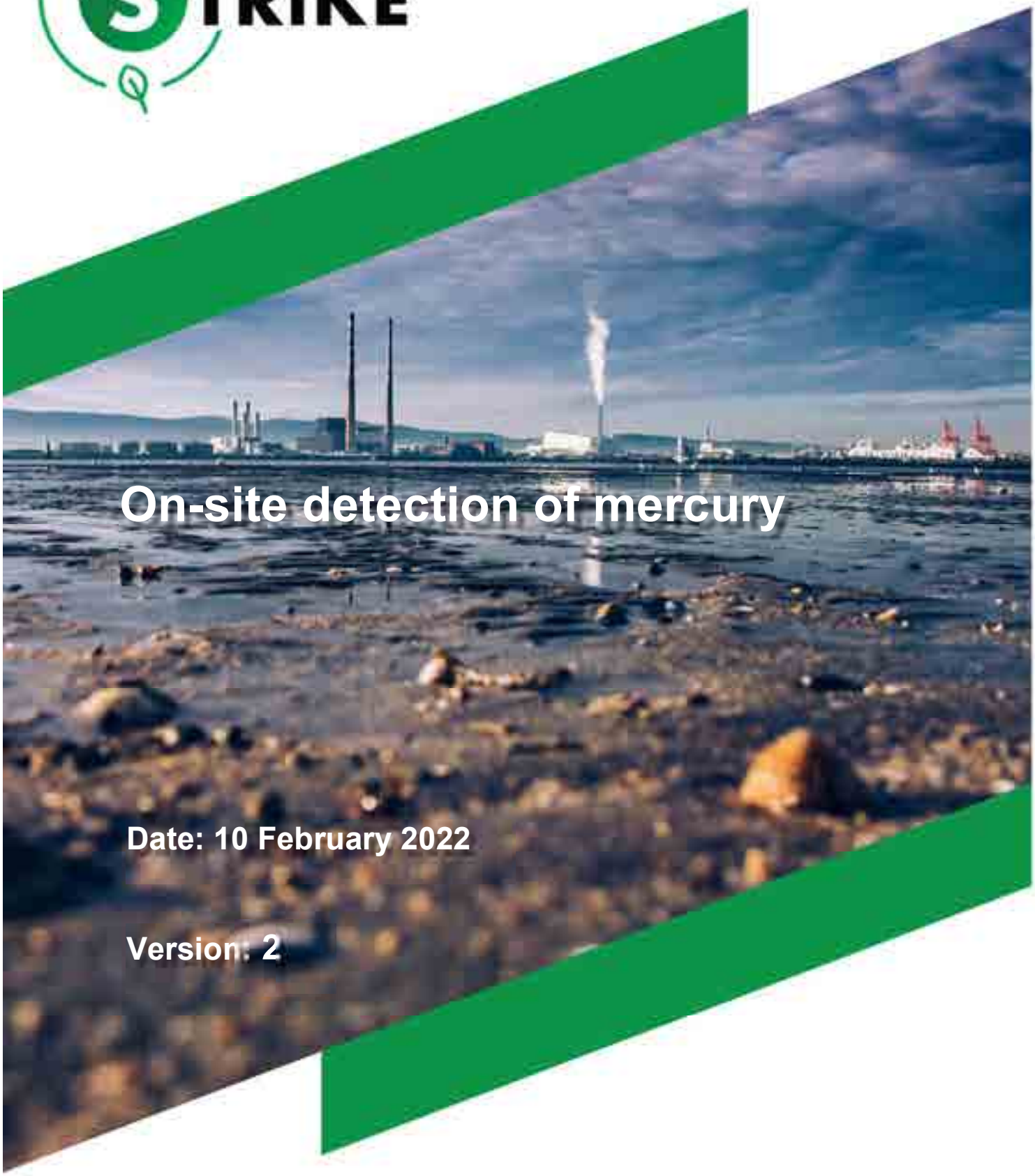

On-site detection of mercury

Date: 10 February 2022

Version: 2

The STRiKE Project is funded by the European Union Internal Security Fund - Police (ISFP-2018-AG-OC-ENV-869173)

Stronger training and increased knowledge for better enforcement waste & mercury

New Tools and Methodologies

On-site detection of mercury

Forensic tools for detection and investigation of waste and mercury crime

Project	Stronger training and increased knowledge for better enforcement waste & mercury
Acronym	STRiKE
Work Package:	WP3 New Tools and Methodologies
Work Package Leader:	Netherlands Forensics Institute
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Notice

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Executive summary

The *Stronger Training and Increased Knowledge for better enforcement waste and mercury (*STRiKE) project aims to enhance operational activities & capacities of authorities involved in addressing illegal trade & management of problematic waste streams (e.g., e-waste, end-of-life vehicles, batteries & mercury bearing wastes), as well as illegal production & trade of mercury-added products (MAPs).

As the toxic effects of mercury on nature and human health have become more widely recognized, efforts to reduce the supply of and the demand for mercury have increased, culminating in the UN Minamata Convention on Mercury in 2013. The Minamata Convention sets several goals at an international level to phase out the use of mercury during production processes and products. The Convention has been ratified by the EU on the 18th of May 2017. Although the phase out date for most of the uses of mercury by manufacture processes and the import or export of mercury added products (MAPs) was set for the 31st of December 2020, mercury bearing wastes and mercury added products (MAP) are still ubiquitous. During inspections the different chemical forms of mercury present in a wide range of products and materials may be encountered. Basic general characteristics to recognise elemental mercury and some common mercury compounds during inspections are:

- Elemental mercury is a silver-coloured fluid and recognisable as such in many products
- Some forms of mercury like mercury sulphide and mercury iodide have a distinctive red colour
- Mercury is heavy

To facilitate the recognition of mercury containing materials in the field Annex I to this report gives an overview of mercury containing materials, products and wastes with photos and other details. Many mercury bearing wastes however lack distinctive characteristics that can make them recognizable by a visual inspection. Information about the origin of the material in combination with the use of mobile equipment may prove useful here.

To further enhance the yield of inspections, the use of field equipment is promising. Field equipment like an X-ray fluorescence (XRF) spectrometer has the potential to replace sampling and chemical analysis in a laboratory. Other methods tested during the STRiKE project like a dedicated mercury air analyser proved superior in the fast on-site detection of the presence of mercury in materials. Due to the use of mobile equipment safety is also better secured.

Environmental inspections and environmental crime scene investigations take place in different mostly unique situations with different safety risks. In actual situations, there is often little time to do a thorough risk assessment. During the STRiKE project a *Mercury Safety Tool* was created that should assist compliance officers in taking the proper safety measures.

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List of abbreviations and definitions

Atomic Absorption Spectrometry (AAS)	Atomic absorption spectrometry (AAS) is an easy, high-throughput, and inexpensive technology used primarily to analyse elements in solution. Atomic absorption spectrometry (AAS) detects elements in samples through the application of characteristic wavelengths of electromagnetic radiation from a light source. Individual elements will absorb wavelengths differently, and these absorbances are measured against standards.
AH	Absolute Hazardous category of the Waste Framework Directive (WFD).
Amalgam	An alloy in general is an admixture of metals or a metal combined with one of the other elements. An amalgam is an alloy of mercury with another metal. Alloys are formed through metallic bonding with the electrostatic attractive force of the conduction electrons working to bind all the positively charged metal ions together into a crystal lattice structure. Most metals can form amalgams with mercury, exceptions are iron, platinum, tungsten, and tantalum.
ANH	Absolute Non-Hazardous category of the Waste Framework Directive (WFD).
ASG mining	Artisanal and small-scale gold mining.
Catalyst	A substance that causes or accelerates a chemical reaction without itself being affected.
CLP	Classification, Labelling and Packaging Regulation.
CV	Coefficient of Variation.
LOD	The limit of detection (LOD) is the lowest quantity of a substance that can be distinguished from the absence of that substance (a *blank value*) with a stated confidence limit.
ECHA	The European Chemicals Agency (ECHA) is the driving force among regulatory authorities in implementing the EU's chemicals legislation for the benefit of human health and the environment as well as for innovation and competitiveness.
Hg	Chemical symbol for mercury.
H-phrase	Standardised hazard phrase or statement used in Classification, Labelling and Packaging (CLP) regulation. H-phrases can be found in the publicly available ECHA database.
Mercury analyser	A mercury analyser is a portable multifunctional atomic absorption spectrometer with Zeeman background correction, which eliminates the effect of interfering impurities. It enables the user to conduct real time air monitoring and detection of mercury vapor.
MAP	Mercury added products.
MH	Mirror Hazardous entry, marked with an asterisk (*), from the Waste Framework Directive.
MNH	MNH=Mirror non-hazardous (MNH) entry from the Waste Framework Directive.
RAMAN	Raman Spectroscopy is a non-destructive chemical analysis technique which provides detailed information about the chemical structure of materials. It is based upon the interaction of light with the chemical bonds.
Standard Deviation	In statistics the standard deviation is a measure of the amount of variation or dispersion of a set of values.
TCM	Traditional Chinese Medicine.
XRF	XRF (X-ray fluorescence) is a non-destructive analytical technique used to determine the elemental composition of materials. XRF analysers measure the fluorescent (or secondary) X-rays emitted from a sample when it is excited by a primary X-ray source. All elements produce a set of characteristic fluorescent X-rays (“a fingerprint”) that is unique for that specific element.
WFD	The Waste Framework Directive (WFD) sets the basic concepts and definitions related to waste management, including definitions of waste, recycling, and recovery (Directive 2008/98/EC, 19 November 2008).

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Objectives

The *Stronger Training and Increased Knowledge for better enforcement waste and mercury (*STRiKE) project aims to enhance operational activities & capacities of authorities involved in addressing illegal trade & management of problematic waste streams (e.g., e-waste, end-of-life vehicles, batteries & mercury bearing wastes), as well as illegal production & trade of mercury-added products (MAPs).

In activity 3.1 of Work package 3 of the STRiKE project, forensic tools for detection and investigation of waste and illegal activities related to mercury are further developed. To increase the yield of inspections, an inventory of processes that use mercury, mercury-added products, raw materials containing mercury and mercury bearing wastes is made in combination with a photo library. Different mobile equipment is selected to test the options to better detect mercury in the field during inspections. To further assist compliance officers in their work a *Mercury Safety Tool* is developed, dedicated to inspections and environmental crime scene investigations.

Research methodology

To collect the information in this report a desk study was performed. With assistance of STRiKE partners and H-lab members mercury containing materials like mercury added products (MAP) and wastes were collected, photographed and characteristics of the materials were described.

The materials collected were used to test the possibilities of different mobile equipment in the detection of mercury and mercury compounds in the field. For air analysis the options of Dräger-Tubes and a mercury analyser were tested. For fluids and solids, the possibilities of a Raman spectrometer and an X-Ray fluorescence (XRF) spectrometer were tested.

A stakeholders meeting was organized for a selected group of experienced environmental and drugs crime scene investigators to collect information for the development of the *Mercury Safety Tool*. The meeting was guided by NFI Safety experts and occupational hygienists of the Dutch Foundation of Post Higher Education Safety Studies (PHOV).

1.Introduction

As the toxic effects of mercury on nature and human health have become more widely recognized, efforts to reduce the supply of and the demand for mercury have increased, culminating in the UN Minamata Convention on Mercury in 2013. The Minamata Convention sets several goals at an international level (UNEP and GRID-Arendal, 2020) *to phase out the use of mercury during production processes and products. The Convention has been ratified by the EU on the 18th of May 2017* (EC no 2017/852, 24 May 2017) (EC SWD (2016), 2 February 2016). *The phase out date for most of the uses of mercury by manufacture processes and the import or export of mercury added products (MAPs) is set for the 31st of December 2020.*

Mercury exists in different chemical forms and is used in a large variety of production processes and products. The different mercury forms not only have different chemical characteristics but also look different. During inspections and environmental crime scene investigations the presence of mercury is therefore not always clear.
The STRiKE report *On-site detection of mercury* summarizes the options for the on-site detection. On-site detection should increase the yield of inspections. The procedure described in this report follows the structure of inspections of materials in general, as follows (see also (Stelling & Bakker, 23 March 2020):

- Control of necessary papers and a check on the origin of the material.
- Visual inspection and determination of other characteristics.
- On-site verification with mobile equipment.
- Finally, if there is still doubt, verification by sampling and subsequent laboratory analysis.

