Users' Manual

Training package for mercury flow analysis to identify and monitor national mercury situation in its entire life cycle

Ver. 1.1

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UN environment programme

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Institute for Training and Research

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EXECUTIVE SUMMARY

Mercury is a chemical element that has existed on Earth since its creation. Mercury is released from natural sources by processes, such as volcanic activity and permafrost melting. In recent years, more mercury has been released through human activities, such as the combustion of fuels, mining activities, and the consumption of mercury-added products. Once emitted to the atmosphere, mercury remains for a long time, and will be transported long distances. Atmospheric mercury is eventually oxidized, and then deposited in the ocean or on land.

Growing concerns for mercury risks have resulted in the adoption and entry into force of the Minamata Convention on Mercury (the Convention). The Parties to the Convention are obliged to inform the Conference of the Parties about the national situation and implementation. For the effective implementation of the Convention, it is crucial to identify the priority areas from available data concerning the status of trade, use, emission/release and disposal of mercury at the national level and to interpret them into domestic policy.

The 'Training package for mercury flow analysis to identify and monitor national mercury situation in its entire life cycle' addresses the economic activities, such as mercury trade, production, use (sales), and manufacturing, as well as emissions and releases to the environment. It introduces a comprehensive mass flow concept to outline the national mercury situation throughout its life cycle. It supports the improvement of national mercury inventories by compiling various types of information. UNEP has developed the Mercury Inventory Toolkit levels 1 and 2, which have been used by many countries and stakeholders for developing their emission/release inventories.

The training package is composed of multimedia files, i.e., videos, which provide substantive information when organizing a training programme. The video material is prepared using Microsoft PowerPoint with pre-recorded narration embedded in each slide and then grouped by deck in each topic/subject. This Users' Manual provides a sample course with full scope that uses the materials in one consistent programme, but the training package does not need to be used in full. The organizer can prepare the 'custom-made' slide decks for its own training programme. The following video lectures are annexed to the Users' Manual:

- The Minamata Convention on Mercury
- Mercury issues and how mercury flow analysis can contribute
- Mercury source categories
- Mass balance principle and examples on process, sectoral and societal level
- Steps in mercury mass flow development

The main body of the training package covers the specific skills in step-by-step guides for developing and improving mercury mass flow analyses and the inventories. It also provides general knowledge on mercury science and its regulatory framework as a foundation and for better understanding of the issues by the audiences who acquires specific skills through this material. However, it is not designed to fit all occasions universally. Therefore, when designing a training programme, the organizer should firstly develop a conceptual idea for a capacity strengthening activity and consider if any part of this material can benefit the purpose of the activity.

This material provides practical and hands-on information to enable self-study to address needs in an online setting, even under travel restrictions such as during the COVID-19 pandemic. Scientists and practitioners of mercury management at national level is the primary target audiences for this material. It can also be used by lecturers or trainers as teaching material as it has been developed with customizable multimedia files to fit to their teaching syllabus.

The training programme can be organized in face-to-face, online, or hybrid settings. In each case, the facilitator(s) will run the programme and guide the audiences/participants to certain direction. Online programmes are an emerging training style which has rapidly developed and expanded in the past few years. New online platforms and applications have been introduced and become more versatile. However, this approach has some limitations for developing mercury mass flow in group settings. The advantages and limitations of online and face-to-face settings are described in this material.

1 BACKGROUND

1.1 Global mercury issues

Mercury is a chemical element that has existed on Earth since its creation. Mercury is released from natural sources by processes, such as volcanic activity and permafrost melting. In recent years, more mercury has been released through human activities, such as the combustion of fuels, mining activities, and the consumption of mercury-added products.

Once emitted to the atmosphere, mercury remains for a long time, and will be transported long distances. Atmospheric mercury is gradually oxidized, and deposited in the ocean or on land. As mercury levels in the air, ocean and soil are in equilibrium, more legacy mercury is re-emitted to the atmosphere. Some inorganic mercury in water bodies can be methylated by microbial activity, and bioaccumulated in biota at higher trophic levels. Eventually, fishing brings mercury back to human society through consumption. Excessive exposure to mercury, especially methylmercury, will pose risks to vulnerable population, particularly pregnant women, as methylmercury actively passes through placenta barrier by amino acid transporter to fetus.

Due to its environmental behaviours and anthropogenic emissions and releases, growing concerns about mercury risks have resulted in the adoption and entry into force of the Minamata Convention on Mercury (the Convention). It is one of the newest multilateral environmental agreements aiming at protecting human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds.

In October 2013, the Diplomatic Conference on the Convention was convened in Kumamoto City in Japan, with a ceremonial opening in Minamata City, to formally adopt the Convention and open it for signature. It entered into force in August 2017 and the Parties to the Convention must abide by the provisions stipulated in the Convention text.

1.2 Context of this training package

For the effective implementation of the Convention, it is crucial to identify the priority areas from available data concerning the status of trade, use, emission/release and disposal of mercury at the national level and to interpret them into domestic policy. The Convention has specific provisions on the identification of individual stocks of mercury and the development of inventories of mercury emissions and releases. The Convention also obliges the Parties to report to the Conference of the

Parties (COP) on the measures taken to implement the Convention. Moreover, the Convention requires the Parties to cooperate to develop and improve inventories of use, consumption, emissions, and releases of mercury. The training package introduces a comprehensive mass flow concept to outline the national mercury situation throughout its life cycle. It supports the improvement of national mercury inventories by compiling various types of information.

UNEP has developed the Mercury Inventory Toolkit levels 1 and 2, which have been used by many countries and stakeholders for developing their emission/release inventories. Most of the Minamata Initial Assessment (MIA) reports use the UNEP Toolkit level 2 although the full application of level 2 is not always possible due to the data limitations. This training package provides guidance on how to conduct country-specific data collection surveys to improve the accuracy of estimations.

Furthermore, this training package addresses the entire life cycle of mercury flow in society. The significant difference from the UNEP Toolkit includes economic activities such as mercury trade, production, use (sales), and manufacturing, as well as emissions and releases to the environment. National mercury policies and plans will cover not only environmental conservation but also the restrictions of mercury mining, export and import, manufacturing of mercury-added products, phase out of mercury-using processes, and environmentally sound interim storage. Those areas are not captured in the current UNEP Toolkit.

Mercury flow analysis is an extended scope of the mercury inventories, or the inventories are a subset of mercury flow analysis, whichever comes first. The results of mercury inventories that already exist will be an important feedstock to analyse mercury flow, which can eventually improve the quality of the inventory data itself by triangulation and cross-checking of different data.

1.3 Development of this training package

UNEP Regional Office for Asia and the Pacific (ROAP) is implementing a Japan-funded project called "Project for promoting the Minamata Convention on Mercury by making the most of Japan's knowledge and experiences[1]" to support its member states, regardless of the ratification status, for the implementation of the Convention.

[1] The Project specifically focuses on the areas of information exchange (Article 17), awareness and education (Article 18), and research, development and monitoring (Article 19) to contribute the early implementation of the Convention. The comprehensive programme is designed to strengthening the enabling capacity, building on the resources in and around Minamata, and employing technologies held by institutions in Japan.

Most of the presentation materials were developed along with the online training programmes of the project between December 2020 and February 2022. They are primarily developed to support the project partner countries in Asia and the Pacific, but the content can be applied universally beyond the geographical regions and sectors. Building on these materials, the training package can be reconfigured to be relevant to more generic needs so that it can be distributed and made available globally.

The training package is composed of multimedia files, i.e., videos, which provide substantive information when organizing a training programme. The video material is prepared using Microsoft PowerPoint with pre-recorded narration embedded in each slide, then grouped by deck in each topic/subject. All contents were compiled in the form of 'Users' manual', which includes not only the presentation videos but also sample training course, pre- and post-training self-test and evaluations, and the background information. This training package enables users to customize their own training programmes by selecting, adding, or modifying the contents. It can easily integrate any additional cross-cutting issues such as gender and human rights available in the reference literature section.

2 Introduction

2.1 Purpose

This document is intended to support the Parties and stakeholders in developing mercury inventories and using them for planning, implementing, and evaluating measures to reduce the environmental and health risks of mercury, based on a mass-balance approach.

The Minamata Convention includes a number of specific measures related to mercury inventories. Firstly, Article 3 provides for the control of supply and trade of mercury, which includes the identification of stocks of mercury and sources of mercury generating such stocks. The Conference of the Parties (COP) adopted guidance on the identification of such stocks and sources.

Secondly, Article 7 provides for national action plans on artisanal and small-scale gold mining (ASGM), which should include the baseline estimates of the amounts of mercury used in such mining.

Thirdly, Articles 8 and 9 requires Parties to establish and maintain inventories of mercury emissions and releases from relevant sources. It should be noted that the emission inventories pursuant to Article 8 only covers point sources listed in Annex D of the Convention, and the releases inventories pursuant to Article 9 only cover relevant point sources as identified by the Parties. The COP adopted guidance on the development of these inventories.

Fourthly, Article 19 provides for cooperation among the Parties on research, development and monitoring, and the inventories of use, consumption, emissions and releases of mercury, as well as information on commerce and trade in mercury, are mentioned as specific areas for research and development.

This document is expected to support the Parties in developing and maintaining inventories as stipulated in the articles above, as well as in planning, implementing, and evaluating the Convention implementation measures not related to specific obligations to develop inventories. The document will also support governments, industry, and other organizations in contributing to the development and use of such inventories. The existing guidance developed under the Convention, as mentioned above, has been fully taken into account in the development of this document, so that the inventories developed using this document can be used to fulfil the specific obligations on inventory.

This material provides practical and hands-on information with multimedia files (video) to enable their self-study to address their needs in online setting even under the travel restrictions such as COVID-19 pandemic. Scientists and practitioners of mercury management at the national level are the primary target audiences for this material. It can also be used by lecturers or trainers as their teaching material as it is developed with customizable multimedia files to fit to their teaching syllabus.

2.2 Limitation

Mercury issues are diverse and the needs at each occasion of different countries are significantly diverse. This training package provides knowledge and skills at an intermediate level within a relatively limited time frame. For further advancement, additional capacity strengthening programmes should be organized to address specific knowledge and skills which are beyond the scope of this training package.

In addition, this training will not completely replace the face-to-face or hands-on training, which can provide more comprehensive and intensive capacity strengthening opportunities. This material will sufficiently cover the flow analysis techniques from introductory to medium levels.

3 TRAINERS' GUIDANCE

3.1 Course design

The needs of capacity strengthening are diverse. Numerous activities have been developed and implemented by many organizations and individuals. Before developing a training programme, it is essential to recognize its purpose and logical relations with the problem that the training programme intends to address. The objective, or desired outcome, is the most important motives for developing a training programme. The needs of the audiences are another important aspect that should be appropriately assessed or set as the first step of the programme development. If the audiences are the internal staff of an organization, the capacity strengthening needs will align with its short- or long-term strategy and should be systematically addressed. It is recommendable to develop a concept note that outlines the background, objective, and key arrangement. The concept note will be shared among stakeholders and discussed when elaborating the training course in detail.

The 'Training package for mercury flow analysis to identify and monitor national mercury situation in its entire life cycle' can serve as substantive input to the activities either partially or entirely. The training package includes the basic concept of mercury mass flow and an initial exercise to familiarise with the principles as a basis for developing more comprehensive mass flow.

This material is configured with lectures and supplemental materials on general knowledge and specific skills (Table 1). The main body of the training package covers the specific skills in step-by-step guides for developing and improving mercury mass flow analyses and the inventories. It also provides general knowledge on mercury science and its regulatory framework as a foundation and for better understanding of the issues by the audiences who acquires specific skills through this material. However, it is not designed to fit all occasions universally. Therefore, when designing a training programme, the organizer should firstly develop conceptual idea for a capacity strengthening activity and consider if any part of this material can benefit the purpose of the activity. It is particularly the case for the cross-cutting topics such as gender and human rights, which could be underlined throughout the programme concept. Key reference literatures are developed by Strategic Approach to International Chemicals Management (2017), UNEP (2016), and UNEP and Minamata Convention (2021), available online. They will provide the fundamental concept of the human-environment interactions in line with the principle of 'leaving no one behind.'.

Table 1 Areas covered by the training package

General knowledge	Specific skill
Science and technology: - Physical and chemical properties, usage, and environmental behaviour	Mass flow principle: - How mercury inventories and mercury mass flows can contribute - Mercury source categories - Mass balance principle and examples on process, sectoral and societal level.
Regulatory framework: - The Minamata Convention - Harmonized trade customs codes	Steps to develop mercury mass flow: - Sector definitions, identifying individual flows, quantification of flows - Quantification of stocks, collection of supplementary data, working with intervals, available online tools and resources - Closing and calibrating the mass balance, identifying and reducing uncertainties, reporting and review

This Users' manual provides a sample course with full scope that uses the materials in one consistent programme, but the training package does not need to be used in full. The organizer can prepare the 'custom-made' slide decks from the editable PowerPoint slides of this manual with pre-recorded narration, to fit for its own training programme.

It is recommendable to appoint facilitator(s) to run the sessions of the training programme. The facilitator is not necessarily an expert in mercury flow analysis as the technical details are provided by the videos in this training package. Nevertheless, it is recommended that (s)he has sufficient understanding of the context and purpose of the organizing programme.

Face-to-face or online

The training programme can be organized in face-to-face, online, or hybrid settings. In each case, the facilitator(s) will run the programme and guide the audiences/participants to a certain direction. Online programmes are an emerging training style which has rapidly developed and expanded in the past few years. New online platforms and applications have been introduced and become more versatile. However, this approach has some limitation for developing mercury mass flow in group settings. The advantages and limitations of online and face-to-face settings are described in Table 2.

Table 2 Advantages and limitations of online and face-to-face programmes

Online programme	Face-to-face programme
Logistical arrangements: - Travel arrangements are not required, travel costs are saved. - More people can participate in the programme.	Logistical arrangements: - In the case of local training, most participants live nearby and easily come together. - Field tour, courtesy visit, or other field activities can improve/broaden the understanding of the issue.
Time management: - Programme date is flexible. Easy to formulate a series of programmes with certain intervals. (e.g., split into two parts and insert intersessional exercise.) - Time zone differences should be considered carefully.	Time management: - Full day programmes are possible to intensify the programme with a shorter duration. - More 'active' participation is expected rather than silent listeners.
Facility: - Internet connectivity of each participant might be different. Connection cost might be high in some countries. - Applications for online platform such as Webex or Zoom should be installed in computers or other communication devices. The available functions vary in different set up.	Facility: - Meeting venue must be secured for the training programme. - Demonstrations of instruments may require dedicated site, room, or facility.
Communications: - Difficult to separate from daily work as the participants are physically sitting at their working places.	Communications: - Interactive communication is facilitated. Teambuilding exercised are effective.
Recording and reporting: - Due to the virtual nature, confirmation of the attendance of the participants is challenging.	Recording and reporting: - Photos and products of the training programmes are more appealing in the activity report.

Multi-country or one country

If the participants of the training programme come from multiple countries or regions, time zone difference should be carefully considered. The time zone table indicates the time differences of major cities and possible time setting to cover large geographic areas. Programmes covering a wide geographical area are efficient to train many participants at once, but time allocation is smaller as participants staying up to midnight or getting up before dawn may not be well prepared. The time zone table guides the online programme organizers in finding appropriate time arrangement depending on the geographical coverage of the planned programmes. Unless essential, inviting participant from across the entire globe should be avoided. Two out of three time zones, i.e., Africa, Asia and America could be targeted at most. Table 3 indicates possible time slot arrangements in such extreme cases. If the geographical coverage or time difference is smaller, more available time allocation can be found, which is more comfortable for the participants.

Table 3 Time zone table when organizing multi-country training

Location	Africa - Asia	Asia - America	America - Africa
Suva (UTC+12)	7pm – 10pm	1pm – 4pm	4am – 7am
Tokyo, Koror (UTC+9)	4pm – 7pm	10am – 1pm	1am – 4am
Manila, Kuala Lumpur, Ulaanbaatar (UTC+8)	3pm – 6pm	9am – noon	0am – 3am
Bangkok, Jakarta, Hanoi (UTC+7)	2pm – 5pm	8am – 11am	11pm – 2am
Yangon (UTC+6:30)	1:30pm – 4:30pm	7:30am – 10:30am	10:30pm – 1:30am
Kathmandu (UTC+5:45)	12:45pm – 3:45pm	6:45am – 9:45am	9:45pm – 0:45am
New Delhi, Colombo (UTC+530)	12:30pm – 3:30pm	6:30am – 9:30am	9:30pm – 0:30am
Male (UTC+5)	Noon – 3pm	6am – 9am	9pm – 0am
Nairobi (UTC+3)	10am – 1pm	4am – 7am	7pm – 10pm
Cape Town (UTC+2)	9am – noon	3am – 6am	6pm – 9pm
Vienna, Geneva (UTC+1)	8am – 11am	2am – 5am	5pm – 8pm
Sao Paulo (UTC-3)	4am – 7am	10pm – 1am	1pm – 4pm
Washington DC (UTC-5)	2am – 5am	8pm – 11pm	11am – 2pm
Chicago (UTC-6)	1am – 4am	7pm – 10pm	10am – 1pm
Los Angeles (UTC-8)	11pm – 2am	5pm – 8pm	8am – 11am
Honolulu (UTC-10)	9pm – 0am	3pm – 6pm	6am – 9am

The advantage of a one country programme is the use of a local language that significantly enhances the understanding of the participants. Although this training package has been developed in English only, all the scripts of the pre-recorded narration are available as texts, which can be easily translated into local languages. The most technical part of the programme, which is usually delivered by international experts who travel to the programme country, is covered by this training package. The organizers, thus, do not have to find and invite such experts to provide lectures.

Invitation or call for participation

Unless the training is planned for internal staff only, e.g., staff training, an invitation or call will be developed and distributed to the relevant parties. A one-page flyer or concept note is useful and effective for attracting the attentions of target populations. There are a variety of methods to register the participants. One example is provided for reference.

Assessment and evaluation

If a training programme is developed as a part of the project activity, the results monitoring is often required. Questionnaire surveys are commonly used for self-assessment on many occasions. Assuming that the programme organizers are not the experts on the issue, this training package provides a sample questionnaire that can serve as pre- and post-training assessment for the participants.

3.2 Sample concept note

Background and Objectives

The Minamata Convention on Mercury (the Convention) is one of the newest multilateral environmental agreements aiming at protecting human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds. In October 2013, the Convention was formally adopted and opened for signature at a Diplomatic Conference on the Convention convened in Kumamoto, with a ceremonial opening held in Minamata City in Japan.

The Convention entered into force in August 2017 and the Parties to the Convention must abide by the provisions stipulated in the Convention text. The Convention has specific provisions on the identification of individual stocks of mercury and the development of inventories of mercury emissions and releases. The Convention also obliges the Parties to report to the Conference of the Parties (COP) on the measures taken to implement the Convention. Moreover, the Convention requires the Parties to cooperate to develop and improve inventories of use, consumption, emissions, and releases of mercury.

The project implemented by [Name of institution] supports participating countries to improve their national mercury-related information base to implement mercury management, especially in the areas of information exchange, awareness and education, research development and monitoring.

The Purpose of this training programme is to support the improvement of national mercury inventories by compiling various types of information. It also introduces a comprehensive mass flow concept to outline the national mercury situation throughout its life cycle.

Participation details

Date: 01, 02, 03 and 04 July 202X

Venue: Virtual meeting, Webex.

Project title: [Title of project, if any]

Training title: Developing and updating mercury mass flow and inventories

Participants: Ministries/agencies responsible for monitoring/management of mercury emissions and releases to air, water and soil. Universities, research institutes or consulting companies that are engaged in development of mercury inventories. The National Focal Points of the Minamata Convention.

Arrangement: The training programme is composed of 4 sessions in 4 days. Participants will form groups to initiate the development and improvement of mercury mass flow and inventories. The results of the group exercise are presented in the final session. Pre- and post-training questionnaire surveys using an online form will be requested to the participants.

Language: English only (no interpretation provided)

3.3 Sample training course

This is a sample training course that is expected to extend basic knowledge on mercury issues and provide the first opportunities to the participants who have some but limited understanding on mercury inventories. There are many other possible variations and shorter trainings with more focused topics for specific audiences. (The Lecture and Section numbers below refer to the PowerPoint slides of the presentation material in Chapter 5)

Configuration

The training course is opened by the organizer with welcome remarks and the expectations of the programme towards achieving the expected impact. The programme is divided into four sessions, in which the following topics are addressed:

- Session 1: Mercury issues and source categories
- Session 2: Principles and practices
- Session 3: Stepwise discovery of mercury mass flows
- Session 4: Initial mass balance setup

Session 1 explains an overviews of mercury issues and the outlines of the Minamata Convention. Additionally, the role of mass flow is explained in this session. Three lectures and one exercise are programmed in this session.

- Lecture: Mercury issues and the Minamata Convention (compilation of Lecture 2 Sections 1-2, and Lecture 1 Section 1)
- Lecture: Role of mercury inventories and flow analysis (compilation of Lecture 2 Section 3, Lecture 5 Part I Section 2, and Lecture 2 Sections 4-6)
- Lecture: Mercury source categories (Lecture 3 Sections 1-5)

Based on the lectures provided, the participants initiate the identification of mercury source types and anticipated data availability in their countries. The instructions for the exercise 1 (Chapter 3.4) are given to the participants and the results are presented in front of the other participants.

Session 2 provides the scientific background of flow analysis. The mass balance principle, quantification, predictions, implications and other techniques are presented.

- Lecture: Mass balance principle (Lecture 4 Sections 1-6)

Session 3 is the most practical part of the programme that provides all the necessary steps to develop a mercury mass flow. The lectures are split into three parts, followed by the second exercise, which is the first opportunities for the participants to experience the process to develop a mercury mass flow.

- Lecture: Steps in mercury mass flow development Part I (Lecture 5 Part I Sections 1-4)

- Lecture: Steps in mercury mass flow development Part II (Lecture 5 Part II Sections 1-5)
- Lecture: Steps in mercury mass flow development Part III (Lecture 5 Part III Sections 1-2)

After the lectures, participants work for the identification and quantification flows. The instructions for the exercise 2 (Chapter 3.4) are given to the participants. The exercise could be improved and expanded using national mercury inventories and mass flows.

Session 4 is the final part of the programme. The participants present their progress on the assigned exercise and feedback is given. The products are the first progress document towards the development of actual mass flows in their countries. Follow-up actions after the training programme are also discussed.

Although the sample course does not provide in-depth discussions on cross-cutting issues on gender and human rights, some reference materials are provided to help the participants understand the importance of this dimension and how it can lead to policy interventions. Adopting an integrated approach on interconnected issues is crucial towards effective policy measures[2].

Programme agenda

Day 1

Opening session		
00:00-00:05 (5min)	**Get started** – technical set-up, connectivity test, housekeeping	
00:05-00:15 (10min)	**Opening remarks**	Organizer
Session 1: Mercury issues and source categories		
00:15-00:25 (10min)	**Introduction** Objectives, expected outcomes, and schedule	Organizer
00:25-00:40 (15min)	**Lecture: Mercury issues and the Minamata Convention** Mercury problem - needs for global actions, the Minamata Convention on Mercury	Video (14’03”)
00:40-01:20 (40min)	**Lecture: Role of mercury inventories and flow analysis** How mercury inventories and flow analysis can contribute	Video (28’38”)
01:20-01:35 (15min)	**Q&A and discussion**	
01:35-01:45 (10min)	**Break**	
01:45-02:10 (25min)	**Lecture: Mercury source categories**	Video (19’31”)

[2] This is in line with the Minamata Convention on Mercury which notes the Parties’ awareness of ‘health concerns, especially in developing countries, resulting from exposure to mercury of vulnerable populations, especially women, children, and, through them, future generations.’ In addition to the health aspects, the Convention further promotes the consideration for the needs of vulnerable populations in health aspects, public information, awareness and education (Article 18), in research, development and monitoring (Article 19), and in effectiveness evaluation (Article 22), are key priorities to be taken forward.

	Raw minerals and fuels, industrial processes, mercury-added products, mercury waste	
02:10-02:25 (15min)	**Q&A and discussion**	
02:25-02:55 (30min)	**Exercise 1** Identifying mercury source types and anticipated data availability	Facilitator
02:55-03:00 (5min)	**Wrap up** Key points of the day.	Organizer

Day 2

Session 1 (continued)		
00:00-00:05 (5min)	**Get started** – technical set-up, connectivity test, housekeeping.	
00:05-00:45 (40min)	**Report back 1** Results of Exercise 1	Facilitator
Session 2: Principles and practice		
00:45-00:55 (10min)	**Introduction** Introduction of Session 2.	Organizer
00:55-01:35 (40min)	**Lecture: Mass balance principle** Mass balance principle and examples on the process, sectoral and societal levels.	Video (25'59")
01:35-01:45 (15min)	**Q&A and discussion**	
01:45-01:55 (10min)	**Break**	
Session 3: Stepwise discovering of mercury mass flows		
01:45-02:05 (10min)	**Introduction** Introduction of Session 3.	Organizer
02:05-02:40 (35min)	**Lecture: Steps in mercury mass flow development** Part I: Sector definitions, identifying individual flows, quantification of flows.	Video (21'49")
02:40-02:55 (15min)	**Q&A and discussion**	
02:55-03:00 (5min)	**Wrap up** Key points of the day	Organizer

Day 3

Session 3 (continued)		
00:00-00:05 (5min)	**Get started** – technical set-up, connectivity test, housekeeping.	
00:05-00.45 (40min)	**Lecture: Steps in mercury mass flow development (continued)** Part II: Quantification of stocks, collection of supplementary data, working with intervals, available online tools and resources.	Video (29'25")
00:45-01:00 (15min)	**Q&A and discussion**	
01:00-01:10 (10min)	**Lecture: Steps in mercury mass flow development (continued)** Part III: Closing and calibrating the mass balance, identifying and reducing uncertainties, reporting and review.	Video (07'31")

01:10-01:25 (15min)	**Q&A and discussion**	
01:25-01:35 (10min)	**Break**	
01:35-02:55 (80min)	**Exercise 2** Identifying and quantifying flows. Improving and expanding the national mercury inventories and mass flow. Introduction, planning and starting improvements.	Facilitator
02:55-03:00 (5min)	**Wrap up** Key points of the day.	Organizer

Day 4

Session 4: Initial mass balance setup		
00:00-00:05 (5min)	**Get started** – technical set-up, connectivity test, housekeeping.	
00:05-00:15 (10min)	**Introduction** Introduction of Session 4	Organizer
00:15-01:10 (55min)	**Exercise 2 (continued)** Preparation of presentations	Facilitator
01:10-01:40 (30min)	**Final presentation for Exercise 2** Presentations of the initial mass balance setup and plans for future work on mercury in the countries including Q&A and discussion.	Facilitator
01:40-01:50 (10min)	**Break**	
01:50-02:20 (30min)	**Final presentation for Exercise 2 (continued)**	Facilitator
02:20-02:50 (30min)	**Discussions** Advancing mercury mass flow and inventory development	Facilitator
02:50-03:00 (10min)	**Wrap up and closing** Way forward.	Organizer

3.4 Group exercises

The group exercises include training that aims to inspire and help the participants to get their mercury mass flow development started. The following two group exercise sessions are suggested:

- Exercise 1: Identifying mercury source types and anticipated data availability
- Exercise 2: Identifying and quantifying flows. Improving and expanding the national mercury inventories and mass flow. Introduction, planning and starting improvements.

Exercise 1

The aim of group exercise 1 is to identify the mercury emission and release sources present in the country and also to identify some potential data sources. The exercise should be conducted after Lecture 3 which presents the mercury source categories. It is a preliminary discussion among the group members, based on their background knowledge and any easily available literature. If the country has already conducted a mercury inventory using the UNEP Mercury Inventory Toolkit methodology, this can be used as a basis for the discussion. If the groups to be trained include people who have taken part in the inventory development, they can lead the discussion. Other participants will benefit from the discussion, but may also add to the discussion, should they have particular insights into some of the mercury source categories (for example representatives from mercury source sectors or academia).

Before the group work, the groups should be introduced to the mercury source list overview file (Annex A) in which each group shall enter:

- Their preliminary knowledge of mercury source sub-categories presented in their country. In case of doubts, the sub-category should be marked with a question mark to highlight the needs for further investigation.
- Their suggestions for data sources; preferably by full title or reference, otherwise in a descriptive manner, which will help the inventory team identify the specific data sources.

