania*8	2,931,926	99	0.6887	0.6887	2003
Luxembourg	566,741	100	0.7130	0.7130	2003
Madagascar	24,234,088	19	0.0229	0.0229	2004
Malawi*14	17,573,607	9	0.0169	0.0083	
Malaysia	30,723,155	99	0.0932	0.0932	2000
Maldives*6	418,403	100	0.0427	0.0427	2004
Mali*6	17,467,905	17	0.0169	0.0063	2004
Malta	427,616	100	0.4239	0.4239	2003
Marshall Islands*8	52,994	69	0.0784	0.0784	2000
Mauritania*8	4,182,341	19	0.0215	0.0215	2004
Mauritius	1,259,456	99	0.1890	0.1890	2004
Mexico*8	125,890,949	97	0.7913	0.7913	2000
Micronesia, Federated States of*8	104,433	95	0.1308	0.1308	2000
Monaco	38,307	100	1.0625	1.0625	1995
Mongolia*8	2,976,877	88	0.1317	0.1317	2002
Montenegro*5	628,178	100	0.3599	0.3599	2002
Morocco	34,803,322	97	0.0995	0.0995	2004
Mozambique	28,010,691	12	0.0169	0.0083	2004
Myanmar	52,403,669	13	0.0279	0.0279	2004
Namibia	2,425,561	34	0.0562	0.0562	2004
Nauru*8*12	11,260	100	0.1308	0.1308	
Nepal	28,656,282	44	0.0169	0.0140	2004
Netherlands	16,938,499	100	0.4805	0.4805	2003
New Zealand*8	4,614,532	87	0.6779	0.6779	2001
Nicaragua	6,082,035	72	0.0445	0.0445	2003
Niger*8	19,896,965	9	0.0169	0.0012	2004
Nigeria	181,181,744	51	0.0200	0.0200	2003
Niue*8	1,629	97	1.0000	1.0000	1996
Norway	5,199,836	100	0.8235	0.8235	2003
Oman	4,199,810	98	0.1853	0.1853	2004
Pakistan	189,380,513	62	0.0500	0.0500	2004
Palau*8	21,288	97	0.1111	0.1111	1998
Panama	3,969,249	88	0.7563	0.7563	2000
Papua New Guinea*6	7,919,825	11	0.0169	0.0169	2000
Paraguay	6,639,119	97	0.5544	0.5544	2002
Peru	31,376,671	86	0.1100	0.1100	1999
Philippines	101,716,359	90	0.1131	0.1131	2000
Poland*8	38,265,226	100	0.2968	0.2968	2003
Portugal	10,418,473	100	0.5477	0.5477	2003
Qatar	2,481,539	99	0.3723	0.3723	2001
Republic of Korea*8	50,593,662	100	0.3361	0.3361	2003
Republic of Moldova*6	4,065,980	99	0.3288	0.3288	2003
Republic of the Congo	4,995,648	37	0.0169	0.0031	2004
Romania	19,876,621	99	0.2202	0.2202	2003
Russian Federation*8	143,888,004	93	0.3209	0.3209	2003
Rwanda*6	11,629,553	6	0.0169	0.0025	2004
Saint Kitts and Nevis	54,288	95	0.1860	0.1860	1997
Saint Lucia	177,206	98	0.0621	0.0621	1999
Saint Vincent and the Grenadines*6	109,455	67	0.0517	0.0517	1997
Samoa	193,759	93	0.1754	0.1754	1999
San Marino*9	32,960	100	0.3478	0.3478	1990
Sao Tome and Principe*8	195,553	60	0.0667	0.0667	2004
Saudi Arabia	31,557,144	99	0.1700	0.1700	2004
Senegal	14,976,994	42	0.0169	0.0094	2004
Serbia*5*8	8,851,280	100	0.3599	0.3599	2002
Seychelles*8	93,742	96	1.1750	1.1750	2004
Sierra Leone*6	7,237,025	12	0.0169	0.0010	2004
Singapore*8	5,535,262	100	0.2648	0.2648	2001