During the STRiKE project the possibilities of different mobile analytical methods were explored. Mobile equipment develops fast and alternative methods for the detection of mercury in the field are on the market. Whether a method is suitable, depends on the type of mercury (or mercury compounds), the material analysed and the concentration levels.

1.1 Minamata Convention and legal aspects

The Minamata Convention on Mercury (http://www.mercuryconvention.org/) is a global treaty to protect human health and the environment from the adverse effects of mercury. The Minamata Convention entered into force on the 16th of August 2017.
The Convention draws attention to a global and ubiquitous metal that, while naturally occurring, has broad uses in everyday objects and is released to the atmosphere, soil, and water from a variety of sources. Controlling the anthropogenic releases of mercury throughout its lifecycle has been a key factor in shaping the obligations under the Convention.
Major highlights of the Minamata Convention include a ban on new mercury mines, the phase-out of existing ones, the trade of mercury, the phase out and phase down of mercury use in several products and processes, control measures on emissions to air and on releases to land and water, and the regulation of the informal sector of artisanal and small-scale gold (ASG) mining. The Convention also addresses interim storage of mercury and its disposal once it becomes waste, sites contaminated by mercury, as well as health issues.

The Minamata Convention has a close relationship with the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (http://www.basel.int/Home/tabid/2202/Default.aspx) for matters related to mercury wastes, their environmentally sound management, and transportation across international boundaries. Mercury bearing wastes are listed in annexes I and VIII of the Basel Convention (BC/UN/UNEP, 15 May 2015).

On the 18th of May 2017, the EU ratified the Minamata Convention (https://ec.europa.eu/environment/chemicals/mercury/index_en.htm). Within the European Union the Mercury Regulation (EU) 2017/852 (EC no 2017/852, 24 May 2017) covers the full life cycle of mercury. It implements the Minamata Convention and complements a large body of existing EU environmental law on mercury, by:

- Prohibiting the export of mercury and mercury compounds.
- Prohibiting the manufacture, export and import of a large range of mercury-added products.
- Putting an end to all uses of mercury catalysts and large electrodes in industrial processes.
- Reducing the use of and pollution from dental amalgam, which is the last large use of mercury in the EU and setting out a process to assess the feasibility of a complete phase out of the use of mercury in dentistry.
- Closing the door to future new uses of mercury in industry and in products.
- Ensuring that all mercury waste is safely taken out of the economic sphere, stabilized in a less toxic form, and stored permanently in environmentally sound conditions. Mercury and mercury compounds, whether

in pure form or in mixtures, from any of the large sources must be considered to be waste within the meaning of the Waste Framework Directive and be disposed of without endangering human health or harming the environment. Such disposal should not lead to any form of reclamation of mercury. The temporary storage facilities must be dedicated to and equipped for this purpose. The operators of facilities undertaking the temporary storage of mercury waste must, as soon as the mercury waste is taken out of temporary storage, issue a certificate confirming that the mercury waste was sent to a facility undertaking disposal operations (see also The Mercury Regulation (EU) 2017/852 (era-comm.eu)).

In accordance with Article 8(7) of Regulation (EU) 2017/852 on mercury, the European Commission has published on the internet an inventory of existing manufacturing processes involving the use of mercury or mercury compounds ('processes') and of existing mercury-added products (MAPs) as well as any applicable marketing restrictions (EC, Revision 1, 29 April 2019). Export, import and manufacturing of many mercury-added products are prohibited by 31.12.2020.

Additional information can be found on the website of the STRiKE project (see STRIKE | UNITAR | Switzerland (strikeproject.org).

2.Mercury in processes, products, raw materials, and wastes

This chapter contains an overview of uses of the different chemical forms of mercury in production processes and products and the presence of mercury in raw materials and waste materials. Information originates from literature and mercury containing products and wastes collected in the Netherlands, Ireland, Slovakia, and Belgium. The outcomes confirm that mercury added products (MAP) and mercury containing wastes are still ubiquitous. Many different products, product types, materials and wastes exist, complicating the construction of a complete overview. Important general characteristics to recognise mercury are:

- *Elemental mercury is a silver-coloured fluid and recognisable as such in many products (see for example photo 1)*
- *Mercury sulphide and mercury iodide have a distinctive red colour (see for example photo 2))*
- *Mercury is heavy*

Many mercury containing wastes lack distinctive characteristics to make them recognisable by visual inspection alone. A combination of information about the origin of the material and the outcomes of measurements will be needed to identify the presence of mercury in these materials.

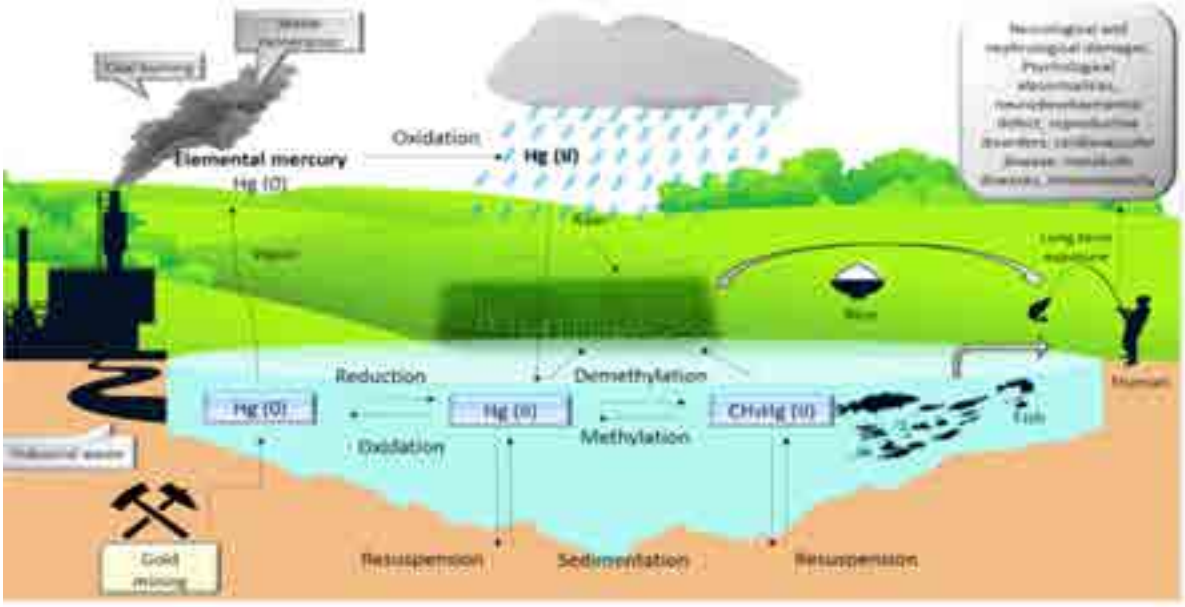

Figure 1: Overview of the mercury cycle. Once emitted into the environment all different chemical forms of mercury become part of this mercury cycle. Figure originates from (Busairi & Syahir, 2018).

Mercury exists in three chemical main forms: inorganic mercury salts, elemental mercury, and organic mercury.

Inorganic mercury salts naturally occur in rocks in the earth's crust. They occur in water and soil originating from the weathering of rocks and from factories or water treatment facilities that release water contaminated with mercury. Dust containing these salts can enter the air from mining deposits of ores that contain mercury. Coal-fired power plants, the burning of municipal and medical waste, non-ferrous metals smelters and factories that use mercury may emit both inorganic mercury salts and elemental mercury. Attached to airborne particles inorganic mercury salts can be transported in the atmosphere over tens to hundreds of kilometres (see figure 1).

In its inorganic form, mercury occurs in the environment, primarily as the mineral's cinnabar (or mercury sulphide) and metacinnabar, and as impurities in other minerals. Other examples of inorganic mercury are mercury(I)chloride, mercury(II)oxide and mercury iodide. Both mercury sulphide and mercury iodide have a bright red colour (see photo 1). This red colour may be recognisable in practice (see also photo 56 of mercury sulphide coated Traditional Chinese Medicine (TCM) in Annex I).

Photo 1: Red colours of mercury sulphide (cinnabar) and mercury iodide. Photo: NFI.

Elemental or metallic mercury can be recognized by the silver-white colour and liquid form at room temperature (see photo 2).

Photo 2: Elemental mercury in devices may be visible as a silver fluid. Photo: KMK Metals Recycling Ltd. Ireland.

Due to a set of unique chemical properties elemental mercury has a wide range of different uses in different processes and products. It is for example used by the preparation of dental amalgam fillings, in mercury-in-glass thermometers and in different types of electrical switches. An overview of processes that use mercury and mercury added products can be found in the tables 1 and 2 below. Photos of the different materials can be found in Annex I.

When dropped, elemental mercury breaks into smaller droplets which can go through small cracks or become strongly attached to certain materials like copper and aluminium. At room temperature, elemental mercury can evaporate partially to become an invisible, odourless, colourless toxic vapor. Elemental mercury vapor can travel thousands of kilometres with the winds. Once emitted it will become part a mercury cycle (see figure 1) and eventually will be deposited on land or in water in some form. Elemental mercury easily reacts with other substances to form compounds, such as inorganic mercury salts or organic methylmercury (see also (Basic Information about Mercury | US EPA)).

Organic mercury is characterised by at least one carbon atom bound to a mercury atom. It can be man-made but also originates from micro-organisms that can combine mercury with carbon, thus converting it from an inorganic to organic form. Methylmercury is the most common organic mercury compound found in the environment and is highly toxic. Like inorganic mercury salts and elemental mercury, organic mercury is part of the mercury cycle (see figure 1).

In the past the options for the general population for exposure to naturally occurring inorganic mercury salts used to be limited. Human activity however has tripled the mercury amounts circulating in our environment, compared to natural concentrations. Making exposures to elevated mercury levels more common. Although the use of mercury in production processes and in consumer products have been discontinued in the developed countries, the different forms of mercury are still widely used in developing countries.

The different uses, occurrences in products and wastes of mercury can be classified in 4 categories[1]:

1. Processes that employ mercury are presented in table 1.
2. Products and applications with mercury added intentionally (MAPs) are given in table 2.
3. Industrial processes that use raw materials with mercury impurities, see table 3 for an overview.
4. Mercury contaminated wastes and materials can be found in table 4.

Photos and other characteristics by which the different mercury containing materials can be recognized in the field can also be found in Annex 1.

[1] See also: (EPA, reporting year 2018) (UN Environment, Version 1.5 November 2019) (BC/UN/UNEP, 15 May 2015) (EC, Revision 1, 29 April 2019) (Parties to the Basel convention, 2011) (UN Environment, 2017) (Mukherjee, Zevenhoven, Brodersen, Hylander, & Bhattacharya, 2004) (Chalkidis, et al., 2020).

Table 1: Processes that employ mercury.

Acetaldehyde production with a mercury sulphate catalyst[2]
Materials used and wastes generated
• Mercury sulphate is used as a catalyst. • Methylmercury contaminated wastewater and treatment sludge may be generated.
Artisanal and small-scale gold mining
Materials used and wastes generated
• Elemental mercury is used during the ASG mining process (photos 14 to 21 Annex I). • Wastes generated are mine tailings and wastewater and significant gaseous mercury emissions.
Chlor-alkali production with mercury-cell technology[3]
Materials used and wastes generated

• Mercury is used as a catalyst in a closed or a semi-open process (see Mercury cell chlor-alkali production | Global Mercury Partnership (unep.org).
• The following routine maintenance operations generate significant mercury emissions:
  ○ Mechanical removal of ''mercury butter'' (calcium and magnesium mercury salts, see photo 22 Annex I) and ''light butter'' [$Hg(OH)_2$] from the bottom of the mercury cells.
  ○ Anode replacement removal and replacement of graphite pellets and internal components within decomposers.
  ○ The repair and replacement of mercury pumps (Kinsey, Anscombe, Lindberg, & Southworth, 2004).
• Other wastes include mercury-containing building materials from decommissioning of the mercury cells and buildings.