It is advised that the participants are pre-assigned to groups, ideally with inventory team members, sector representatives, government officials, or academia. distributed evenly among the groups. Also, the groups should be asked to identify a group lead and a group rapporteur in advance of the group work, from participants willing to be group leads and group rapporteurs, as having these roles will involve some additional work. These group leads can ideally continue their roles throughout all group work sessions.

The completed data files shall be submitted to the inventory team for follow up. In the report back session, the group rapporteurs shall briefly present to the plenary the group's work, focusing on key findings, as well as any questions or challenges that were observed in the exercise. It is not the intention that the groups run through every mercury source sub-category in detail at the report back session.

Exercise 2

The aim of group exercise 2 is to identify and visualise mercury flows present in the country, and then to populate the visualisation with quantities for each flow, and to identify remaining data gaps as much as possible.

The task is to indicate all the flows of mercury in its life cycle in the country. This will include imports, exports, emissions, consumption, releases and flows between different life cycle steps (=sectors), as well as the relevant waste treatment and any recycling sectors present in the country. Note that some source sub-categories pertain to not only mercury-added products and mercury-using industrial processes, but also sources which mobilise mercury through the use of raw minerals and fuels with trace mercury concentrations. Examples of the latter are coal combustion, cement production and non-ferrous metal extraction.

In case the workshop is held in person, the visualisation of flows can be done on a physical whiteboard. This has the advantage of a potentially higher interaction among participants. Periodically taking photos is beneficial to document the flow development. Alternatively, if a data viewer is present, it can be chosen to make the visualization in a virtual whiteboard. This has the advantage that the resulting digital visualization can easily be integrated in the project reporting.

If the flow visualisation is conducted on an online whiteboard, which may be new to some participants, careful instruction would be needed on how to indicate mercury source categories (sectors/processes), flow arrows, flow tonnages and comments in the platform.

Due to the unavailability of information, the results of the group exercise 2 cannot be expected to be final. Substantial supplementary data collection may be needed, and if applicable, intersessional work on flow quantification can be an advantage. The group exercise 2 can be considered as a starting point of the quantification work, to be followed up and completed later. Consequently, the group exercise 2 can also include group discussions of strategies for filling data gaps and involving more stakeholders.

In the final group presentations, the group rapporteurs are invited to present to the plenary the status of their mercury flow development, the results of their discussions of follow-up activities, and any key successes and challenges encountered.

3.5 Pre- and post-training self-test and evaluations

It is important to collect information from the training participants to ensure the participation of target audiences and to assess the effectiveness of the programme. It should be disaggregated by gender and age range when a questionnaire is analysed.

Full-registration questionnaire

<Personal information> (all mandatory)

- First name
- Family name
- Gender (single choice): Male, Female, Prefer not to tell
- Age range (single choice): 19 or below, between 20-29, between 30-39, between 40-49, between 50-59, 60 or above
- Country / Region
- Email

<Work-related information> (all mandatory)

- Name of Institution:
- Position in Institution:
- Your role(s) in the institution (Select all that apply to you): Management, administrative work, policy development and implementation, education and lecture, sample/specimen collection and analysis, research planning and experiment, machine operation and maintenances, data processing and analysis, consulting, public relation and communications, student, other (please specify)
- How much of your routine work relates to mercury (single choice): Less than 10%, between 10-50%, more than 50%

<Baseline survey for progress monitoring>

Please respond to these questions based on your own personal knowledge (this is NOT an exam!)

Q1: Have you ever calculated mercury emissions and releases in the following sectors? (Select all that apply to you).

- Annex D processes: ☐coal-fired power plant, ☐coal-fired industrial boiler, ☐Non-ferrous metal smelting, ☐waste incineration plant, ☐ cement clinker production
- ASGM: ☐extraction & processing, ☐amalgamation and burning of amalgam gold, ☐refining

- Mercury-added products: ☐production, ☐emission and release during usage, ☐waste collection and disposal
- Mining: ☐mercury mine, ☐non-ferrous metal mine, ☐limestone mine, ☐other please specify,
- Any other sector: ☐ please specify

Q2: Do you know the differences between elemental mercury and methylmercury in the following areas? (Select all that apply to you).

- ☐Physical property,
- ☐Biological property,
- ☐Toxicity,
- ☐Environmental behaviour,
- ☐Source of generation

Q3: Are you able to explain why mercury is used in the following products and processes?

- Battery: ☐Yes thoroughly, ☐to some extent, ☐not really
- Lamp: ☐Yes thoroughly, ☐to some extent, ☐not really
- Vaccine: ☐Yes thoroughly, ☐to some extent, ☐not really
- Switch: ☐Yes thoroughly, ☐to some extent, ☐not really
- Dental restoration: ☐Yes thoroughly, ☐to some extent, ☐not really
- Thermometer: ☐Yes thoroughly, ☐to some extent, ☐not really
- Sphygmomanometer (manometer): ☐Yes thoroughly, ☐to some extent, ☐not really
- Vacuum pump: ☐Yes thoroughly, ☐to some extent, ☐not really
- Tire balancer: ☐Yes thoroughly, ☐to some extent, ☐not really
- Photographic film and paper: ☐Yes thoroughly, ☐to some extent, ☐not really
- Propellant for satellites: ☐Yes thoroughly, ☐to some extent, ☐not really
- Chlor-alkali production: ☐Yes thoroughly, ☐to some extent, ☐not really
- Vinyl-chloride production: ☐Yes thoroughly, ☐to some extent, ☐not really

Q4: Can you explain how anthropogenic mercury emissions result in the elevated mercury levels in fish?

- ☐Yes thoroughly, ☐to some extent, ☐not really

Q5: Can you properly design and undertake mercury surveys for the following sectors?

- Mercury trade: ☐Yes thoroughly, ☐to some extent, ☐not really
- Emissions and releases: ☐Yes thoroughly, ☐to some extent, ☐not really

- Mercury waste particularly end-of-life products: ☐Yes thoroughly, ☐to some extent, ☐not really

Q6: Can you differentiate the environmental and health risks of cupellation, amalgamation and cyanidation processes for gold and silver extraction?

- ☐Yes thoroughly, ☐to some extent, ☐not really

Post-training evaluation questionnaire

Each answer should be linked with the registration information so that the personal attributes can be used for statistical analysis.

<Personal information> (all mandatory)

- First name
- Family name
- Country / Region
- Email

<About the training programme >

Q1: Could you rate the overall level of the presentations that you received in comparison with your personal competency?

- ☐Too high, ☐slightly high, ☐just fit to me, ☐slightly low, ☐too low

Q2: Could you select one presentation/topic that interests you the most? (Single choice)

(List all presentations or topics here)

Q3: Who do you think was the most suitable people/section in your institution to participate in this training programme? (Select all that apply to you).

- ☐Myself, ☐my co-workers, ☐ specific section of the institution (please specify), ☐no one in my institution

Q4: What will you do with the information received in this training programme? (Select all that apply to you).

- ☐Apply it to my daily work, ☐share it to my colleagues and others, ☐ask UNEP for more/specific information, ☐ other (please specify), ☐none at this moment

Post-training evaluation for progress monitoring

These questions are asked to measure the contribution of the training programme to developing capacity. The numbers are respective to the baseline survey for progress monitoring done prior to the training.

Q2: Do you think the programme helped to improve your understanding on the differences between elemental mercury and methylmercury in the following areas? (Select all that apply to you).

- ☐Physical property,
- ☐Biological property,
- ☐Toxicity,
- ☐Environmental behaviour,
- ☐Source of generation

Q3: Do you think the programme helped you to understand why mercury is used in the following products and processes?

- Battery: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme
- Lamp: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme
- Vaccine: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme
- Switch: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme
- Dental restoration: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme
- Thermometer: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme
- Sphygmomanometer (manometer): ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme
- Vacuum pump: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme
- Tire balancer: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme
- Photographic film and paper: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme

- Propellant for satellites: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme
- Chlor-alkali production: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme
- Vinyl-chloride production: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme

Q4: Do you think the programme helped you to understand that the anthropogenic mercury emissions results in the elevated mercury levels in fish?

- ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme

Q5: Do you think the programme helped your ability to properly design and undertake the mercury surveys for the following sectors?

- Mercury trade: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme
- Emissions and releases: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme
- Mercury waste particularly end-of-life products: ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme

Q6: Do you think the programme helped you to differentiate the environmental and health risks of cupellation, amalgamation and cyanidation processes for gold and silver extraction?

- ☐ Helped a lot, ☐helped to some extent, ☐no difference, ☐more confusing to me, ☐ the item was not relevant in this programme

4 SUPPLEMENTARY INFORMATION AND LITERATURE

Background and in-depth information is compiled in this chapter. The users can refer, as necessary, to the materials to add values to their own training programmes. Some information is slightly beyond the scope of this training package, but it will serve as a guidance for extended self-study.

4.1 Outlines of the Minamata Convention on Mercury

The Minamata Convention on Mercury is a multilateral legally-binding environmental agreement aiming to protect the human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds. The text was adopted in October 2013, and is composed of a preambular text, 35 articles, and 5 annexes. The Convention entered into force on 16th August 2017, on the 90th day after the deposition of the 50th instrument of ratification, acceptance, approval, or accession.

In its preamble, the Convention recognises the substantial lessons of Minamata disease, in particular the serious health and effects resulting from the mercury pollution, and makes aware of the health concerns to women, children, and future generation. The Convention sets out a range of measures throughout the entire life cycle of mercury to meet its objective, which include measures to control the supply and trade of mercury, and to control mercury-added products and manufacturing processes in which mercury or mercury compounds are used, as well as artisanal and small-scale gold mining. The text also includes the articles on emissions and releases of mercury, on environmentally sound interim storage, on mercury waste, and contaminated sites.

Articles 3 – 12 relate to the operational provisions describing Parties' obligations to reduce emissions and releases, with controls along their life cycle. Articles 13 – 21 facilitate the implementation of these measures including provisions related to support for the Parties, information and awareness raising and reporting. Articles 22 – 35 cover the overall management of the Convention. It is also worth noting that the Convention promotes consideration of the needs of vulnerable populations in health aspects; in public information, awareness and education; in research, development and monitoring; and in effectiveness evaluation; are key priorities to be taken forward. Annexes A and B list the mercury-added products and manufacturing processes to be controlled by the Convention. Annex C sets the items to be included in the national action plans for artisanal and small-scale gold mining (ASGM). Annex D lists the point source categories for emission control.

Table 4 Article-by-article outlines of the Minamata Convention

Article	Outline
Preamble	Recognition of mercury risks, substantial lessons of Minamata Disease
Article 1 Objective	Protection of the human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds.
Article 2 Definitions	Definition of terms in the Convention.
Article 3 Supply and trade	Control of primary mercury mining by setting the phase out period. Prohibition of international trade of mercury except for the use allowed under the Convention.
Article 4 Mercury-added products	Control (including phase out and phase down) of production, import and export of the mercury-added products in Annex A.
Article 5 Manufacturing processes	Control (including phase out) of mercury uses in the processes specified in Annex B.
Article 6 Exemptions	Registration of exemptions from the phase-out dates specified in Annexes A and B.
Article 7 ASGM	Reduction (or elimination wherever feasible) of mercury use in ASGM for the countries having more than insignificant ASGM activities. Development and implementation of national action plans in accordance with Annex C.
Article 8 Emissions	Control of emissions into air from the source categories listed in Annex D based on the best available techniques and best environmental practices. Preparation of inventory.
Article 9 Releases	Identification of relevant source categories that are not addressed in other provisions of the Convention. Control of releases to land or water. Preparation of inventory.
Article 10 Interim storage	Environmentally sound interim storage of mercury other than waste mercury.
Article 11 Mercury wastes	Management of mercury wastes in an environmentally sound manner, taking into account the guidelines developed by the Basel Convention.
Article 12 Contaminated sites	Identification and assessment of sites contaminated by mercury or mercury compounds.
Articles 13 – 14 Finance, technical assistance	Financial resources and mechanisms, capacity-building, technical assistance and technology transfer.
Article 15 Compliance	Establishment of a Committee as a subsidiary body of the COP, to promote implementation and review of compliance.
Article 16 Health	Development and implementation of the health strategies and programmes to protect populations at risk. Development of science-based educational and preventive programmes on occupational exposures. Appropriate health-care services for affected populations. Strengthening capacity for diagnosis, treatment and monitoring of health risks.
Articles 17 – 18 Information, awareness, education	Exchange of scientific, technical, economic and legal information among the Parties. Promotion and facilitation of the provision of information to the public.

Article	Outline
Article 19 Research, monitoring	Cooperation for research and development on inventories, modelling and monitoring, impacts on human health and the environment, fate and transport, commerce and trade, mercury-free alternatives, etc.
Article 20 Implementation plans	Development and execution of implementation plans taking into account the domestic circumstances.
Article 21 Reporting	Periodical reporting to the COP on measures taken by the Parties.
Article 22 Effectiveness evaluation	Evaluation of the effectiveness of the Convention on the basis of available scientific, environmental, technical, financial and economic information.
Articles 23 – 28 COP, Secretariat, etc.	The COP, secretariat, settlement of disputes, amendments, voting.
Articles 29 – 35 Ratification, etc.	Signature, ratification, entry into force, reservation, withdrawal, depositary, and authentic texts.
Annex A Mercury-added products	Introductory text: General exceptions. Products essential for civil protection and military uses Products for research, calibration of instrumentation, for use as reference standard Where no feasible mercury-free alternative for replacement is available Products used in traditional or religious practices Vaccines containing thiomersal as preservatives Part I: Products to be phased out Batteries; switches and relays; lamps; cosmetics; pesticides, biocides and topical antiseptics; non-electronic measuring devices Part II: Dental amalgams.
Annex B Manufacturing processes	Part I: Chlor-alkali production, acetaldehyde production. Part II: Vinyl chloride monomer, sodium or potassium methylate or ethylate, polyurethane.
Annex C ASGM national action plans	Content of national action plan.
Annex D Point sources of emissions	Coal-fired power plants, coal-fired industrial boilers, smelting and roasting processes used in the production of non-ferrous metals, waste incineration facilities, and cement clinker production facilities.
Annex E Arbitration	Arbitration and conciliation procedures.

Source: Minamata Convention (2013). Text of the Minamata Convention on Mercury for adoption by the Conference of Plenipotentiaries.

Table 5 Mercury-added products listed in Annex A

Mercury-added products	Timeline
(a) Products essential for civil protection and military uses. (b) Products for research, calibration of instrumentation, for use as reference standard. (c) Where no feasible mercury-free alternative for replacement is available, switches and relays, cold cathode fluorescent lamps and external electrode fluorescent lamps (CCFL and EEFL) for electronic displays and, measuring devices. (d) Products used in traditional or religious practices; and (e) Vaccines containing thiomersal as preservatives.	Excluded from Annex (no timeline)
Part I	
Batteries, except for button zinc silver oxide batteries with a mercury content < 2% and button zinc air batteries with a mercury content < 2%	2020

Mercury-added products	Timeline
Switches and relays, except very high accuracy capacitance and loss measurement bridges and high frequency radio frequency switches and relays in monitoring and control instruments with a maximum mercury content of 20 mg per bridge, switch or relay	2020
Compact fluorescent lamps (CFLs) for general lighting purposes that are ≤ 30 watts with a mercury content exceeding 5 mg per lamp burner	2020
Compact fluorescent lamps with an integrated ballast (CFL.i) for general lighting purposes that are ≤ 30 watts with a mercury content not exceeding 5 mg per lamp burner	2025
Linear fluorescent lamps (LFLs) for general lighting purposes: (a) Triband phosphor < 60 watts with a mercury content exceeding 5 mg per lamp; (b) Halophosphate phosphor ≤ 40 watts with a mercury content exceeding 10 mg per lamp	2020
High pressure mercury vapour lamps (HPMV) for general lighting purposes	2020
Mercury in cold cathode fluorescent lamps and external electrode fluorescent lamps (CCFL and EEFL) for electronic displays: (a) short length (≤ 500 mm) with mercury content exceeding 3.5 mg per lamp (b) medium length (> 500 mm and ≤ 1 500 mm) with mercury content exceeding 5 mg per lamp (c) long length (> 1 500 mm) with mercury content exceeding 13 mg per lamp	2020
Cold cathode fluorescent lamps (CCFL) and external electrode fluorescent lamps (EEFL) of all lengths for electronic displays, not included in the listing directly above	2025
Cosmetics (with mercury content above 1ppm), including skin lightening soaps and creams, and not including eye area cosmetics where mercury is used as a preservative and no effective and safe substitute preservatives are available[3]	2020
Pesticides, biocides and topical antiseptics	2020
The following non-electronic measuring devices except non-electronic measuring devices installed in large-scale equipment or those used for high precision measurement, where no suitable mercury-free alternative is available: (a) barometers; (b) hygrometers; (c) manometers; (d) thermometers; (e) sphygmomanometers.	2020
Strain gauges to be used in plethysmographs;	2025
The following electrical and electronic measuring devices except those installed in large-scale equipment or those used for high precision measurement, where no suitable mercury free alternative is available: (a) Melt pressure transducers, melt pressure transmitters and melt pressure sensors	2025
Mercury vacuum pumps	2025
Tyre balancers and wheel weights	2025
Photographic film and paper	2025
Propellant for satellites and spacecraft	2025
Part II	
Dental amalgam	Phase down (no timeline)

Source: United Nations Environment Programme (2022). Annex A to the Minamata Convention on Mercury, as amended by the Conference of the Parties at its fourth meeting.

[3] The intention is not to cover cosmetics, soaps or creams with trace contaminants of mercury.

Table 6 Manufacturing processes listed in Annex B

Mercury-using processes	Timeline
Chlor-alkali production	Phase out by 2025
Acetaldehyde production in which mercury or mercury compounds are used as a catalyst	Phase out by 2018
Vinyl chloride monomer production	50 % use reduction by 2020
Sodium or potassium methylate or ethylate	Phase out as fast as possible and within 10 years of the entry into force of the Convention 50 % emission reduction by 2020
Production of polyurethane using mercury containing catalysts	Phase out as fast as possible and within 10 years of the entry into force of the Convention

Source: Minamata Convention (2013). Text of the Minamata Convention on Mercury for adoption by the Conference of Plenipotentiaries.

Table 7 Lists of mercury waste falling under paragraph 2 of Article 11

Type of waste
List of mercury waste consisting of mercury or mercury compounds (subparagraph 2 (a) of article 11)
Recovered elemental mercury
Elemental mercury
Mercury (I) chloride and mercury (II) chloride
Mercury (II) oxide (mercuric oxide)
Mercury (II) sulphate (mercuric sulphate)
Mercury (II) nitrate (mercuric nitrate)
Cinnabar concentrate
Mercury sulphide
Non-exhaustive list of waste containing mercury or mercury compounds (subparagraph 2 (b) of article 11)
Non-electronic measuring devices containing mercury (barometers, hygrometers, manometers, thermometers, sphygmomanometers)
Electrical and electronic switches, contacts, relays and rotating electrical connectors with mercury
Fluorescent bulbs, high intensity discharge (HID) bulbs (mercury vapour bulbs, metal halide and high-pressure sodium bulbs), neon/argon lamps
Batteries/accumulators containing mercury
Biocides and pesticides containing mercury and their formulations and products
Paints and varnishes containing mercury
Pharmaceuticals containing mercury for human and veterinary uses, including vaccines
Cosmetics and related products containing mercury
Dental amalgam
Scientific instrument used for the calibration of medical or scientific devices containing mercury
Indicative list of waste contaminated with mercury or mercury compounds (subparagraph 2 (c) of article 11)
Waste from industrial pollution control devices or cleaning of industrial off-gases
Bottom ash
Wastewater treatment residues/slurries
Sludge
Oil and gas refining catalyst
Tailings and extraction process residues
Rubble, debris and soil

Type of waste
Other waste from manufacturing processes using mercury or mercury compounds
Other waste from the manufacturing of mercury-added products
Other waste from natural gas cleaning
Wastes from waste treatment facilities

Source: United Nations Environment Programme (2019). MC-3/5: Mercury waste thresholds, In Decision adopted by the third Conference of the Parties to the Minamata Convention on Mercury.

4.2 Mass balance and mass flows

The mass balance principle is described below in general.

- Mercury is a chemical element and persistent in the environment. This means:
  - It is not destructible,
  - It is not created in processes,
  - It is only "fed" into processes, or "society", and released via process outputs to the environment (including waste deposits)
- Total input = total outputs: accumulation in times of changing activities (+/-)
- "What goes in must come out" – only the output pathways differ.

Figure 1 below gives an example of the mass balance for a coal-fired power plant where all mercury inputs come with the coal (natural trace concentrations) and the output pathways are influenced by the air emission control systems installed in the facilities.

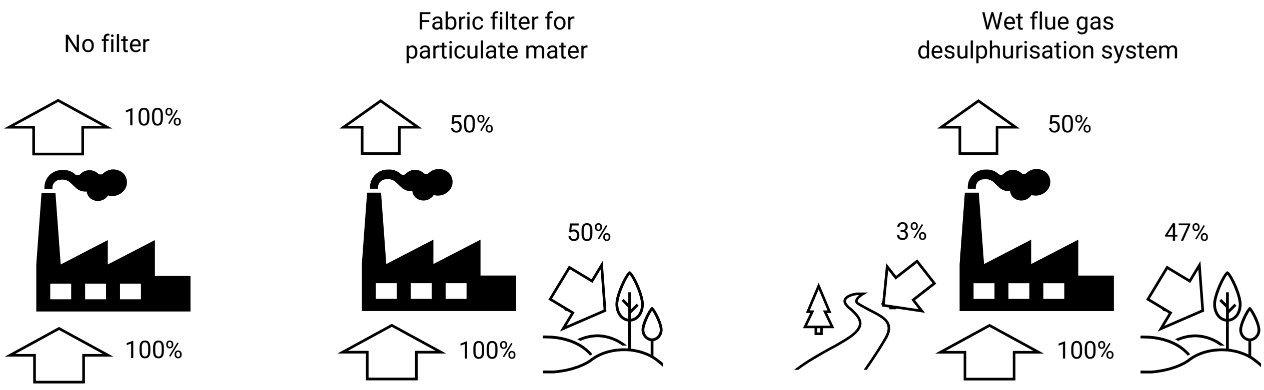


Figure 1 Mass balance for a coal-fired power plant

The mass balance equation is given below for the general case:

$$Inputs + Formation = Outputs + Degradation + Accumulation$$

For the specific case of an element such as mercury, which is neither formed nor degraded4, it can be simplified as:

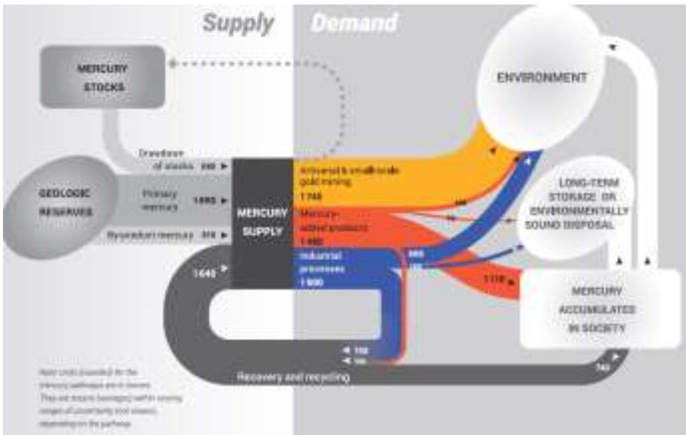
$$Inputs = Outputs + Accumulation$$

Looking at a country or another "economic" system, this equation can be detailed as:

$$Inputs = Import + Production = Releases(including\ Emissions) + Export + Accumulation$$

[4] In theory, a nuclear reaction can change one element to another, but cases where it has practical relevance are rare/irrelevant.

A mass flow can be well presented using a Sankey diagram, where the widths of the arrows illustrate the quantities of the flow. For example, the global supply of intentionally used mercury was estimated in an UNEP report as shown in Figure 2 :



Source: United Nations Environment Programme (2017). Global mercury supply, trade and demand.

Figure 2 Global mercury flow in Sankey diagram

During the development of a mass flow diagram, the quantities may not be included at the beginning, but the flows could be illustrated as an intermediate product as shown in Figure 3 below. The diagram can then be improved by adding information obtained from surveys and studies.

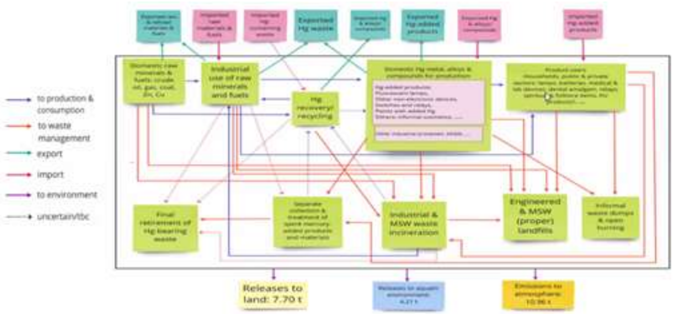


Figure 3 Intermediate product of mercury flow analysis

4.3 Emission factors, and input and output distribution factors

The UNEP Mercury Inventory Toolkit (UNEP 2019b) does not work with traditional emission factors. This is because it is mass-balance derived, and therefore allows a full coverage of emissions and releases to all environmental media. Instead, the Toolkit works on a higher level of detail with so-called input factors and output distribution factors. The input factor is the amount of mercury entering into the system/ sector/ facility per unit of feed material or per product produced, for example, g Hg/tonne of coal combusted or g Hg/thermometer. The output distribution factors are unit-less fractions of the total mercury Input anticipated to be released/ emitted through a particular pathway. By definition (and with a few special exceptions in the Toolkit), the sum of the output distribution factors is always 1 (meaning 100% of the total mercury input).

$$Mercury\ release\ to\ pathway = Activity\ rate \times Input\ factor \times Output\ distribution\ factor$$

Parameter	Description
Activity rate	Amount of feed material or product (e.g., tonnes or pieces per year)
Input factor	Mercury content (e.g., grams of mercury) per unit of feed material processed or product produced (background data)
Output distribution factor	Fraction of the mercury input that is released through a particular pathway; air, water, land, products, general waste, or sector specific waste treatment (background data)

So-called default factors, based on literature data, are automatically applied in the Toolkit Inventory level 1, and pre-entered, but editable in the Toolkit Inventory Level 2. To increase the accuracy of the estimates, it is encouraged to use local factors in level 2, provided that well documented data is available and reported explicitly by users in their inventory reports. The UNEP Mercury Inventory Toolkit and its default estimation factors can be found in the Inventory Level 2 calculation spreadsheet and with more detail and background in the Toolkit Reference Report.

Other (air) emission estimation systems, such as pollution release and transfer registers (PRTR), typically work with traditional emission factors at their basic inventory level (Tier 1), for example g Hg emitted to the air per ton of coal used (meaning that they are not derived from mass-balance).

Some examples of input and output factors are given below for mercury-filled thermometers (Table 8 and Table 9) and coal-fired power plants (Table 10 and Table 11). The units depend on the subject in question, and the default output distribution factors depend on the mercury control/management schemes in place. All the default input and output distribution factors can be found in the Toolkit Reference Report.

Table 8 Preliminary default mercury input factors, by thermometer type

Thermometer type	Mercury content (g Hg/item)
Medical thermometers	0.5-1.5
Ambient air temperature thermometers	2-5
Industrial and special application thermometers (e.g., marine engine control)	5-200
Miscellaneous glass thermometers with Hg, including for laboratories	1-40

Table 9 Preliminary default mercury output distribution factors for the 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, secure disposal in old mines.
*2 Mercury inputs to disposal are the amounts of mercury per thermometer type, combined with disposed amounts of the respective thermometer type. If annual supply data from a few years earlier (for the same thermometer type) is available, it can be used to approximate disposed amounts.
*3 Outputs are the share of mercury input to production in the country. If the mercury amounts supplied to production cannot be obtained, they can be approximated by the amount of mercury in the produced products.

Table 10 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)

Table 11 Default output distribution factors for mercury in coal for energy production 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 anthracite:						
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					

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
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. Output to water occurs if not all Hg in wash media is retained in residues.

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

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

CYC – Cyclones; DS – Dry scrubber; ESP – Electrostatic precipitator; FF - Fabric filter (or "bag filter"); FGD – Flue gas desulphurisation; 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 desulphurisation.