Slovakia	5,439,318	98	0.4376	0.4376	2003
Slovenia	2,074,788	99	0.6037	0.6037	2002
Solomon Islands*6	587,482	16	0.0613	0.0613	1999
Somalia*8	13,908,129	30	0.0169	0.0019	1997
South Africa	55,291,225	75	0.1326	0.1326	2004
Spain	46,397,664	100	0.4872	0.4872	2003
Sri Lanka	20,714,040	77	0.0648	0.0648	2004
Sudan	38,647,803	36	0.0315	0.0315	2004
Suriname*8	553,208	84	0.0169	0.0094	2000
Sweden	9,763,565	100	0.8199	0.8199	2002
Switzerland	8,319,769	100	0.5019	0.5019	2003
Syrian Arab Republic	18,734,987	93	0.7194	0.7194	2001
Tajikistan*8	8,548,651	85	0.1513	0.1513	2003
Tanzania*6*13	53,879,957	12	0.0413	0.0413	
Thailand	68,657,600	99	0.1717	0.1717	2000
The former Yugoslav Republic of Macedonia*8	2,079,308	97	0.5528	0.5528	2001
Timor-Leste	1,240,977	17	0.0169	0.0013	2003
Timor-Leste	1,240,977	22	0.0549	0.0549	2004
Togo	7,416,802	20	0.0169	0.0038	2004
Tonga	106,364	23	0.3235	0.3235	2001
Trinidad and Tobago	1,360,092	99	0.0840	0.0840	1997
Tunisia	11,273,661	100	0.2468	0.2468	2004
Turkey*8	78,271,472	100	0.2411	0.2411	2003
Turkmenistan*8	5,565,284	100	0.1827	0.1827	2002
Tuvalu*8	11,001	92	0.1818	0.1818	2002
Uganda	40,144,870	9	0.0169	0.0136	2004
Ukraine	44,657,704	100	0.3989	0.3989	2003
United Arab Emirates	9,154,302	100	0.3314	0.3314	2001
United Kingdom	65,397,080	100	1.0109	1.0109	1997
United Republic of Tanzania	53,879,957	14	0.0169	0.0074	2002
United States of America	319,929,162	100	1.6269	1.6269	2000
Uruguay	3,431,552	98	1.1607	1.1607	2002
Uzbekistan	30,976,021	100	0.1382	0.1382	2003
Vanuatu*8*12	264,603	27	0.1308	0.1308	
Venezuela, Bolivarian Republic of	31,155,134	99	0.5527	0.5527	2001
Viet Nam*4	93,571,567	98	0.0284	0.0284	
Yemen	26,916,207	40	0.0410	0.0410	2004
Zambia	16,100,587	19	0.0449	0.0449	2004
Zimbabwe	15,777,451	42	0.0240	0.0240	2004
Other OECD country		100	0.7358		
Other non-OECD country		68	0.23		

Aggregates	
OECD average of dental density	0.735785881
Non-OECD average of dental personnel density	0.231390132
Non-OECD 20% percentile	0.016919938
Non-OECD average, electrification rates	68

Table notes:

*1: Source: WHO: World health report 2006, Annex, Table 4: Global distribution of health workers in WHO Member States. Accessed June 2012

Figures computed by WHO to ensure comparability; they are not necessarily the official statistics of Member States, which may use alternative rigorous methods. See explanatory notes for sources and methods.

For non-OECD countries with dental personnel density values below the 20% percentile for this group in the original data, the 20% percentile was used in calculations in order to eliminate errors of reporting.

http://www.who.int/whr/2006/annex/en/index.html

*2: Percent of population with access to electricity. Data source: IEA, Electricity access Today – WEO-2011 new Electricity access Database (2009 data country-by-country), accessed June 2012. Except for a few countries; see notes *6, *8 and *9.

http://www.worldenergyoutlook.org/resources/energydevelopment/accesstoelectricity/

*3: Data source: United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision, DVD Edition. (Population estimates from year 2015).

https://population.un.org/wpp/DataQuery/

*4: Dental personnel density assumed as average of Lao and Cambodia

*5: Assumed as Serbia and Montenegro in 2002 (or 2007, see report)

http://www.reeep.org/file_upload/296_tmpphpW16ncV.pdf

*6 Data source for electrification rate: Datamarket.com, accessed Aug. 2012. Data compiled by World Bank staff from households surveys.

http://datamarket.com/data/set/1459/household-electrification-rate-of-households#!display=line&ds=1459!g6f=6.12.15.n.g

*7 Electrification rate assumed as Spain, Italy and France.

*8 Data source for electrification rate: reegle www.regel.info -> Resources & Services (mostly 2000 data)

http://www.reegle.info/countries

*9 Data source for electrification rate: The U.S. National geophysical data center: If no other data/estimations were available, this source was used. The data are based on areas with electrification, and not by population.

http://www.ngdc.noaa.gov/dmsp/pubs/Elvidge_WINTD_20091022.pdf

*10: Assumed = average of (mainland) China and Japan.

*11: Electrification rate assumed as Gabon.

*12: Electrification rate assumed as Micronesia, Federated States of.

*13: Dental personnel density assumed as Kenya.

*14: Dental personnel density assumed as Mozambique..

8.5 Test of waste and waste water default input factors

In the Toolkit, default factors used for calculation of mercury releases from the waste handling categories are based on examples of mercury contents in waste and wastewater in other countries for which such data have been available. This may differ from actual waste in your country, primarily due to differences in the consumption pattern of mercury added products and intentional use of mercury in processes. The default input factors used in this Toolkit for waste and wastewater were derived from data from developed countries only. You can make a simple test based on your Inventory Level 1 results, that will indicate if the default input factor for general (municipal) waste might over-estimate the mercury releases in your country.

Is the sum of the calculated INPUTS to all general waste sub-categories is more than 2 times larger than the sum of WASTE OUTPUTS from intentional mercury uses in products plus processes (and these are well covered in the inventory)? If so, please describe this in your inventory report (with sum numbers) and state that mercury flows to general waste sub-categories may be over-estimated, and that more detailed investigations may be needed on this issue.