Dental procedures with amalgam
Materials used and wastes generated
• Dental amalgam fillings consist of an alloy of mercury (generally 44-51% mercury by weight) with silver, copper, and tin (UN Environment, 2017) (Chalkidis, et al., 2020). • Waste originates from excess amalgam (see photo 23 Annex I) and chair-side strainers (photos 24 and 25 Annex I). As from 1 January 2019, all dental facilities that use amalgam and/or removing dental amalgam fillings within the EU must be equipped with amalgam separators ensuring the retention and collection of amalgam particles (EC, 2018). Amalgam separator waste is a sludge of dental amalgam mixed with excavated tooth material.
Methamphetamine production
Materials used and wastes generated
• Mercury(II)chloride is used as a catalyst during the production (see photo 26 Annex I). • Wastes containing water, organic solvents, elemental mercury, and other process residues are produced (photo 27 Annex I).

[2] This process was the cause of the mercury contamination in the Minamata bay in Japan caused by a chemical company between 1932-1968.

[3] This process was the cause of a severe mercury contamination caused by a pulp and paper company in Ontario Canada between 1962-1970.

Vinyl-chloride monomer production with mercury chloride catalyst
Materials used and wastes generated
• The vinyl chloride monomer is mainly used to produce PVC (a plastic mostly used in construction, window frames, and other applications). In countries where coal is used as a cheap feedstock, the carbide-based process is used. This production process requires $HgCl_2$ (mercury(II)chloride) carried by activated carbon as a catalyst. The $HgCl_2$ content varies from 4.5% to 12% (weight) (Lin, Wang, Wu, & Larssen, 2016). • Generated wastes are exhausted catalysts with around 5% of mercury and activated carbon filters for which the mercury contents vary considerably (UN Environment, 2017).

Table 2: Mercury Added Products
Mercury-added products are listed in Part 1 of Annex A ("Products subject to Article 4, paragraph 1") to the Minamata Convention and Annex II of EU Regulation 2017/852 on Mercury. For a detailed list, see also the UN Environment Mercury Inventory Toolkit (UN Environment, Version 1.5 November 2019).

Batteries (EC, Revision 1, 29 April 2019)
• Mercury oxide also called mercury-zinc cells, all sizes • Button cell size silver oxide and zinc air, zinc carbon and alkaline manganese The European Union's Batteries Directive (2006/66/EC) is in force since September 26, 2008. It stipulates that all batteries or accumulators shall not contain more than 0.0005% (5 ppm) of mercury by weight. See photos 28 to 31 and figures 6 and 7 of Annex I for examples of mercury containing batteries.
Cosmetics
• Antiseptic soaps, skin lightening, and anti-aging creams may contain mercury. The products are usually marketed as skin lighteners and anti-aging treatments that remove age spots, freckles, blemishes, and wrinkles (FDA, 26/07/2016). • Check the label for the words "mercurous chloride," "calomel," "mercuric," "mercurio," or "mercury". An extensive list of mercury containing skin creams can be found in the report (EEB ZMWG, November 2018) of the Zero Mercury Working Group of the European Environmental Bureau. See also photo 32 and figure 8 Annex I.
Switches and relays
• Mercury-added switches and relays are a diverse product group due to the range of applications, the range of mercury content, and the differences in product life expectancy (UN Environment, 2017) (Naturvardsverket, november 2003). Examples include mercury tilt switches, high-current mercury switches and so-called read relays. See photos 33-38 and figure 9 Annex I).
Gauges, manometers, barometers, hydrometers, sphygmomanometers and other non-electronic measuring and clinical devices
• Blood pressure gauges (also called sphygmomanometers), see photo 50 Annex I. • Barometers, see photo 51 Annex I. • Generally U-shaped manometers with significant mercury amounts in it, see photo 52 Annex I. • A variety of other instruments that are not empowered by batteries or main electric currents.

Lamps

- This category consists of different types of discharge lamps: fluorescent lamps (photos 39 and 40 and figures 10 and 11), mercury and sodium vapour lamps (photos 42, 44 and 46 and figure 12), metal halide lamps, ultraviolet lamps (photo 43) and backlighting lamps (photo 41) used in older LCD, TV and computer displays (Science for environment policy, 2017). Mercury in the form of elemental mercury (Hg^0) and Hg^{2+} may be present in different concentrations ranging from 3 mg to 30 mg mercury per lamp.
- In used lamps most of the mercury is present in the light powder in the lamp. During separate collection in the waste stage and recycling processes mercury contaminated fluorescent powder (see photo 47 Annex I) is separated from the glass (photo 45) and metal parts (photo 46).

Paints

- Paints can contain mercury and mercury compounds (like cinnabar) as pigments and as additives to impede bacteria formation (bactericides) and hinder fungus attacks (fungicides). Varnishes can use mercury and mercury compounds to enhance look and durability (EC, Revision 1, 29 April 2019). See photo 53 Annex I.

Pesticides

- These group of products consisted of a wide group of biocidal products. Overviews of products and active ingredients can be found in older literature (EPA, 1971) and on the site of the Food and Agricultural Organization (FAO (www.fao.org)). 43 Mercury-containing compounds (like inorganic compounds e.g. mercuric chloride, alkyl compunds e.g. methylmercury hydroxide, alkyloxyalkyl and aryl compounds e.g. phenylmercuric hydroxide) that were used in numerous pesticidal applications (FAO/UNEP, April 2010) are known. The FAO hosts a database called FAOSTAT that gives insight in the international pesticides trades among which are mercury containing pesticides (FAO, 2020).
- No legal use in the EU is known (Chalkidis, et al., 2020) (Parties to the Basel convention, 2011) (EU, revision 1, 29 April 2019), but mercury containing pesticides are known to be still used (see figure 13 Annex I).

Pharmaceuticals (EC, Revision 1, 29 April 2019)

- Vaccines for human or veterinary use in which mercury compounds including thiomersal may still be used as antimicrobial preservative in some multidose vaccines outside the EU.
- Homeopathic medicinal products for human or veterinary use. Mercury (compounds) may be used as active ingredient, intermediate solution or starting material.
- Diuretics containing mercury or mercury compounds used as renal diuretic.

Thermometers

- Use of elemental mercury, visible if in glass tubes (see photos 48 and 49 Annex I) or in long steel tubes in ship engines.

Traditional medicine

- Mercury sulphide or cinnabar is a regular component in traditional Chinese medicine (photo 55, Annex I). Mercury and mercury compounds are also known to be used in cultural/ritual in Latin America and the Caribbean and in India. The amounts used are largely unknown.

Other (EC, Revision 1, 29 April 2019)

- Mercury fulminate used in ammunition as a primer (Beldowski, et al., 15 July 2019) (Wallace, 1998).
- Mirrors using mercury as reflective coating.
- Jewelry, glassware, beads containing mercury for aesthetic, artistic or traditional reasons.
- Tattoo inks using mercury compounds as colorant.

Table 3: Industrial processes that use raw materials with mercury impurities. (UN Environment, Version 1.5 November 2019).

Extraction and use of fuels/energy sources, like coal-fired power plants, biomass combustion, oil, and gas production.
• Coal-fired, and to a lesser extend mineral oil-fired plants with emission reduction systems generate sludges (wet filters) or solid (dry filters) flue gas cleaning residues that contain mercury (UN Environment, Version 1.5 November 2019). Bottom ash/slag may contain mercury, but generally less than in flue gas filter residues. • Gas production (and sometimes oil production) in areas with elevated mercury trace concentrations generate filter absorbents containing mercury (if filters are applied) and/or pipes/equipment with absorbed mercury (at high concentrations, filters are normally applied to save the equipment from deterioration due to the mercury).
Primary gold, silver, zinc, copper, lead, aluminum production
• Primary gold (industrial scale), silver, zinc, copper, lead production releases mercury naturally present in the ores used. The mercury-bearing by-products produced include: o Calomel (mercury chloride) which is considered waste within the EU (from which mercury may not be reclaimed), but which is still allowed as a mercury source under the Minamata Convention. o Technical grade sulphoric acid. o Activated carbon filters. o Other solid filter residues. o Wet filter effluents, depending on the specific process. For details see (UN Environment, Version 1.5 November 2019). • Bauxite, the ore of which aluminum is made, contains trace amounts of mercury (0.02 -1.5 mg/kg). Due to the large amounts processed, still a large amount of mercury may be emitted, predominantly in the form of elemental mercury vapor (Amano & Ntiri-Asiedu, 2020). Aluminum production generates (in the bauxite to alumina step) the residue called red mud, that can contain mercury.
Cement
• Mercury is present in the raw material (e.g., limestone) and the fuel used during the cement manufacturing process (e.g., coal). Mercury is emitted with streams of flue gas and part of cement clinkers (an intermediary product) and dust removed from the flue gas (Kogut, Gorecki, & Burmistrz, 2021).
Scrap metal, mercury recovery
• Scrap metal facilities and mercury recycling facilities may be equipped with dedicated mercury filters which generate mercury-enriched activated carbon (adsorbents).
Nickel, manganese, antimony & ferrous metal production, lime, pulp, paper, carbon black, coke, phosphate, and other production applying raw materials and fuels containing mercury
• These activities will release any mercury present in the raw materials and fuels used, and therefore mercury will be present in solid, or fluid residues/discharges generated; see (UN Environment, Version 1.5 November 2019) for details.

Table 4: Treatment, incineration and final disposal of mercury bearing wastes

Municipal, hazardous, medical & sewage sludge incineration
• Flue gas cleaning residues, fly & bottom ash, wastewater treatment sludge. • Sewage, hospital & industrial treatment wastewater, treatment sludge, other.
Waste landfills
• Mercury occurs in landfills due to the presence of mercury added products (MAP), like batteries, fluorescent lamps, thermometers, thermostats, and electrical switches, etc. Because landfills reduce waste volume by generating methane with anaerobic bacteria, these systems also generate methylated mercury compounds. Total gaseous mercury in concentrations in the µg per m^3 range in the off gas are measured, while methylated compounds may occur at concentrations in the ng per m^3 range (Lindberg, et al., 2001).
Crematoria
• Where filters are applied, flue gas cleaning residues, wastewater treatment sludge, fly & bottom ash.

3.Use of mobile equipment to detect mercury during inspections

The different forms of mercury have different chemical characteristics. Various mobile equipment may be used to detect mercury and mercury compounds in different situations. To investigate the possibilities 2 methods for the detection of mercury in air were tested. These consisted of Dräger-Tubes and the more advanced mercury analyser. For the detection of mercury in fluids and solids a Raman spectrometer and an X-ray fluorescence spectrometer were tested. The performance of the field equipment was tested with the materials and wastes collected during the STRiKE project and presented in Annex I. Possibilities of mobile equipment develop fast and additional methods exist for the detection of mercury. Especially for water samples that require techniques with low detection limits alternative methods may be interesting (Wei, et al., 2014) (Metrohm, 2020) .

Photo 3: Use of the laser pointer of a mobile Raman. Photo: NFI.

3.1 Detection of mercury in air

3.3.1 Dräger-Tubes

For the detection of mercury in air Dräger-Tubes (see photo 4) are an easy and cheap option. The tubes are used in combination with a pump. The Dräger-Tube is a sealed glass vial that contains a solid carrier material with a chemical reagent that reacts to the presence of a specific volatile substance with a characteristic change of colour. To cause this reaction, a fixed pre-determined volume of air is drawn through the tube with a pump.

Different tubes are available for the quantitative detection of different volatile substances. The measurement time is in between 10 seconds and 15 minutes, depending on the specific Dräger-Tube and sampling pump (Drager, 2005). For mercury the detection limit is 0.05 mg/m³ (or 50 000 ng/m³). The occupational exposure limit value of inorganic forms of mercury is 0.02 mg/³ as a time weighted average over 8 hours in most European countries (Commission Directive 2009/161/EU, 17 December 2009)

Photo 4: Dräger-Tubes in combination with an electrical pump. Photo: NFI.

Some advantages of Dräger-Tubes are:

- Cheap and easy to perform.
- They have a high precision.
- In combination with other tubes the pump can be used for a wide range of other volatile substances.

Disadvantages:

- It is a point measurement over a limited time span.
- The detection limit is relatively high, making the use of the tubes compared with a dedicated mercury analyser less interesting (see also results shown in table 5).
- The discolouration of the tubes for the detection of mercury in case of a positive measurement is not always very clear.