4.4 Customs codes and international trade data

Import/export statistics are a valuable data source for several mercury source sub-categories, especially the statistics for the trade of mercury-added products, metal mercury and in some cases mercury compounds. The data sources may be national (sometimes they offer a higher level of detail), or international using the UN COMTRADE system. The relevant link to the UN COMTRADE and guidance on relevant product and materials groups, current customs codes, and analysis of the obtained trade results can be found in the Toolkit's Guideline for Inventory level 1, Appendix 2 (UNEP 2019c)

Most countries use so-called Harmonized System (HS) customs codes, supplemented by the customs codes used at the regional and national levels. The easiest data to obtain would be the six-digit HS codes (for example at UN COMTRADE). A problem that is always encountered in mercury inventory and mass flow development is, that many customs codes are NOT specific to mercury-added versions of similar products. It should be noted that a guidance document has been developed for the use of customs codes to identify mercury-added products. As the mercury-containing and the mercury-free products are registered under the same customs code, additional data gathering from importers is needed to establish the estimated fraction containing mercury.

Data for the following product/material groups in Table 12 can be sought with meaningful results in the UN COMTRADE database:

Table 12 HS codes for possible mercury containing product and material

Product/material name in the Toolkit Inventory Level 1	Use this search word	Examples of product name(s) and code(s) in the Comtrade (others may exist)		Remarks
		Names	HS codes	
Ore concentrates				
5.2.3 Zinc concentrates	Zinc concentrates	… Zinc ores and concentrates	260800	
5.2.4 Copper concentrates	Copper concentrates	… Copper ores and concentrates	260300	
5.2.5 Lead concentrates	Lead concentrates	… Lead ores and concentrates	260700	

Product/material name in the Toolkit Inventory Level 1	Use this search word	Examples of product name(s) and code(s) in the Comtrade (others may exist) Names	HS codes	Remarks
5.3.1 Cement		… Portland cement, aluminous cement, slag cement, super sulphate cement and similar hydraulic cements, whether or not coloured or in the form of clinkers.	2523	- This is a generic category which includes both cement and cement clinker
5.3.1 Cement	Cement	… White cement, whether or not artificially coloured	252321	
		… Other than white	252329	
		… Aluminous cement	252330	
		… Other hydraulic cements	252390	
5.3.1 Cement clinker	Cement clinker	… Cement clinkers	252310	
5.5.1 Thermometers	Thermo-meter	… Thermometers & pyrometers, not combined with other instr., liquid-filled, for direct reading	902511	- May include thermometers with other types of liquids
5.5.2 Electrical switches and relays with mercury				
Switches	Switch	Isolating switches and make-and-break switches, for a voltage exceeding 1,000 volts	853530	
	Switch	Electrical apparatus for switching, protecting or making connections for a voltage exceeding 1,000 volts	853590	
	Switch	Switches, for a voltage not exceeding 1,000 volts	853650	
Relays	Relay	Relays, for a voltage not exceeding 1,000 volts	853640	
	Relay	Relays for a voltage not exceeding 60 volts	853641	
	Relay	Relays for a voltage greater than 60 volts and not exceeding 1,000 volts	853649	
Thermostats	Thermostat	Electronic thermostats, other thermostats	903210	
5.5.4 Batteries	Battery cell	… Primary cells and primary batteries.	8506	- This is a generic customs code that include all types of non-rechargeable batteries, including several batteries without mercury

Product/material name in the Toolkit Inventory Level 1	Use this search word	Examples of product name(s) and code(s) in the Comtrade (others may exist)		Remarks
		Names	HS codes	
Other button cells (zinc-air, alkaline button cells, silver-oxide, mercuric oxide)		… Primary cells & primary batteries, air-zinc	850660	- Includes only part of the battery types in the Toolkit category, as there is no separate 6-digit HS code for button cell alkaline batteries (may be available in national 8-digit HS codes)
		… Cells and batteries; primary, silver oxide	850640	
		Cells and batteries; primary, mercuric oxide	850630	
Other batteries [potentially] with mercury (plain cylindrical alkaline, permanganate)		… Manganese dioxide	850610	
		Other primary cells and batteries	850680	
5.5.3 Light sources with mercury	Lamp			
Fluorescent tubes (double ended) and Compact fluorescent lamps (CFL single ended)		… Electric discharge lamps (excl. ultra-violet lamps), fluorescent, hot cathode	853931	- The 6-digit HS code includes both "Fluorescent tubes (double ended)" and "Compact fluorescent lamps (CFL single ended)", but not the distribution on the types; distribution on types must be based on other data.
Other light sources containing mercury (see guideline)		… Electric discharge lamps other than fluorescent (hot cathode), mercury or sodium vapour, metal halide or ultraviolet lamps	853939	- Includes some lamps with high mercury contents, but not all. - Includes mercury containing ultra-violet fluorescent lamps used for tanning beds as well as infra-red lamps which do not contain mercury.
		mercury/sodium vapour lamps; metal halide lamps	853932	
Other relevant product/material groups that can potentially be used for cross-checking of mercury inputs				
Metal mercury	Mercury	Mercury	280540	
Mercury compounds	Mercury compounds	… Inorganic or organic compounds of mercury, excluding amalgams, whether or not chemically defined	2852	
		… Inorganic or organic compounds of mercury, excluding amalgams, chemically defined	285210	
		… Inorganic or organic compounds of mercury;	285290	

Product/material name in the Toolkit Inventory Level 1	Use this search word	Examples of product name(s) and code(s) in the Comtrade (others may exist)		Remarks
		Names	HS codes	
		excluding amalgams, not chemically defined		
5.5.6 Biocides and pesticides	Pesticides	… disinfectants and similar products	380850	- Insecticides, rodenticides, fungicides, herbicides, anti-sprouting products and plant growth regulators, disinfectants and similar products
		Insecticides	380891	
		Fungicides	380892	
		Herbicides, anti-sprouting products and plant growth regulators	380893	
		Other	380899	
	Paint	… dispersed or dissolved in a non-aqueous medium (excluding those based on polyesters and acrylic or vinyl polymers)	3208	- Paints and varnishes to which a mercury compound has been added for its biocidal or fungicidal properties
		… dispersed or dissolved in an aqueous medium	3209	
5.5.9 Cosmetics and related products	Cosmetics	Lip make-up preparations, Eye make-up preparations, Manicure or pedicure preparations, Other, Powders, including compacts, Skin creams, Other	3304	
	Soap	For toilet use (including medicated products), Soaps for toilet use (incl. medicated), Other, Soap in other forms, Organic surface-active products and preparations for washing the skin, in the form of liquid or cream and made available for retail sale, whether or not containing soap	3401	- Soap and organic surface-active products and preparations, in the form of bars, cakes, moulded pieces or shapes, and paper, wadding, felt and non-woven, impregnated, coated or covered with soap or detergent
5.6.1 Dental amalgams	Dental amalgams	… Pharmaceutical goods; dental cements and other dental fillings, bone reconstruction cements	300640	- There is no distinct code for mercury amalgam. This code may include other types of dental fillings
		Amalgams of precious metals; etc.	284390	
5.6.2 Manometers and gauges	Manometer	Devices for measuring blood pressure	901890	

Product/material name in the Toolkit Inventory Level 1	Use this search word	Examples of product name(s) and code(s) in the Comtrade (others may exist)		Remarks
		Names	HS codes	
		Other instruments, including barometers, other instruments: hygrometers	902580	
		Instruments and apparatus for pressure measurement or control, manometers	902620	
5.2.2 Gold (for all extraction techniques)	Gold	… Metals; gold, non-monetary, unwrought (but not powder)	710812	- This includes bars which for the purposes of marketing have a smooth surface and a hallmark. - Grains of silver and its alloys are classified in this code, provided that they are not powdered. - These codes exclude bars obtained by drawing or rolling.
		… Metals; gold, semi-manufactured	710813	

4.5 Development of a mercury flow diagram (case in Japan)

The term "material flow" or "mass flow" refers to the overall flow of a substance in a system by capturing the input to and output from the system to the environment, along with the flow of the substance in each process and the flow of the substance between the processes within the system. This section refers to the mercury material flow (MMF) developed in Japan as an overview of its national mercury flow (MOEJ 2020). The MMF in Japan provides an overall picture of the domestic flow of mercury. It identifies priority areas where further actions or greater attention may be necessary.

Meanwhile, "inventory" is often referred to the amounts of the substance released into the environment. In Japan, the "Mercury Atmospheric Emission Inventory" focusing on atmospheric emissions of mercury has also been developed. The MMF and the emission inventory are important tools to support the process for reviewing the effectiveness of policy measures.

Composition of MMF

The MMF in Japan is composed of the information categorised in Table 13:

Table 13 Categories of MMF in Japan

Category	Component
Raw minerals and fuels	- Import of raw minerals and fuels - Domestic production of raw minerals and fuels - Processing and industrial use of raw minerals and fuels and waste incineration
Mercury and mercury compounds	- Import and export of mercury and mercury compounds
Mercury-added products	- Production and trade of mercury-added products
Mercury wastes	- Mercury recovery from mercury wastes - Final disposal (landfilling) - Import of mercury wastes
Mercury emissions and releases	- Mercury emissions into the air - Mercury releases to water - Mercury releases to land

Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

Raw minerals and fuels

Japan used the data from the trade statistics on imports of raw minerals and fuels and information about their mercury concentrations obtained from interviews with relevant industry associations and literatures in order to estimate the amount of mercury imported as impurities. Table 14 shows an example of coal.

$$Hg\ content\ in\ imported\ raw\ minerals\ and\ fuels$$
$$= Amount\ of\ imported\ raw\ materials\ and\ fuels \times Hg\ concentration$$

The same approach can be applied for the domestic production of raw minerals and fuels.

Table 14 Mercury import as impurities in coal

Raw minerals and fuel		Import Amount	Import Unit	Hg concentration	Hg content	
Coal	Anthracite	5,779	x10^3 t/yr	0.039 g/t	7,473 kg-Hg/yr	7.5 t-Hg/yr
	Bituminous coal	172,566				
	Other coals	11,070				
	Briquette, oval briquette, etc.	80				
	Lignite	19				
	Peat	114				
	Coke, etc.	1,988				
Information source		Trade Statistics		Interviews with the Federation of Electric Power Companies	Estimation result	

Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

Based on interviews with relevant industry associations and individual companies, processing and industrial uses of raw minerals and fuels and waste incineration which could be the potential source of mercury were identified.

- Non-ferrous metal smelting facility
- Coal-fired power plant
- Coal-fired industrial boiler
- Primary iron production facility
- Secondary iron production facility
- Oil and gas production facility
- Cement production facility
- Waste incineration facility

The limitations to develop the material flow were the availability and reliability of data. Various methodologies and information sources should be used to best estimate the amounts (quantitative data). For example, if the data on the target year for which the material flow is being developed is not available, then the values of the nearest year, or the average values over several years should be used for the calculation/ estimation.

Example: Coal-fired power plants

In the example of the mercury material flow for coal-fired power plants, interviews with relevant industry associations were conducted to obtain data, which was extrapolated to the nation-wide data. Data on input (coal consumption amount) and output (amount of fly ash, sludge etc.) was obtained from the Federation of Electric Power Companies of Japan. The information from this Federation is limited to that of its member companies. Hence, the national data was estimated by extrapolating that amount to the national level by using the coal consumption ratio to cover those plants which do not participate in the Federation.

Electric Power Survey Statistics published by the Agency for Natural Resources and Energy provides a nation-wide data, but the data is limited to the amount of coal consumption only. The results of the interview with the stakeholders, i.e., members of the Federation, include various data such as the coal consumption, and generation/ utilization/ disposal of ash, gypsum and sludge.

In FY2016, the amount of coal consumption based on the statistics was 11,086 t/year while the amount based on the interview with the Federation was 7,310 t/year. The ratio of these amounts, 152:100, was used to extrapolate the generation, utilization and disposal amounts of coal ash (Table 15), de-sulphurised gypsum (Table 16) and sludge generated at the national level.

Table 15 Coal-fired power generation: Mercury amount in generation, utilization and final disposal of fly ash (FY2016)

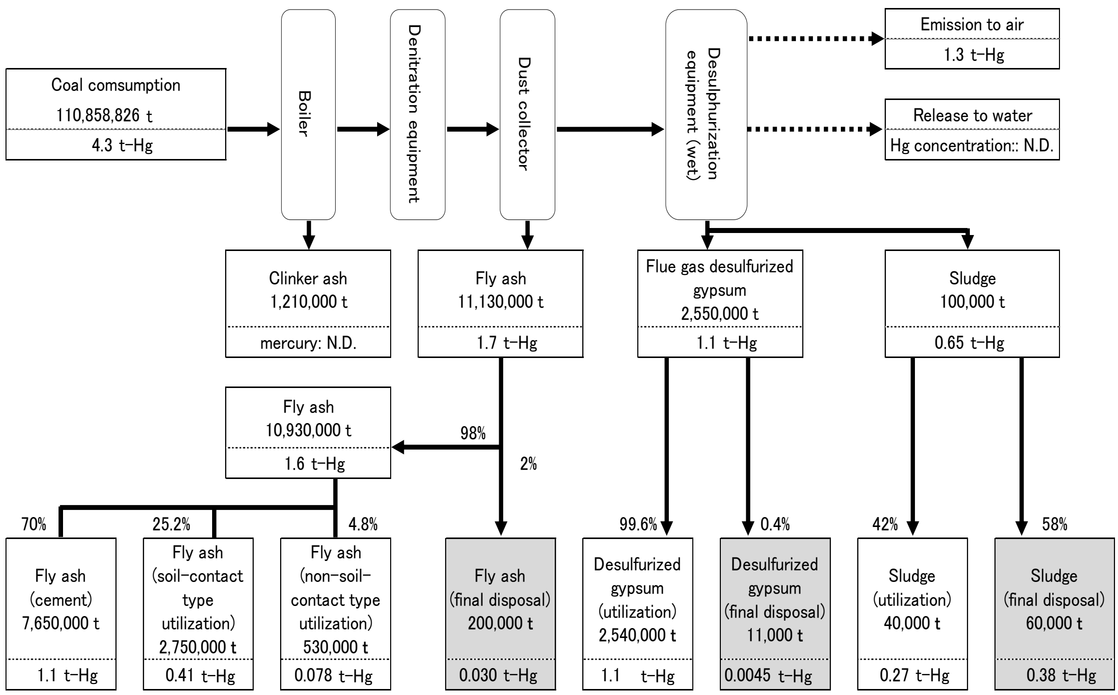
	Surveyed data (100)	Extrapolated data (152)		
Fly ash	Federation of Electric Power Companies data (10,000 t)	Nationwide data (extrapolated) (10,000 t)	Mercury concentration in fly ash (mg/kg)	Mercury amount in fly ash (t-Hg)
Generation	733.6	1,113	0.149	1.7
Utilization	720.4	1,093		1.6
Final disposal	13.2	20		0.030

Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

Table 16 Coal-fired power generation: Mercury amounts in generation, utilization and final disposal of gypsum (FY2016)

	Surveyed data (100)	Extrapolated data (152)		
Flue gas desulphurised gypsum	Federation of Electric Power Companies data (10,000 t)	Nationwide data (extrapolated) (10,000 t)	Mercury concentration in flue gas desulphurised gypsum (mg/kg)	Mercury in flue gas desulphurised gypsum (t-Hg)
Generation	168.2	255	0.428	1.1
Utilization	167.5	254		1.1
Final disposal	0.70	1.1		0.0045

Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

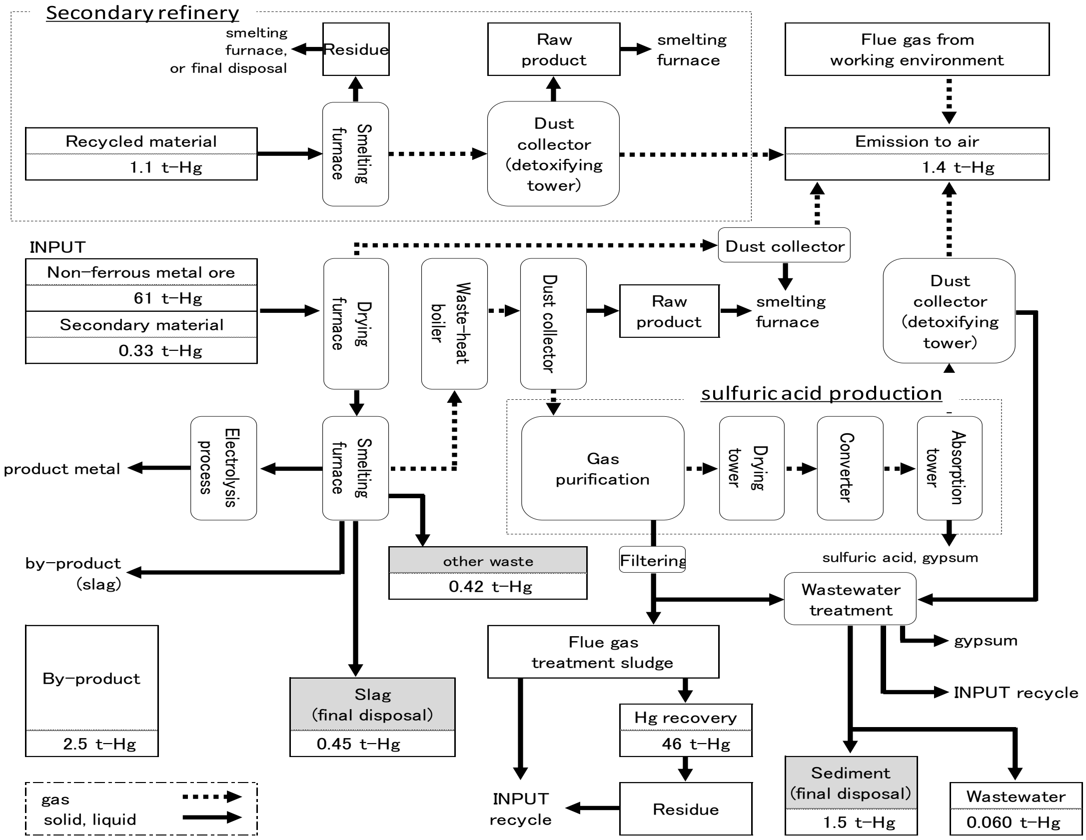


Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

Figure 4 Process example of coal-fired power plant

Example: Non-ferrous metal smelting facilities

As mercury is contained in input feeds (non-ferrous metal ore, recycled material), the outputs such as sludge, sediment and wastewater from the flue gas treatment, by-product (gypsum), and slag may contain mercury. This is an example where data is primarily obtained through Interviews with stakeholders. The Japanese Mining Industry Association covers the majority of non-ferrous metal smelting facilities in Japan, and can collect data belonging to the individual facilities. An interview was conducted to obtain data on the amounts of inputs and outputs and the mercury contents. The estimated mercury emissions were obtained from the Mercury Atmospheric Emission Inventory.



Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

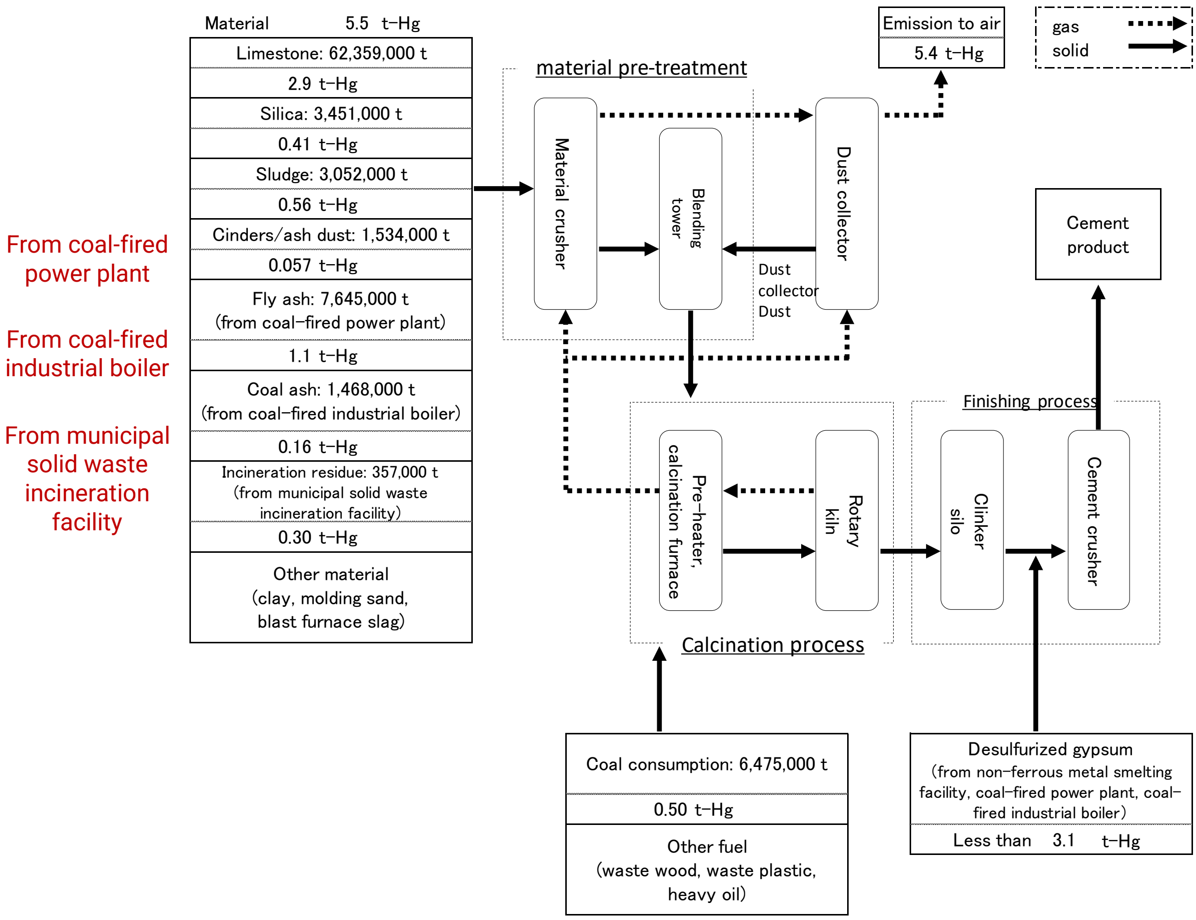
Figure 5 Process example of non-ferrous metal smelting facility

Example: Cement production facilities

This third example is for the use of information about outputs partially from other facilities. The mercury inputs with limestone, silica, sludge, and cinders/ash dust were obtained from the interview with the Japan Cement Association. The data on fly ash, coal ash, and incineration residues was taken from other sources, e.g., the interview with the Federation of Electric Power Companies.

The mercury emissions were estimated from the Mercury Atmospheric Emission Inventory (FY2016), where the general emission factor was multiplied by the production amounts of clinkers.

The emission factor (from FY 2014 inventory) was calculated by using data provided by voluntary measurements conducted by the Japan Cement Association.



Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

Figure 6 Process example of cement production facility

Mercury and mercury compounds

The mercury import in FY2016 was 0.005 tons according to the supply and demand dynamics statistics for non-ferrous metals. The three-year average of export amount in the same statistics was 101 tons. (Table 17)

According to the interview with the Japan Lighting Manufacturers Association in FY2018, the amount of mercury contained in imported mercury alloys used for manufacturing lamps was 0.41 tons.

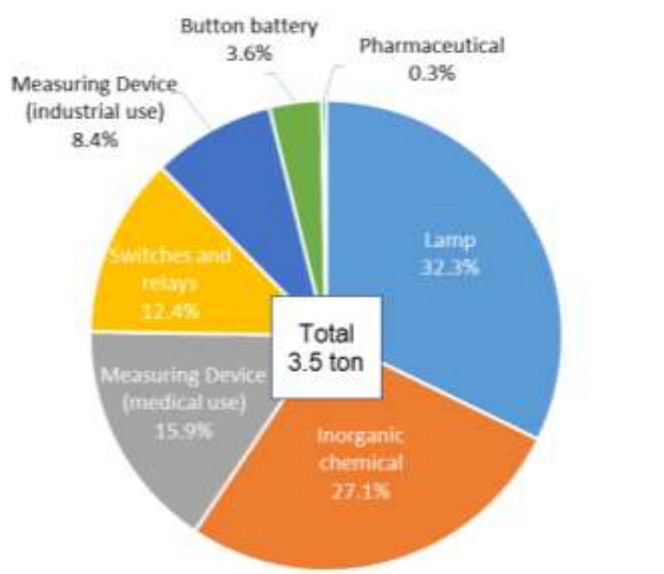
Table 17 Survey results of mercury export and import

Activity	Quantity (t/year)	Period	Information source
Export	101 (India, Colombia, etc.)	Ave. 2015-2017	Trade Statistics of Japan, Ministry of Finance (HS code: 2805.40-000)
Import	0.005 (USA)	FY2016	Trade Statistics of Japan, Ministry of Finance (HS code: 2805.40-000)

Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

Mercury-added products

To calculate the amount of mercury contained in produced/imported/exported products, mercury content per unit of each product was multiplied by the numbers of products produced, imported, or exported.



Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

Figure 7 Mercury use for domestically manufactured mercury-added products (FY2016)

The total amount of mercury used in domestically manufactured products was estimated as 3.5 tons sown in Figure 7, while mercury contents in imported and exported products were estimated as 0.88 tons and 1.1 tons, respectively.

Mercury wastes

Mercury recovery from mercury waste is extensively practiced in Japan. A survey targeting the business entities involved in mercury recovery was conducted to obtain the amounts of mercury recovered from the discarded mercury-added products, waste metallic mercury, sludge including that from non-ferrous smelting facilities, waste liquid, dental amalgam, silver oxide batteries, etc. The total amount of mercury recovered from waste in FY2016 was 65 tons as shown in Table 18 with the largest amount recovered from non-ferrous metal smelting sludge.

Specified hazardous wastes imported to Japan classified as Y29 (containing mercury or mercury compounds) under the Basel Convention is also included.

Table 18 Amounts of mercury recovered from mercury waste (FY2016)

Category	Type of mercury wastes	Recovered mercury	(unit: ton)
(a) wastes consisting of mercury	Mercury discarded from business entities	4.5	8.2
	Mercury discarded from schools and universities	1.1	
	Mercury discarded from lighthouses	0.1	
	Mercury discarded from hospitals	0.9	
	Mercury discarded from municipal waste incineration facilities	0.3	
	Imported specified hazardous wastes	0.9	
	Others	0.4	
(b) wastes contaminated with mercury	Sludge and waste liquid originated from industrial wastes	2.4	49
	Non-ferrous metal smelting sludge	46.6	
	Dental amalgam (non-waste valuable)	0.2	
	Silver oxide batteries (non-waste valuable)	0.004	
(c) wastes containing mercury	Measuring devices (thermometers and sphygmomanometers)	6.8	7.7
	Lamps	0.3	
	Batteries	0.3	
	Dental amalgam (industrial waste)	0.08	
	Switches, relays, manometers	0.2	
Total			65

Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

The amount of mercury contained in the final disposal of waste and residues generated from the processing/industrial use of raw materials and waste incineration was 7.8 tons as shown in Table 19. However, directly landfilled municipal waste was not included in the material flow since the amount of discarded mercury-added products to be landfilled as non-combustible waste was not available.

Table 19 Amount of mercury in final waste disposal

Emission source	Medium	Waste disposas (t)	Hg contained in waste disposal (t-Hg)
Non-ferrous metal smelting facility	Wastewater treatment sludge	N/A	1.5
	Slag, etc.	N/A	0.45
	Other waste	N/A	0.42
Coal-fired power plant	Fly ash	200,000	0.030
	Flue gas de-sulphurised gypsum	11,000	0.0045
	Sludge	60,000	0.38
Coal-fired industrial boiler	Coal ash	23,000	0.0025
	Flue gas de-sulphurised gypsum	3,200	0.0036
Primary iron-manufacturing plant	Desulfurization sludge	2,464	0.021
	Wet dust	3,602	0.0026
Secondary iron-manufacturing plant	Precipitator dust	58,773	0.12
Oil and natural gas processing facility	Wastewater treatment sludge	640 or more	N/A
Municipal solid waste incineration facility	Incineration residue	3,054,279	2.6
Industrial waste incineration facility	Ash dust	N/A	2.2
	Cinders	N/A	Small amount
		Total	7.8

Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

Mercury emissions and releases

Mercury emissions to the atmosphere (g/year) are estimated using two methods:

- $Flue\ gas\ emission\ volume\ (m^3/year) \times Mercury\ concentration\ in\ flue\ gas\ (g\_Hg/m^3)$
- $Activity\ rate\ (t/year) \times Mercuryemission\ factor$

Table 20 summarizes the mercury emissions from each source category in Annex D.