In the (unaltered) IL2 spreadsheet the test is done as follows: Select the tab "Level 2-Summary", check if cells

(E62+E66+E68+E671) > 2*(J24 + ∑(J37 to J56)).

A similar test should be performed and discussed in the report for wastewater treatment: Is the sum of the calculated INPUTS to waste water treatment is more than 2 times larger than the sum of OUTPUTS TO WATER from intentional mercury uses in products plus processes (and these are well covered in the inventory)? If so, please describe this in your inventory report (with sum numbers) and state that mercury flows to waste water treatment may be over-estimated, and that more detailed investigations may be needed on this issue.

In the IL2 spreadsheet the test is done as follows: Select the tab "Level 2-Summary", check if cell

E72 > 2*(G24 + ∑(G37 to G56)).

In the inventory report template, a suggestion for text discussing these issues is pre-entered. If the tests are negative, simply erase the proposed discussion text (see the report template).

These tests should be understood as giving certain evidence that the defaults factors are overestimated, but they do give an indication of this. In principle, mercury flows to waste and wastewater from other sectors (without intentional mercury use) could also contribute, but they would more often not be contribute to the general waste/wastewater stream, but rather to sectors specific streams.

8.6 Indicative lifetime estimates for mercury-added products

While developed for Inventory Level 3, the below list of indicative lifetime estimates for mercury-added products can also be used in Inventory Level 2, when collecting data to quantify mercury amounts available for disposal in the base year. For more details, see the Guideline for Inventory Level 3.

Table 8-1 Default suggestions for average product and materials lifetimes (overleaf).

Sub-C	**Source category**	**Average lifetime, y *1**		**Source of information**
		Range *2	**"Best estimate"**	
5.5.1	**Thermometers with mercury**			
	Medical thermometers	1-10	3	1-2 months in hospitals (AGHTM, 2000 as cited by Maag et al.); 5 years by consumers (Barr, 2001)
	Ambient air thermometers	3-10	5	Thermometers: 5 years (Floyd et al., 2002); 5 years (Barr, 2001)
	Industrial and special thermometers	3-20	10	As above combined with expert assessment
	Other glass Hg thermometers	3-8	5	Thermometers: 5 years (Floyd et al., 2002); 5 years (Barr, 2001)
5.5.2	**Electrical switches and relays with mercury**	10-50	15	Switches in building walls: 30-50 years (IL2 Reference Report). Electrical and electronic equipment and cars: 15-20 years (IL2 Reference Report); In electronic equipment: 5-10 years (Floyd et al., 2002).
5.5.3	**Light sources with mercury**			
	Fluorescent tubes (double end)	4 – 10	5	5 years (Barr, 2001); 5 years (NJ MTF, 2002); 8-10 years (Skårup et al., 2003)
	Compact fluorescent lamp (CFL single end)	4 – 10	5	5 years (Barr, 2001); 5 years (NJ MTF, 2002); 8-10 years (Skårup et al., 2003)
	High-pressure mercury vapour	5-15	10	Expert estimate - the high-pressure mercury lamps have relatively long operating life
	High-pressure sodium lamps	5-15	10	As above
	UV light for tanning	4 - 8	5	The lifetime is assumed to be comparable to fluorescent tubes
	Metal halide lamps	5-15	10	Expert estimate - the metal halide lamps have relatively long operating life
5.5.4	**Batteries with mercury**			
	Mercury oxide (all sizes); also called mercury-zinc cells	2-10	5	Expert estimate. Mercury oxide cells have relatively long shelf life and service life, and therefore have some strategic uses (stocks).
	Zinc-air button cells	2-3	3	Expiry date 2 years (Panasonic, 2022)
	Alkaline button cells	2-4	3	Expiry date 3 years (Panasonic, 2022)
	Silver oxide button cells	2-3	3	2 years (Sathaiyan, 2013); expiry date 2 years (Panasonic, 2022)
	Alkaline, other than button cell shapes	2-3	3	2-3 years (EPBA 2008 as cited by Lassen et al. 2008)
5.5.5	**Polyurethane with mercury catalysts**	5-20	10	Expert estimate. Polyurethane parts are used for many different applications and included in various products.
5.5.6	**Biocides and pesticides with mercury**	0-1	0	Expert estimate