2.3.2 Mercury analyser

For the detection of mercury vapor in air several dedicated mercury analysers are available. The technique is based on atomic absorption spectrometry (AAS) using high frequency modulation of light polarization. During the STRiKE project a mercury analyser RA-915+ or Lumex was used (see photo 5). A Lumex has a so called Zeeman correction for background absorption, which ensures that the measurements experience no interference and enables to conduct real time monitoring and detection. (Sholupov, Pogarev, Ryzhov, Mashyanov, & Stroganov, 2004) (Oikari, Häyrinen, Hernberg, & Kettunen, 2002) (Lumex Instruments, 2018 version 13). The detection limit of a Lumex is 0.5 ng/m³ mercury in ambient air.

To test the possibilities of the Lumex mercury analyser samples of materials collected during the STRiKE project were used (see Annex I). Mercury concentrations in air were measured in a laboratory setting in a fume hood at different heights.

The results (see table 5) demonstrate that the Lumex can detect mercury in the air above all mercury containing materials. The results also show that concentrations decrease with increasing height. Since mercury is heavy, this is in line with theoretical expectations. Compared to the occupational exposure limit of elemental mercury and inorganic mercury compounds of 0.02 mg mercury/ m³ (Commission Directive 2009/161/EU, 17 December 2009) the concentration levels measured in air at 35 and 70 cm distance from the sample surface are low. The results in table 5 show that at short distance from the sample surface (15 cm) the occupational exposure limit may be exceeded.

Photo 5: Mercury analyser RA-915+ (Lumex).

Advantages of a mercury analyser:

- It can detect mercury in the air above materials even if the mercury level in the material itself is low. This makes it suitable for fast on-site detection of mercury.
- It can be used for real-time monitoring, which is also useful for safety reasons.
- It is easy to operate and relatively cheap.

Disadvantages of a mercury analyser:

- Since there is no obvious relation between mercury concentrations in the air and the concentrations in the sample, additional sampling and laboratory analyses might still be needed (see figure 2).
- It only measures mercury. For compliance officers who are confronted with a range wide of different chemicals this is inconvenient.

Photo 6: Sample with broken thermometers.
Air measurements were performed at short range of the surface in the sample container (see table 5 for results).
Photo: NFI.

Table 5: Results of air measurements performed with a Lumex mercury analyser.
Mercury concentrations in the air above the samples were measured at different hights.

Sample name	In air at 15 cm distance (in sample container)	In air at 35 cm distance from table surface (working position hands)	In air at 70 cm distance from table surface (eye-breathing level)	Mercury levels in material as measured with mobile XRF
Amalgam	145155 ng/m³	1241 ng/m³	710 ng/m³	256686 mg/kg
Dewatered week sample	2800 ng/m³	1091 ng/m³	560 ng/m³	9.18 mg/kg
Decanter sludge	1070 ng/m³	859 ng/m³	696 ng/m³	168.59 mg/kg
Mercury butter	91987 ng/m³	1348 ng/m³	618 ng/m³	6038.65 mg/kg
Solid waste sludge	792 ng/m³	791 ng/m³	484 ng/m³	10.91 mg/kg
Pyrolysis residue	2471 ng/m³	735 ng/m³	395 ng/m³	5.93 mg/kg
Elemental mercury	5460 ng/m³	3459 ng/m³	1478 ng/m³	-
Active coal	12498 ng/m³	4582 ng/m³	774 ng/m³	180 mg/kg
Fly ash	7399 ng/m³	2785 ng/m³	1532 ng/m³	60.62 mg/kg
Broken thermometers	33370 ng/m³	1359 ng/m³	904 ng/m³	-
Filters	12908 ng/m³	2669 ng/m³	1615 ng/m³	304359.90 mg/kg
Wet sludge	3257 ng/m³	1084 ng/m³	7039 ng/m³	21.34 mg/kg
Dry sludge	1632 ng/m³	1085 ng/m³	678 ng/m³	783.25 mg/kg

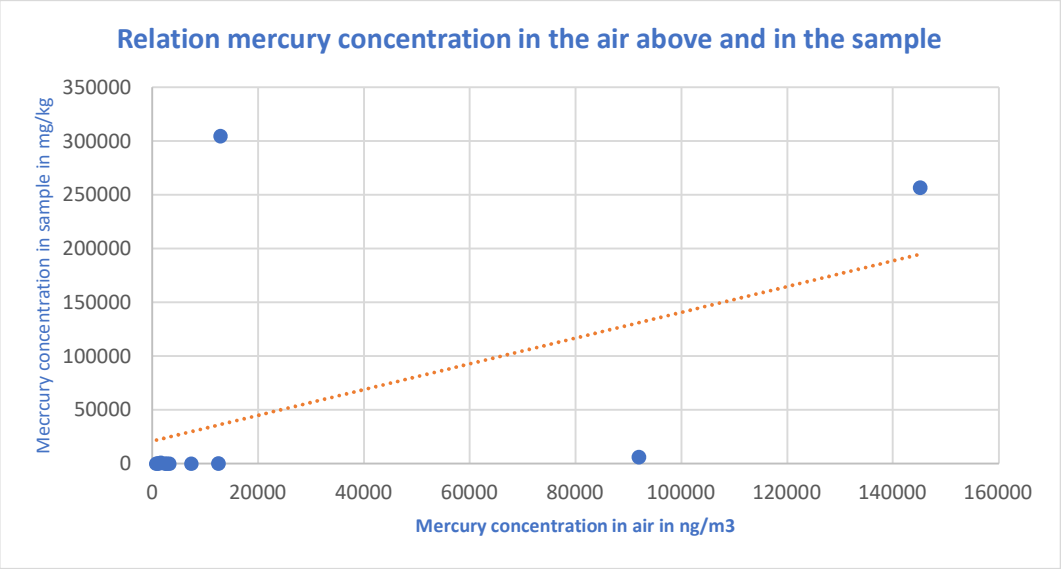

Figure 2: Relation between the mercury concentration in the sample and in the air above the sample. The graph shows the mercury concentrations in the air 15cm above the sample surface (shown on the y-axis) and the mercury concentrations measured with XRF in the samples (shown on the x-axis).

3.2 Detection of mercury in fluids and solids

3.2.1 Raman Spectroscopy

Raman Spectroscopy is a non-destructive chemical analysis technique which provides detailed information about the chemical structure of materials. It is based on the interaction of light with the chemical bonds within materials. The sample is irradiated with a laser and some of the scattered light is analysed with a spectrograph (dispersive or FT technology). A Raman makes a spectrum that shows characteristic signals or "bands" for the material under investigation. Figure 3 shows the Raman spectrum of mercury(II)sulphide.

For the STRiKE project a handheld Raman (FirstDefender™ RMX Handheld Chemical Identification, n.d.) was used, see photo 7. Measurements can be performed by placing a sample in a specific Raman vial (see photo 8) in the equipment or by using a laser pointer. A laser makes sampling redundant (see also photo 3) and creates the option to perform measurements through packaging. Tests results show that measurements through packaging with a laser work well for almost clear plastic (see photo 9) or glass packaging's. The test results are shown in the Raman spectrum of figure 3. The Raman can detect mercury(II)sulphide insight the polypropylene tube of photo 9 but also indicates that polypropylene is present. For more coloured, darker packaging's no positive results were obtained.

Photo 7 Raman spectrometer with laser pointer. Photo: NFI.

Of the materials collected during the STRiKE project only positive results were obtained for the identification of mercury(II)sulphide in Traditional Chinese Medicine (see photo 55 Annex I) and mercury(II)chloride, used as a catalyst in the production of methamphetamine (photo 26 Annex I).

Photo 8: Raman sample vials. Photo: NFI.

Photo 9: Polypropylene tubes. Photo: NFI.

Some advantages of a RAMAN:

- It can detect the type of compounds (like mercury(II)sulphide) present in a sample, whereas an XRF only measures the individual elements (like mercury and sulphide) but not the specific combination.
- The laser pointer may make sampling redundant.
- The laser pointer can be used to perform measurements through specific types of packaging like plastics and glass.
- For the materials tested (mostly mercury contaminated wastes) the added value of the Raman was limited. A Raman has however (standard) library that can be expanded easily, making it useful to detect all kinds of other materials.

Disadvantages of the Raman used were:

- Relatively high concentrations are needed.
- Only a rough indication of concentrations is obtained.
- In the absence of chemical bonds, a Raman is not able to detect of elemental mercury, neither is able to detect mercury iodide (the chemical bonds are too strong).

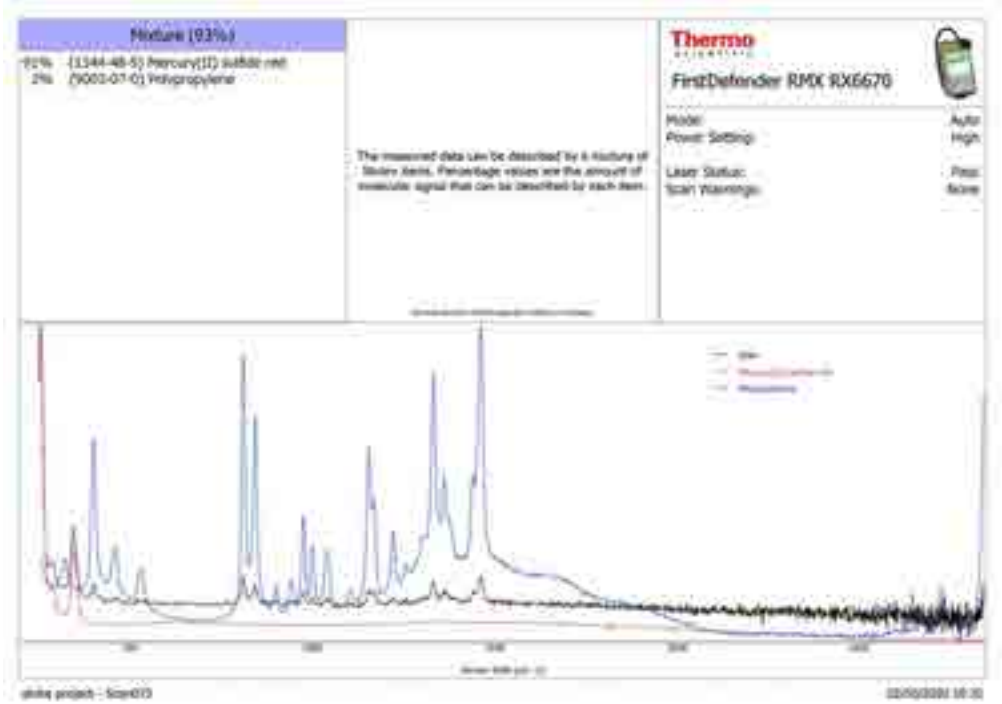

Figure 3: Raman scan of mercury(II)sulphide measured through a plastic polypropylene tube of the type shown on photo 9. The black line represents the result of the scan, the blue line is the reference polypropylene and the red line the reference mercury(II)sulphide.

3.2.2 X-Ray Fluorescence Spectrometer

An X-Ray Fluorescence (XRF) Spectrometer is a non-destructive analytical technique used to determine the elemental composition of materials. The analysis of major, minor and trace elements in various kinds of samples can be performed qualitatively as well as quantitatively. Figure 4 shows a visual representation of the working principle of a mobile XRF (X-ray fluorescence, 2018).

A mobile XRF can be used handheld or in combination with a portable benchtop system also called workstation (photo 10). During the STRiKE project a mobile XRF (Olympus Vanta) was used in combination with a workstation. The workstation is designed to hold back the radiation emitted by the XRF and therefore to be preferred for safety reasons.

Photo 10: Mobile XRF portable benchtop system. Photo: NFI.