Table 20 Mercury emissions to the atmosphere

Source category	Emission source		Emission (t-Hg/year)
Sources listed in Annex D of the Minamata Convention	Coal-fired power plants		1.3
	Coal-fired industrial boilers		0.22
	Smelting and roasting processes used in the production of non-ferrous metals		1.4
	Waste incineration	Municipal solid waste	1.5
		Industrial waste	2.4
		Sewerage sludge	1.4
	Cement clinker production facilities		5.4
Subtotal			14

Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

Mercury releases to water is obtained from interviews with business organizations involved in processing/industrial use of raw minerals and manufacturers of mercury-added products, in addition to the data obtained from the Japanese PRTR (Table 21).

Table 21 Mercury releases to water

Release source	Release (t-Hg)	Information source
Processing/industrial use of raw minerals	0.060	Interviews with industries
Production process of mercury-added products	0	Interviews with industries
Mercury recovery process *1	0.00029	Interviews with industries
PRTR (Notification amount + Estimation of amount not subject to notification due to threshold) *2	0.14	PRTR
Total	0.20	

Notes:
*1: Includes releases from the treatment of wastewater from mines.
*2: Releases from "non-ferrous metal production" are excluded from the PRTR data to avoid the double-counting with processing/industrial use of raw minerals.
Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

Mercury releases to land shown in Table 22 refers to the amount of mercury released to land from the portion that either comes in direct contact with, or gets mixed with soil, or is utilized by directly spreading over the soil (e.g., Sewage sludge used as compost).

Table 22 Mercury releases to land

Release source	Release (t-Hg)	Information source
Coal-fired power plants (fly ash)	0.41	Interviews with industries
Coal-fired industrial boilers (coal ash)	0.049	Interviews with industries
Other (sewage sludge)	0.12	Interviews with industries
Total	0.58	

Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

4.6 Survey design and example

The development of a mercury material flow requires comprehensive data collection to quantify each flow. There are several approaches to obtain such information.

- Statistics
- Interviews with stakeholders
- Existing literatures
- Questionnaire survey

Statistics and interviews with stakeholders

The mercury content in imported raw minerals and fuels (t-Hg/year) is calculated from the amount of imported raw minerals and fuels (t/year) multiplied by the mercury concentration (g/t). The data used for the amounts of imported raw minerals and fuels is from the Trade Statistics, and Electric Power Survey Statistics of the Agency for Natural Resources and Energy. The mercury concentration information is collected from research data and interviews with stakeholders.

$$\begin{aligned}&Mercury\ content\ in\ imported\ raw\ minerals\ and\ fuels\\&\qquad = Amount\ of\ imported\ raw\ minerals\ and\ fuels \times Mercury\ concentration\end{aligned}$$

The amount of imported/exported elemental mercury relies on the HS code. The mercury content and concentration in imported coal were determined using a mixture of different data collection methods, such as the trade statistics and interviews with stakeholders.

The mercury content in produced or traded products is calculated from the amount of trade or produced products multiplied by the mercury content of each product, and these data have been collected through interviews with product manufacturers. Another example of specific information gained from interviews with stakeholders is the mercury used for domestic production, and mercury contents in the imported and exported products, for different types of mercury grouped by product category.

Interviews with stakeholders

Interviews with industries are direct means of obtaining relevant information for mercury flow development. Such interviews cover items including the amounts of mercury used for manufacturing products, the amounts of mercury in the imported/exported products, and mercury emissions/releases to the environment through the manufacturing processes. Usually, different ministries supervise particular industries, thus coordinated contact with the relevant industries is important. The following diagram (Figure 8) shows an example in Japan.

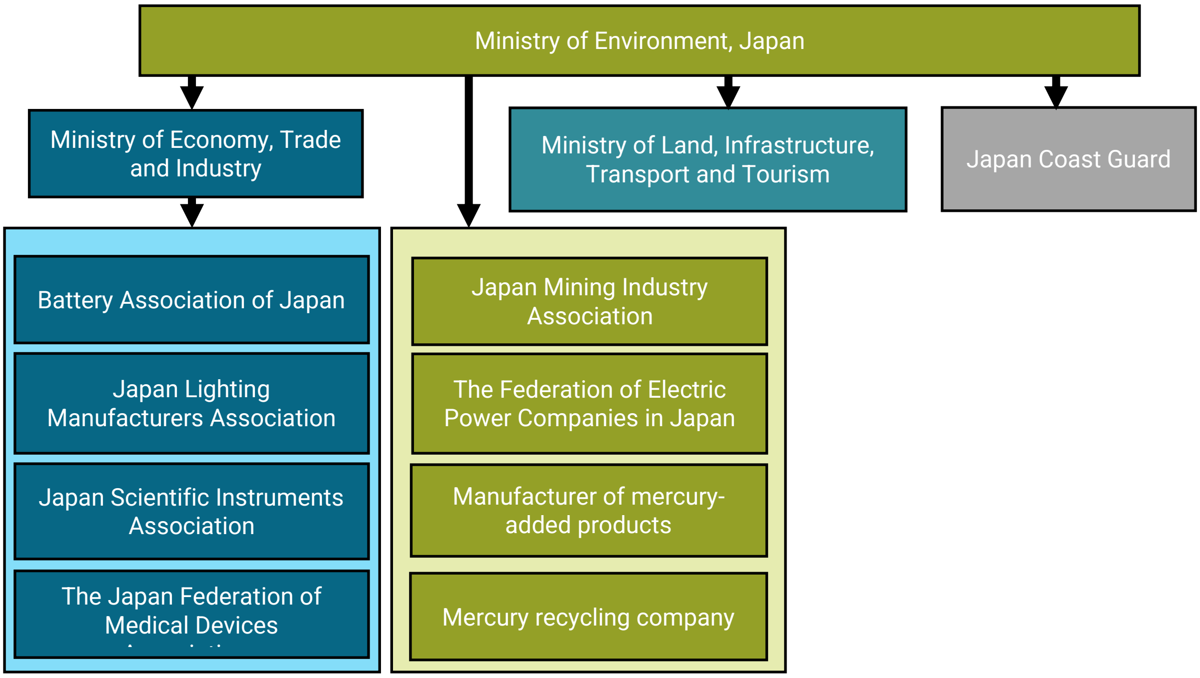


Figure 8 Data collection by interviewing stakeholders

The following information in Table 23 was obtained through interviews with the industries.

Table 23 Information obtained through interview with stakeholders

Product Category		Hg used for domestic production (t-Hg)	Period	Hg in imported products (t-Hg)	Hg in exported products (t-Hg)	Period
Button batteries	Alkaline manganese	0	CY2016	Unknown	0	FY2016
	Zinc silver oxide	0.12	CY2016	0	0.11	FY2016
	Zinc air	0.010	CY2016	0.61	0.025	FY2016
Mercury containing dry cells		0	CY2016	Unknown	0	FY2016
Switches and relays		0.44	FY2016	Unknown	0.33	FY2016
Lamps	Fluorescent lamps	0.81	FY2016	0.13	0.017	FY2016
	HID lamps	0.31	FY2016	0.074	0.15	FY2016
	Neon lamps	0.017	FY2016	Unknown	Unknown	FY2016

Product Category		Hg used for domestic production (t-Hg)	Period	Hg in imported products (t-Hg)	Hg in exported products (t-Hg)	Period
Measuring devices	Glass mercury thermometers	0.21	FY2016	0.0050	0.019	FY2016
	Mercury-filled thermometers	0.011	FY2016	Unknown	Unknown	
	High temperature diaphragm seal manometers	0.021	FY2016	Unknown	Unknown	
	Reference liquid column manometers	0.0030	FY2016	0	0	FY2016
	Liquid column barometers	0	FY2016	Unknown	0	FY2016
	Vacuum gauges	0.049	FY2016	Unknown	Unknown	
Medical measuring devices	Mercury thermometers	0	FY2016	0.062	0	FY2016
	Sphygmomanometers	0.56	CY2016	0	0.48	CY2016
Dental mercury		0	FY2016	0	0	FY2016
Pharmaceuticals	Vaccine preservatives	0.00016	FY2016	0.00013	0	FY2016
	Merbromin solution	0.010	FY2016	0	0	FY2016
	Products containing merbromin solution	0.00077	FY2016	0	0	FY2016
Inorganic chemicals	Vermilion (mercury sulphide)	0.91	FY2016	Unknown	Unknown	
	Mercury compounds	0.044	FY2016	Unknown	Unknown	
Total		3.5		0.88	1.1	

Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

Existing literatures

Using existing literature, such as the mercury emission inventory developed by Ministry of the Environment, Japan is another option. In Japan, mercury emissions to the atmosphere (g/year) are estimated either by the amounts of flue gas emissions (m^3/year) multiplied by the mercury concentration of flue gas (g/m^3), or the activity rate (g/year) multiplied by the mercury emission factor. Both the amounts of flue gas emissions and activity rate are data obtained from industries, while the mercury concentration of flue gas and emission factor rely on monitored and researched data. This type of information is compiled and integrated into the mercury emission inventory and mercury material flow, which have been periodically published by the Ministry.

Questionnaire survey

In Japan, a questionnaire survey for waste treaters was employed to gather information about mercury recovery or relevant emissions, and mercury releases to the environment in the waste processing. The questionnaire survey focused on the waste treatment companies who have a license to treat industrial mercury waste.

The questionnaire received 179 responses from about 293 targets, resulting in approximately 61% of response rate. The questions included the types and amounts of waste mercury added to the products treated, the purity of the elemental mercury recovered from waste, how to handle the mercury recovered from waste, and the types of waste treated other than mercury added products, as summarized in Table 24. The data demonstrated that mercury was recovered from different types of mercury waste, and also showed how much mercury was recovered from different types of waste of mercury-added products. The origins of recovered mercury were the industrial waste and municipal waste.

Table 24 Mercury recovered from waste mercury-added products (FY2014, actual values)

Discarded product type	Intermediate treatment* (t)		Recovered mercury (t)	
	Industrial waste	Non-industrial waste	Industrial waste	Non-industrial waste
Button batteries	20.837	0.084	0.042	0
Dry cell batteries	1,428.224	11,215.069	0.029	0.224
Switches & relays	13.214	0	0.13	0
Fluorescent lamps	7,384.3	4,477.318	0.226	0.179
Cold cathode fluorescent lamps	58.193	0	0.002	0
HID lamps	122.015	0.473	0.012	0
Lamps (mixed)	2,386.122	0	0.087	0
Measuring devices for industrial use	0.657	0	0.096	0
Mercury thermometers	3.931	0.318	0.289	0.031
Sphygmomanometers	13.125	0.824	0.63	0.041
Total			1.544	0.475

Note: * Intermediate treatment of waste includes crushing/sorting, incineration melting, cement solidification, mercury sulphuration and mercury recovery
Source: Japan, Ministry of the Environment (2020). Overview of mercury material flow in Japan (FY2016).

Comparison of data collection methods

The advantages, disadvantages, and limitations of different methodologies are summarised in Table 25:

Table 25 Advantages, disadvantages and limitations of different data collection methods

	Advantage	Disadvantage	Limitation
Statistics	- High credibility - Nationwide data coverage	- Data is modified irregularly due to the changes in data collection and compilation methods.	- Availability of data
Interviews with stakeholders	- Efficient data collection	- Industry associations may not always have relevant data of affiliated companies. - Individual companies may not accept interviews. - Time-consuming	- Can only be used if relevant associations exist and collect data necessary for the mercury material flow. - Interviews with association or individual company may not cover the nation-wide situation.
Existing literatures	- Efficient data collection - Less resource-intensive	- Period of data coverage may be different depending on literatures. - Some values need to be treated as reference values for limited samples.	- Availability of literatures
Questionnaire surveys	- Comprehensive data collection	- Data collection and compilation are resource intensive. - Response rate may not be high.	- Can only be undertaken if there is enough time and human resources.

It is important to plan to secure enough resources, including human resources and time when planning for data collection. Recently in Japan, the mercury material flow has been developed every three years. Developing a roadmap including the target facilities and the data collection methods was undertaken in the first year. The information sources for data collection and concrete estimation method to estimate the mercury flow were developed in the following two years based on the roadmap. Therefore, it is necessary to plan well ahead.

The development of the flow is a resource-intensive work. Therefore, it is necessary to understand which information is available or mission to realise efficient data collection. By building upon available information, the survey should be able to have a strategy to secure resources to fill the data gaps.

If data collection is started without having an outlook on the estimation method, it may become necessary to return to the data collection step in the last stage. Therefore, identifying an estimation method before data collection is highly recommended for efficiency. Sometimes, combining different methods is effective to address the cases where uncertainty arises.

Coordination or cooperation with relevant departments and ministries is important for the data collection. Each department or ministry administers different sectors and stakeholders. Better coordination results in better information.

Alternative approaches should be considered if data cannot be obtained because relevant industry association does not exist in the country, or if it exists but does not have relevant data. It will be important to learn from other countries experiences, such as Japan's mercury material flow, or learn from material flows of other substances.

Inputs from experts will enhance the credibility of the flow, so consulting with relevant experts is particularly useful when data uncertainty arises. Formulating an expert committee on the material flow is useful to ensure the transparency of the results especially if the flow will be published by a government agency.

4.7 Example to address uncertainty

Table 26 shows a hypothetical example on considering uncertainties and intervals. It provides a good illustrative case study of how to handle data, uncertainty and ranges. Due to the severe competition, many manufacturers do not wish to indicate their own consumption. However, they are sometimes willing to provide an estimate of the total consumption for the field of application. This indicates that the exact values of internal data are often part of business confidentiality, but estimated market values are more openly discussed.

Table 26 Example to address uncertainty

Case
General introduction This box describes an example of the collection and evaluation of data from manufacturers. The example is hypothetical, but may be considered representative of the type of assessment to be carried out as part of substance flow analyses for chemical substance at the national level. Based on statistical information, the annual consumption of the substance X for manufacturing of products in Denmark is known to be approximately 1,500 tons. It is also known that this consumption is distributed over the fields of applications A, B, C, D and E. The task is to determine the flows as precisely as possible. For the field of application A, the Danish Technological Institute informs that three large-scale manufacturers exist in Denmark each of which has a market share of 20-30 % besides five to six small-scale manufacturers. It is decided to collect information from the three large manufacturers as well as two small ones. Due to severe competition, most manufacturers do not wish to indicate their own consumptions. However, they are willing to provide an estimate of the total consumption for the field of application A in Denmark. The following information is obtained: Manufacturer 1: Total consumption estimated at 200-250 tons Manufacturer 2: Total consumption estimated at 200-300 tons Manufacturer 3: Total consumption estimated at approximately 250 tons Manufacturer 4: Own consumption approx. 2 tonnes. Market share estimated at 5-10 % Manufacturer 5: Total consumption estimated at 100-200 tons As the manufacturers 1-3 are the 'large-scale' manufacturers, they are presumed to have a better impression of the market than the manufacturers 4-5. The preliminary figure for the consumption within the field of application A is therefore estimated at 250 tons with an inaccuracy of ± 50 tons. The final figure can only be determined when information has been collected for all the fields of applications A-E. The total consumption estimated on the basis of the information collected from the manufacturers amounts to 1,500-1,800 tons. As the statistical information is considered to be reasonably reliable (at any rate, more reliable than much of the information obtained from the manufacturers), the total consumption for the fields of applications A-E is estimated to be approximately 1,500 tons. Consequently, the information for each field of application has to be re-evaluated in order to find out where there is any estimate that may be too high. As a result of this re-evaluation, it is decided to change the estimate for field application A to approximately 200 tons with an inaccuracy margin of ± 50 tons.

Source: Lassen and Hansen (2000). Paradigm for substance flow analyses.

4.8 Report preparation: principles and processes

Reporting principles

It is important to highlight the key data needed for mass flow in the report. The activity rates coming from import, production, and export data, as well as any local input factors and output distribution factors should be presented. Associated information may be annexed to the main report with full references for example:

- Personal contacts: Institution's name, institution's city, contact person, date of contact
- Literature: Author, year of publication, title of publication, institution or publisher, city, country

Data uncertainty should be discussed in the report as transparent as possible. It is a good scientific principle to discuss the uncertainty for the benefit of the readers. The best available approximation is much better than omitting data with uncertainty. The data gaps should also be reported so that the readers can differentiate between assessed zero and no data obtained. In the report, explicit expression of 'no data' should be placed instead of leaving table cells empty.

Finally, full references to all the data used are presented in the report. This is important for following up the results and updating the information. It also informs the global community that the data in the report is valuable and reliable.

Chapter outlines

The document should be prepared in a logical sequence. An indicative structure of the report is shown in Table 27. Firstly, the mercury source in question is introduced briefly. Then, the hard facts obtained during the research are presented. They will include quantitative figures on import, export, production, output scenarios on which mercury controls are installed, output distribution factors, input factors and so fourth.

In most cases, the hard facts will be incomplete and supplemented by indicative evidence. For example, trade data for liquid-filled thermometers in the statistics do not say whether they contain mercury or not. Thus, the indicative evidence is the interview with importers to estimate how much of the statistical figures actually consist of mercury-filled thermometers. The indicative evidence will include partial data, assumptions, approximations and extrapolations, unit conversions and so on, which should be explained very explicitly.

The next section discusses the data used in the calculations with sufficient judgement based on the information assessed. The report is concluded with the data gaps to indicate the weakness of evidence and for future follow up.

Table 27 Indicative structure of mercury flow analysis report

Chapter	Content	Remarks
General introduction		
Hard facts for national situation	- Activity rates: Import, production, export - Output scenarios (filters, etc.), output distribution factors - Input factors (mercury content/concentration)	- Data and observations
Indicative evidence	- Partial data - Assumptions - Approximations and extrapolations - Unit conversions	- Report very explicitly
Discussion and assessment on data to use in calculations	- Conclude by choosing and listing data to be used	
Data gaps for future follow up		

Review by stakeholders and feedback incorporation

Once the report is drafted, it is recommended to have it reviewed by stakeholders and incorporate useful feedback into the report. Selected resource persons with relevant expertise in key internal stakeholders such as organizations composing of the mercury mass flow developing team will be invited for review.

In some cases, external key stakeholders such as industrial associations may also be invited for review before publication. They may provide additional useful information or at least their standpoints to the results. The feedback does not have to be reflected in full, but useful and reliable feedback can be incorporated into the report.

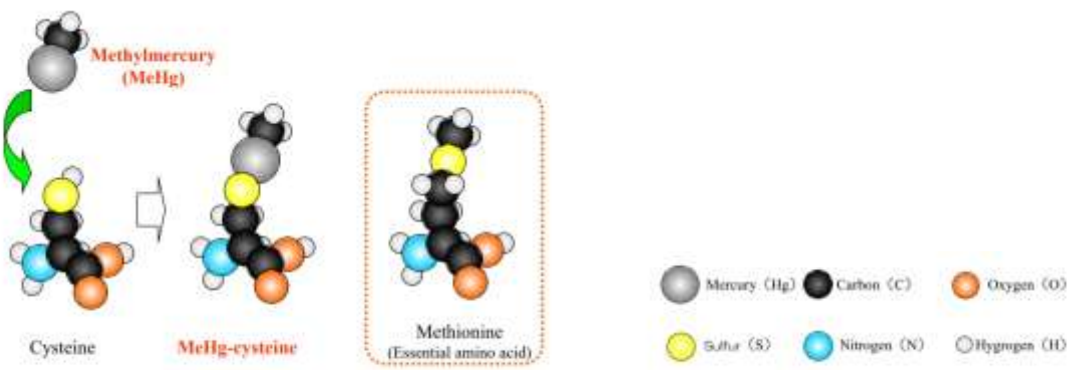
4.9 Physical and chemical properties, usage, and environmental behaviours of mercury

Physical and chemical properties of mercury

Mercury is a chemical element that exists in various forms with unique physical properties. With an atomic number of 80, which is next to gold, mercury is the only metal element that exists in liquid form at normal temperatures. In addition, mercury has a low boiling point among metallic elements, and it is volatile with a high vapour pressure. The abundance of mercury in Earth's crust is similar to that of silver, but mercury has a much lower market price than precious metals.

Table 28 Physical properties of elemental mercury

Physical properties
Atomic number: 80
Atomic weight: 200.59
Melting point: -38.8 °C
Boiling point: 356 °C
Specific gravity: 13.6 at 0 °C
Thermal conductivity: 8.3 W/m°C
Saturated vapor concentration: 13.2 mg/m3 at 20 °C
Abundance in Earth's crust: 0.05 - 0.08 ppm
Emission spectrum at ultra-violet band: 254 nm (UV-C)
Forming amalgam with many metallic elements



Source: Japan, National Institute for Minamata Disease (2013). Mercury and health V4.1.

Figure 9 Molecular similarity of methylmercury-cysteine complex and methionine

Methylmercury is a mercury compound of great concern due to its high toxicity. Methylmercury binds cysteine, a kind of amino acid, to form a complex with a molecular structure similar to methionine, an essential amino acid (Figure 9). Due to this similarity, the complex is actively absorbed via an amino acid transporter. Then, it is incorporated into body tissues made of protein including the brain and fetus.

Most mercury and mercury compounds have certain toxicities, but their biological behaviours and toxicity levels differ. Main exposure pathways, symptom and treatment for three types of mercury and mercury compounds are shown in Table 29. The absorption rates of inhaled elemental mercury and ingested methylmercury are very high, while the absorption rate of inorganic mercury is rather low. Ingested elemental mercury is usually directly excreted without absorption. Absorbed mercury is gradually oxidized and excreted in urine as inorganic mercury. Elemental mercury passes through the blood-brain barrier and causes mercury poisoning of the central nervous system. Accidental high-level exposure to mercury vapour in the workplace can be fatal, but acute symptoms are usually reversible. The symptoms of chronic low-level exposure to elemental mercury were known as mad hatter's disease. Methylmercury is transported actively to form body tissues made of protein. The adverse effects depend on the body parts into which methylmercury is incorporated. Ingested inorganic mercury causes inflammation of the digestive tract and kidney damages if the amount is very high. Acute mercury exposure is usually treated by stimulating the excretion. For chronic exposure, stopping exposure is the most important measure.

Table 29 Exposure pathway, symptom and treatment

	Elemental Mercury	Inorganic Mercury	Methylmercury
Exposure pathway (absorption rate)	- Inhalation (75-85%) - Ingestion (0.01% or less).	- Ingestion (5-10% or less) - Dermal (not expected to be high).	- Ingestion (90% or more)
Behaviour and fate	- Unoxidized form passes through blood-brain barrier (by diffusion) - Gradually oxidized to divalent inorganic mercury	- Excreted in urine	- Passes through blood-brain and placenta barrier (by amino acid transportation) - Gradually oxidized to divalent inorganic mercury

	Elemental Mercury	Inorganic Mercury	Methylmercury
Symptom	- Respiratory distress - Central nervous system effects (tremor, personality change, tooth pain, excessive salivation) - Referred to as 'mad hatter's disease'	- Corrosion in digestive tract (vomiting, chest pain, abdominal pain, and bloody diarrhoea) - Kidney damage - Renal insufficiency	- Central nervous system effects (sensory nerve dysfunction, ataxia, and constriction of visual field) - Fetal exposure (non-specific cerebral palsy-like features)
Treatment	- Stimulation of mercury excretion	- Gastric lavage, excretion with chelating agent	- No effective treatment

Source: Japan Public Health Association (2001). Preventive Measures against Environmental Mercury Pollution and Its Health Effects.

Mercury products and uses

Mercury is one of a few elements known since ancient times. It has been used for various purposes for many thousands of years as shown in Figure 10. Red pigments and the preservation of corpses are among the oldest applications. The demand of mercury has increased as new uses have been invented over time. The supply side, that is, mercury mining, has also been well developed to support the demand for mercury. Today, some mercury-added products and processes have been replaced by non-mercury alternatives, but many are still widely used globally. The Minamata Convention controls the products and processes stipulated in the Annexes, but even after phase out, mercury waste will continue to be generated for a long time. Thus, proper management of mercury waste is very important.

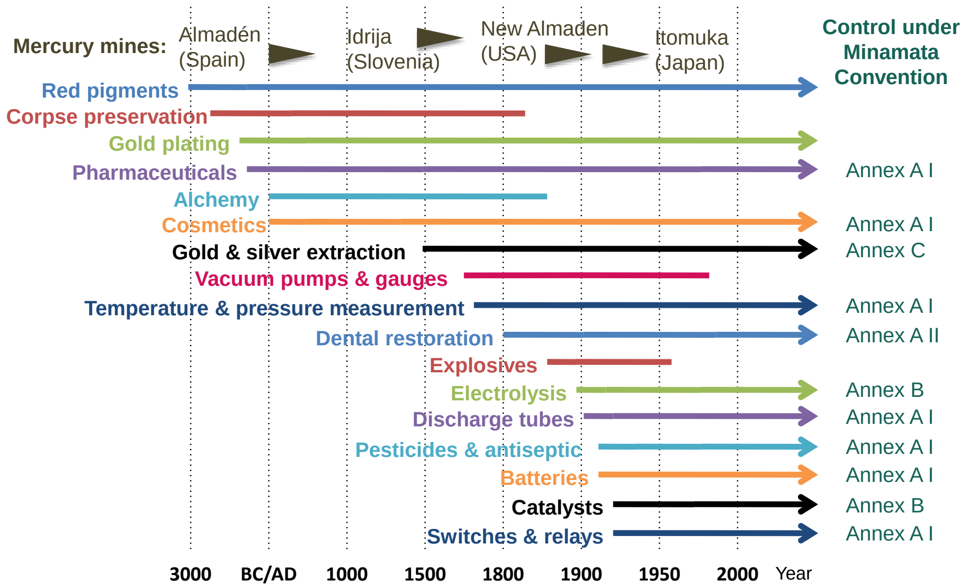
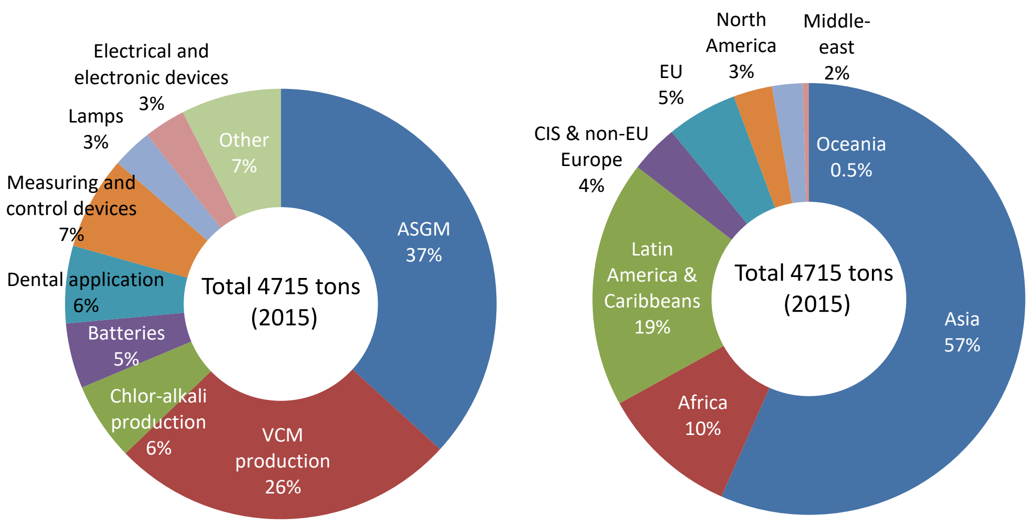


Figure 10 Historical mercury supply and use

As shown in Figure 11, global mercury use is estimated to be approximately 4700 tons per year as of 2015. Artisanal and small-scale gold mining is the largest mercury consumer, and Asia, Africa, Latin America and the Caribbean are the regions consuming a large amount of mercury.



Source: United Nations Environment Programme (2017). Global mercury supply, trade and demand.

Figure 11 Global mercury uses by sector and by region

Use of elemental mercury

Elemental mercury is used for measuring purposes. As a high-density liquid, it is suitable for measuring pressure. Devices such as manometers, barometers, and sphygmomanometers, enable precise pressure measurement without using electricity. For official purposes, "mmHg" or "inHg" can still be used as non-SI units of measurement. Mercury is also useful for measuring temperature because it exists in liquid form in a wide temperature range (-38.8 °C to 356 °C). As a metallic element, mercury has high a thermal conductivity, which provides a quick response. These mercury-added measuring devices are subject to phase out under the Minamata Convention.