Sub-C	Source category	Average lifetime, y *1		Source of information
		Range *2	"Best estimate"	
5.5.7	**Paints with mercury**	0-1	0	The value takes into account possible shelf-life. Once applied, the half-life of mercury in water-based paints has been estimated to be about 1 year i.e. that half of the mercury content is released each year (NJMTF, 2002 as cited by Lassen et al., 2008). Assumed that no mercury is present when the paint is removed.
5.5.8	**Pharmaceuticals for human and veterinary uses**	0-1	0	Used either the year it is produced or the subsequent year
5.5.9	**Cosmetics and related products with mercury**	0-1	0	Used either the year it is produced or the subsequent year
5.6.1	**Dental mercury-amalgam fillings**	10-20	15	See Reference Report for further references
5.6.2	**Manometers and gauges with mercury**			
	Manometers	10-20	15	Manometers: 10 years (Floyd et al., 2002); 20 year (ECHA, 2011)
	U-shaped manometers	10-20	15	Same as above
	Manometers for milking systems	10-20	15	Same as above
	Manometers and barometers used for measuring air pressure	10-20	15	Same as above
	Barometers	10-20	15	Same as above
	Environmental manometers	10-20	15	Same as above
	Pressure valves in district heating plants	20-40	30	Expert estimate. May be phased out. Liquid mercury was used for topping up, but a similar amount may be released to air while in use.
	Pressure gauges	10-20	15	Expert estimate
5.6.3	**Laboratory chemicals and equipment with mercury**			
	Laboratory chemicals	0-1	0	Mercury is used as consumable for the analysis i.e. disposed of same year as sold for the purpose
	Mercury drop electrode	0-1	0	Mercury is used as consumable for the analysis i.e. disposed of same year as sold for the purpose
	Porosimeters and pycnometers	0-1	0	Mercury is used as consumable for the analysis i.e. disposed of same year as sold for the purpose
	Blood gas analyser	5-15	10	Experts estimate assuming the average lifespan of measuring equipment is slightly higher than for consumer electronics
	Mercury electrodes (calomel)	5-15	10	Same as above
	Blood lead analyser	5-15	10	Same as above
	Coulter counter	5-15	10	Same as above
	Sample collector for oil offshore	5-15	10	Same as above

Sub-C	Source category	Average lifetime, y *1		Source of information
		Range *2	"Best estimate"	
	Electron microscope	5-15	10	Same as above
	Other measuring equipment (not further specified)	5-15	10	Same as above
	Centrifuges	5-15	10	Expert estimate
	Thermostats	15-25	20	Thermostats: 20 years (Barr, 2001)
	Mercury lamps for atomic absorption spectrophotometers and other equipment	4 - 8	5	Experts estimate assuming same lifespan as CLFs
	Overall average suggested for laboratory equipment		10	
5.6.4	**Mercury metal use in religious rituals and folklore medicine**	0-1	0	Experts estimate
5.6.5	**Miscellaneous product uses, mercury metal uses, and other sources**			
	Infrared detection semiconductors	5-15	10	Experts estimate assuming the average lifespan of measuring equipment is slightly higher than for consumer electronics
	Bougie tubes and Cantor tubes	10-30	20	Expert estimate
	Educational uses	0-1	0	Mercury is used as consumable i.e. disposed of same year as sold for the purpose
	Gyroscopes with mercury	5-15	10	Experts estimate assuming the average lifespan of measuring equipment is slightly higher than for consumer electronics
	Vacuum pumps with mercury	5-15	10	Expert estimate
	Use of mercury as a refrigerant in certain cooling systems	5-15	10	Expert estimate
	Light houses (Marine navigation lights)	30-80	50	Expert estimate. Liquid mercury is frequently used for topping up but a similar amount is assumed to be released to air.
	Mercury in large bearings of rotating mechanic parts in for example older waste water treatment plants	20-50	30	Expert estimate. Liquid mercury may frequently be used for topping up but a similar amount is assumed to be released to air.
	Seam welding machines	20-50	30	At least 30 years (KemI 2004 as cited by Lassen et al., 2008)
	Tanning	?	0	Mercury is assumed evaporated over lifetime
	Pigments	5-20	10	Expert estimate. Hg pigments may be used for various products.
	Browning and etching steel	0	0	Mercury is assumed not present in products
	Certain colour photograph paper types	?	0	Information is missing
	Recoil softeners in rifles	5-50?	25?	Expert estimate; assuming Hg encapsulated

Sub-C	Source category	Average lifetime, y *1		Source of information
		Range *2	"Best estimate"	
	Explosives (mercury-fulminate a.o.)	0-1	0	Mercury is consumed in explosion
	Fireworks	0-1	0	Mercury is used as consumable i.e. disposed of same year as sold for the purpose
	Executive toys	5-20	5	Expert estimate

Table notes: *1 The average lifespan indicates the number of years from production/import to the products are discarded. An average lifespan of 0 years designates that the products are disposed of within one year after its production/import i.e. the quantities disposed of are calculated on the basis of production/import the same year. Likewise for mercury used as consumables, e.g. for laboratory analysis: A lifespan of 0 years designate that the mercury-containing waste is disposed of the same year as the mercury is sold for the purpose.

*2 The range represent the range on the average lifespan for the type of products and not the range of the lifespan of an individual product.

9 Annexes

9.1 Spreadsheet for facilitating calculations of mercury releases on Inventory Level 2

1515. To supplement this Toolkit, a separate Inventory Level 2 Excel spreadsheet is available electronically, intended to facilitate the calculation of inputs and outputs of the different source categories. The spreadsheet is available on-line at the UN Environment Chemicals mercury toolkit website https://www.unenvironment.org/explore-topics/chemicals-waste/what-we-do/mercury/mercury-inventory-toolkitor can be obtained by contacting UNEP Chemicals at the address given on the inside cover of this document.