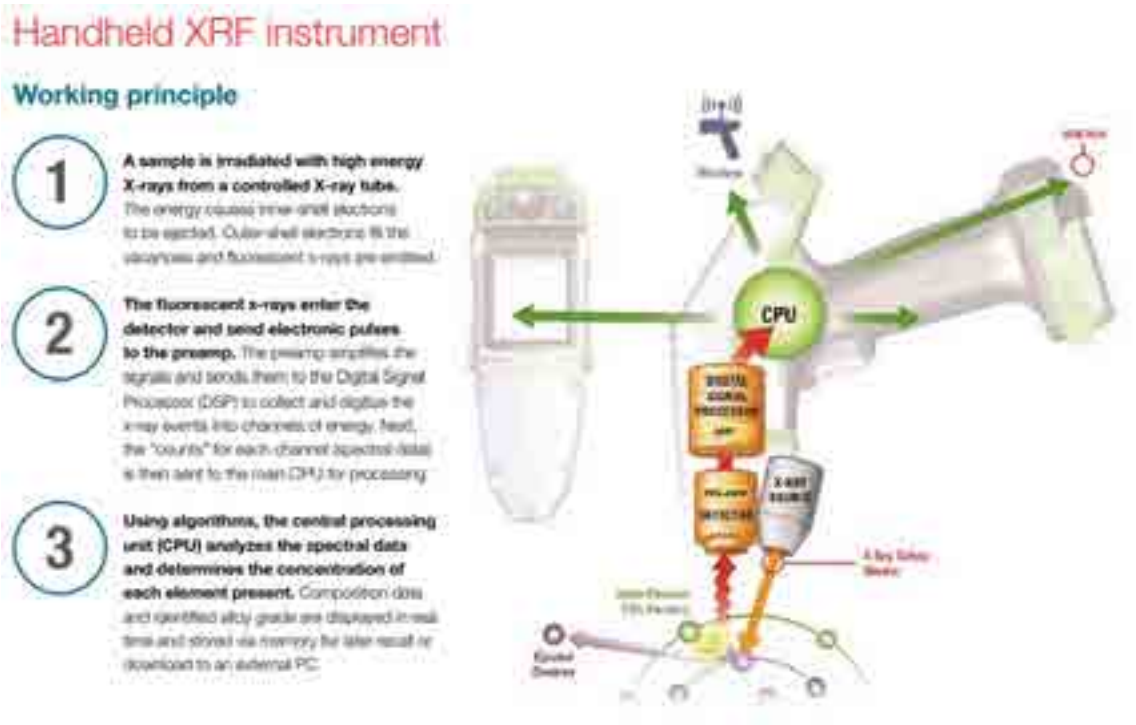

Figure 4: Working principle of a mobile XRF. https://www.thermofisher.com/blog/mining/xrf-its-all-in-this-free-ebook/

If the XRF is used in combination with a workstation, samples (XRF cubs) with a special thin film must be prepared (see photo 11).

Photo 11: XRF sample cup with prolene film. Photo: NFI

XRF cups can prepared with different types of thin films[4]. An XRF is a surface technique meaning that only the composition of the outer surface of materials in direct contact with the detector (see figure 4) is determined. The thin film of the XRF sample cup enables the detector to get into close contact with the material (material and detector are in fact only separated by the film).

To test the performance of the XRF in practice, the materials collected during the STRiKE project were used. The reliability of the measurements was estimated by preparing and analysing 8 XRF cubs for each material. The number of 8 originates from validation standards (Netherlands Normalisation Institute (NEN), December 2012). The measurements were performed under the following conditions:

- To mimic the situation in the field samples were not pre-treated.
- Sample cups were covered with a thin film of the type prolene.
- The measurement time was set at a standard 3x30 seconds. Extending the measurement time may lower the limit of detection (LOD). If after a measurement time of 3x30 seconds no mercury was detected, the measurement was repeated with a measurement time of 3x90 seconds.

The measurement results are shown in table 6. Table 6 shows the mean mercury concentration of the different materials, the standard deviation[5] and the coefficient of variation (CV). The coefficient of variation is calculated as follows:

$$CV = \frac{Standaard\ deviation}{mean}\ x\ 100 \qquad \text{Formula (1)}$$

Since the standard deviation tends to increase with increasing concentrations, a coefficient of variation is a more stable measure. The coefficient of variation is expressed as a percentage. The lower the coefficient of variation, the less dispersion of the data and the more precise is the estimate of the mean concentration.

In general, the reliability of the estimate of the mean can be increased by increasing the number of measurements. Since performing measurements is time consuming it is however also relevant to restrict the number of measurements as much as possible. The following formula (CEN/TC 292, 2006) can be used to calculate the optimum number of measurements for different materials:

$$n = \left(\frac{U_a}{d}\right)^2\ x\ (standard\ deviation)^2 \qquad \text{Formula (2)}$$

N= number of samples or measurements
D =desired precision
U_a = a critical value of the Student's *t*-distribution (can be looked up in statistical tables). For a 95% confidence level[6], U_a=1.96

[4] See the Chemplex thin-film selection guide Thin-Film Selection Guide Chemplex Industries, Inc.

[5] A measure for the dispersion of the data.

[6] A 95% confidence level is generally used as a standard.

Table 6: XRF results of materials collected during the STRiKE project (see Annex I). The mean value, standard deviation and coefficient of variation are shown. All samples were measured 8 times in duplicate. The initial measurement time for all samples was 3x30 seconds. For the samples indicated (*) the measurement time was extended to 3x90 seconds. Due to leakage of the prolene film the sample paint, indicated with (**) was measured 4 times instead of 8 times. Since the calculations based on fewer measurements the results for this sample are less reliable.

Sample	Mean mercury concentration (mg/kg)	Standard deviation (mg/kg)	Coefficient of variation (%)	Photo number Annex I
Amalgam	256686	14623	5.69	Photo 23
Dewatered week sample	9.18	6.54	71.24	Photo 66
Decanter sludge	168.59	136.13	80.74	Photo 65
Gas condensate	573	452	79.5	Photo 61
Mercury butter	6038.65	713.22	11.81	Photo 22
Solid waste sludge	10.91	3.85	35.31	Photo 64
Pyrolysis residue*	5.93	0.79	13.46	Photo 59
Spent activated carbon	180	37.76	20.97	Photo 58
Fly ash	60.62	9.19	15.17	Photo 56
Filters	304359.90	108540.80	35.66	Photo 57
Wet sludge	21.34	2.08	9.78	Photo 63
Dry sludge	783.25	365.12	46.61	Photo 62
Paint**	10.43	1.41	13.53	Photo 53
Fluorescent powder	1331.84	33.17	2.49	Photo 47
Traditional Chinese medicines	18927.38	2572.62	13.59	Photo 55

To illustrate the working of formula (2) the results of the fly ash shown in table 6 were taken as an example. Suppose that the legal limit in an imaginary case is 50 mg/kg mercury, and our material (fly ash) has a mean mercury concentration of 60.62 mg/kg, then our preferred precision would be 10 mg/kg (=60.62 minus 50 mg/kg).

The desired confidence level is set at 95%, so U_a=1.96 and the standard deviation is 9.19 (taken from table 6). Then the optimum number of measurements can be calculated with formula (2) as follows:

$$n = \left(\frac{1.96}{10}\right)^2 x\ 9.19^2 = 3.2 \text{ or } 4 \text{ measurements}$$

If the preferred precision is smaller or the standard deviation is larger, the number is of measurements has to increase to obtain a 95% confidence.

The detection limit of the XRF used (Olympus Vanta) was estimated to be 1.5 ppm (parts per million). For water relevant legal limits are generally much lower. Other mobile techniques with detection levels as low as 5 µg/l are on the market (Wei, et al., 2014) (Metrohm, 2020) and more suitable for the detection of mercury in water.

Some advantages of an XRF are:

- It is fast and relatively easy to operate.
- Samples can be analysed without sample pre-treatment.
- It measures a wide range of elements in addition to mercury.
- In combination with a well-designed sampling strategy, it can replace laboratory research.

Disadvantages are:

- Relative expensive.
- Interpretation of the results is not always straightforward, results may for example be influenced by the matrix of the material.
- An XRF is a source of radiation and special safety requirements apply.
- Limits of detection are variable and are in some cases too high, although for most of the mercury-added product and mercury containing wastes tested during the STRiKE project the limit of detection was low enough.
- An XRF is a surface technique and only determines the composition of a small part of the material.

4.Safety instructions for mercury related situations

General safety guidelines for handling the different chemical forms of mercury are pre-existing (see box 1). Inspections and environmental crime scene investigations however take place in different situations with different safety risks. Working in full safety equipment (see phot 12) is demanding and not always necessary. In this chapter a procedure is presented to assist compliance officers to make the necessary decisions with respect to relevant safety measures. The focus is on the risks associated with activities with mercury. Note that the procedure and protective measures are advisory. Beware that legal safety guidelines may be variable among countries and that in addition to an exposure to mercury other risks may be present as well.

Photo 12: Safety equipment suitable for a high mercury exposure, consisting of chemical resistant overalls, safety boots, full face masks with respiratory equipment, latex gloves covered with chemical resistant gloves. Photo: NFI.

4.1 Mercury Safety Tool users guide

During the work with mercury containing materials inhalation of mercury and skin contact must be always prevented. Protective measures must be taken if inhalation and/or skin contact is unavoidable. For an effective assessment of the safety risks context information is needed, like:

- The specific mercury compounds that are expected, including the hazard definitions or H-phrases.
- The type of activity that is to take place with the material.
- The amount of ventilation.
- Housekeeping of the area.
- The possibility of reactivity with other substances.
- The condition of packages
- The on-site temperature, at temperatures above 20°C the expected mercury exposure is much higher.

The ***Mercury Safety Tool*** (see table 7) consists of 7 columns and is designed to use the input from the first four columns with respect to the context information to recommend the relevant safety measures, as indicated in the last three columns.

Below an explanation of the terms used in each of the columns is summarized. If you don't understand any of the following: do not use the tool and consider consulting a health and safety professional.

Input (columns 1 to 4)

1. Chemical form of mercury: if the expected mercury form (elemental mercury or mercury compound) is known, it is easy to find the corresponding hazard

statements (H-phrases). H-phrases can be found for example in de database of the European Chemicals Agency (ECHA): Information on Chemicals - ECHA (europa.eu). The H-phrases are the basis for the risk-assessment and the appropriate safety measures:

- H300-309: hazard if **swallowed**
- H310-319: hazard in contact with **skin**
- H330-334: hazard if **inhaled**

Choose the option **combination/unknown**:

- if multiple different chemical mercury forms with different H-phrases are present, or
- if the mercury (compound) has multiple H-phrases, or
- if it is unknown which mercury forms are present.

2. Container: choose **yes** if, during all inspection activities, the mercury (compound) is contained in a hermetically sealed container, which is undamaged and clean on the outside. If one or more of these conditions is not met or uncertain, choose **no**. If the container is to be opened during the inspection: choose **no**.

3. Amount: The amount is **small** if it can be inspected (assessed, investigated, or send in for analysis) as a whole. If it is necessary to sample, select or collect material, the amount is defined as **large**. When in doubt, choose **large**.

4. Setting: the setting of the inspection activities is assessed based on several criteria[7]:

- Adequate ventilation is present.
- The situation is sufficiently clear, clean, and neat.
- The situation is stable.
- No other chemical substances pose a risk in relation to the mercury.

Only if all conditions are met with certainty, choose **yes**, otherwise choose **no**.

More than the other factors, the setting lends itself to modification, for instance by creating adequate ventilation or by moving the material to be inspected to a more suitable location. If, in preparation of the inspection activities, the circumstances can be adjusted in such a way that the above criteria are met, choose - after the adjustments are made - **yes**.

Safety measures (columns 5 to 7)

Take at least the safety measures as indicated in the next three columns. If there are any indications of additional risks, increase the safety measures accordingly. Downscaling the safety measures is advised only after a thorough analysis of the actual situation by or under the responsibility of a health and safety professional. Measurements of actual air concentrations can be part of such an analysis.

Respiratory protection (column 5)

In this column three levels of respiratory protection are indicated:

- **none**: no respiratory protection needed.
- **resp:** respirator with a “HG-P3” filter.
- **full**: full face respirator with a “HG-P3” filter.

If respiratory protection is used the filter must be specifically suited for mercury, as indicated by the “HG” symbol. These types of filters are also recognizable by a red band, see figure 5 for an example). The respiratory protection for mercury is in these filters combined with a particle matter filter, as indicated by the symbol “P3”.

Figure 5: Example of a respiratory protection filter for mercury vapor as indicated by the red band.

Skin protection (column 6)

There are two levels of skin protection:

- **low**: disposable gloves, optionally complemented with any relevant and suitable skin protection, such as a coverall, safety goggles, safety shoes etc.

[7] It is hard to give concrete definitions for these criteria. The adequacy of the ventilation should be judged in relation to other circumstances, like temperature and duration of the inspection activities. Clarity, cleanliness, and neatness influence the possibilities to carry out the inspection activities in an orderly and controlled way. Stability takes the possibility of sudden changes in the circumstances into account. Other chemicals could pose a risk, if they can react with the mercury (compound) and if contact is possible. When in doubt, choose **no**.