A discharge tube is an electronic device that contains gas or vapour at low pressure, and through which conduction takes place when a high voltage is applied. The mercury arc rectifier was an important device for converting high voltage alternating current (AC) to direct current (DC). As modern electricity supply networks were developed with AC, rectification was required if the industry required DC. Today, this function is mostly performed by power semiconductors. Several gaseous elements, including mercury vapour, emit various wavelengths of light. Mercury discharges ultra-violet ray (UV-C) which is invisible to humans. As UV-C damages DNA, mercury vapour lamps are used for microbial disinfection. Fluorescent lamps convert UV-C to visible light for lighting applications. The light emitted from discharge tubes are also used for various lighting applications, such as indoor and outdoor lighting, signage, and the headlamps of vehicles.

As mercury is electrically conductive, it is used for various electric controls. The mercury switch has several advantages for closing and opening electrical circuits. As the contact surface is concealed, no oxidation occurs, and the surface remains clean with a low resistance due to the wetting nature of mercury. Application includes: tilt switches to activate lights on the boot lids of vehicles, rollover warning device for vending machines, anti-lock braking systems that detect acceleration force, high-speed switch as mercury relay does not cause chattering, and mercury slip rings that transmit signals or power to devices over 360° of rotation.

Mercury is added to batteries for safety purposes to prevent hydrogen gas generation. Abnormal reactions at the zinc anode causes cell rupture or leakage, but mercury inhibits such abnormal reactions. Although most dry cells have stopped using mercury, a few types of button cells still use mercury for this purpose. Lithium coin cells do not use water as the electrolyte, so no mercury is added.

Elemental mercury is also used for many other purposes. Some are being phased out as non-mercury alternatives are becoming increasingly available. It is important to be aware that not all uses of mercury are subject to the Minamata Convention, so legitimate uses of mercury will remain. The applications of elemental mercury are summarized in Table 30.

Table 30 Applications of elemental mercury

Type	Theory / Principle	Application	Remarks
Measuring devices	- High density liquid	- Manometer (pressure in system, facility, etc.) - Barometer (atmospheric pressure) - Sphygmomanometer (blood pressure)	- No electric supply required. - No equivalent alternative for high temperature devices. - Extensively used for measuring blood pressure.

Type	Theory / Principle	Application	Remarks
Ditto	- Liquid in wide temperature range - High thermal conductivity	- Thermometer (temperature) - Hygrometer (wet bulb, relative humidity)	- No electric supply required. - Quick response. - No equivalent alternative for high temperature device.
Discharge tubes	- Electric valve effect	- Mercury arc rectifier (rectifying high voltage AC to DC)	- Large power supply capacity for industries requiring DC. - Largely replaced by power semiconductors.
Ditto	- Emitting UV-C (254nm)	- Neon lamp (signage, display) - Fluorescent lamp (lighting) - High-pressure discharge lamp (projection, lighting, sun tanning, headlamp of vehicles) - Low pressure mercury vapour lamp (disinfection)	- No filament in bulb, long life. - UV-C emitting efficiency is higher than LED.
Switches and relays	- Electrically conductive liquid - Wetting effect on contact surface	- Tilt switch/alarm (activating lights for boot lids of vehicles) - Acceleration censor (anti-lock braking systems) - Mercury-wetted relay (power/signal transmission for 360° rotating devices)	- Low resistance and no chattering at contact surface. - Allows high frequency switching.
Batteries	- Hydrogen overpotential	- Button cell (preventing hydrogen gas generation at zinc anode)	- Lithium coin cell does not use water, thus no mercury is added.
Vacuum pumps	- High density liquid - Air induction	- Mercury column pump (1Pa) - Mercury rotary pump (10^{-2}Pa) - Mercury diffusion pump (10^{-3}Pa)	- Replaced with oil-based fluid.
Balancers	- High density liquid	- Wheel balancer - Trim and heel controller (submarines)	- Non-mercury (solid) balancers are available.
Laboratory instruments	- High surface tension	- Porosimeter	- Used to analyse porosity of material surfaces.
Fluid bearings	- High density liquid	- Lighthouse rotation unit	- Floating Fresnel lens.
Electric conductors	- Electrically conductive liquid	- Slip ring (360° rotation)	- Brushless contact.
Mirrors	- Liquid with high reflectance	- Liquid zenith telescope	- Rotating mirror to form paraboloid mirror.
Propellants	- Easy ionization	- Ion thruster (satellites)	- Replaced by xenon.

Use of amalgam

Mercury can form various alloys with other metals, which are called amalgam. Amalgam has been an important material for many industries as final products or in production processes. Dental amalgam is a mixture of silver and tin powder, which is gradually hardened to fill dental cavities. Tin amalgam was used for the reflective surfaces of mirrors.

Gold and silver extraction and refining have been practised for many thousands of years. The oldest method called cupellation used lead and was invented in BC era. There was a risk for lead poisoning with this method. The amalgamation method was then invented in the 16th century, when silver mining in Latin America was at its peak. Due to the melting and boiling points of mercury being lower than those of lead, the consumption of heat sources, i.e., firewood, was reduced, which preserved forests in the region. The amalgamation method for ASGM accounts for the largest usage of mercury today and disproportionally affects marginalised and less privileged groups. The cyanide method was invented in the late 19th century during the Gold Rush era. This method is currently predominantly used for large-scale gold mining operations, but its application to ASGM is being explored.

NaCl, which is the chemical form of edible salt, can generate chlorine gas and caustic soda by electrolysis. Caustic soda is used for manufacturing products such as soap and glass, and chlorine gas is used for producing disinfection and bleaching agents as well as PVC. Mercury is used as the electrode for the mercury-cell process, which was invented in the early 20th century and still is used in some countries. Chlorine ions are oxidized at the anode and become chlorine gas. On the cathode side, where mercury is used, sodium ions are reduced to metallic sodium, which forms an amalgam with mercury. The sodium amalgam is then sent to an amalgam decomposer, where caustic soda is formed. The key to this electrolysis process is blocking sodium back-flow to the anode side. The diaphragm process physically blocks this backflow with the fibrinous structure of asbestos. This system is still used, but the risk of asbestos is a concern. The membrane process has a similar configuration to the diaphragm process, but an ion exchange membrane allows the selective permeation of sodium ions to the cathode side, which is more energy efficient and avoids toxic substances.

Special applications of amalgam includes low-temperature thermometers with thallium amalgam, which is melting temperature of approximately minus 60 °C. However, mercury is problematic in the oil and gas sector. Mercury erodes aluminium equipment, such as heat exchangers, and inactivates palladium-based catalysts. The applications of amalgam are summarized in Table 31.

Table 31 Applications of amalgam

Type	Theory / Principle	Application	Remarks
Dental filling	- Gradually hardening after mixing	- Dental cavity restoration (filling silver tin amalgam into dental cavities)	- No electric supply required. - Mercury waste is released into drainage. - Mercury is gradually vapourised in the mouth.
Gold/ silver industry	- Absorption of metallic elements - Low boiling point	- Gold/silver extraction (predominantly used for ASGM) - Gold plating (gold amalgam is smeared on metallic surface and then heated)	- Workers and some community members are exposed to mercury vapour. - Cyanide method is an alternative for extraction but requires higher management skill.
Mirror surfaces	- Gradually hardening after mixing	- Mirror (tin amalgam forms the reflective surfaces)	- Replaced by silver mirror reaction.
Electrolysis	- Absorption of metallic elements	- Chlor-alkali production (separating sodium from brine after electrolysis)	- Ion exchange membrane process is an alternative with a higher energy efficiency.
Measuring devices	- Low temperature alloy	- Low temperature thermometer	- Melting temperature of thallium amalgam is -60°C.
Oil and gas (problematic)	- Creating unwanted amalgam	- Aluminium equipment (eroding surface of equipment) - Palladium catalyst (inactivating the catalytic function)	- Mercury removal process should be installed in the system.

Use of mercury compounds

Mercury sulphide is naturally found as cinnabar, which exists as blood red crystals or dark red stones. Red is one of the oldest colours that humans have intentionally used since the pre-historic era. Three major red pigments have been used. Iron oxide provides brownish red, and is easily available from red clay soil. By contract, mercury sulphide needs laborious refinement from ore, so it was an expensive pigment. It can also be synthesized from mercury and sulphur. Due to its preciousness, mercury sulphide was used for more important occasions, such as ceremonial and religious purposes. Lead oxide is also a synthesized pigment with a bright orange colour.

Cosmetics also use colour, which are predominantly consumed by women. Red, white, and black are the three base colours for cosmetics. Red pigments, such as cinnabar, were used for bodypainting in some indigenous societies. More broadly, white face powder has been used for makeup. Calomel, mercury (I) chloride, is a white powder used for such purposes. Other chemicals, including lead white and talc, have also been used. Lead poisoning by face powder was problematic in the past few centuries. Currently, concerns have been raised about talc, which contains asbestos as an impurity. Mercury use for skin-whitening cream is another concern, as it is still widely used globally. The preference to lighter coloured skin is still prevalent in many countries where the skin care industry keeps feeding illegal products into market.

The 'biocidal action' of mercury is used for fungicides and preservatives. Organic mercury compounds such as phenylmercury have been used for seed dressing, as fungicides for crops such as rice and wheat. Among inorganic mercury compounds, mercury chloride has been used for wood preservation and red mercury oxide has been used for anti-fouling ship paint. In some products that are directly applied to humans, mercury compounds are still used as preserving agents. For example, thiomersal preserves vaccines at normal temperatures, which is important when providing vaccines to remote areas where no cold chain is available.

Mercury has been used in pharmaceuticals since ancient times. Traditional Chinese and Ayurveda medicines still include mercury products. One of the most significant historical uses of mercury for pharmaceutical purposes is the treatment of syphilis patients. Syphilis emerged in the late 15th century and rapidly spread over the globe. Many types of mercury compounds were used for medical treatment from the 16th century until being replaced by penicillin in the 1940s. Mercurochrome is a water solution of the organic mercury compound merbromin, which was invented in the early 20th century and has been widely used for treating minor wounds. Its less painful nature and cheap price allowed various applications in both clinical and household settings. Mercury inhibits the growth of microorganisms. This characteristic has been used for many preservation and antiseptic purposes.

A catalyst is a substance that facilitate or accelerates a chemical reaction, but its form remains unchanged. The elements in the zinc group, which includes mercury, have been used as catalysts for organic synthesis, particularly for the production of vinyl polymers by accelerating addition reactions from acetylene. The catalysts form intermediate compounds to promote addition reactions. Minamata disease was caused by the mercury catalyst, mainly mercury (II) sulphate, used for acetaldehyde production, which was methylated in the factory and then released into the environment. To avoid the use of mercury, ethylene can be used for the feedstock instead of acetylene. Another type of catalyst is the initiator for polymerising polyurethane elastomer, called latent catalyst, which triggers the process in moulded products or coatings. There are many types of mercury and non-mercury catalyst used as the latent catalyst, among which phenylmercury acetate is commonly used for this purpose. Although mercury acts as a catalyst for this process, it remains in the final product.

Batteries, especially chemical batteries utilize the oxidation and reduction of chemical compounds to store electricity. The mercury cell is a type of battery that has mercury oxide cathode. Once electricity is consumed, mercury oxide is reduced to metallic mercury, which flows out of the cathode. This product is subject to phase out under the Convention. However, mercury use for research, calibration, and reference is exempt from the Convention, so standard cells such as the Weston cell are not subject to phase out.

Various mercury compounds are used for many other purposes. One of historical uses is mercury (II) nitrate for hat making. A process called 'carroting' was extensively used for the preparation of felt. Mercury (II) fulminate was also an important mercury compound used extensively during wars as a material for the detonation caps of explosives. A new use has been examined for mercury (II) sulphide for the final disposal of mercury waste because stabilisation is required in some countries to dispose of mercury. The applications of mercury compounds are summarized in Table 32.

Table 32 Applications of mercury compounds

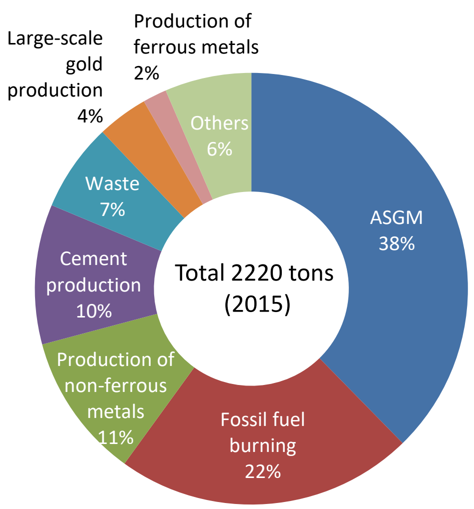
Type	Theory / Principle	Application	Remarks
Mercury sulphide/ cinnabar	- Low solubility and stable chemical form. - Reddish colour	- Red pigment (vermillion refined from cinnabar or synthesised from mercury and sulphur). - Bodypainting (ancient indigenous custom) - Waste mercury (stabilisation for final disposal)	- Iron oxide (brownish red ochre) and lead oxide (bright orange red) have also been used.
Mercury (I) chloride / calomel	- Bactericidal & fungicidal actions - White colour - Stable electrode potential	- Pharmaceuticals (syphilis) - White face powder - Saturated calomel electrode	- Lead white (lead poisoning), talc (contaminated with asbestos). - Silver chloride reference electrode is an alternative.
Mercury (II) oxide	- Forming liquid mercury once reduced - Biocidal action	- Battery (cathode for mercury cell) - Antifouling paint for ship's bottom	- Mercury cell has been replaced with non-mercury alternatives. - Replaced with copper-based ship paint.

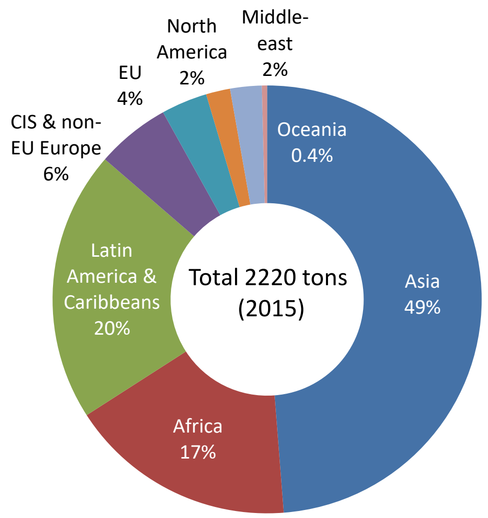
Type	Theory / Principle	Application	Remarks
Mercury (II) sulphate	- Forming intermediate with acetylene - Forming liquid mercury once reduced	- Catalyst (acetaldehyde production) - Weston standard cell (producing highly stable voltage for calibration)	- Acetylene-based acetaldehyde production has been replaced with ethylene-based system.
Mercury (II) nitrate	- Fulling fur	- Carroting (preparation of felt)	- Extensively used for hat making in the 19th century.
Mercury (II) chloride	- Bactericidal & fungicidal actions - Water solubility - Reducing silver halide (photo) - Forming intermediate with acetylene	- Fungicide (wood preservation, seed dressing) - Preservative (pulp & paper) - Standard solution (mercury analysis) - Push-processing for photo, motion picture and X-ray films - Catalyst (vinyl chloride monomer production)	- Volatile compound, which sublimates easily.
Ammoniated (II) mercury	- Bleaching effect - Inhibition of bacterial growth	- Skin whitening cream (bleaching melamine) - Antiseptic ointment	- Widely used in developing countries.
Phenylmercury	- Bactericidal & fungicidal actions - Initiating polymerization reaction	- Fungicide (seed dressing against rice blight) - Preservative (for latex paint, pulp & paper) - Latent catalyst (polyurethane elastomer)	- Widely used in paddy fields.
Thiomersal	- Bactericidal action	- Preservative (vaccines and eye area cosmetics)	- Vaccines can be stored at normal temperatures without refrigeration.
Merbromin	- Inhibition of bacterial growth - Water solubility	- Mercurochrome (topical antiseptic for minor wounds)	- Less absorbed from skin surface (due to hydrophilic nature).
Mercury (II) iodide	- Thermochromism	- Thermochromic paint	- Alters crystal structure at certain temperature.
Mercury (II) fulminate	- Explosiveness	- Detonation cap (blasting dynamite, bullet cartridge)	- Replaced by DDNP.
Mercury (II) thiocyanate	- Chemical reaction spewing out ash	- Pharaoh's snake (firework)	- Generates toxic smoke and residue

Mercury emissions and releases and its risks

As a chemical element, mercury has existed on Earth since its creation. Mercury is released from natural sources by processes, such as volcanic activity and permafrost melting. Once released, mercury poses risks to human health and the environment. In recent years, more mercury has been released through human activities, such as the combustion of fuels, mining activities, and the consumption of mercury-added products. Mercury is a trace element found in many minerals and fuels such as coal, natural gas, oil, non-ferrous ore. Mercury emitted to the atmosphere remains for a long time and will be transported long distances. Atmospheric mercury is gradually oxidized and deposited in the ocean or on land. Inorganic mercury in water bodies can be methylated by microbial activity, and bioaccumulated in biota at higher trophic levels. Eventually, fishing brings mercury back to human society through consumption. Excessive exposure to mercury, especially methylmercury, will pose risks to vulnerable population and pregnant women, in particular, as methylmercury actively passes through placenta barrier by amino acid transporter to fetus.

Similar to mercury usage, the largest mercury emission source is ASGM, which disproportionally affects marginalised and less privileged groups, such as children and women of child-bearing age. Asia, Africa, Latin America and the Caribbean are the regions emitting large amounts of mercury as shown in Figure 12. The burning of fossil fuel and the production of cement and non-ferrous metals all remove mercury from the soil and emit it to the atmosphere. More importantly, such mercury by-product might increase with the economic development of developing countries.





Source: United Nations Environment Programme (2019). Global mercury assessment 2018.

Figure 12 Global atmospheric mercury emissions by sector and by region

4.10 Reference literatures and websites

Due to the Minamata Convention, a lot of literatures on mercury data has been published from many countries. The Minamata Convention and the UNEP Global Mercury Partnership provide platforms to access relevant information. Global statistics are available from a few institutions where consistent data retrieval is possible. Information on mercury-free alternatives and phasing out/down of mercury-added products is published by many organizations that are not listed below.

Mercury surveys and statistics

Online databases

International Energy Agency (2022). Data and statistics. http://www.iea.org/statistics/. Accessed 28 April 2022.

United Nations Statistics Division (2022). UN Comtrade database. https://comtrade.un.org/data/. Accessed 28 April 2022.

United States Geological Surveys (2022). International minerals statistics and information. http://minerals.usgs.gov/minerals/pubs/country/. Accessed 28 April 2022.

Assessment reports

Arctic Monitoring and Assessment Programme and United Nations Environment Programme (2019). *Technical Background Report for the Global Mercury Assessment 2018*. Tromsø: AMAP Secretariat, The Fram Centre, and Geneva: UN Environment Programme Economy Division. https://wedocs.unep.org/bitstream/handle/20.500.11822/29831/gma_tech.pdf. Accessed 8 April 2022.

United Nations Environment Programme (2002). *Global mercury assessment.* Geneva: UNEP Chemicals. https://wedocs.unep.org/bitstream/handle/20.500.11822/12297/final-assessment-report-25nov02.pdf. Accessed 14 February 2022.

United Nations Environment Programme (2013). *Global mercury assessment, source, emissions, releases and environmental transport*. Geneva: UNEP Chemicals Branch. https://wedocs.unep.org/bitstream/handle/20.500.11822/7984/-Global%20Mercury%20Assessment-201367.pdf. Accessed 14 April 2022.

United Nations Environment Programme (2017). *Global mercury supply, trade and demand*. Geneva: UN Environment Economy Division. https://wedocs.unep.org/bitstream/handle/20.500.11822/21725/global_mercury.pdf. Accessed 10 February 2022.

United Nations Environment Programme (2019a). *Global mercury assessment 2018*. Geneva: UN Environment Programme Economy Division. https://wedocs.unep.org/bitstream/handle/20.500.11822/27579/GMA2018.pdf. Accessed 10 February 2022.

Inventory development and guidance

Mercury Inventory Toolkit

United Nations Environment Programme (2022). Mercury Inventory Toolkit. https://www.unep.org/explore-topics/chemicals-waste/what-we-do/mercury/mercury-inventory-toolkit. Accessed 28 April 2022.

United Nations Environment Programme (2019b). *Toolkit for identification and quantification of mercury releases, Reference report and guideline for inventory Level 2, Version 1.5, November 2019*. Geneva: UN Environment Chemicals and Health Branch. https://wedocs.unep.org/bitstream/handle/20.500.11822/30684/HgTlktRef.pdf. Accessed 10 February 2022.

United Nations Environment Programme (2019c). *Toolkit for identification and quantification of mercury releases, Reference report and guideline for inventory Level 1, Version 2.1, November 2019*. Geneva: UN Environment Chemicals and Health Branch. https://wedocs.unep.org/bitstream/handle/20.500.11822/30686/HgTlkitIL1.pdf. Accessed 8 April 2022.

National inventories

Christensen C. L., Skårup, S, Maag, J., and Jensen S., H. (2004). *Mass flow analysis for mercury 2001*. Ministry of the Environment, Environmental Protection Agency, Denmark. https://www2.mst.dk/udgiv/publications/2004/87-7614-287-6/pdf/87-7614-288-4.pdf. Accessed 8 April 2022.

Japan, Ministry of the Environment (2019). *Overview of mercury material flow in Japan (FY2014)*. Information from Japan upon the request from the Minamata Convention Secretariat on capacity building, technical assistance and technology transfer on the Minamata Convention on Mercury, Ministry of the Environment, Japan. https://www.mercuryconvention.org/sites/default/files/documents/submission_from_government/Japan_Article14.pdf. Accessed 8 April 2022.

Japan, Ministry of the Environment (2020). *Overview of mercury material flow in Japan (FY2016)*. http://www.env.go.jp/chemi/materialflow/materialflow_2016-2.pdf. Accessed 28 April 2022. [In Japanese]

Lassen, C. and Hansen, E. (2000). *Paradigm for substance flow analyses*. Danish EPA, Denmark. https://www2.mst.dk/udgiv/publications/2000/87-7944-327-3/pdf/87-7944-328-1.pdf. Accessed 8 April 2022.

United States of America, Environment Protection Agency (2018). *2014 national emission inventory, version 2*. Technical support document. US Environmental protection Agency: North Carolina. https://www.epa.gov/sites/default/files/2018-07/documents/nei2014v2_tsd_05jul2018.pdf. Accessed 5 August 2022.

Guidance and training materials

European Monitoring and Evaluation Programme (2019). *EMEP/EEA air pollutant emission inventory guidebook 2019*. Technical guidance to prepare national emission inventories, Copenhagen: European Environment Agency. https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/at_download/file. Accessed 24 April 2022.

United Nations Institute for Training and Research (2022). MercuryLearn training. https://mercurylearn.unitar.org/. Accessed 28 April 2022.

Legal framework and mercury management

Minamata Convention

Minamata Convention (2013). *Text of the Minamata Convention on Mercury for adoption by the Conference of Plenipotentiaries*. UNEP(DTIE)/Hg/CONF/3. https://www.mercuryconvention.org/sites/default/files/documents/working_document/CONF_3_Minamata_Convention_on_Mercury_final_26_08_e.pdf. Accessed 21 July 2022.

United Nations Environment Programme (2019). MC-3/5: Mercury waste thresholds, In *Decision adopted by the third Conference of the Parties to the Minamata Convention on Mercury*. UNEP/MC/COP.3/Dec.5.

https://www.mercuryconvention.org/sites/default/files/documents/decision/UNEP-MC-COP3-Dec5-MercuryWasteThresholds.EN.pdf. Accessed 31 July 2022.

United Nations Environment Programme (2022). *Annex A to the Minamata Convention on Mercury, as amended by the Conference of the Parties at its fourth meeting*. UNEP/MC/ COP.4/Dec.3/Add.1. https://www.mercuryconvention.org/sites/default/files/documents/decision/4_Dec3_Add1_Amendment.English.pdf. Accessed 31 July 2022.

Mercury-added products

Madagascar, Ministry of Environment, Ecology, Sea, and Forests (2015). *Replacing mercury-added products and promoting improved management of mercury-added products waste in Madagascar*. https://wedocs.unep.org/bitstream/handle/20.500.11822/13845/Madagascar-final-report.pdf. Accessed 28 April 2022.

Norden (2007). *Mercury substitution priority working list*. Copenhagen: Nordic Council of Ministers. https://wedocs.unep.org/bitstream/handle/20.500.11822/13874/TN2007541.pdf. Accessed 28 April 2022.

United Nations Environment Programme Global Mercury Partnership (2022). *List of alternatives to mercury-added products*. https://wedocs.unep.org/bitstream/handle/20.500.11822/13866/flyer_final1_mercury-free_alternatives.pdf. Accessed 28 April 2022.

World Health Organization (2015). *Developing national strategies for phasing out mercury-containing thermometers and sphygmomanometers in health care, including in the context of the Minamata Convention on Mercury*. Geneva: World Health Organization. https://apps.who.int/iris/rest/bitstreams/1091404/retrieve. Accessed 28 April 2022.

Dental amalgam (phase down and alternatives)

United Nations Environment Programme (2016). *Lessons from countries phasing down dental amalgam use*. Geneva: UNEP Chemicals and Waste Branch. https://wedocs.unep.org/bitstream/handle/20.500.11822/31212/Dental.pdf. Accessed 28 April 2022.

United Nations Environment Programme and World Health Organization (2014). *Promoting the phase down approach of dental amalgam in developing countries*. https://wedocs.unep.org/bitstream/handle/20.500.11822/13865/dental_mercury_phase_down_project_brochure_FINAL_lr.pdf. Accessed 28 April 2022.

World Health Organization (2009). *Future use of materials for dental restoration*. Geneva: World Health Organization. http://apps.who.int/iris/bitstream/handle/10665/202500/9789241500647_eng.pdf Accessed 28 April 2022.

Health aspects

Japan Public Health Association (2001). *Preventive measures against environmental mercury pollution and its health effects*. http://nimd.env.go.jp/english/kenkyu/docs/manual.pdf. Accessed 28 April 2022.

National Institute for Minamata Disease Japan (2013). *Mercury and health V4.1*. http://nimd.env.go.jp/english/kenkyu/docs/Mercury_and_health.pdf. Accessed 28 April 2022.

World Health Organization (2000). 6.9 Mercury, In *Air quality guidelines for Europe, Second edition*. Copenhagen: WHO Regional Publication. 157-161. https://www.euro.who.int/__data/assets/pdf_file/0004/123079/AQG2ndEd_6_9Mercury.PDF. Accessed 14 February 2022.

Cross-cutting issues

InforMEA (2022). Mercury and gender. https://elearning.informea.org/course/view.php?id=99. Accessed 28 September 2022.

Strategic Approach to International Chemicals Management (2017). Gender and the sound management of chemicals and waste. SAICM/IP.2/6. http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_6_gender_document.pdf. Accessed 11 August 2022.

United Nations Environment Programme (2016). Global Gender and Environment Outlook, The Critical Issues. United Nations Environment Programme, Nairobi, Kenya. https://wedocs.unep.org/bitstream/handle/20.500.11822/7628/-Global_gender_and_environment_outlook_The_critical_issues-2016ggeo_summary_report.pdf.pdf. Accessed 11 August 2022.

United Nations Environment Programme and Minamata Convention (2021). Gender equality and mercury. Minamata Convention on Mercury Secretariat. https://www.mercuryconvention.org/sites/default/files/documents/2021-08/Gender_Equality_Mercury_May_2021.pdf. Accessed 11 August 2022.

Other

United Nations Institute for Training and Research (2020). *Guiding questions for designing leaning events (face-to-face and online)*. United Nations Institute for Training and Research. https://unitar.org/sites/default/files/media/file/Designing%20Learning%20Events.pdf. Accessed 14 February 2022.