1516. The Excel spreadsheet consists of a number of individual work sheets - first, a summary worksheet providing an overview of the main outputs for each category, thereafter, nine individual worksheets covering each source category.

1517. Specific instructions on how to use the spreadsheet are available with the spreadsheet itself. It is extremely important that users read the Toolkit chapters carefully before using the spreadsheet, as it is not self-explanatory and there is a clear risk of making serious mistakes, if the user does not acquaint himself/herself with the methodology used and the proposed principles and data are not read and understood carefully. Also, before working with an individual source sub-category in the spreadsheet, the Toolkit section describing the source category must be studied first.

1518. Chapter 5, which provides detailed descriptions of the various potential source categories of mercury releases, suggests default input and output factors for a number of sub-categories for use in cases where source specific data are not available. Default calculation formulas have been entered in the Excel spreadsheet for sub-categories where such default factors are suggested. Where default ranges are suggested, the maximum default factor is used in the calculation formula. As already emphasized throughout the Toolkit, well documented national or local input and output factors should always be preferred, if available. If this is the case, the input and output factors in the worksheets must be changed manually. Also, where no default factors have been suggested, users must enter the appropriate data and calculation formula applicable for the specific conditions under consideration.

1519. The primary purpose of using these default factors is to get a first impression of whether the sub-category is a significant mercury release source in the country. Usually release estimates would have to be refined further (after calculation with default factors) before any far reaching action is taken based on the release estimates.

1520. The actual spreadsheet with the individual source category worksheets is not reproduced in the Toolkit, however, for illustrative purposes Table 9-1 and Table 9-2 show two examples of individual worksheets for source categories 5.1 Extraction and use of fuels/energy sources and 5.5 Consumer products with intentional use of mercury. See the updated Inventory Level 2 spreadsheet at https://www.unenvironment.org/explore-topics/chemicals-waste/what-we-do/mercury/mercury-inventory-toolkit.

1521. When all the nine Excel worksheets for the different source categories have been filled in, a summary table is automatically generated to show the total releases from all categories. An example of a summary table is given in Table 9-3.below, taken from the ACAP Arctic Mercury Release Inventory (ACAP, 2005). Note - the table in the example has been adapted to fit Danish conditions, and is outlined slightly differently from the spreadsheet table, and the source categories are not fully identical.

Table 9-1 Example of an Excel worksheet showing input and output data for releases to different media for category 5.1 Extraction and use of fuels/energy sources.

Spreadsheet of UNEP Chemicals' Toolkit for identification and quantification of mercury releases
Read "introduction" before starting