- **high**: chemically impermeable gloves, splash resistant coverall, chemically resistant (safety) shoes, face protection (face shield or full-face mask).

To prevent skin exposure, nitrile rubber gloves are best suited. Other options may be butyl rubber or PVC gloves. Gloves must be at least 0.11 mm thick to prevent penetration (ISO 274, 2018). Make sure that the skin of the arms, face and neck is also proper protected when exposure to mercury(di)chloride or methylmercury is expected. These substances are classified as fatal if in contact with skin.

Specific measures (column 7)

If **no**, no additional measures are needed. If **yes**, specific measures are to be considered. To decide on suitable specific measures, a thorough analysis of the actual situation by or under the responsibility of a health and safety professional is necessary. Measurements of actual air concentrations can be part of such an analysis.

Table 7: ***Mercury Safety Tool***

1. Relevant H-phrases related to specific chemical form of mercury	**2. Container**	**3. Amount**	**4. Setting**	**5. Respiratory protection**	**6. Skin protection**	**7. Specific measures**
	Completely closed, sealed, undamaged and clean		***Adequate ventilation; clear, clean, and neat; stable; free from other chemicals***			
	Unknown = no	Unknown = large	Unknown = no			
H-phrase skin	yes	small	yes	none	low	no
H-phrase inhalation	yes	small	yes	none	low	no
H-phrase ingestion	yes	small	yes	none	low	no
Combination/unknown	yes	small	yes	none	low	no
H-phrase skin	yes	small	no	none	low	yes
H-phrase inhalation	yes	small	no	none	low	yes
H-phrase ingestion	yes	small	no	none	low	yes
Combination/unknown	yes	small	no	none	low	yes
H-phrase skin	no	small	yes	none	high	no
H-phrase inhalation	no	small	yes	none	high	no
H-phrase ingestion	no	small	yes	none	high	no
Combination/unknown	no	small	yes	none	high	no
H-phrase skin	no	small	no	full	high	yes
H-phrase inhalation	no	small	no	resp	high	yes
H-phrase ingestion	no	small	no	resp	high	yes
Combination/unknown	no	small	no	full	high	yes
H-phrase skin	no	large	yes	full	high	no
H-phrase inhalation	no	large	yes	full	high	no
H-phrase ingestion	no	large	yes	full	high	no
Combination/unknown	no	large	yes	full	high	no
H-phrase skin	no	large	no	full	high	yes
H-phrase inhalation	no	large	no	resp	high	yes
H-phrase ingestion	no	large	no	resp	high	yes
Combination/unknown	no	large	no	full	high	yes

To keep exposure to mercury during the anticipated activities as low as possible, the following additional measures are relevant:

1. Perform air measurements before entering the area of work to make a first estimate of the exposure. Make an inventory of other substances present (e.g.,

acids, bases, metals etc.) that may react with elemental mercury and/or mercury compounds and may lead to additional risks (e.g., impact-sensitive compounds).

2. Perform measurements during work to ensure exposure is monitored and documented. Wear for example a SafeAir® Detection Badge specific suited to mercury (see photo 13).

Photo 13: SafeAir™ Detection Badges.
Single-level screening badges provide economical daily exposure monitoring for different substances. Photo: Morphix Technologies SafeAir™ Detection Badges \| Fisher Scientific

3. Ventilate the area of work as much as possible by opening windows and doors. Install where appropriate fans. Be aware of the air movement that is created due to this in relation to exposure.
4. If possible, keep containers closed. Do not head near/in packages to look or shuffle but keep a distance of at least 0.5 meters (package to breathing zone) in case containers are open (inspect also the results of table 5).
5. Wear appropriate personal protective equipment:
   a. To prevent inhalation of mercury specific filters are needed.
   b. To guarantee the proper protection factor it is recommended to organize a “Face Fit Test” of the full-face masks annually for employees that use respiratory protection.
6. Do not eat, drink, or smoke at the workplace to prevent indirect exposure. Wash hands and face well before eating, drinking, and smoking. Make sure there are good facilities to clean the skin.
7. Do not sit in the car with contaminated clothing but change on a clean place near the work area and wrap the possible contaminated clothing in a sealed bag. This will prevent contamination of the vehicle and prevents unwanted exposure during driving. The (contaminated) workwear must be cleaned professionally and should not be taken home.
8. Prepare a first aid instruction in case an undesirable exposure has taken place (see also box 1).

Box 1:Safety information for elemental mercury, source: https://echa.europa.eu/registration-dossier/-/registered-dossier/5169/9

First aid measures

Eye Contact: Immediately flush eyes with plenty of water for at least 15 minutes, lifting lower and upper eyelids occasionally. Get medical attention immediately
Skin Contact: Immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Get medical attention immediately. Wash clothing before reuse. Thoroughly clean shoes before reuse.
Ingestion: Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Get medical attention immediately.
Inhalation: Get medical aid immediately. Remove from exposure and move to fresh air immediately. If breathing is difficult, give oxygen. Do NOT use mouth-to-mouth resuscitation. If breathing has ceased apply artificial respiration using oxygen and a suitable mechanical device such as a bag and a mask.
Notes to Physician: The concentration of mercury in whole blood is a reasonable measure of the body-burden of mercury and thus is used for monitoring purposes. Treat symptomatically and supportively. Persons with kidney disease, chronic respiratory disease, liver disease, or skin disease may be at increased risk from exposure to this substance.
Antidote: The use of d-Penicillamine as a chelating agent should be determined by qualified medical personnel. The use of Dimercaprol or BAL (British Anti-Lewisite) as a chelating agent should be determined by qualified medical personnel.

Fire-fighting measures

General Information: In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full facepiece operated in the pressure demand or other positive pressure mode. Undergoes hazardous reactions in the presence of heat and sparks or ignition.
Smoke may contain toxic mercury or mercuric oxide. Smoke may contain toxic mercury or mercuric oxide.
Fire Extinguishing Media: Use any means suitable for extinguishing surrounding fire. Do not allow water runoff to enter sewers or waterways.
Explosion: Not considered to be an explosion hazard.
NFPA Rating: (estimated) Health: 3; Flammability: 0; Instability: 0

Accidental release measures

General Information: Use proper personal protective equipment.
Spills/Leaks: Absorb spill with inert material (e.g., vermiculite, sand, or earth), then place in suitable container. Avoid runoff into storm sewers and ditches which lead to waterways. Clean up spills immediately, observing precautions in the Protective Equipment section. Provide ventilation.

Handling and storage

Handling: Wash thoroughly after handling. Remove contaminated clothing and wash before reuse. Minimize dust generation and accumulation. Keep container tightly closed. Do not get on skin or in eyes. Do not ingest or inhale. Use only in a chemical fume hood. Discard contaminated shoes. Do not breathe vapor.
Storage: Keep container closed when not in use. Store in a tightly closed container. Store in a cool, dry, well-ventilated area away from incompatible substances. Keep away from metals. Store protected from azides.

Important sources of information

http://www.mercuryconvention.org/

The Minamata Convention on Mercury is a global treaty to protect human health and the environment from the adverse effects of mercury. It was agreed at the fifth session of the Intergovernmental Negotiating Committee on mercury in Geneva, Switzerland at 7 a.m. on the morning of Saturday, 19 January 2013 and adopted later that year on 10 October 2013 at a Diplomatic Conference (Conference of Plenipotentiaries), held in Kumamoto, Japan. Their website holds all kind technical information as well information with respect to supply, trade, and demand of mercury.

https://echa.europa.eu

The European Chemicals Agency (ECHA) is the driving force among regulatory authorities in implementing the EU's chemicals legislation for the benefit of human health and the environment as well as for innovation and competitiveness. The ECHA databases contain information on correct allocation of hazard phrases to substances, toxicological information, safety aspects about handling and information about production processes.

Mercury - EEB - The European Environmental Bureau

The EEB set up the Zero Mercury Campaign in 2004, with the goal of achieving ‘zero’ emissions, demand, and supply of mercury, from all controllable sources. The campaign aims to reduce mercury in the environment to a minimum both in the EU and globally.

By engaging with the United Nations Environment Program (UNEP) and international mercury meetings, the EEB and the Zero Mercury Working Group have supported the drafting, adoption, and implementation of the Minamata Convention.

About FAO | Food and Agriculture Organization of the United Nations

The Food and Agriculture Organization (FAO) is a specialized agency of the United Nations that leads international efforts to defeat hunger. Its goal is to achieve food security for all and to make sure that people have regular access to enough high-quality food to lead active, healthy lives. With over 194 member states, FAO works in over 130 countries worldwide. The FAO hosts a database called FAOSTAT that gives insight in the international pesticides trades among which are mercury containing pesticides (FAO, 2020).

Mercury | UNEP - UN Environment Programme

UN Environment is working with governments and other stakeholders to reduce mercury pollution and its negative impacts. UN Environment’s key activities on mercury include:

- Minamata Convention on mercury
- Global Mercury Partnership
- Global Mercury Assessment
- The planetGOLD Programme
- Mercury inventory toolkit
- Global mercury monitoring

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Annex 1 Photos and characteristics of mercury containing materials

The tables 8, 9, and 10 below present pictures and information about elemental mercury, some mercury compounds and mercury-added products targeted by the Minamata Convention and/or the EU mercury regulation and mercury containing wastes that may originate from these uses of mercury. The tables are not complete, other uses of mercury and alternative variants of the presented products and wastes exist.

The tables contain options for classification of the different materials and wastes according to the European Waste Framework Directive (WFD) or Basel Convention. In practice however origins or compositions of materials and wastes may fluctuate leading to different classifications. The given options for classifications should be interpretated as suggestions. The tables use the following WFD (EC 2018/C 124/01, 9 April 2018) codes:

- AH= Absolute hazardous entry (marked with an asterisk (*)), wastes assigned to AH entries cannot be allocated to non-hazardous entries without any further assessment.
- ANH=Absolute non-hazardous entry, wastes which are assigned to ANH entries cannot be allocated to hazardous entries and should be classified as non-hazardous without any further assessment.

Mirror entries can be defined as two or more related entries where one is hazardous and the other is not. In contrast to AH or ANH entries, if waste is to be allocated to a group of alternative entries, further steps in the assessment for allocation must be undertaken. The alternative entries consist at least of the following entries:

- MH=Mirror Hazardous entry , marked with an asterisk (*).
- MNH=Mirror non-hazardous (MNH) entry.

Regarding "Examples of customs codes"
The codes shown are examples of codes for products and materials that may contain or do contain mercury. Customs codes marked with "Hg" always contain mercury (as an integral part of their function).

Disclaimer: The code examples provided here should not be considered complete or exclusive; it is the readers own responsibility to check for relevant codes in the customs codes system used in their country.

The customs codes shown in the tables below were derived from three sources:

- HS customs codes for Minamata Convention's Annex A products (for which manufacture, import and export is restricted) UNEP/MC/COP.4/27, available at https://www.mercuryconvention.org/sites/default/files/documents/working_document/4_27_CustomsCodes.English.docx (accessed 21Jan2022). Note that this document also includes suggestions for future mercury-specific codes for many products, which may be encountered in future inspection situations.
- The UNEP mercury inventory Toolkit Reference Report, Technical Annex 8.1: Harmonised Commodity Description and Coding System (HS) custom codes relevant for mercury (as adapted from search in the UN COMTRADE database, accessed January 2022 at https://comtrade.un.org/data/). The Toolkit can be accessed at https://www.unep.org/explore-topics/chemicals-waste/what-we-do/mercury/mercury-inventory-toolkit
- The EU Combined Nomenclature, version 2022, accessed January 2022 at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2021:385:FULL&from=EN.

HS and CN codes are in principle aligned; however, the CN system sometimes have additional codes applicable for the EU. Additionally, a few discrepancies were observed when comparing the 2022 CN version with the HS codes available on Comtrade.un.org/data/. The reason for this may be that the latter also display older codes than the most resent version to allow for search in older data.

In the following, codes only found in the search of the CN system (and not the HS system) are marked with "CN". Codes only found in the search of the HS system (and not the CN system) are marked with "HS only". Codes with no CN nor HS noted are taken from the HS system, but all/most also apply in the CN system.