4.11 Glossary, acronyms, and abbreviations

ASGM	Artisanal and small-scale gold mining: gold mining conducted by individual miners or small enterprises with limited capital investment and production.
BAT	Best Available Techniques: Techniques that are the most effective to prevent and, where that is not practicable, to reduce emissions and releases.
BEP	Best Environmental Practices: Application of the most appropriate combination of environmental control measures and strategies.
CAS	Chemical Abstracts Service
CFL	Compact fluorescent lamp
COP	Conference of the Parties
CY	Calendar year
CYC	Cyclones
DNA	Deoxyribonucleic acid
DS	Dry scrubber
ECC	Environmental Compliance Consultancy
EEA	European Environment Agency
ESP	Electrostatic precipitator
EXRI	EX Research Institute
FF	Fabric filter (or "bag filter")
FGD	Flue gas desulfurization
FY	Fiscal year
GEF	Global Environment Facility
GHG	Greenhous gas
HS	Harmonized System
IEA	International Energy Agency
IL1	Inventory Toolkit Level 1
IL2	Inventory Toolkit Level2
Mercury-added product	Product or product component that contains mercury or a mercury compound that was intentionally added.
MIA	Minamata Initial Assessment
MMF	Mercury material flow
MOEJ	Japan, Ministry of the Environment
MOYAI Initiative	A Japan's commitment made at the Diplomatic Conference in 2013 to support developing countries and to promote voices and messages from Minamata.
MSW	Municipal solid waste
NAP	National action plan
OECC	Overseas Environmental Cooperation Center
PM	Particulate matter (or PM filter)
PRTR	Pollution release and transfer register
PS	Particle scrubber
PU/PUR	Polyurethane
PVC	Polyvinyl chloride
ROAP	Regional Office for Asia and the Pacific
SAICM	Strategic Approach to International Chemicals Management
SCR	Selective catalytic reduction
SD	Spray dryer

SDA	Spray dryer adsorber
SIP	Specific International Programme
SNCR	Selective non-catalytic reduction
UN	United Nations
UNEP	United Nations Environment Programme
UNITAR	United Nations Institute for Training and Research
uPOPs	Unintentional persistent organic pollutants
USGS	United States Geological Survey
UV	Ultra-violet
VAT	Value-added tax
VCM	Vinyl-chloride monomer
wFGD	Wet flue gas desulphurisation
yr	Year

5 EDITABLE POWERPOINT FILES

This Chapter provides the reading scripts of the pre-recorded narration embedded in the multimedia files.

5.1 List of slide decks

Lecture 1: The Minamata Convention on Mercury (36 slides, 25'38")

- Section 1: Outlines of the Minamata Convention (4 slides, 3'49")
- Section 2: Mercury supply, trade, and use (8 slides, 6'19")
- Section 3: Environmentally sound management of mercury (8 slides, 5'05")
- Section 4: Provisions facilitating the implementation of measures (11 slides, 7'56")
- Section 5: Overall management of the Convention (4 slides, 2'13")

Lecture 2: Mercury issues and how mercury flow analysis can contribute (43 slides, 33'44")

- Section 1: Mercury problems – needs for global actions (6 slides, 5'47")
- Section 2: Addressing mercury problems (5 slides, 4'27")
- Section 3: How mercury flow analysis can contribute (6 slides, 5'10")
- Section 4: Policy implication (case in Japan) (10 slides, 6'56")
- Section 5: Introduction of UNEP mercury inventory Toolkit (11 slides, 9'15")
- Section 6: Toolkit guidance elements (4 slides, 1'56")

Lecture 3: Mercury source categories (23 slides, 19'31")

- Section 1: Raw minerals and fuels (4 slides, 3'34")
- Section 2: Industrial processes using mercury (3 slides, 2'14")
- Section 3: Mercury-added products (7 slides, 6'11")
- Section 4: Mercury waste management (6 slides, 5'19")
- Section 5: Miscellaneous categories (2 slides, 2'03")

Lecture 4: Mass balance principle and examples on the process, sectoral and societal level (31 slides, 25:59)

- Section 1: Mass balance principle (7 slides, 7'41")
- Section 2: Key mass balance equations (4 slides, 2'30")
- Section 3: System definition and boundaries (4 slides, 2'54")
- Section 4: Accumulation: quantification, predictions, and implications (5 slides, 4'48")
- Section 5: Relations between mercury mass flows and the UNEP Mercury Inventory Toolkit (8 slides, 6'58")
- Section 6: Other mercury quantification tools (2 slides, 0'46")

Lecture 5: Steps in mercury mass flow development (79 slides, 58’52”)

Part I: Sector definitions, identifying individual flows, quantification of flows (36 slides, 21’49”)

- Section 1: Sector definitions (13 slides, 6’47”)
- Section 2: Identification of flows (7 slides, 5’21”)
- Section 3: Quantification of flows (6 slides, 5’40”)
- Section 4: Examples of sector flows (9 slides, 3’51”)

Part II: Quantification of stocks, collection of supplementary data, working with intervals, available online tools and resources (32 slides, 29’25”)

- Section 1: Quantification of stocks (12 slides, 10’17”)
- Section 2: Data sources (10 slides, 10’36”)
- Section 3: Data collection principles and methods (3 slides, 4’28”)
- Section 4: Uncertainties and working with intervals (4 slides, 2’28”)
- Section 5: Use of online helper tools (2 slides, 1’22”)

Part III: Identifying and reducing uncertainties, reporting and review (10 slides, 7’31”)

- Section 1: Identifying and reducing uncertainties and gaps (6 slides, 4’54”)
- Section 2: Reporting principles and review (3 slides, 2’24)

5.2 Lecture 1 The Minamata Convention on Mercury

‘0’ This lecture explains the legally-binding provisions of the Minamata Convention on Mercury particularly the measures that the Parties are to implement for sound mercury management.

Section 1: Outlines of the Minamata Convention

‘1’ This section explains the background and scope of the Minamata Convention on Mercury.

‘2’ The Minamata Convention on Mercury is a multilateral legally-binding environmental agreement aiming to protect the human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds. The Convention, in its preamble, recognizes the substantial lessons of Minamata Disease and the need to ensure proper management of mercury and the prevention of such events in the future. The text was adopted in October 2013, and is composed of a preambular text, 35 articles, and 5 annexes. The Convention entered into force on 16th August 2017, on the 90th day after the deposition of the 50th instrument of ratifications, acceptance, approval, or accession.

‘3’ In its preamble, the Convention recognises the substantial lessons of Minamata disease, in particular the serious health effects resulting from the mercury pollution, and makes aware of the health concerns to women, children, and future generations. The Convention sets out a range of measures throughout the entire life cycle of mercury to meet its objective. Articles 3 – 12 relate to the operational provisions describing the Parties’ obligations to reduce emissions and releases, with controls throughout their life cycle, which include measures to control the supply and trade of mercury, mercury-added products, manufacturing processes in which mercury or mercury compounds are used, as well as artisanal and small-scale gold mining, ASGM. The text also includes the articles on emissions and releases of mercury, environmentally sound interim storage, mercury waste, and contaminated sites. Articles 13 – 21 facilitate the implementation of these measures including provisions related to support for the Parties, information, awareness raising, and reporting. Articles 22 – 35 cover the overall management of the Convention. Annexes A and B list the mercury-added products and manufacturing processes to be controlled by the Convention. Annex C sets the items to be included in the national action plans for ASGM. Annex D lists the point source categories for emission control.

‘4’ This Convention covers all forms of mercury, as element, and mercury compounds. Specific mercury compounds are subject to control in Article 3, supply and trade, and Article 10, interim storage. Article 4 specifies mercury-added products to be phased out or phased down by the Parties.

Section 2: Mercury supply, trade, and use

‘5’ This section explains the measures stipulated in the Convention on mercury supply, trade, and use.

‘6’ Article 3 Mercury supply sources and trade: Each Party shall not allow new primary mercury mining and shall only allow existing primary mercury mining operating for a maximum of 15 years after becoming a Party. Each Party shall also endeavour to identify individual stocks of mercury or mercury compounds exceeding 50 metric tons as well as sources of mercury supply generating stocks exceeding 10 metric tons. Each Party shall not allow the export and import of mercury unless some conditions stipulated in the Convention are met.

‘7’ Existing primary mercury mining is allowed for a period of up to 15 years after the entry into force of the Convention for the Party. Mercury from such mining shall only be used for mercury-added products and in manufacturing processes in accordance with Article 4 and 5, respectively. Or it shall be disposed of in accordance with Article 11.

‘8’ Mercury trade between Parties or a Party and a non-Party requires a written consent from the importing country and shall be allowed only for the use allowed under the Convention or for environmentally sound interim storage. Exporting Party shall ensure that importing non-Party is compliant with Articles 10 and 11 of the Convention. Likewise, importing Parties shall obtain certification from exporting non-Party which ensures that the mercury is from allowed sources, noting that there are restrictions on the use of mercury from primary mining or decommissioning of chlor-alkali facilities.

‘9’ Article 4 Mercury-added products: Each Party shall not allow the manufacture, import or export of mercury-added products listed in Part I of Annex A after the phase-out date, which is 2020 for the products originally listed and 2025 for those newly listed by the amendment of Annex A in 2022. Each Party also shall take measures to phase down the use of mercury-added products listed in Part II of Annex A, which is dental amalgam. Each Party shall take measures to prevent the incorporation of mercury-added products into assembled products and discourage the manufacture and distribution of new mercury-added products. The Secretariat shall collect and maintain information on mercury-added products and make it publicly available. The Conference of the

Parties, COP, shall review Annex A and may consider amendments. The first amendment was adopted by the COP at its fourth meeting in 2022.

‘10’ Article 5 Manufacturing processes in which mercury or mercury compounds are used: Each Party shall not allow the use of mercury or mercury compounds in the manufacturing processes listed in Part I of Annex B, and shall take measures to restrict the use of mercury or mercury compounds in the manufacturing processes listed in Part II of Annex B. Each Party shall also take measures to address emissions and releases of mercury or mercury compounds from these facilities. Each Party shall not allow the use of mercury or mercury compounds in new facilities and discourage their use of mercury or mercury compounds in new processes. The Secretariat shall collect and maintain information on processes using mercury or mercury compounds and make it publicly available. The COP shall review Annex B and may consider amendments.

‘11’ Article 6 Exemptions available to a Party upon request: Any Party, may register, on becoming a Party, exemptions from the phase-out date listed in Annex A and B for five years or less or withdraw the registered exemption. The Secretariat shall establish and maintain the register and make it publicly available. The COP may decide to extend an exemption for five years.

‘12’ Article 7 Artisanal and small-scale gold mining: Each Party with ASGM in its territory shall take steps to reduce, and where feasible eliminate, the use, emissions and releases of mercury and its compounds. Each Party with more than insignificant ASGM in its territory shall notify the Secretariat and develop and implement a national action plan, which shall be submitted to the Secretariat within three years after the development of the plan. Thereafter, a review of the progress made shall be conducted every three years.

Section 3: Environmentally sound management of mercury

‘13’ This section explains the environmentally sound management of mercury particularly control measures to reduce mercury risks stipulated in the Convention.

‘14’ Article 8 Emissions: A Party with relevant sources shall take measures to control emissions from sources listed in Annex D. Each Party shall require the use of best available techniques, BAT, and best environmental practices, BEP, to control emissions for new sources within five years after becoming a Party, and implement one or more measures for existing sources within 10 years after becoming a Party. Each Party shall also establish and maintain an inventory of emissions. The COP adopted the guidance on BAT/BEP, including goals and emission limit values for existing sources, the guidance on criteria to identify source categories, and methodology for preparing the inventory. The BAT/BEP guidance was adopted by the COP at its first meeting in 2017.

‘15’ The relevant sources subject to this Article are listed in Annex D. Different control measures are required for new sources and existing sources.

‘16’ Article 9 Releases: Each Party shall identify the relevant point source categories, which are not addressed in the other provision of the Convention, no later than three years and on a regular basis thereafter. Each Party shall take measures to control releases, and establish and maintain an inventory of releases. The COP shall adopt guidance on BAT/BEP and methodology for preparing inventories.

‘17’ For both new and existing sources that are not covered by the other provisions of the Convention such as release limit values, use of BAT/BEP, a multi pollutant control strategy, or alternative measures, at least one measure listed in the Convention shall be implemented.

‘18’ Article 10 Environmentally sound interim storage of mercury, other than waste mercury: Each Party shall take measures to ensure that the interim storage of mercury and mercury compounds intended for a use allowed under the Convention is undertaken in an environmentally sound manner. The COP adopted guidance on the environmentally sound interim storage of mercury and mercury compounds at its second meeting in 2018.

‘19’ Article 11 Mercury wastes: Mercury wastes means substances or objects consisting of, containing or contaminated with mercury or mercury compounds in a quantity above the relevant thresholds defined by the COP. Each Party shall take measures to manage mercury waste in an environmentally sound manner. Each Party shall also ensure that the recovery, recycling, reclamation or direct re-use of mercury waste is for an allowed purpose or for environmentally sound disposal only. For the Party to the Basel Convention, mercury waste shall not be transported across international boundaries except for the purpose of environmentally sound disposal. The COP shall define relevant thresholds for mercury wastes.

‘20’ Article 12 Contaminated sites: Each Party shall endeavour to develop appropriate strategies for identifying and assessing sites contaminated by mercury or mercury compounds. Actions to reduce the risks shall be performed in an environmentally sound manner. The COP adopted guidance on managing contaminated sites in its third meeting in 2019.

Section 4: Provisions facilitating the implementation of measures

‘21’ This section explains the provisions of the Conventions that facilitate the Parties implementing the measures to fulfil the objective of the Convention.

‘22’ Article 13 Financial resources and mechanism: Each Party undertakes to provide resources such as domestic funding, bilateral and multilateral funding as well as private sector involvement for national activities. The mechanism shall include the Global Environment Facility, GEF, and the specific international programme, SIP.

‘23’ The GEF provides predictable, adequate and timely financial resources to meet the agreed incremental costs of global environmental benefits. The GEF shall be operated under the guidance of and be accountable to the COP. The SIP supports capacity-building and technical assistance. All parties and other relevant stakeholders are invited to provide financial resources on a voluntary basis.

‘24’ Article 14 Capacity-building, technical assistance and technology transfer: Parties shall cooperate to provide capacity-building and technical assistance to developing country Parties and Parties with economies in transition. Developed country Parties and other Parties shall, within their capability, promote and facilitate development, transfer and diffusion of, and access to, up-to-date environmentally sound alternative technologies. The COP shall consider information on existing initiatives and progress made, and the needs of Parties in relation to alternative technologies, and identify challenges experienced by Parties in technology transfer. The COP also shall make recommendations on how capacity-building, technical assistance and technology transfer could be further enhanced.

‘25’ Article 15 Implementation and compliance committee: A Committee is established as a subsidiary body of the COP. The Committee shall promote implementation of, and review compliance with, all provisions of the Convention. It shall examine both individual and systemic issues of implementation and compliance and make recommendations to the COP.

‘26’ Article 16 Health aspects: Parties are encouraged to promote the development and implementation of strategies and programmes to identify and protect populations at risk. They are also encouraged to promote the development and implementation of science-based educational and preventive programmes on occupational exposure to mercury and mercury compounds, and to promote appropriate health-care services for prevention, treatment and care for populations affected by the exposure to mercury or mercury compounds. Furthermore, they are encouraged to establish and strengthen the institutional and health professional capacities for the prevention, diagnosis, treatment, and monitoring of health risks related to the exposure to mercury and mercury compounds.

‘27’ Article 17 Information exchange: Each Party shall facilitate the exchange of scientific, technical, economic, and legal information. Additionally, it shall facilitate the exchange of information such as on the reduction or elimination of the production, use, trade, emissions, and releases of mercury, on technically and economically viable alternatives to products, processes, and activities, and epidemiological information. The Secretariat shall facilitate cooperation in the exchange of information.

‘28’ Article 18 Public information, awareness, and education: Each Party shall promote and facilitate the provision to the public of available information, and education, training and public awareness related to the effects of exposure to mercury and mercury compounds.

‘29’ Article 19 Research, development and monitoring: Parties shall endeavour to cooperate to develop and improve inventories of use, consumption, and anthropogenic emissions and releases of mercury. The cooperation also includes modelling and monitoring of mercury in vulnerable populations and in environmental media, assessments of the impact of mercury on human health and the environment, in addition to social, economic, and cultural impacts, information on the environmental cycle, transport, transformation and fate of mercury, information on commerce and trade in mercury and mercury-added products, and information and research on the technical and economic availability of mercury-free products and processes and on BAT/BEP to reduce and monitor emissions and releases of mercury. Additionally, Parties should build on existing monitoring networks and research programmes.

‘30’ Article 20 Implementation plans: Each Party may, following an initial assessment, develop and execute an implementation plan. It may review and update its implementation plan, referring to guidance from the COP and other relevant guidance. Parties should consult national stakeholders to facilitate the development, implementation, review and updating of their implementation plans.

‘31’ Article 21 Reporting: Each Party shall report to the COP on the measures to implement the Convention and on the effectiveness of such measures, which include the information as called for in Article 3, 5, 7, 8, and 9. The COP agreed on the timing of the reporting at its first meeting for full reports every four years and biennial reports every two years.

Section 5: Overall management of the Convention

‘32’ This section explains the provisions of the Conventions that provide overall management of the Convention particularly evaluating the effectiveness of measures to achieve the objective of the Convention.

‘33’ Article 22 Effectiveness evaluation: The COP shall evaluate the effectiveness of the Convention, beginning no later than six years after entry into force and periodically thereafter. To facilitate the evaluation, the COP shall initiate the establishment of arrangements for providing itself with comparable monitoring data on the presence and movement of mercury in the environment, and trends in levels of mercury observed in biotic media and vulnerable populations.

‘34’ The evaluation shall be conducted on the basis of available scientific, environmental, technical, financial and economic information including reports and other monitoring information, national reports submitted, information and recommendations on compliance provided, and reports and other relevant information on the operation of the financial assistance, technology transfer and capacity-building arrangement.

‘35’ Articles 23 to 28 cover various rules and processes for operationalising the Convention by establishing the Conference of the Parties, secretariat, or by stipulating rules for settlement of disputes, amendments, voting, etc. Article 29 to 35 cover the provisions on the formality of the Convention, including signature, ratification, entry into force, reservation, withdrawal, depositary, and authentic texts.

5.3 Lecture 2 Mercury issues and how mercury flow analysis can contribute

'0' This lecture explains current mercury issues and values of mercury mass flow that can contribute to sound mercury management.

Section 1: Mercury problems – needs for global actions

'1' This section explains the backgrounds of mercury issues and challenges for the needs for global actions.

'2' Mercury is a chemical element with unique physical properties. Methylmercury is a form of mercury compound of great concern due to its high toxicity, but many other mercury compounds also have certain level of toxicity. Mercury has been used widely because of its practical and technical characteristics. Although mercury has existed on Earth since its formation, recent anthropogenic activities have increased mercury levels in the environment, resulting in elevated exposure to some populations. This is why mercury is regarded as a global pollutant that requires global action.

'3' One of the important properties of mercury is its persistence and long-range transport. It is released from various sources in various chemical forms and stays in circulation for a long time and cycles globally. It is estimated that due to anthropogenic activities, mercury emissions to the atmosphere have increased by 4.5 times compared to the purely natural level. Mercury, particularly methylmercury, is toxic to the central nervous system at the development stage and bioaccumulates in wildlife via the food chain. Mercury changes its chemical forms and moves across multiple media, for example, air, water, soil, biota, etc. The main mercury sink is the bottom sediment of the ocean. Such a natural mercury elimination process is slow and not sufficient to resolve recent mercury problems.

'4' In recent years, more mercury has been released through human activities, such as combustion of fuels, mining activities, and consumption of mercury-added products. Some evidence shows that human activities have raised mercury levels in the environment. The ice core record of deposition from Wyoming, United States of America, indicates an increase in the global environmental mercury level since the onset of global industrialization in the 19th century. The figure also indicates a few spike peaks that might be associated with local and/or regional sources, and large volcanic activities.

‘5’ Most of the mercury and mercury compounds have certain toxicities, but their biological behaviours and toxicity levels are distinct. Elemental mercury is easily evaporated and absorbed by inhalation. Mercury is not corrosive in its elemental form, but once oxidized by metabolic activity, it becomes corrosive. Alkylmercury, particularly methylmercury, forms a complex with one of the amino acids and is assimilated into body tissues as a protein that alters its normal function. Mercury compounds are eventually metabolized to divalent mercury ions and excreted into urine, but the metabolic rates are different in different chemical forms.

‘6’ Mercury circulates in air and water in elementary or oxidized inorganic form, but most of the mercury that exists in humans and biota is methylmercury. Methylation occurs mainly in the bottom sediment of the seabed, where anaerobic conditions are dominant. Some sulphate-reducing bacteria produce methylmercury by reducing oxidized inorganic mercury. The absorption rate of inorganic mercury is lower than that of methylmercury, thus methylmercury is selectively assimilated. Species with large sizes and long lifetimes tend to accumulate methylmercury. Some animal species have obtained the metabolism to safely store insoluble inorganic mercury particles in their bodies.

Section 2: Addressing mercury problems

‘7’ This section explains the relevance of the Minamata Convention to address global mercury problems.

‘8’ Mercury emissions and releases spread globally. It moves quickly in the atmosphere and more slowly in rivers and ocean currents. The main anthropogenic source categories of mercury emissions and releases are the following: extraction and processing of raw materials that have natural trace concentrations contents of mercury such as coal and non-ferrous metal ores, production process that use mercury intentionally including ASGM, and mercury-added products where mercury is added intentionally for a purpose.

‘9’ Regarding natural sources and remobilization, there is very little that can be done to reduce them. Mercury impurities in raw materials can be lowered by reducing consumption or, in some cases, substituting with other materials or processes. For example, reducing the use of coal to reduce climate impacts will have a large effect on mercury releases as well. Otherwise, the reduction is done by so-called “end of pipe” techniques, or mercury control techniques.

‘10’ There are several other sources of mercury input to the global economy. Dedicated mercury mining is a primary source. In addition, other non-ferrous metal mining such as zinc, lead, copper, and industrial scale gold mining contribute to the mercury market as mercury is naturally occurring in the ore of these metals. Mercury in the ore may be sold for use, emitted to the atmosphere, or disposed of locally. As mercury has been extracted for many years, it is accumulated in the global market and traded. The sale of mercury from such stocks is, however, restricted in some countries as a part of mercury management. Finally, mercury circulates with products globally and some of them are collected for recovery of mercury, which is another mercury source to the economy. However, mercury is now gradually being permanently retired during final disposals in many countries to avoid future environmental impacts.

‘11’ This slide gives an overview of the known intentional mercury inputs and their outputs globally. The geological reserves of primary mercury and mercury by-product account for the major mercury input. The recovery and recycling are also large and come from industrial processes such as vinyl chloride monomer production or mercury recovered from mercury-added products. Much of the mercury ends up in the environment. Additionally, there is some long-term storage of mercury and environmentally sound disposal. Finally, the accumulation of mercury in society in products and in processes is shown, and this contributes to recovery and recycling, as well as to environmental emissions and releases.

Section 3: How mercury flow analysis can contribute

‘12’ This section explains how mercury flow analysis can contribute to global mercury problems.

‘13’ Material flow analysis is a systematic method to quantify flows and stocks of the target material. It can include substance or product and assesses human activities that change the physical and social properties of the material. The analysis involves two main principles, setting boundaries and modelling process balances. The inflow to and outflow from a boundary will affect the accumulation or depletion of the stock within the boundary if the mass balance is maintained. Material flow is applicable at many levels and purposes depending on the purpose and use.

‘14’ The origin and pathways of the mercury releases that need to be reduced are sometimes complex. Mass balances help to see the intricate links between sources and releases in the life cycle of mercury. Therefore, mass balances help in developing policy by setting target mercury sources where they are most effective. For example, a key source of mercury to agricultural land may be sewage sludge used as fertilizer, where mercury from dental amalgam use, thermometers spills, etc. end up via wastewater treatment facilities.

‘15’ Minamata Convention is vital in efforts to reduce mercury’s adverse impacts. Many developed countries have significantly reduced their mercury releases and emissions since as early as the 1970s in response to the serious health effects caused in Minamata and a few other locations. The creation of the Minamata Convention triggered many activities globally to investigate mercury, and to implement measures to reduce mercury exposure in most countries of the world.

‘16’ The Minamata Convention sets out a range of measures throughout the entire life cycle of mercury to meet its objective. For the effective implementation of the Convention, it is crucial to identify the priority areas as a basis for effective and efficient domestic policy. Mercury inventory and flow analysis can serve as fundamental tools in the identification of key mercury source types and mercury’s fate in society. Understanding the intricate linkages between mercury, socio-economic status and gender is important towards effective policies and interventions. Poverty is one of the main drivers for pushing women into mining and is further compounded by deterioration in subsistence farming. Thus, utilising a gender-responsive approach where relevant is recommended. Currently, National Action Plans under the Minamata Convention, are required to address women and children’s exposure to mercury in ASGM.

‘17’ The Minamata Convention targets many aspects of the mercury problem. Mercury flow analysis can contribute to identifying mercury trade, stock and sources. It will be used to monitor several measures taken by the Parties such as the phase-out or phase-down of mercury-added products and processes and the implementation of ASGM national action plans. Mercury emission and release inventories will be direct products of mercury flow analysis. Overall, the information can be widely used for communications, education, research, and so on.

Section 4: Policy implication (case in Japan)

‘18’ This section introduces an actual case study in Japan where mercury flow is used for national policymaking and implementation.

‘19’ Ministry of the Environment, Japan has developed and is maintaining mercury flow analysis to capture mercury use for manufacturing processes and emissions and releases to the environment. Currently, the analysis versions in fiscal years 2010, 2014, and 2016 are available. It includes import and export of mercury and mercury compounds as well as mercury waste and recovery processes to capture the entire life cycle at the national level.

‘20’ This analysis is used as base information among stakeholders for discussing domestic mercury management policies and plans. Japan has established a new “Act on Preventing Environmental Pollution of Mercury” and “The National Implementation Plan for Preventing Environmental Pollution of Mercury” to implement the Minamata Convention. The new Act is planned to be reviewed at 5 years after entering into force, and the data collected through the development of the mercury flow can be utilized for their reviews. Additionally, Japan is using the knowledge and experiences obtained through the development process for international cooperation for other countries.

‘21’ Import and export of mercury and mercury containing raw materials and products are compiled and converted to mercury amounts. The table below shows the trend between 2014 and 2016. The three-year average value is used for those with large yearly fluctuation.

‘22’ The amount of mercury exports from Japan greatly exceeds the amount of mercury imports as most mercury comes into the country as impurities in raw minerals and fuels. Considering the impact of exported mercury, the implementation of mercury export regulations is essential. In addition, the fate of mercury in importing countries is of concern to prevent inappropriate use; thus, exporters of mercury are responsible for reporting on final use from importing countries under the Foreign Exchange and Foreign Trade Act. Mercury flow analysis is useful to understand the long-term trend of mercury as well as the short term to take appropriate measures to address the findings.

‘23’ Domestic manufacturing of mercury-added products is still ongoing in Japan, although the total mercury amount used for the production is steadily declining.

‘24’ The decreasing trend seems to continue as manufacturers are moving towards mercury-free alternatives. Even though mercury-free is not possible, technology development enables mercury reduction per unit of product. It is important to raise citizens’ awareness to select mercury-free alternatives to their consumable products.

‘25’ The mercury recovery industry exists in Japan and produces a significant amount of recycled mercury every year. The annual production level fluctuates but remains at a certain amount.

‘26’ It is likely that waste of mercury-added products would continue to be generated in the future, even after the manufacture of some types of mercury-added products are phased out. Thus, the effective collection of discarded products should be further promoted by stakeholders, such as municipalities and industries. As the domestic mercury demand can be fulfilled by mercury recovered from waste, only a small amount of mercury and mercury alloys is imported. After the Minamata Convention entered into force, the mercury demand was expected to decline, resulting in disincentives to recover mercury from waste. As sound mercury waste management is an important factor for long-term mercury management, a framework for controlling high concentration mercury waste is deliberately discussed.

‘27’ The 2016 version of Japan’s mercury flow still needs further refinement. Stock of mercury-added products in households and offices, which are also called hoarded stocks, should be identified and evaluated. The results will guide the responsible entities in each sector for the proper separation, discharge and collection of the products. Manufacturers storing a certain amount of mercury are subject to reporting on the management of their mercury under the new mercury act in Japan. Such reports provide the trend on stocks after the law enforcement. Those who manage materials traded as recyclable resource containing mercury are also required to report on the management of their resources under the new act. Such information is used for identifying flows of such resources.