															Enter output distribution factors (unitless)						Calculated Hg output, Kg/y						
C	Su-C	Source category /phase	Exists? (y/n/?)	Default input factor	Unit	Enter input factor	Unit	Enter activity rate	Unit	Calculat. Hg input	Unit	"Output scenario (where relevant)	Enter Hg input	Unit	Air	Water	Land	Products	General waste	Secto r specific treatment/disposal	Air	Water	Land	Products	General waste	Sector specific treatment/disposal	Remarks
5.1		**Source category: Extraction and use of fuels/energy sources**																									
	5.1.1	**Coal combustion in large power plants**	y																		**354.00**	**0.00**	**0.00**	**0.00**	**406.00**	**0.00**	
		/Coal wash	n	0.05-0.5	g Hg/t	0.5	g Hg/t		t coal/y	0	Kg Hg/y			Kg Hg/y		0.01		0.8	0.19		0.00	0.00	0.00	0.00	0.00	0.00	
		/Combustion	y	0.05-0.5 (a	g Hg/t	0.5	g Hg/t	1,520,000	t coal/y	760	Kg Hg/y (a	Emis. Red. Devices: None (a		Kg Hg/y	1						0.00	0.00	0.00	0.00	0.00	0.00	
												General ESP or PS (a		Kg Hg/y	0.9				0.1		0.00	0.00	0.00	0.00	0.00	0.00	
												FF or other high PM retention (a		Kg Hg/y	0.5				0.5		0.00	0.00	0.00	0.00	0.00	0.00	
												PM+SDA (a	260	Kg Hg/y	0.4				0.6		104.00	0.00	0.00	0.00	156.00	0.00	
												PM+wet FGD (a	500	Kg Hg/y	0.5				0.5		250.00	0.00	0.00	0.00	250.00	0.00	
	5.1.2	**Other coal use**																			**225.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	
		Coke production	n	0.05-0.5	g Hg/t	0.5	g Hg/t		t coal/y	0	Kg Hg/y				1						0.00	0.00	0.00	0.00	0.00	0.00	
		Coal combustion	y																		0.00	0.00	0.00	0.00	0.00	0.00	
		/Coal wash	n	0.05-0.5	g Hg/t	0.5	g Hg/t		t coal/y	0	Kg Hg/y					0.01		0.8	0.19		0.00	0.00	0.00	0.00	0.00	0.00	
		/Combustion	y	0.05-0.5 (a	g Hg/t	0.5	g Hg/t	450,000	t coal/y	225	Kg Hg/y (a	Emis. Red. Devices: None (a	225		1						225.00	0.00	0.00	0.00	0.00	0.00	
												General ESP or PS (a			0.9				0.1		0.00	0.00	0.00	0.00	0.00	0.00	
												FF or other high PM retention (a			0.5				0.5		0.00	0.00	0.00	0.00	0.00	0.00	
												PM+SDA (a			0.4				0.6		0.00	0.00	0.00	0.00	0.00	0.00	
												PM+wet FGD (a			0.5				0.5		0.00	0.00	0.00	0.00	0.00	0.00	
	5.1.3	**Mineral oils - extraction, refining and use**																			**335.20**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	
		/Extraction																			0.00	0.00	0.00	0.00	0.00	0.00	
		/Use of crude oil:																									
		Uses (other than combustion)	?	10 - 300	mg Hg/t	300	mg Hg/t		t oil/y	0.00	Kg Hg/y				1						0.00	0.00	0.00	0.00	0.00	0.00	
		Residential heating with no controls	?	10 - 300	mg Hg/t	300	mg Hg/t		t oil/y	0.00	Kg Hg/y				1						0.00	0.00	0.00	0.00	0.00	0.00	
		Other oil combustion facilities	y	10 - 300	mg Hg/t	300	mg Hg/t	256,000	t oil/y	76.80	Kg Hg/y	Oil Combustion Facility with no emissions controls	77		1						76.80	0.00	0.00	0.00	0.00	0.00	
												Oil Combustion Facility with PM control using an ESP or scrubber			0.9				0.1		0.00	0.00	0.00	0.00	0.00	0.00	
		/Refining	y	10 - 300	mg Hg/t	300	mg Hg/t	675,000	t oil/y	202.50	Kg Hg/y		203		1						202.50	?	?	?	?	?	Ditribution from refining is unknown. For simplicity 100% of Hg input is considered released to air.
		/Use of gasoline, diesel and other distillates:																									
		Uses (other than combustion)		1 - 100	mg Hg/t	100	mg Hg/t	325,000	t oil/y	32.50	Kg Hg/y		33		1						32.50	0.00	0.00	0.00	0.00	0.00	
		Residential heating with no controls		1 - 100	mg Hg/t	100	mg Hg/t	234,000	t oil/y	23.40	Kg Hg/y		23		1						23.40	0.00	0.00	0.00	0.00	0.00	
		Other oil combustion facilities		1 - 100	mg Hg/t	100	mg Hg/t		t oil/y	0.00	Kg Hg/y	Oil Combustion Facility with no emissions controls			1						0.00	0.00	0.00	0.00	0.00	0.00	
												Oil Combustion Facility with PM control using an ESP or scrubber			0.9				0.1		0.00	0.00	0.00	0.00	0.00	0.00	
	5.1.4	**Natural gas - extraction, refining and use**																			**2.35**	**0.00**	**0.00**	**15.72**	**0.00**	**1,556.28**	
		/Extraction/refining	y	2 - 200	µg Hg/Nm3 gas	200	µg Hg/Nm3 gas	7,860,000,000	Nm3 gas/y	1,572.000	Kg Hg/y		1,572					0.01		0.99	0.00	0.00	0.00	15.72	0.00	1,556.28	Sector specific treatment is: Hazardous waste combustion of gas condensate
		/Use of raw or pre-cleaned gas	?	2 - 200	µg Hg/Nm3 gas	200	µg Hg/Nm3 gas		Nm3 gas/y	?	Kg Hg/y				1						?	?	?	?	?	?	
		/Use of pipeline gas (consumer quality)	y	0.03 - 0.4	µg Hg/Nm3 gas	0.4	µg Hg/Nm3 gas	5,870,000,000	Nm3 gas/y	2.3	Kg Hg/y		2		1						2.35	0.00	0.00	0.00	0.00	0.00	
	5.1.5	**Other fossil fuels - extraction and use**																			**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	
		Combustion of peat	n	40 - 193 (b	mg Hg/t (dry weight)	193	mg Hg/t (dry weight)		t peat/y	0.00	Kg Hg/y				1						0.00	0.00	0.00	0.00	0.00	0.00	
		Use of oil shale	n			?	?		t oil shale/y	?	Kg Hg/y				1						0.00	0.00	0.00	0.00	0.00	0.00	
		Combustion of other fossil fuels	n												1												
	5.1.6	**Biomass fired power and heat production**	y	?	?	?	?	?	?	?	Kg Hg/y				1						**?**	**?**	**?**	**?**	**?**	**?**	
	5.1.7	**Geothermal power production**		?	?	?	?	?	?	?	Kg Hg/y				1						**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	

Notes:
(a: Important: If coal wash is aplied, the Hg input to combustion is the calculated output "Products" from coal wash. For more complicated mixes, see the relevant section in the toolkit report.
(b: Based on one data set only

Table 9-2 Example of an Excel worksheet showing input and output data for releases to different media for category 5.5 Consumer products with intentional use of mercury.