Table 8: Materials and wastes associated with processes that employ mercury

Wastes from acetaldehyde production with a mercury sulphate catalyst	
Type of material *Visual* *Chemical*	Mercury sulphate is used during the production of acetaldehyde. Methylmercury contaminated effluents are generated. Within the EU member states (EU28) the acetaldehyde production does not use mercury anymore (EC SWD (2016), 2 February 2016). - Materials were not available during the STRiKE project.
Options for classification	Chapter 7 WFD *Wastes from organic chemical processes* code 07 01 11* *Sludges from on-site effluent treatment containing hazardous substances* MH (Mirror hazardous) or entry A1030 Basel Convention (Parties to the Basel convention, 2011) (EC 2018/C 124/01, 9 April 2018).
Examples of customs codes	2620 60 00_ _Slag, ash and residues (other than from the manufacture of iron or steel), containing metals, arsenic or their compounds: -Containing arsenic, mercury, thallium or their mixtures, of a kind used for the extraction of arsenic or those metals or for the manufacture of their chemical compounds.
Elemental mercury for artisanal and small-scale gold mining	
	 **Photo 14: Illegally traded elemental mercury in paint cans. Mercury spill is visible on the lid. Photo: NFI.**
	 **Photo 15: Elemental mercury is covered with a water film to prevent evaporation. Photo: NFI.**

Photo 16: Elemental mercury traded for illegal gold mining in soda bottles. Here in Zimbabwe with water above the mercury to reduce evaporation (Lassen, Warming, & Maag, 2016).

Photo 17: Standard size mercury flasks. The flaks contain 34,5 kg of mercury (76 pounds) (Pronk, Februari 2018). Photo was taken by COWI.

Photo 18: Chinese mercury flaks in wood crates. Source: https://www.made-in-china.com/price/silver-mercury-flask-price.html

Photo 19: Mercury flasks (76Lb) and a larger container for mercury. Source: BethlehemApparatus.com

Photo 20: Plastic container with approximately ½ kg mercury. Sold to miners by local gold buyers in Uganda (Lassen, Warming, & Maag, 2016).

Photo 21: Elemental mercury sold on the internet as chemical in plastics bottles.
Source: https://www.purechemics.com/product-page/1-2-flask-silver-mercury.

Type of material *Visual* *Chemical*	Elemental mercury, used during the ASG mining process. Pure elemental mercury looks like a silver fluid and is recognisable by a combination of visual characteristics and very high weigth. Elemental mercury evaporates and can react with substances from its surroundings. It can amalgamate (mix) with a number of other non-ferrous metals such as zinc, copper, aluminium, silver, gold and therefore vary in purity.
Other characteristics *Other wastes generated*	Heavy. The density of elemental mercury is 13,6 g/ml. In containers the mercury may be covered with a water film to prevent evaporation (see photos 15 and 16). Mercury contaminated wastewater, treatment sludges and flue gas cleaning residues.
Options for classification	WFD category 16 03 off-specification batches and unused products with code 16 03 07* AH. Another option is Basel Convention code Y29 (BC/UN/UNEP, 15 May 2015) *Wastes having as constituents: mercury, mercury compounds*. If the material is considered a product, it should be labeled according the Classification, Labelling and Packaging (CLP) regulation with the H-phrases: • H330 *Fatal if inhaled* • H360D *Reproductive toxic* • H373 *Causes damage to organs* • H400 *very toxic to aquatic life* • H410 *very toxic to aquatic life with long lasting effects*
Examples of customs codes	2805 40 10^{Hg} Mercury in flasks of a net content of 34,5 kg "standard weight", of a fob value per flask of <= € 224 2805 40 90 ^{Hg}Mercury (excl. in flasks of a net content of 34,5 kg "standard weight", of a fob value per flask of <= € 224).

Wastes from chlor-alkali production with mercury-cell technology

Photo 22: Mercury butter from mercury cell chlor-alkali production. Material is obtained from BMT International (The Netherlands). BMT is specialized in developing practical Total Mercury management solutions for mercury containing wastes. Photo: NFI.

Type of material	During the process mercury is used in a closed or semi-open process. During maintenance operations the ''mercury butter'' (calcium and magnesium mercury salts, see photo 14) and ''light butter'' [$Hg(OH)_2$] from the bottom of the cells are mechanically removed. Excess metal mercury may also be sold as waste from mercury-cell chlor-alkali plants. With the EU member states (EU28) the vinyl-chloride production does not use mercury anymore (EC SWD (2016), 2 February 2016).
Visual	Dark brown paste like material.

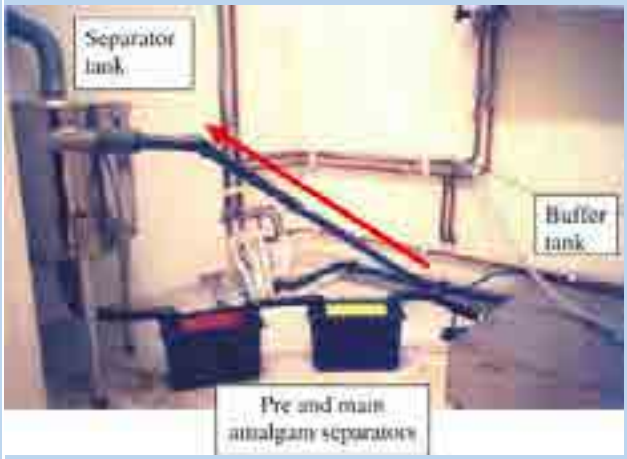
Chemical	The mercury butter as shown on photo 22 contained 6039 mg/kg mercury, determined with mobile XRF and a concentration of 91987 ng/m^3 mercury in the air 15 cm above the surface of the sample determined with a Lumex mercury analyzer.
Other characteristics *Other wastes generated*	Characteristic strong sickening smell. Anode replacement, removal and replacement of graphite pellets and internal components within decomposers, the repair and replacement of mercury pumps, and notably mercury cell decommissioning (dismantling) also generate mercury bearing wastes.
Options for classification	WFD Chapter 6 *Wastes from inorganic chemical processes might be applicable*, the relevant code would be 06 04 04* W*astes containing mercury* (AH). Relevant Basel Convention Code may be A1030 *Wastes having as constituents or contaminants: mercury; mercury compounds.*
Examples of customs codes	2620 60 00_ _Slag, ash and residues (other than from the manufacture of iron or steel), containing metals, arsenic or their compounds: – Containing arsenic, mercury, thallium or their mixtures, of a kind used for the extraction of arsenic or those metals or for the manufacture of their chemical compounds.
Dental amalgam wastes	
	 **Photo 23: Dental amalgam spilling from dental treatment. Material obtained from BMT International (The Netherlands). BMT is specialized in developing practical Total Mercury management solutions for mercury containing wastes. Photo: NFI.**
	 **Photo 24: Amalgam separators from dental clinic, example of design. Source: (Hylander, Lindvall, & Gahnberg, 2006).**

Photo 25: Amalgam separator interior. Designs are variable. Source: (Hylander L. , Lindvall, Uhrberg, Lindh, & Gahnberg, August 2006).

Type of material	Dental amalgam fillings consist of an alloy of mercury (44-51% mercury by weight) with the least three metals (silver, tin, copper) varying in percentage depending on the amalgam characteristics desired (UN Environment, 2017) (Chalkidis, et al., 2020). During the process treatment larger solid residues are collected in chair-side strainers and sometimes collected separately. If amalgam separators are present, they are designed to collect smaller particles (a sludge with amalgam particles and human tissue).	
Visual	Dark grey coarse-grained material.	
Chemical	Material of photo 23 contained around 250 000 mg/kg (or 25%) mercury measured with mobile XRF. The mercury concentration in the air 15 cm above the surface of the sample was 145 000 ng/m^3 measured with a Lumex mercury analyser (see table 5).	
Other characteristics	Heavy	
Other wastes generated	-	
Options for classification	WFD code 18 01 10* *Amalgam waste from dental care* AH is applicable. Relevant code under the Basel Convention is A1010 *Metal wastes and waste consisting of alloys of mercury.*	
Examples of customs codes	2843 90 10 ^{Hg}	Amalgams of precious metals
	2853 00 90 ^{Hg}	Inorganic compounds, n.e.s.; amalgams (excl. of precious metals)
	2620 60 00	Slag, ash and residues (other than from the manufacture of iron or steel), containing metals, arsenic or their compounds: – Containing arsenic, mercury, thallium or their mixtures, of a kind used for the extraction of arsenic or those metals or for the manufacture of their chemical compounds.

Methamphetamine production, raw materials, and waste		
	 Photo 26: Mercury(II)chloride	 Photo 27: Elemental mercury in methamphetamine waste. Photo: NFI
Type of material *Visual* *Chemical*	Mercury (II) chloride is a white powder (photo 26) and is used as catalyst. Waste containing elemental mercury (see photo 27) is generated. White powder or brown fluid with sediment in the form of elemental mercury. Mercury (II) chloride is used as a raw material and expected to be more or less pure. The wastes generated during the production process area mixture of water with methanol (or some other alcohol like isopropanol or ethanol), methylamine, low concentrations of methamphetamine and BMK (benzyl methyl ketone, also called phenylacetone) and a grey sediment consisting of elemental mercury with aluminum hydroxide salts (see photo 27). The fluid may be strongly alkaline.	
Other characteristics *Other wastes generated*	Strong smell. Aluminum foil.	
Options for classification	The production of synthetic drugs is an illegal activity, and it is questionable whether the waste codes of the WFD are applicable. If the production process is taken as a starter chapter 7 "*Wastes from organical chemical processes*" is relevant (European Commission, 2018). The subparagraph could be 07 07 *Wastes from the MFSU of fine chemicals and chemical products not otherwise specified*. The different wastes could be classified as: • 070701* aqueous washing fluids and mother liquors (AH). • 070704* other organic solvent, washing fluids and mother liquors (AH). • 070708* other still bottoms and reaction residues (AH).	
Examples of customs codes	2852 00 00 ^{Hg} 2852 00 10 ^{Hg} 2852 00 90 ^{Hg} 2852 10 00 ^{Hg}	Compounds, inorganic or organic, of mercury (excl. amalgams) Compounds, inorganic or organic, of mercury (excl. amalgams), chemically defined Compounds, inorganic or organic, of mercury (excl. amalgams), not chemically defined Inorganic or organic compounds of mercury, whether or not chemically defined, excluding amalgams

Vinyl-chloride monomer production with mercury chloride catalyst, raw materials, and waste		
		
Type of material *Visual* *Chemical*	Mercury(II)chloride is ued as a catalyst in activated carbon - Exhausted catalysts contain around 5% of mercury. In spent activated carbon filters mercury contents are variable (UN Environment, 2017).	
Other characteristics *Other wastes generated*	- -	
Options for classification	Basel code A3170 *Wastes arising from the production of aliphatic halogenated hydrocarbons* (such as chloromethane, dichloro-ethane, vinyl chloride, vinylidene chloride, allyl chloride and epichlorohydrin). Classification in the WFD might be under chapter 16 08 S*pent catalysts,* code 16 08 02* *Spent catalyst containing hazardous transition metals or hazardous transition metal compounds* (MH). Other relevant codes under the Basel Convention might be A2030 *Waste catalysts but excluding such wastes specified on list B* and A4160 *Spent activated carbon not included on list B.*	
Examples of customs codes	2852 00 00 ^{Hg} 2852 00 10 ^{Hg} 2852 00 90 ^{Hg} 2852 10 00 ^{Hg} 2853 00 90 ^{Hg}	Compounds, inorganic or organic, of mercury (excl. amalgams) Compounds, inorganic or organic, of mercury (excl. amalgams), chemically defined Compounds, inorganic or organic, of mercury (excl. amalgams), not chemically defined Inorganic or organic compounds of mercury, whether or not chemically defined, excluding amalgams Inorganic compounds, n.e.s.; amalgams (excl. of precious metals)

Table 9: Mercury Added Products (MAP)

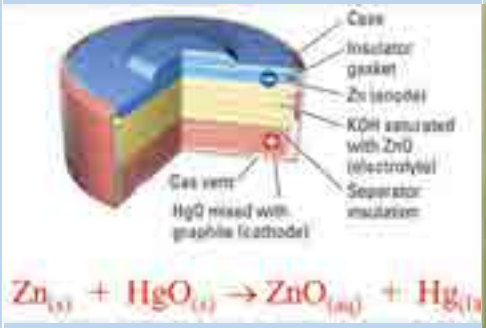
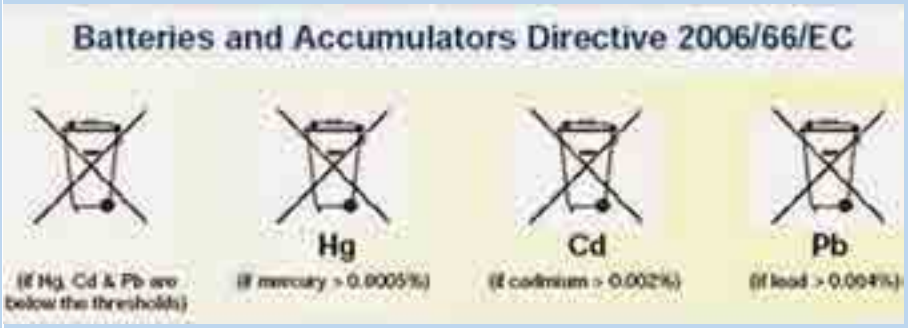
Batteries with mercury		
	 Figure 6: Schematic overview of a button cell mercury oxide battery or mercury zinc battery. Source: B. Hampton, Intersection no12 Batteries Gaterade.	 Photo 28: Example of a mercury oxide battery. Source: Varta (old photo).
	 Photo 29: Example of a 9 Volt vintage mercury battery. Source: Battery for Transistor Radios - 9 Volt 006P Power-S Mercury Radio & (radiomuseum.org)	 Photo 30: National Mercury Battery H-Ya (MR 20) Source: Https: // radiomuseum.org/r/Matsushita_national_mercury_battery.html.
	 Figure 7: Crossed out wheeled bin symbol for batteries within the EU.	