Section 5: Introduction of UNEP mercury inventory Toolkit

‘28’ This section introduces UNEP Mercury Inventory Toolkit, which provides information directly relevant for mercury mass flows. It is used by many countries as the de facto standard for mercury inventory development.

‘29’ The UNEP mercury inventory toolkit is based on the mass balance principle with some simplifications to make inventory development easier for users. The toolkit currently focuses on the quantification of mercury emissions and releases. Mass flows add another layer of revealing how mercury sources are inter-linked and contribute to the overall mercury exposure pattern.

‘30’ Therefore, understanding the Toolkit is very beneficial for work with mass flows because most of the key guidance is already given, such as methodologies, system boundaries, and sectors defined. There is always value in using the Toolkit for work. Other emission inventory systems can also be used if available. More than 95 countries, mostly developing and with economies in transition, have used the Toolkit for their mercury quantifications as part of their Minamata Initial Assessments.

‘31’ The Toolkit uses national data on different levels. In the simple Level 1, activity rates are used to show how much has happened in the relevant sectors. In the more detailed Level 2, it is recommended to use more national data to increase the accuracy of the estimates formed. Furthermore, the Toolkit estimates emissions and releases to all environmental media, and this is also needed for mass flow work.

‘32’ The Toolkit applies the mass balance principle, which refers to ‘what comes in must come out’. The Toolkit works with input factors and output distribution factors. Default factors are available for backup, based on the literature, but using local or national factors are encouraged wherever available. Using specific factors, however, requires more data, and this has been a challenge in many developing countries. Data availability is the main limitation in doing so. In the Toolkit inventories of the current Level 2 methodology, the precision of the estimation will increase if specific data are available.

‘33’ This slide shows the key equation used in the Toolkit. It works with the activity rates, which are typically the amount of materials fed into the process or the amount of products produced. The activity rate is multiplied by the input factor to obtain the overall mercury amount into this sector or process to society. The input factor is the mercury concentration or content per unit, so it could be the mercury concentration in coal or the mercury content of a thermometer. The output distribution factor estimates the release pathways to air in this formula. This is the unit-less fraction of the mercury input that is released through a particular pathway, such as air, water, land, product, general waste, or sector-specific waste treatment. By this definition, all the output distribution factors should add up to 100%. There are a few exceptions, although, to this principle to make inventory development easier for users.

‘34’ Toolkit Level 1 is very simple to use. Only activity rate data are needed to develop an inventory. It also has an optional function to add data on control measures such as filters. The calculation spreadsheet for Level 1 offers much help in entering data. It provides protected formulas, and feedback suggestions for potentially incorrect data. The results are automatically calculated and used to create a standardized inventory. As it applies a simplified model, these results are less accurate due to the use of default calculation factors.

‘35’ Because it uses a model with some limitations, and there are some local variations that are not incorporated, the results in Level 1 should be used with caution. For example, the mercury concentration in coal may vary by a factor of ten or more. Level 1 can reflect improved pollution control systems but with default factors only. Additionally, associated uncertainties are not reflected automatically, but they need to be addressed when developing reports. Such models applied in Level 2 are generally complex, which requires some extra work.

‘36’ In Level 2, the default factors are still pre-populated for back-up, but they can be modified to improve the accuracy. Almost all mercury control regimes are reflected in Level 2. The output distribution factors can also be modified if well documented local data are available. Level 2 can fully reflect local settings and mercury management solutions. It is a strong monitoring tool to see the improvements over time when implementing the Minamata Convention. It is customizable to a great extent for enhancing the precision of the results, but some caution must be considered when preparing the inventory report. Such modification should be clearly documented to avoid misinterpretation by readers and peer reviewers.

‘37’ The Toolkit includes default calculation factors, which are based on the available literature. It should be noted that published data are still scarce for some factors, thus, there is still room for improvement. Measurement or detailed study for local inventory development may also inform the Toolkit for its improvement.

‘38’ The full background of all default factors is presented in the Toolkit Reference Report, which is open to any new data being made available with good documentation. The default factors for stationary mercury sources have been harmonized with the Global Mercury Assessment methodology, whereas for products, the methodologies differ, focusing more on national data.

Section 6: Toolkit guidance elements

‘39’ This section introduces useful tools and materials to guide the development and improvement of mercury mass flows.

‘40’ The Toolkit Level 1 includes a guideline, including advice and sources for data collection, which are useful for Level 2 work as well. It also includes a calculation spreadsheet, the reporting template, and examples of data collection letters for inspiration. The reporting templates are ready-to-use materials when making an original inventory. An online e-learning tool called MercuryLearn hosted and developed by UNITAR is also available online.

‘41’ A cornerstone in the Toolkit Level 2 is the Toolkit Reference Report. It is a guideline for Level 2, but more importantly, it is a compendium on mercury source categories that describes the key features of all mercury source types. It provides valuable insight into the original source of mercury, examples of mercury inputs and release patterns from the literature, documentation for default factors used, and guidance for the source-specific inventory work involved on the Toolkit Level2. The Toolkit Level 2 also includes a spreadsheet and designated reporting template.

‘42’ Leaning materials about the Toolkit give instructions and advice on inventory development using the Toolkit at both levels.

5.4 Lecture 3 Mercury source categories

‘0’ This lecture explains mercury source categories and classification of mercury use and releases.

Section 1: Raw minerals and fuels

‘1’ This section explains the source categories that mobilize mercury in raw minerals and fuels.

‘2’ Raw minerals and fuels account for most mercury emissions. Mercury exists as impurity that is emitted unintentionally except in artisanal and small-scale gold mining, ASGM, where mercury is intentionally added to the ore to extract gold. ASGM accounts for the largest mercury emission source and disproportionally affects marginalised and less privileged groups, such as children and women of child-bearing age.

‘3’ Fuel production and energy consumption are significant mercury emission sources. Coal, oil and natural gas contain trace amounts of mercury, which is either removed by the fuel production process or emitted during energy consumption. As mercury is troublesome in the oil and gas process, it is usually removed beforehand, and refined oil and gas products do not contain mercury at a significant level. Coal is provided either washed or unwashed. The coal washing process removes a certain amount of mercury and provides higher quality and price. Mercury is present in all biological and mineral fuels, including renewable fuels such as firewood, and straw. Biomass-fired power and heat production contribute to mercury emissions due to the high volumes used. Geothermal power production extracts only underground heat, not minerals, but the natural mercury concentration at a geothermal location is usually elevated. When a power plant release mercury-containing vent for power production, it can become a local mercury source.

‘4’ Primary metals and material production are also significant mercury sources. Mercury mines extracting and processing mercury as a primary mineral are always major mercury sources. Non-ferrous metals such as zinc, lead, gold, and copper often co-exist with mercury in their veins due to their chemical affinity; thus, mineral extraction results in a mercury source. When mercury is not used for gold extraction, the natural trace concentrations of mercury in the ore are released in the process, particularly in large-scale gold production. Even at lower concentrations, ferrous metal production is also a possible mercury source, as the scale of activity is large. Cement production is also a major source because the amount of raw material, such as limestone, used for the production is significantly large.

Section 2: Industrial processes using mercury

‘5’ This section explains the industrial processes that use mercury as catalysts or other purposes for producing products other than mercury-added products.

‘6’ There are several known mercury-using processes that are controlled under the Minamata Convention. Vinyl-chloride monomer, VCM, production is the largest mercury-using process while acetaldehyde production has moved to the mercury-free process. Mercury-using processes account for approximately one-third of the global mercury use.

‘7’ Important processes using mercury are acetylene-based chemical production, where mercury compounds serve as catalysts accelerating the addition reaction. To avoid the use of mercury, ethylene will be used for the feedstock instead of acetylene. Another type of catalyst is the initiator for polymerization of polyurethane elastomer that triggers the process in the moulded products or coating. Although mercury works as a catalyst, it actually remains in the product. Another mercury use is as the electrode for electrolysis or electrorefining. One of the major products is sodium hydroxide and chlorine gas using the mercury amalgamation method, where sodium amalgam plays a key role in extracting sodium ions from brine solution. Alcoholates such as sodium ethylate are used as catalysts for producing biofuel. Gold plating is also a possible mercury source under this category where gold amalgam is smeared on the metallic surface to gild the object.

Section 3: Mercury-added products

‘8’ This section explains the mercury-added products that contain mercury or a mercury compound that was intentionally added. This definition differentiates such products containing mercury from an impurity in raw materials.

‘9’ Mercury-added products account for approximately one-fourth of global mercury use. Mercury is used for many products in various sectors if historical uses are included. Although mercury-free alternatives have been developed to a great extent, mercury-added products are still widely used. Major products that consume substantial amounts of mercury are controlled under Minamata Convention, but some essential uses are excluded from phase-out.

‘10’ Elemental mercury has some unique properties that are utilized for developing various products. A non-electrical pressure gauge is one of the typical examples that uses the property of a high-density liquid that is suitable for the purpose. Mercury is in liquid form between -38.8 and 356 degrees C, so it is used for temperature measurement. Its high thermal conductivity also benefits the quick response to temperature change. Discharge tubes are another popular use of mercury. Mercury vapour emits ultraviolet rays when excited, which can be used for lighting and disinfection purposes. Elemental mercury is added to the battery to avoid the generation of hydrogen gas that causes rupture and leakage.

‘11’ The mercury switch and relay also provide a unique function in electric circuits. As an electrically conductive liquid, mercury-added electric appliances can provide many functions, such as tilt switching and acceleration sensing. Liquid mercury has a wetting effect on other metals, so it provides ideal contact on the surface of the mercury relay that enables very high frequency switching without chattering. Elemental mercury has many other applications, such as vacuum pumps and balancers. However, many of them have been replaced by mercury-free alternatives. One exception is for laboratory instruments, which are excluded from the phase-out list of the Minamata Convention. The porosimeter measures the surface pore volume and distribution in the size of pores on the material surface.

‘12’ Amalgam is an alloy of mercury and other metals. Most metallic elements can form amalgam with a few exceptions such as iron, platinum, manganese, nickel, etc. Silver tin amalgam is the most widely used amalgam product for dental restoration. It gradually hardens after mixing such that it fills the dental cavities of the dental patients. This 3-metal amalgam can control the degree of expansion / contraction to avoid gaps between the filling and tooth. Thallium amalgam has the unique property of a low melting temperature and can be used for thermometers with a lower temperature range than mercury thermometers.

‘13’ Mercury compounds have been used as red pigments since the Stone Age. Mercury sulphide, or cinnabar, is the chemical form found in mercury ore. Due to its low solubility and high chemical stability, the painted colour does not fade out for centuries. Mercury chloride one, or calomel, is another common mercury compound with wide applications. Its bactericidal and fungicidal properties are applied as a preservative. The lower solubility and white colour enabled calomel to also be used as a facial powder. In the science field, saturated calomel electrodes are commonly used as stable electrode potentials. Mercury oxide two was used for the cathode of the mercury cell to obtain a stable voltage. It was also used for antifouling paint for the ship’s bottom.

‘14’ Many more mercury compounds have been used for various products. Agricultural chemicals such as fungicides, preservatives, and topical antiseptics are biocidal applications. Some mercury compounds have bleaching effects that are used for skin whitening cosmetics, which is still widely used by many women in the societies where lighter coloured skin is preferred. One of the unique compounds is mercury fulminate two, which is explosive and used for detonation caps for dynamite and firearms.

Section 4: Mercury waste management

‘15’ This section explains the mercury waste management and release from the facilities.

‘16’ The amount of mercury emissions from the waste sector is substantial but less significant in comparison with the amount of mercury handled. Mercury waste management is significantly different between countries. The special collection and treatment of mercury waste is challenging, although it has become increasingly practised. Some mercury is recycled or recovered from waste streams, which reduces mercury release from waste. Both waste incineration and open burning are significant emission sources to the atmosphere while landfills can serve the final mercury sink if they are properly managed.

‘17’ Mercury entering the waste stream has several types and properties that require different waste management schemes. Mercury and mercury compounds that are discarded need special care, such as stabilization as mercury in this form is an important source of mercury contamination. End-of-life mercury-added products are mixed with general waste or collected separately. If a hazardous waste collection scheme is in place, mercury can be removed before such waste is disposed of. Some non-ferrous metals and other sludge and incineration ash contain mercury. Depending on the concentration level, such waste should be treated as mercury waste. Fly ash from coal-fired power plants contains a certain concentration of mercury but is often mixed with cement for construction work. At mining sites, mining waste and tailings may contain trace amounts of mercury depending on the geological characteristics of the mines. Mine tailings of gold mines where amalgamation methods were used may be contaminated with substantial levels of mercury. Mining waste and tailings are very large in volume, so the amount of mercury could also be significant. Finally, in the event when some facilities or buildings are dismantled, mercury could be released if mercury-containing materials were handled in such buildings or facilities. Dismantling could generate a large quantity of waste contaminated with mercury and special care, including worker safety measures, should be put in place.

‘18’ Recycling is an important process for mercury waste management. Mercury waste will include different waste streams such as household waste segregated at the source, hazardous industrial waste, second-hand components containing mercury, scavenged materials at waste stations or landfill sites, etc. Recycling can recover mercury as well as useful materials, which makes recycling economically profitable. Instead, recycling for other materials could also be a potential source of emissions if mercury-added products are contained in the waste. In the past, cars used mercury switches, displays, etc. Thus automotive shredding residue was contaminated with mercury.

‘19’ Incineration is a waste management scheme practised widely for many types of waste. Although incineration is a good waste management practice for certain types of waste, it is a potential mercury emission source. Incineration without emission control devices can release almost all mercury in the incinerated waste, which is equivalent to open burning of waste in terms of mercury management in the waste sector.

‘20’ Waste landfill is the final process of the waste management scheme. The purpose of mercury waste management is to immobilize mercury at landfill sites. Stabilization and disposal of mercury waste can effectively prevent mercury release to the atmosphere and water environment. The amount of mercury released to the environment may vary between well controlled and uncontrolled landfills, but a certain level of mercury stays in the landfill site unless spontaneous waste burning occurs.

Section 5: Miscellaneous categories

‘21’ This section explains miscellaneous source categories that have some contribution to mercury releases.

‘22’ Mercury is a chemical element and presents every corner of the world. The types of mercury usage in products and processes are also diverse. There are some minor use or source categories of mercury that may have some contribution to mercury releases. Crematoria and cemetery are potential mercury sources from human remains. Crematoria burns bodies that emit mercury into the atmosphere, while cemetery buries bodies that may result in mercury release into water bodies. Particularly for the population with dental restoration using mercury amalgam, mercury releases from crematoria and cemetery may account for a certain level. There are wastewater treatment facilities that accumulate aquatic pollutants in the sludge. The reuse of such sludge should be carefully considered for its chemical safety. Finally, some potential categories that are less surveyed are explained. There are uses for mercury in some religious and traditional purposes in particular cultures. For example, some ayurvedic and homeopathic remedies contain mercury. It is not practised globally but could be a substantial source for particular countries and regions. There are known military-related uses that are excluded from international frameworks.

5.5 Lecture 4 Mass balance principle and examples on the process, sectoral and societal levels

‘0’ This lecture explains the mass balance principle and examples on the process, sectoral and societal levels, relationship between mercury mass flows, the UNEP Mercury Inventory Toolkit, and other mercury inventory tools.

Section 1: Mass balance principle

‘1’ This section explains the mass balance principle and introduces several examples at different scales.

‘2’ In general, the mass balance principle is described as follows: Mercury is a chemical element and persistent in the environment. This means that it is not destroyed, nor is it created in processes. It is only "fed" into process, or "society“ and released via process outputs to the environment, including waste deposits. When mercury is extracted from soil as a mineral or a trace element of other material, it enters society where it needs to be managed to reduce or avoid its adverse impacts. Thus, the first option would be avoidance for mercury from being brought into society as much as possible. Total inputs equal total outputs, meaning that what goes in must eventually come out. The only difference is the output pathways. In a timewise manner, however, mercury may accumulate if the activity rate changes over time. The accumulation may be positive or negative depending on the balance between inputs and outputs.

‘3’ The figures give a simple example of the mass balance for a coal-fired power plant where all mercury inputs come with the coal in natural trace concentrations, which accounts for the hundred percent to the incoming arrows. The output pathways are influenced by the air emission control systems installed in the facilities. If there is no filter on the stack, then all mercury leaves through the stack because mercury is evaporated at such high temperatures. If a high-efficiency fabric filter for particulate matter is introduced, it may reduce mercury emissions up to 50 % but may actually vary significantly. Mercury trapped to the filter goes for disposal. If a wet process is introduced such as desulphurisation system, some part of mercury may be released to the aquatic environment. The same principle applies for other emission control technologies.

‘4’ The mass balances for non-ferrous metal smelting facilities in Japan are presented as a process-level example. Non-ferrous smelting facilities are complex facilities with various types of chemical processes involved. Mercury is included in input feed, that is non-ferrous metal ore, in sludge, sediment and wastewater from flue gas treatment, by-product gypsum slag etc. The data are primarily obtained through interviews with the Japan Mining Industry Association in fiscal year 2016. In this example, a very small portion of the mercury input is released to the environment. Mercury is recovered from the system as calomel or metal mercury. It also flows out of the system with by-products, such as acid and gypsum, which may contain low concentrations of mercury.

‘5’ Life cycle and mass balance of dental amalgam of Denmark in 2001 is a mass flow example at the sector level. Amalgam is placed on people’s teeth in dental clinics, thereby increasing the mercury stock in society. From the stocks of amalgam in people’s teeth, mercury is lost to waste when teeth fall out, through excavations in the dental clinics, to cemeteries when the corpses are buried, or to the atmosphere if they are cremated. Dental treatment in clinics results in mercury release to air, water, and soil. It also produces mercury-bearing wastes, which may be released to wastewater or municipal solid waste if the amalgam is not segregated at the source. Dental amalgam waste should be separated into hazardous waste and specially treated. This mass balance is approximately 20 years old, and today, there is hardly any use of dental amalgam in Denmark because it has been regulated already. However, older people still have dental amalgam fillings, and they make their teeth drilled out or fall out, so mercury waste management must continue, which is the typical legacy mercury issue.

‘6’ A national-level example of mercury mass balance is shown here. The diagram describes the overall summary of mercury flow in Denmark in 2001. The incoming arrow on the left is the overall import of mercury with products and materials. The outgoing arrow indicates exports, mainly as waste. There are also losses to air, soil and water, and to waste deposition at a significant level. As a whole, the accumulation at that time showed negative accumulation, which means a decrease in social stock.

‘7’ The previous diagram was simple, but background work to develop it was substantial. This diagram is the detailed version of the same diagram that indicates sector- or product-level figures. The negative accumulation is seen widely in the world today, thanks to the Minamata Convention, but the mercury waste issue will continue for decades. The use of mercury-added products was much higher in the past. It is now replaced by mercury-free alternatives or disposed of as waste. The legacy problems need to be addressed in the long term while implementing the Convention.

Section 2: Key mass balance equations

‘8’ This section explains key mass balance equations that estimate the amount of mercury flow in the system.

‘9’ The mass balance equation is given in the first formula for the general case. For the specific case of an element such as mercury, which is neither formed nor degraded, it will be simplified to the second formula. Looking at a country or another “economic” system, it can be detailed in the third formula.

‘10’ When the overall mass balance equation is used from a national perspective, all life cycle steps taking place in the country should be included. More specifically, all life cycle steps taking place inside the system boundaries, typically the country’s borders, should be considered. This may be raw materials processing, product or materials manufacturing, use phase, waste disposal and recycling. For example, in the case of dental amalgam fillings, the steps may include filling preparation in dental clinics, waste collection and treatment from dental clinics, recycling of filling material, wastewater discharge, evaporation loss of mercury from the fillings in the mouths, loss of teeth over the lifespan of a person and the fate of the teeth, and output to land in cemeteries or to air from cremation.

‘11’ Domestic consumption equals production and imports minus exports. The terms domestic consumption and supply are often used interchangeably. In some studies, consumption refers to the true value while supply indicates statistical data because trade statistical data can include discrepancies due to less strict use of Harmonized Customs codes.

Section 3: System definition and boundaries

‘12’ This section discusses the system definition and boundaries that enable a snapshot of the flow profile.

‘13’ It is a basic concept to delineate the boundaries to monitor the flow crossing them so that incoming and outgoing amounts can be quantified. A typical physical boundary is a national territory, that is, the national economy within its territory. Using the national economy is easiest because the trades and production statistics follow this boundary. Flow analysis within national boundaries is also relevant to national reporting required by the Minamata Convention. Typically, in mass flow analysis, emissions and releases to the environment are considered losses or outputs from the economy. Atmospheric and waterway deposition coming from outside the territory is included as input in some mercury flow analyses.

‘14’ Additionally, a boundary in time has to be defined. This is typically one year, which is called the base year or reference year. It could be a calendar year or fiscal year, whichever is easier in the national setting. It is practical to have this base year a few years ago to ensure that the statistical data are available for that year. If more qualified data become available later, they can be indicated in the inventory report. In case recent data are not available, slightly older data can also be used as an approximation, but it must always be stated the year in question for each dataset.

‘15’ In the practical work for developing a mass flow, other boundaries can be delineated. For example, a mass flow for the whole coal-fired power plant sector in the country can be developed. Sometimes, a mass flow is developed at the process level. It could be just for one individual coal-fired power plant, which is for disclosure and data sharing. Such individual data can also inform the approximation of the entire sector through extrapolation if the presented data are accurate.

Section 4: Accumulation: quantification, prediction, and implications

‘16’ This section discusses the accumulation including its quantification, prediction, and implications.

‘17’ The total accumulation used here equals the total ‘stock’, which is the amount of material, mercury, currently present within the system boundaries. In year zero, when mercury was introduced into the economy, there was no accumulation or stock. In the following years, the input to society equals the output, which is called a steady state situation, and there will be no accumulation. However, if the input is larger than the output, accumulation will start forming in society. Assuming the early days when new mercury-added products were introduced, an increased amount of mercury built up in a society. Today, mercury has already accumulated in society that needs to be handled. If the input becomes smaller than the output by reducing mercury consumption or enhancing discarding mercury in use, the accumulation will decrease. Even though the mercury stock is decreasing in some countries, the accumulated mercury can still result in releases to the environment.

‘18’ The mass balance concept and mathematical expression of accumulation are described in the differential equations. The node is the focus of the mass balance calculation, which can be at various scales. The stock in the node is a function of time, delta T, and initial stock, S zero. It is important to be aware of dynamics, which change over time among input, output, and stock in the node.

‘19’ There are various types of stocks of different natures. The total stock in society is the sum of all stocks, including the following examples. Consumer products still in use or not in use but still kept by consumers are practically regarded as a stock. In industry, mercury-added products still in the production line, purchased for later internal use, or phased out but not yet disposed of, should also be stocks. The elemental mercury in chlor-alkali plants is stored for manufacturing use in the future or absorbed in plant facilities over the years. In recycling or recovering facilities, stocks will be found either in the form of waste material not yet processed or recovered mercury. There are also stocks in mercury trade companies accumulated for sale. There are also examples of government stocks of mercury as mercury is an important commodity for national security reasons. In the European Union and the USA, the sale of mercury in such stocks has now been prohibited because of the environmental impacts.

‘20’ The accumulation of mercury in products in use in society means that mercury consumed previously still needs to be managed. Such delayed releases are due to the life of mercury-added products in use or hoarded. The red curve shows the consumption of a mercury-added product, or sales to consumers, industry, etc, over a range of years. It takes time before the product is no longer used, and people do not dispose of it immediately after use. In reality, the disposal curve would have a longer tail due to the variation in the lifetime of the product. This illustrates the need to handle legacy mercury waste for many years after sales have stopped.

Section 5: Relations between mercury mass flows and the UNEP Mercury Inventory Toolkit

‘21’ This section discusses the relations between mercury mass flows and the UNEP Mercury Inventory Toolkit.

‘22’ The Toolkit is based on the mass balance principle, but with some simplifications to make it easier to operate. This made Toolkit inventories much more accomplishable for the key targeted users, namely developers of the inventories. The Toolkit methodology also makes inventories more standardized, and thereby more comparable. The idea to simplify the methodology assumed that data for full mass balances for mercury are still lacking in most countries. Previously mass flows for mercury have been made in countries where there is relatively good access to data. Today, the database is increasing gradually through the works implementing the Minamata Convention. Simplified inventories have been developing over time for many countries, thus opening for more detailed inventories and mass flows.

‘23’ A few simplifications or deviations from the mass balance principle were introduced to the UNEP Toolkit. One of the major simplifications was the separate calculation of the inputs to waste treatments, which is a major deviation from a mass balance principle. This was because the flows to waste of mercury-added products were generally underestimated in developing countries due to a lack of data. The advantage of this simplification is, therefore, the emphasis of waste management, which should not be ignored. The disadvantage is that inputs to waste treatment are detached from the inputs to mercury-added products. This discrepancy can be accommodated if actual mass balances are developed.

'24' For the outputs from engineered landfills, the default factors for releases to air and water, meaning leachate, are not derived from mass balance. This is simply because no mass balance data are available for landfills. The advantage of it is to signal the possible outputs from engineered landfills. There is some evidence that mercury evaporates from landfills and that water leachates contain mercury. The disadvantages are that the calculated values do not reflect the true mass balance derived values but are the best assumption under current knowledge. In addition, unprotected landfills, or waste dumping sites, are considered direct releases to land in the Toolkit.

'25' To avoid complex mass balance decisions for users, the mass flow from life cycle step one to step two is separately calculated in several cases to make data collection easier. It also saves users from handling potential double counting. For example, the output of mercury in products from domestic manufacturing is calculated separately from the input to the use phase for products. Additionally, the results are obtained with the production amount of mercury products without detailed mass balance studies. Instead, there is a disadvantage that moderate mismatch between total inputs and total outputs is seen in some Toolkit inventories due to the mismatching data. One hundred percent accuracy is usually not expected for mercury inventory within the available budgets. However, it will be improved if more data are available.

'26' The calculations for dental amalgam are also semi-balanced in Inventory Toolkit Level one. The major reason is to avoid the need for older input data to reflect current releases from drilling in old fillings. Instead, it will obscure the effect of large changes in dental amalgam inputs over time. Inventory Level two can be fully balanced if sufficient information is available.

'27' In some cases input factors are aggregated because detailed data are often hard or impossible to obtain. For cement clinker production in the Toolkit, inputs of mercury from raw materials are aggregated as tonnage of cement produced instead of getting mercury data for the clay, lime and other materials. Additionally, the inputs of mercury from fuels are aggregated by fuel type. This simplification can provide results without knowing the exact raw material mix and fuel mix. Instead, it gives moderate deviations from so-called true values and requires more work to use local input factors.

'28' Another example is the use of mercury catalysts in polyurethane production where the inputs of mercury are aggregated with grams of mercury per population based on EU data with an adjustment for technological development level. This is because obtaining actual data for the share of polyurethane elastomers with mercury and the supply in one country is very difficult or almost impossible; thus, simplification can allow for indicative results.

Section 6: Other mercury quantification tools

‘29’ This section provides information on other available mercury emission estimation tools.

‘30’ Multi-pollutant air emission estimation guidance is available for use in PRTR systems developed under the Kyiv Protocol of the Aarhus Convention. It focuses on air emissions, applies different principles and sector definitions and is less detailed than the UNEP Toolkit for many source categories. The method is, however, used in many countries covered by this Convention, and some other countries that have PRTR systems.

5.6 Lecture 5 Steps in mercury mass flow development

'0' This lecture explains steps in mercury mass flow development.

Part I: Sector definitions, identifying individual flows, quantification of flows

'1' This part describes sector definitions, identification and quantification of flows.

Section 1: Sector definitions

'2' This section guides the sectors defined by the UNEP Inventory Toolkit.

'3' Using the sector definitions in the UNEP Mercury Inventory Toolkit is recommended for national mercury mass flow analysis. Many things have been given and predefined in the Toolkit, and it is therefore practical to use the sector definitions given therein. They are based on the flows of mercury focusing on where mercury enters society, and therefore it is practical to use them. Inventory Level 2 offers users the possibility to add extra sectors.