Spreadsheet of UNEP Chemicals' Toolkit for identification and quantification of mercury releases
Read "introduction" before starting

															Enter output distribution factors (unitless)					Calculated Hg output, Kg/y					
C	Su-C	Source category /phase	Exists? (y/n/?)	Default input factor	Unit	Enter input factor	Unit	Enter activity rate	Unit	Calculat. Hg input	Unit	"Output scenario"	Enter Hg input	Unit	Air	Water	Land	General waste	Secto r specific treatment/disposal	Air	Water	Land	General waste	Sector specific treatment/disposal	Remarks
5.5		**Source category: Consumer products with intentional use of mercury**																							
	5.5.1	**Thermometers with mercury**																		**20.45**	**61.34**	**0.00**	**61.34**	**61.34**	Sector specific treatment is: Recycling of mercury
		/Production (a										**/Production (a**		Kg Hg/y	0.01		0.01			0.00	0.00	0.00	0.00	0.00	
		Medical thermometers	n	0.5-1.5	g Hg/item	1.5	g Hg/item		items/y	0	Kg Hg/y			Kg Hg/y											
		Ambient air thermom.	n	2-5	g Hg/item	5	g Hg/item		items/y	0	Kg Hg/y			Kg Hg/y											
		Industrial and special th.	n	5-200	g Hg/item	200	g Hg/item		items/y	0	Kg Hg/y			Kg Hg/y											
		Other glass Hg thermometers	n	1-40	g Hg/item	40	g Hg/item		items/y	0	Kg Hg/y			Kg Hg/y											
		/Use+disposal:									Kg Hg/y	**/Use+disposal:**		Kg Hg/y											
		Medical thermometers	y	0.5-1.5	g Hg/item	1.5	g Hg/item	56,700	items/y	85	Kg Hg/y	(a1) No separate collection. Waste handl. controlled		Kg Hg/y	0.1	0.3		0.6		0.00	0.00	0.00	0.00	0.00	
		Ambient air thermom.	n	2-5	g Hg/item	5	g Hg/item		items/y	0	Kg Hg/y	(a2) No separate collection. Informal waste handl. widespread		Kg Hg/y	0.2	0.3	0.2	0.3		0.00	0.00	0.00	0.00	0.00	
		Industrial and special th.	y	5-200	g Hg/item	200	g Hg/item	567	items/y	113	Kg Hg/y	(a3) Separate collection. Waste handl. controlled	204	Kg Hg/y	0.1	0.3		0.3	0.3	20.45	61.34	0.00	61.34	61.34	Sector specific treatment is: Recycling of mercury
		Other glass Hg thermometers	y	1-40	g Hg/item	40	g Hg/item	150	items/y	6	Kg Hg/y														
	5.5.2	**Electrical switches and relays with mercury**																		**125.00**	**0.00**	**125.00**	**500.00**	**500.00**	Sector specific treatment is: Recycling of mercury
		/Production	n	?		?						**/Production**			?	?	?	?	?	0.00	0.00	0.00	0.00	0.00	
		/Use+disposal:	y	0.02-0.25	g Hg/(y*inhabitant)	0.25	g Hg/(y*inhabitant)	5,000,000	Inhabitants	1,250	Kg Hg/y	**/Use+disposal:**													
												(a1) No separate collection. Waste handl. controlled			0.1		0.1	0.8		0.00	0.00	0.00	0.00	0.00	
												(a2) No separate collection. Informal waste handl. widespread			0.3		0.4	0.3		0.00	0.00	0.00	0.00	0.00	
												(a3) Separate collection. Waste handl. controlled	1,250		0.1		0.1	0.4	0.4	125.00	0.00	125.00	500.00	500.00	Sector specific treatment is: Recycling of mercury
	5.5.3	**Light sources with mercury**																		**2.86**	**0.00**	**0.00**	**45.76**	**8.58**	Sector specific treatment is: Recycling of mercury
		/Production	n	?		?					Kg Hg/y	**/Production**			?	?	?	?	?	?	?	?	?	?	
		/Use+disposal:	y								Kg Hg/y	**/Use+disposal:**													
		Fluorescent tubes (double end)		10 - 40	mg Hg/item	40	mg Hg/item	1,200,000	items/y	48	Kg Hg/y	(a1) No separate collection. Waste handl. controlled			0.05			0.95		0.00	0.00	0.00	0.00	0.00	
		Compact fluorescent lamp (CFL single end)		5 - 15	mg Hg/item	15	mg Hg/item	500,000	items/y	7.5	Kg Hg/y	(a2) No separate collection. Informal waste handl. widespread			0.3		0.3	0.4		0.00	0.00	0.00	0.00	0.00	
		High pressure mercury vapour		30	mg Hg/item	30	mg Hg/item	10,000	items/y	0.3	Kg Hg/y	(a3) Separate collection. Waste handl. controlled	57		0.05			0.8	0.15	2.86	0.00	0.00	45.76	8.58	
		High-pressure sodium lamps		10 - 30	mg Hg/item	30	mg Hg/item	30,000	items/y	0.9	Kg Hg/y														
		UV light for tanning		5 - 25	mg Hg/item	25	mg Hg/item	10,000	items/y	0.3	Kg Hg/y														
		Metal halide lamps		25	mg Hg/item	25	mg Hg/item	10,000	items/y	0.3	Kg Hg/y														
	5.5.4	**Batteries with mercury**																		**0.00**	**0.00**			**0.00**	
		/Production (a	n									**/Production (a**		Kg Hg/y	0.005	0.005	?	?	0.01	0.00	0.00			0.00	
		Mercury oxide (all sizes); also called mercury-zinc cells		320	kg Hg/t batteries	320	kg Hg/t batteries		t bat/y	0	Kg Hg/y														
		Zinc-air button cells		12	kg Hg/t batteries	12	kg Hg/t batteries		t bat/y	0	Kg Hg/y														
		Alkaline button cells		5	kg Hg/t batteries	5	kg Hg/t batteries		t bat/y	0	Kg Hg/y														
		Silver oxide button cells		4	kg Hg/t batteries	4	kg Hg/t batteries		t bat/y	0	Kg Hg/y														
		Alkaline, other than button cell shapes		0.25	kg Hg/t batteries	0.25	kg Hg/t batteries		t bat/y	0	Kg Hg/y														

Notes: **(a: Note that output distribution factors should not sum up to 1 for this source or phase.**

Table 9-3 Reported mercury inputs and outputs to all media in Denmark, 2001; metric tons mercury/year. For details on estimation and uncertainties, see the questionnaire response in the appendix of the referenced document (ACAP, 2005).

	New inputs to biosphere:		**Reported releases/outputs to (means of ranges):**								
Means and sums are rounded	Range	Mean	Air	Water	Soil	Municipal waste	Haz /Med waste	Sector waste deposit *1	Waste water system	By-products	**Sum, rep. releases (means)**
Mobilisation of mercury impurities											
Large coal combustion plants	0.6-1	0.8	0.3	0	0	0	0	0.1	0	0.3	**0.7**
Other coal combustion and use		0	0	0	0	0	0	0	0	0	**0**
Extraction and use of oil, gas and biofuels	0.06-0.33	0.2	0.06	0.06	0.003	0.006	0	0.01	0.002	0	**0.1**
Cement production	0.1-0.3	0.2	0.1	0	0	0	0	0.03	0	0.09	**0.2**
Other primary extraction and processing of materials	0.011-0.04	0.03	0	0	0.03	0	0	0	0	0	**0.03**
Sub-sum, mobilisation of mercury impurities		**1.2**	**0.4**	**0.06**	**0.03**	**0.006**	**0**	**0.2**	**0.002**	**0.4**	**1.1**
Intentional mercury use											
Dental amalgam fillings	1.1-1.3	1.2	0.2	0	0.07	0.1	1.2	0	0.2	NR	**1.8**
Batteries	0.07-0.15	0.1	0	0	0	0.4	0.4	0	0	NR	**0.8**
Thermometers	0.016-0.024	0.02	0	0	0	0.03	0.1	0	0.03	NR	**0.2**
Manometers, blood pressure gauges and education	0.013-0.049	0.03	0.04	0	0	0.04	0.3	0	0.04	NR	**0.4**
Switches, relays and contacts	0-0.024	0.01	0	0	0	0.2	1.1	0	0	NR	**1.3**
Light sources	0.06-0.17	0.1	0.005	0	0	0.07	0.07	0	0	NR	**0.1**
Other products and processes	0.135-2.021	1.1	0	0	0	0.4	0.05	0.03	0.01	NR	**0.5**
Sub-sum, intentional mercury use		**2.6**	**0.2**	**0**	**0.07**	**1.3**	**3.2**	**0.03**	**0.2**	**0**	**5.1**
Waste treatment and waste water systems											
Incineration of general/municipal waste	NR	NR	0.6	0	0	0	0	2.5	0	NR	**3.1**
Incineration of hazardous/medical waste	NR	NR	0.008	0.001	0	0	NR	0	0	NR	**0.009**
Landfills/deposits *3	NR	NR	NA	0	0	0.08	0	2.8	0.003	NR	**2.9**
Waste water systems	NR	NR	0.04	0.2	0.08	0	0	0.06	NR	NR	**0.4**
Recycling of other materials	NR	NR	0.04	0	0.04	0.005	0	0.2	0	0.9	**1.2**
Other waste treatment	NR	NR	0	0	0	0	0	0	0	0	**0**
Sub-sum, waste treatment and waste water systems *2			**0.71**	**0.20**	**0.12**	**0.085**	**0.0**	**5.5**	**0.003**	**0.9**	

Notes:

*1: Sector specific waste deposits, is an "other controlled deposition" category, including for example special deposits for coal combustion residues in some countries and industry's own deposits (subject to authorities control).

*2: Note that doubling counting can not be ruled out in overall sums for waste treatment - depends on national practices and how data were reported in questionnaire responses. Therefore, these sums were not included in the table.

*3: The output figures from landfills/deposits to municipal waste and hazardous/medical waste describe the distribution on these two deposit types, and not mercury being physically moved from deposits to municipal or hazardous wastes.

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