'4' This table shows the definitions, or sub-categories, of the Toolkit for extraction and use of fuels and other energy sources. The first column refers to the Toolkit Reference Report chapter number, which also serves as the subcategory number. The next column shows the subcategory name, such as coal combustion in power plants. The output pathways are described in the following five columns starting from air, water, land, product, and waste. In the output estimations, waste is further subdivided into two sub-outputs: general, or municipal, solid waste and sector-specific waste. They are assessed in two ways, either the release pathway expected to be predominant for the sub-category, or additional to be considered depending on the specific source and national situation. The last column is the information on the life cycle phases to be included in the mass flow assessment. Coal combustion includes coal washing, coal combustion, and residue and discharge management. Coal washing is often done at the coal mine and may not be the case at the plant site. There will be a flow to the atmosphere from the power plant. There may be discharges to water if the facility has wet flue gas cleaning. There will also be a mercury flow to land if fly ash containing mercury is deposited directly on land or used as a construction material contacting land. If there is a wet or semi-dry de-sulphurisation filter, they sometimes produce gypsum for wall boards as by-products, which may contain trace mercury. Solid waste residuals from the filters and the slags may be sent to a general landfill, to a special depot, or whatever is appropriate in the specific circumstances.

‘5’ This table presents the primary metal production sectors, or sub-categories that produce virgin metal, which are categorized in 5.2 series.

‘6’ This table presents the production of other minerals and materials with mercury impurities, where cement clinker production is one of the major ones.

‘7’ This table presents the intentional use of mercury in industrial processes. It includes chlor-alkali plants with mercury cells, VCM production with mercury containing catalysts, and so on.

‘8’ This table presents consumer products with intentional use of mercury, which are called mercury-added products. There may be significant mercury outputs from the production, use and disposal of such products.

‘9’ This table presents other intentional products and process uses. The prominent ones in this sub-category are dental amalgam, manometers, and gauges, which are not considered other products in the Toolkit’s Level 2 because mercury may be sold separately for these purposes. Manometers, for example, may be sold empty for refilling with mercury after purchase. For simplification, the Toolkit’s Inventory Level 1 does not have this distinction.

‘10’ This table presents the production of recycled mercury and other recycling industries, or secondary metal production.

‘11’ This table presents the waste incineration and open waste burning of different waste fractions.

‘12’ This table presents waste deposition, landfilling and dumping, as well as wastewater treatment.

‘13’ This table presents crematory and cemeteries, or burial sites.

‘14’ This table lists mercury hot spots that may cause secondary releases or may be called contaminated sites. Basically, they are closed or abandoned sites where building materials, underground, or the surroundings are often polluted. Mine tailings are also potential secondary sources of mercury if they are handled, dumped or deposited in larger amounts.

Section 2: Identification of flows

‘15’ This section introduces the steps for identifying mercury flows in comparison with the mercury inventory.

‘16’ A flow is any movement of the material, that is, mercury in this case, from one physical place or environmental medium to another. There is any flow going into and coming out of one physical place or environmental medium. It also includes the flow to another sector or environmental medium within the boundary. For example, onsite dumping of waste in an industrial facility does not cross the boundary, but it is considered a flow. The most important outflow from each source sub-category, or sector, is indicated in the source category of the Toolkit Reference Report. Other output flows may exist, but they are usually considered insignificant.

‘17’ The following slides show a simple example to develop a flow diagram by assuming that only two major mercury emission and release sources exist in the system, namely, mercury-added products, and coal-fired power plants. Once the sectors are identified, the mercury flows are visualized with arrows.

For the mercury inventory concept, mercury emissions and releases into the environment are identified flows and the amount of mercury may be estimated for each flow.

‘18’ The first question to be addressed is “where is mercury coming from?” Mercury inflow to the system is composed of at least 3 processes, which are input of elemental mercury, domestic manufacturing or production, and use in society.

Mercury-added products are supplied to households or industries by either domestic manufacturing or import of the products.

Elemental mercury for domestic manufacturing of mercury-added products is either imported or domestically produced. For most countries, importing mercury is still legal, but illegal import may also exist. It may come from primary cinnabar mining although it is not prevalent, or it may come from recovery or recycling from mercury waste.

For the coal-fired power plants, there may be domestic coal production or import of coal, which is fed to the coal-fired power plant.

If any preparation process for coal, such as coal washing, occurs in countries before being fed into the power plants, it should also be incorporated into the diagram.

It should be noted that some mercury-added products manufactured domestically may be exported.

‘19’ The second question is “Where does mercury go from those sectors?”.

Mercury emissions and releases to the environment from these sectors could be already identified when developing a mercury inventory.

When mercury-added products become waste, they may be dumped or burned in open air, landfilled, or collected and treated to recover mercury if a separate collection system is in place.

Recovered mercury may be reused if there is still a market for allowed use both domestically and internationally.

Mercury from coal-fired power plants is trapped by pollution control devices. Fly ash may be used in cement production as an auxiliary material added into the cement for construction.

From all these processes, there are emissions and releases to the environment as well.

‘20’ The complexity of mercury mass flow is significantly different in appearance from that of the mercury inventory. Mercury mass flow is inclusive of the inventory information but is much more comprehensive because it describes the relationship between sectors and the fate of mercury.

‘21’ The information that the UNEP Inventory Toolkit provides is limited to the emission and release data only.

Section 3: Quantification of flows

‘22’ This section describes the necessary data types for quantifying mercury flows, which means how much mercury follows each flow path.

‘23’ The major part of national mercury flows can be quantified directly with results from the Inventory Toolkit, partly from the main results and partly from the sub-calculation results available in the Toolkit Level 2 spreadsheet. In some cases, the inventory made may not have accounted for all flows individually, and additional data may need to be collected. The data types needed in inventory Level 2 are, the activity rate at the national level, local input factors, and local output distribution factors for major sources. Mercury content in the coal mix used in the country is one of the important local input factors to improve data quality. When the higher level of refinement of the mercury inventory is required, local output distribution factors for major sources are critically important. For setting such distribution factors, information about the pollution abatements equipment in place and its efficiency regarding mercury retention would be helpful.

‘24’ The amount of mercury flow is calculated as the product of the activity rate, input factor, and output distribution factor. The input factor is the mercury content per unit of feed material processed or product produced, and the output distribution factors are the fraction of the mercury input that is released through a particular pathway such as air, water, land, by-products, general waste and sector specific waste. The default set of input and output distribution factors are available in the Toolkit, but it is good to have their own factors relevant to the local context. The activity rate is always needed for calculation.

‘25’ Additional data are also required for developing mercury mass flows. The first example is the production data, import and export data from specific sectors or from individual companies, if possible, taking note of confidentiality. Another example is the data on the sector specific waste treatment, what is actually done with the waste, for example, in the non-ferrous metal production. How much mercury is recycled from the waste in the sector and put into the market, or how much mercury is contained in the waste that is landfilled. The way waste is treated varies greatly among countries and even among individual facilities. To address sector-specific waste properly, the waste treatment sector should be subdivided, and additional information should be obtained from the facilities involved in each of the sub-sectors. The fate of wastewater is also commonly missing information. Wastewater released directly into the environment has a different fate in terms of mercury flow from wastewater fed into wastewater treatment facilities. Waste with high-volumes but trace mercury, such as paper, plastic, wood, and other metals is often left out of the mass flow calculation, as it is not classified as mercury waste.’

‘26’ Mass balance results from the Inventory Toolkit Level 2 spreadsheets will have to be partly collected from the main results, and partly from sub-calculations. There is currently a standard calculation of mercury inputs to waste treatments in the Level 2 spreadsheet. For re-connecting the outputs to waste from products with inputs to waste management, the spreadsheet needs some modification. The spreadsheet can be modified to reflect mass flow-derived inputs to waste management sub-categories. What can be done for mass flow quantification is to bypass this standard input calculation for waste treatment. Instead, calculate the input to each waste treatment sub-category as the sum of all outputs from products and processes to that waste output pathway.

‘27’ The mercury mass flow for mercury-added products and coal-fired power plants has identified the flows of mercury. Then, the amount of mercury in each pathway will be added to the diagram.

For the flows where the amounts are unknown, a question mark should be added to indicate that this is a data gap for later follow-up based on a prioritisation of the most important flows in terms of quantities or political priorities.

Section 4: Examples of sector flows

‘28’ This section shows the examples of sector flows that illustrate the complexity and the data types needed.

‘29’ This diagram shows mercury flow for non-ferrous metal smelting facilities in Japan. The inputs and outputs are marked with blue and red ovals respectively. The diagram has many process steps because of the need to separate the different fractions of outputs.

‘30’ This diagram shows mercury flow for primary iron production facilities. Compared to that for non-ferrous metal production facilities, the diagram has fewer outputs because primary iron production has a somewhat simpler process, and mercury comes in with the coal and other minerals used.

‘31’ This diagram shows mercury flow for secondary iron production facilities, or iron and steel scrap processing where mercury also must be handled. There may be mercury switches and mercury-containing lamps in scrap cars, etc., so these are inputs of mercury that result in emissions and disposal of collected dust.

‘32’ This diagram shows mercury flow for oil and natural gas production facilities. Mercury is present in oil and gas from the nature, and if the mercury concentrations are low at the production site, no special treatment may be performed to remove mercury. However, in some areas, mercury concentrations are quite high, for instance, in the Gulf of Thailand, some places on the west coast of the United States of America and in the Mediterranean region, where natural concentrations of mercury underground are elevated. The area is called the geological mercury belt. Mercury concentrations may also be elevated elsewhere and may vary significantly within even smaller areas.

‘33’ This diagram shows mercury flow for cement production facilities. All raw materials and fuels used for cement production contain mercury at low concentrations, which results in mercury emissions to the atmosphere unless properly managed. If there are effective air pollution control systems, mercury captured in the dust will be purged into the final cement product. However, generally, much mercury evades dust filters and is emitted into the air.

‘34’ This diagram shows mercury flow for municipal solid waste incineration facilities. The waste includes the products and materials containing mercury. Unless captured by air pollution control systems, mercury goes to air. Solid residues contain the captured mercury.

‘35’ This diagram shows mercury flow for industrial waste incineration facilities. Similar to municipal solid waste incineration facilities, mercury is emitted to air or captured in the residue.

‘36’ This diagram shows mercury flow for sewage sludge incineration facilities. Where this process takes place, the mercury sources are similar to the solid waste brought to the incineration facilities.

Part II: Quantification of stocks, collection of supplementary data, working with intervals, available online tools and resources

‘37’ This part describes the quantification of stocks, collection of supplementary data, working with intervals, and available online tools and resources.

Section 1: Quantification of stocks

'38' This section describes the recommended data collection steps to quantify mercury stocks.

'39' For the identification and quantification of physically confined stocks of mercury and its compounds, the general method is to conduct interviews and questionnaire surveys with companies or organizations that may have such stocks. This is a time-consuming exercise but is normally shorter and easier during the second time or follow up once such process was completed. This is because most of the relevant stakeholders are already identified, and the inquiry items are usually the same.

'40' The following steps are recommended to collect mercury stock data. First, statistical trade data on the import and export of mercury and amalgam are examined for as many years back as is relevant and consistent for the purpose. The consumption is then calculated with import plus production minus export. If possible, the amount of mercury illegally imported may be estimated as an indicative value. Illegal import of mercury may take place, especially in countries with small-scale gold mining, and where the borders may be porous.

'41' The major intentional mercury use sectors are identified from mercury input estimates. This could be artisanal and small-scale gold mining, producers of mercury added products, chlor-alkali production with mercury cells, etc. For chlor-alkali production, technology applied for the facility is important. The mercury cell plant contains a large amount of elemental mercury, which accounts for several tons per facility, used as the electrode. If technology conversion takes place at a mercury cell plant, then the mercury in the electrode will become unnecessary and disposed of, sold, or stored in the facility.

'42' Once major intentional mercury users are identified, information on mercury stock will be asked. It includes the amount of mercury stocks in their custody at present and, preferably, their stock records for at least the last five years or more if they are willing to share. Traders, producers, or recyclers could be mercury suppliers; therefore, they can be contacted for obtaining relevant information. Non-ferrous metal smelters are also important stakeholders as they have the by-product mercury.

'43' Mercury suppliers are asked for providing their information. They could be mercury traders or producers. The inquiry will include the total mercury supply to the countries of interest in the past five years or more. The amount of mercury stored in their facilities at present, and, if possible, annual exports and imports in the past five years or more are also asked. For waste recyclers, the amount of unprocessed waste in stock by waste types and the estimated amount of mercury to be recovered from them will also be asked, which may constitute significant amounts.

‘44’ There are two types of stocks requiring attention for reporting under the Minamata Convention. They are large stocks of more than 50 tons at a premise, and mercury suppliers that supply more than 10 metric tons per year. Reporting obligation falls on to each Party to the Convention, which will not add up across countries for a multinational company.

‘45’ Another type of stock needs to be investigated to make mercury mass balances. These are stocks of products and processes where mercury is at workplaces, which is sometimes called consumer stocks. They include the amounts of mercury in active use in products, or not in use anymore but not yet disposed of, which is also called hoarded products.

‘46’ First, existing publications are examined to identify the estimates of product in active use and in stocks. Earlier publication fits better for consideration. For some product types, the literatures, or expert statements about when the products were originally introduced into the market could be found. It is important to be aware that the information found may not cover the entire market and may need extrapolation before applying for analysis.

‘47’ Any production statistics, import and export data are collected as far back in time as possible to ensure the consistency of data. Any changes in the HS coding system, if they exist, should be taken note of to capture older coding numbers for the same items. The UN COMTRADE database, for example, allows the use of generic search words such as ‘lamp’ to extract all relevant customs codes relating to lamps. It is also beneficial to collect data on estimating mercury content per product over time. It is particularly useful, for example, for discharge lamps. They always use mercury but the amount per lamp has been diminished over time partly due to technological advancement or pressure from regulations. Mercury content in a fluorescent lamp today is approximately one-fourth to one-fifth of the one several decades ago. Information on the average lifetimes of the products in question is also needed. This is important in terms of obtaining an idea of the time gap between the time of sales of a product and the time of disposal of a product.

‘48’ Data on mercury product amounts received by recyclers and other waste treaters will be used for cross-checking. The amount may likely be underestimated especially in such countries where recycling is performed in the informal sector. A stock for a particular year, Y1, will be calculated in relation to the base year, Y0, by adding or subtracting the annual accumulations. Consumption is also called as supply from producer side which is the input to the society. Disposal or release to the environment is the output from the society. By making this calculation for every product, the total product stocks in society will be obtained. There is a lot to do, especially for the first time, to obtain the results, and it is a complex exercise. Thus far, it is understood that no quick answer will be available for it. Estimated amount of product stocks in society is important information for making forecasts of mercury waste.

‘49’ Mercury is also used in some production facilities, and sometimes with a significant amount at workplace. A similar approach should be used for estimating mercury stocks in the industries. Interviews and questionnaires are two major methods used to collect information. The response rate and accuracy are usually high for well-managed interviews. When using questionnaires, what is reported is often not the full picture and requires proper extrapolation to estimate the total value. The relevant information for estimation includes the mercury purchase data for the last 5 or 10 years, if possible, data on the recorded disposal of mercury for the same time frame and the mercury concentrations in the products and materials in question. It should be noted that there is a hidden stock in the facility as mercury may be absorbed in building materials, process lines, etc. that will become mercury waste when dismantling such a facility.

Section 2: Data sources

‘50’ This section introduces available and possible data sources for mass flow development.

‘51’ There are useful internet sources for many people and countries. One of the very important data sources is the UN COMTRADE database, which covers import and export data at a global level as far as countries have reported them. Guidance on how to extract relevant data is given in the Toolkit Inventory Level 1 guidelines annexes as well as in the ‘MercuryLearn’ e-learning platform. The guidance in the Inventory Level 1 guidelines is relevant for both levels. It includes names of the relevant products that are used in the Toolkit, suggestions for search words, and some examples of product codes in the table. Product codes may have more than what are provided. Extracting data is easy but the information is not always perfect.

‘52’ The International Energy Agency database provides statistics on fuel uses. Data are given in terajoules, not in tonnes of fuels, that requires unit conversion. The Toolkit Level 1 guideline annex also gives a table on how to use the IEA data.

‘53’ The United States Geological Survey website provided mineral yearbooks for most of the countries in the world, which are freely available. Sometimes countries are pooled together in one report. The reports give key data on mining and minerals production, and sometimes semi-quantitative information, for example on how much gold is from small scale mining and how much is from large scale mining.

‘54’ The international databases can provide many easily available data. However, they can provide only a number of important source categories. There are many other mercury sub-categories that are not addressed in these databases. That is where research for national data is needed. First, easily available existing data sources such as national literature on the relevant sectors will be examined. It may not be a publication on mercury but may give some relevant data. For example, it may contain the amounts of coal, tonnes of diesel fuel used, etc. relevant to developing an inventory for the energy sector. Sometimes national economic surveys may also be used. They provide information on trade volumes or monetary values, which requires unit conversion, but indicative data such as those can be useful. Another good data source is dioxin and furan inventories, which many countries have developed as a part of the obligations under the Stockholm Convention. They could contain information about the amounts of waste generated and how the waste is treated. Pesticide inventories or other POPs inventories could also be useful in some cases. Greenhouse gas inventories are also developed by many countries. They could contain the amounts of waste burnt, coal used, oils used, etc. Although the estimation methodology for greenhouse gas inventories is sometimes slightly less precise than that for mercury emissions, they also have very useful information. The guidance document on GHG inventories provides the advice on data collection and estimation. Some countries also have waste inventories and detailed waste characterization studies where some quantitative information is available. There are a number of other information available on the internet, universities and other knowledge centres as potential sources.

‘55’ Public statistics can also provide good insights for mercury flow development. Some countries periodically produce commodity statistics that include production data in addition to import and export. Access to detailed customs statistics may be restricted, but customs departments may provide a special dataset without confidential data. PRTRs are very useful, if available; however, most PRTRs have cut off thresholds for reporting; therefore, mercury information is often left out. If certain sectors have many facilities with a low mercury release level below the threshold, then the mercury amount could be underestimated in the PRTR system.

‘56’ For the market situation, trade and industry associations can be very important partners and should be invited for mass flow development. Sometimes, such associations are not well-known but individual companies may introduce them for obtaining information to the survey team. Public service providers may be important sources of information. They would include waste collectors and hazardous waste treatment facilities. Large producers or users of products or processes in which mercury is used can also be possible information sources. When analysing mercury emissions and releases from large point sources, producers or suppliers of emission and release reduction equipment may have valuable data. Retailer chains represent a large part of the consumer market and may provide a good overview of the domestic flow of mercury-added products. The survey may be conducted at the headquarters level for overall figures, or the shop level to determine the products on the shelves.

'57' If financially and technically feasible, the measurement of mercury concentration of input and output is another option. It can make a breakthrough in the mass flow development by providing information never existed before. As the measurement is an expensive exercise, it should be prioritised to identifying the most significant part of the information. Therefore, it is recommended to first examine the existing data sources as much as possible. Identifying the key data gaps and key uncertainties will be examined by sensitivity assessment. Examples of prioritised measurements could typically be mercury concentration of inputs to and outputs from cement kilns, such as raw materials, fuels, and flue gas because the concentrations vary locally. Another frequent data gap is the mercury concentration in nationally manufactured or imported products with little information available in the literature such as skin lightening creams and soaps, and button cell batteries. Water-based paints that may sometimes contain mercury compounds as preservatives. Artist paints can also contain mercury in the form of cinnabar pigment although they are usually not large in volume. Additionally, very little is known about the production of polyurethane elastomers that uses mercury catalysts that remain in the final products. As mercury is one of the catalysts used for polymerization, special attention should be taken in case large quantities are produced or used.

'58' Measurements made should be on a mass balance basis, meaning including all inputs and outputs from a facility or process. However, output distribution factors of the Toolkit may be strategically applied for effectiveness reasons, and the actual measurement can be focused on the mercury inputs, such as the raw materials and fuels for cement kilns. If needed, supplementary output measurements, such as air emissions, can be performed. Then, the other outputs can be estimated with the default output distribution factors of the Toolkit. Alternatively, another strategy could be employed to measure less costly media such as solid materials compared to sampling and analysis of flue gas.

'59' Unit conversion is a necessary pre-treatment of data. An incorrect unit means an inaccurate result. The Inventory Toolkit spreadsheet provides a unit conversion tab for some data types where conversion is often needed.

Section 3: Data collection principles and methods

'60' This section introduces the data collection principle and methods.

‘61’ Getting inventory data cannot be a one-go process. First, it could result in just a fraction of information and then will be narrowed down to more precise information by follow up actions. Creativity and flexibility are rather important to dive deeper into the matter. Generally, data collection approaches vary significantly and case-by-case arrangements to whom to talk or how to address need to be developed. It is important to collect data for the same base year, if possible, to develop an inventory and mass flow for a specific year. If data for the target year are not available, use data for adjacent years and report this explicitly. It is good to look at the average value of the data for a few years before and after the base year, which can also give the recent trend and degree of variations. An interview can include supplementary questions about the other informants to be asked. Once data are collected, the relevance will be verified before use. Liquid-filled thermometers may include both mercury-filled and alcohol-filled thermometers under the same customs code. One approximation method could be simply asking the importers of thermometers about an impression of the share of mercury-filled thermometers. In the case of mercury compounds, their weight should be converted to that of mercury of the compound. Triangulation, which is the land surveying method to check one location from two different checkpoints, is a good practice to qualify collected data. For example, producers’ data and consumers’ data may be compared.

‘62’ It is common that national data are missing for some mercury source types and that they are incomplete; therefore, if data are available from one part of the country, an attempt to extrapolate such data using the national situation, based on population, for example, or some other relevant extrapolation basis. If data are available for some of the companies in one sector, their market share can be asked to extrapolate the value. If data are available for a part of the domestic market, the extrapolation can be done with available indicators of the national situation. For example, in the case of blood pressure gauges with mercury manometers, one possibility is to ask a few major hospitals and large private clinics. The questions will include the numbers of devices in stock and annual purchase subdivided by mercury-contain and mercury-free. The hospital beds will be supplementally asked to extrapolate it to the total number of hospital beds in the country. Although extrapolation introduces uncertainties, mercury inventories, or mass flows of any kind, have the strength of seeing the overall picture. Instead, the individual numbers are always associated with uncertainty, which needs to be lowered by getting more data. Describing clearly about the approximation method applied and dataset used for the approximation is recommended. Such an explanation in the report will be helpful especially when revisiting a few years later for the next inventory.

Section 4: Uncertainties and working with intervals

‘63’ This section explains uncertainties and working with intervals.

‘64’ All data are in fact associated with some degree of uncertainty including the data of measurements. It is therefore recommended to work with intervals, based on the variation in the real data in society for the same item. In cases where there are significant amounts of data, statistical analyses may be conducted to form a distribution function. The uncertainty and confidence intervals can be calculated with these distribution data. A much simpler way is to use minimum to maximum ranges, or the best estimate plus or minus with self-judgement. Proper explanation of how to reach the uncertainty estimation is always necessary in the report.

‘65’ Crosscheck improves the credibility to a great extent. It may be asked for example, “does the supply of raw materials or semi manufactured goods registered in the statistics correspond to the amounts used at manufacturers?” A few more examples are presented in the slide. Some of them look difficult, but creative thinking is important to crosschecking between two different types of data as much as possible.

‘66’ It is recommended to show values of mercury mass flow in a range, based on the observed variation in the data used. The summation can be simply done by adding up all minimum values to get the low end and all maximum values to get the high end. Although it overestimates the uncertainty, it is the easy way for readers to understand. It is also possible to use stochastic variables, which reduces the uncertainty intervals for the results, but it is a long process and becomes more “black box” to readers. Many of such numeric datasets form famous distribution patterns such as log-normal distributions, or Weibull distributions.

Section 5: Use of online helper tools

‘67’ This section briefly introduces some online helper tools when the inventory and mass flow development is performed online.

‘68’ ‘Work together online’ is the new business style, which will likely become more common in the future. There is a rapid development of interactive online business tools that help collaborative work from a distance. The internet ‘whiteboard’ is a non-text-based online tool that is suitable for drawing up the process flows and illustrating them during the process. MIRO and MURAL are some of the typical applications that provide practical platforms. Real-time document sharing services, including Google Docs and Microsoft Office 365, work for common real-time multi-user text authoring and editing. The service includes common share folders and files accessible among inventory development team members. To make more sophisticated mass flow charts such as a Sankey diagram, several applications including Rawgraph or Sankeymatic are available on the internet.

Part III:I Identifying and reducing uncertainties, reporting and review

‘69’ This part focuses on identifying and reducing uncertainties, closing and calibrating the mass balance, reporting and review.

Section 1: Identifying and reducing uncertainties and gaps

‘70’ This section describes identifying and reducing uncertainties and gaps.

‘71’ To check the accuracy of mass flow, the numbers that affect the overall results the most should be carefully identified. High numbers with medium or high uncertainties are particularly of concern. If possible, an actual sensitivity analysis will be conducted. In addition, all identified data gaps should be carefully listed and reported. Additional data with priority on the most important ones may be collected this time, or next time when updating the mass balance for quality improvement.

‘72’ Estimated values of mass flow may present discrepancy, and it is necessary to investigate its cause and improve the estimation. The figure assumes the case where a chain of mass flow subject to the analysis has different amount of the input and output. There are several possibilities. It could be a real change in accumulation within the process, or some differences may be due to incompleteness or errors in the data although the input and the output were balanced in reality. If the difference comes from incompleteness or errors, additional data collection is necessary. Once the reasons for the observed difference are identified, appropriate interpretation and possible modification are expected in reporting.

‘73’ If the output from process 1 is the direct input to process 2, the figures of the input and the output are expected to be identical. If a difference is found, a possible cause may be incomplete or erroneous data, although the output and the input are actually equal. Alternatively, the output and input may be truly different due to some other processes, which was not identified at the time of the study, but is influencing the flow between process 1 and process 2. Alternatively, the flow tends to fluctuate, and the data may have been taken at different times. In any case, it should be investigated to determine the cause.

‘74’ More frequently, such a case will be encountered in which information on input to process 2 is not available or difficult to estimate. Theoretically, efforts should be made to obtain independent data that can qualify the estimates, but the most commonly applied option would be to assume the output from process 1 as an input to process 2 without substantial information for the input to process 2. Making the numbers fit together could sometimes be complicated but it is always recommended to explore other ways to bridge the data gap, whenever possible.

‘75’ Once the data are collected and examined, the next step is to close the mass-balance, that is, to make the numbers fit together into one big picture. First, the estimation of all emissions and releases as well as data on mercury outputs from waste treatment are needed for this exercise. Many countries at this moment do not have reliable mercury data from waste treatment. If it is confirmed that the sum of all the inputs to the economy matches the sum of all the outputs from the economy, it gives a strong indication that the mass flow is balanced. If they do not, some of the numbers may be missing, wrong or misinterpreted. When re-assessing the estimate, the most uncertain numbers or the largest numbers could be examined first. If additional data will be collected to improve the balance, such data may influence the whole mass balance as all the flows are interconnected. Therefore, the additional data collection process stops the entire process until the mass flow is fully reinstated.

Section 2: Reporting principles and review

‘76’ This section describes the reporting principles and review.

‘77’ It is important to highlight the key data needed for mass flow in the report. The activity rates coming from import, production, and export data, as well as any local input factors and output distribution factors should be presented. Associated information may be annexed to the main report. Data uncertainty should be discussed in the report as transparent as possible. It is a good scientific principle to discuss the uncertainty for the benefit of the readers. The best available approximation is much better than omitting data with uncertainty. The data gaps should also be reported so that the readers can differentiate between assessed zero and no data obtained. In the report, explicit expression of ‘no data’ should be placed instead of leaving tables cells empty. Finally, full references to all the data used are presented in the report. This is important for following up the results and updating the information. It also informs the global community that the data in the report are valuable and reliable.

‘78’ Once the report is drafted, it is recommended to have it reviewed by stakeholders and incorporate useful feedback into the report. Selected resource persons with relevant expertise in key internal stakeholders such as organizations composing of the mercury mass flow developing team will be invited for review. In some cases, external key stakeholders such as industrial associations may also be invited for review before publication. They may provide additional useful information or at least their standpoints to the results. The feedback does not have to be reflected in full, but useful and reliable feedback can be incorporated into the report.

6 LIST OF ANNEXES

Annex A: Mercury inventory data source overview (Excel)

Annex B: Lecture 1: The Minamata Convention on Mercury (PowerPoint)

Annex C: Lecture 2: Mercury issues and how mercury flow analysis can contribute (PowerPoint)

Annex D: Lecture 3: Mercury source categories (PowerPoint)

Annex E: Lecture 4: Mass balance principle and examples on the process, sectoral and societal level (PowerPoint)

Annex F: Lecture 5: Steps in mercury mass flow development (PowerPoint)

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