Photo 31: Examples of vintage mercury batteries. Source: More Batteries (ericwrobbel.com)

Type of material	• Mercury oxide batteries (cyclindrical and button) • Alkaline cyclindrical cell. Note: in recent years mercury content in cyclindrical alkaline cells has been reduced/eliminated in many battery brands • Button shaped cells of most types (UN Environment, Version 1.5 November 2019) Mercury is used in high concentrations (about 30-32% w/w) in mercury oxide batteries (sometimes called zinc-mercury batteries), where mercury oxide serves as the positive electrode in the battery. These have probably mainly been sold as button shape cells in the West, but also in larger cylindrical and other shapes. Marketing of mercury oxide batteries is now severely restricted in several countries. Some specific uses may still be exempted (for instance military uses in some countries). In the US, for example, mercury-oxide batteries are now prohibited, but were previously used in transistorized equipment, hearing aids, watches, calculators, computers, smoke detectors, tape recorders, regulated power supplies, radiation detection meters, scientific equipment, pagers, oxygen and metal monitors, and portable electrocardiogram monitors. In the following other battery types, mercury has served as reaction modifier, preventing gas development (and thus breakage) during use of the battery, and a corrosion inhibitor. Alkaline cylindrical cells on the European market had mercury concentrations up to around 1%. Due to environmental restrictions mercury consumption with cylindrical alkaline batteries decreased. Some nationally or regionally traded brands of alkaline batteries with mercury added, may still exist. Button cell shaped batteries of alkaline, silver oxide and zinc/air types still contain mercury in most cases (at concentrations up to around 1% w/w). Note that batteries may be imported and exported in substantial amounts in the package of other products like electronics, toys, greeting cards with sounds etc (UN Environment, Version 1.5 November 2019).
Visual	If intact the label should contain information, but this is not always the case. The battery type is normally noted on the package.
Chemical	Mercury concentration vary in between 1% to 32% in mercury oxides batteries.
Other	Alkali button batteries might have the letters “LR” on their shell, silver-oxide the letters “SR”, zinc-air the letters “PR” and mercury batteries the letters “NR” or “MR” (Asia-Pacific Economic Cooperation (APEC), June 2020). Within the EU Batteries with more than 5 ppm mercury must be marked with the chemical symbol for the metal concerned below the crossed-out wheeled bin symbol (see figure 7).
Wastes generated	Spent batteries.
Options for classification	WFD chapter 16 06 *Batteries and accumulators*, code 16 06 03* *Mercury-containing batteries* or Basel Convention code A1170 *Unsorted waste batteries excluding mixtures of only list B batteries*.

Examples of customs codes		
	8506 10 10	Alkaline manganese dioxide primary cells
	8506 10 20	(Other) manganese dioxide primary cells

	8506 10 30	Manganese dioxide batteries
	8506 30 00 [Hg]	Mercuric oxide batteries
	8506 40 10	Silver oxide primary cells with external volume less than or equal to 300 cm3
	8506 40 90	(Other) silver oxide primary cells
	8506 60 10	Air-zinc primary cells (with external volume less than or equal to 300 cm3)
	8506 60 90	(Other) air-zinc batteries
	8506 80 01	Other primary cells and batteries

Cosmetics

Photo 32: Mercury containing skin creams. Creams were identified during a study of the European Environmental Bureau (EEB) Zero Mercury Working Group. Photo: (EEB ZMWG, November 2018).

Country of purchase	Country of manufacture	Manufacturer	Brand name	Lumex (ng/m³ air)	Thg (ppm)
Thailand	Thailand	Inter Progress Cosmetic	Cleome White	1,750	8,300
Thailand	Thailand	OK Cosmetics Limited Partnership	O White Whitening Cream Premium Package	2,200	7,300
Thailand	Thailand	Lola rose Cosmetics company	White Rose Whitening	500	6,500
Thailand			Whitening Pearl and Snow Lotus Cream	1,040	4,300
Thailand	South Korea		Whitening Ginseng and Pearl Cream	575	2,100

Note: Creams analyzed in 2018 by Enthalpy Analytical using cold vapor atomic absorption spectroscopy.

Figure 8: Thai skin creams purchased 2018 with more than 1 ppm mercury. Results originate from the EEB Zero Mercury Working group study (EEB ZMWG, November 2018).

Type of material
This category consists of many products with different brand names

Visual
Check if the label mentions the words “mercurous chloride,” “calomel,” “mercuric,” “mercurio,” or “mercury”, but mercury is often not mentioned on the label. The products are usually marketed as skin lighteners, anti-aging treatments that remove age spots, freckles, blemishes, and wrinkles and antiseptic soap (FDA, 26/07/2016). Mercury-added cosmetics were labeled to be produced in China, Jamaica, Japan, Thailand, the Philippines and in other places not specified (UN Environment, 2017).

Chemical
Different chemical compounds are used, like: Mercury(I) chloride (also called calomel), mercury(II)chloride, mercury(I)iodide (or red mercury), mercury (II)iodide (or red mercury), mercury(I)oxide (also called hydragyri oxydum rubrum), mercuric amido chloride (with the chemical formula $HgNH_2Cl$), thiomersal (or merthiolate), phenylmercury acetate, mercury(II)acetate. Mercury concentrations may exceed the 1 ppm (1 mg/kg) total mercury concentration mentioned in the Minamata Convention as a maximum. Mercury is measurable in the air above the creams in concentrations of 500- 35 000 ng/m^3 (EEB ZMWG, November 2018). Some results are shown in figure 8.

Other characteristics
In addition to the EEB ZWMG study in the US a product with the name “Manning Beauty Cream” was discovered containing approximately 8% mercury by weight. The product was labeled to contain calomel (mercury chloride) (see (US Import Alert 53-18, 12/10/2020)). In the Netherlands mercury was detected in the past in “Crème c.t.r. contre les taches de rousseur”, “Original antiseptic soap” (1% mercury) and “Facial cream with AHA” containing 0.15% mercury (Dutch Food and Safety Authority, June 2009).

Wastes generated
Besides unused creams/soaps, most of the mercury will be lost to wastewater from washing of the skin. Some mercury may evaporate.

Options for classification
Since these materials are products, classification under the WFD is not straightforward. The WFD has a chapter 16 03 off-specification batches and unused products with a code 16 03 07* metallic mercury (AH). It is however unlikely that metallic mercury is present. If the mercury is present in the form of for example mercury(I)chloride (CAS no 7546-30-7). The following H-phrases are relevant[8]:

- H300 category 2: Fatal if swallowed
- H310 Category 1: Fatal in contact with skin
- H330 category 2: Fatal if inhaled
- H375: may cause damage to organs

[8] Information extracted European Chemicals Agency (ECHA) database visited on 2nd August 2021 under CAS (chemical abstract service) number 7546-30-7.

	• H410 category 1: very toxic to aquatic life with long lasting effects Based on these H-phrases HP (hazardous property) 6: *Acute toxicity* of the WFD is relevant (EC 2018/C 124/01, 9 April 2018). If the material is considered a waste, it can be classified as hazardous waste if the concentration levels exceed 0.25% or 2500 ppm.	
Examples of customs codes	3304 10 01	Lip make-up preparations
	3304 20 01	Eye make-up preparations
	3304 30 00	Manicure or pedicure preparations
	3304 90 00	Other
	3304 91 01	Powders, including compacts
	3304 99 01	Skin creams
	3304 99 99	Other
	3401 11 01	Soaps for toilet use (incl. medicated)
	3401 19 00	Other
	3401 20 01	Soap in other forms
	3401 30 01	Organic surface-active products and preparations for washing the skin, in the form of liquid or cream and put up for retail sale, whether or not containing soap

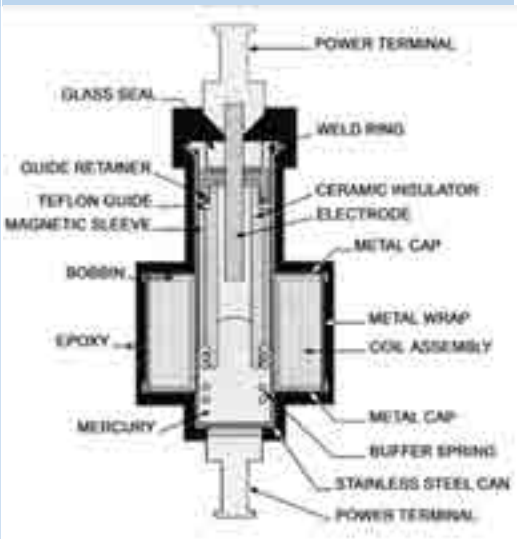
Switches and relays

Photo 33: Mercury switch. Mercury switches have one or more sets of electrical contacts in a sealed glass envelope that contains elemental mercury. Photo: Mercury switch - Wikipedia.

Photo 34: Mercury wetted relay. Other models can be found in (Naturvardsverket, november 2003). Photo: File:Clare HGRM-55211-P00 mercury-wetted reed relay.jpg - Wikimedia Commons

Photo 35: Mercury wetted contact

Photo 36: Mercury level switch.

	Photos 35 and 36 were obtained from KMK Metals Recycling Ltd. Ireland. KMK Metals Recycling is the industry leader in certified resource recovery solutions and plays a crucial role in achieving Ireland's recycling targets.
	 **Photo 37: Closed mercury relay, with a coil around the top of the tube and adjustable angle. Photo: internet A. Dingley**  **Figure 9: Schematic overview mercury relay. Source internet: Solid State Relays vs Mercury Relays | Wolf Automation**
	 **Photo 38: Mercury relay.** **Photo: https://www.wolfautomation.com/mercury-relay-2-poles-100a-nc-120vac-1/**
Type of material *Visual* *Chemical*	Used products. Elemental mercury may be visible, check for labels. Mercury content is expected to be diverse.
Other characteristics *Wastes generated*	As photos show, the shape and size of contacts and relays with mercury vary greatly; from small components in specialized electronic equipment to large relays used in high-current the electricity grid. The spent products, sometimes inside larger equipment.

Options for classification	WFD code 20 01 21* *Fluorescent tubes and other mercury containing waste* is relevant or Basel convention code A1180 *Waste electrical and electronic assemblies or scrap containing components such as accumulators and other batteries included on list A, mercury switches* etc.	
Examples of customs codes		**Isolating switches and make-and-break switches, for a voltage exceeding 1,000 volts**
	8535 30 01	Make-and-break switches
	8535 30 13	Switches for rated current less than or equal to 1,600 amps, vacuum cut-off without actuating device (vacuum bottles or ampoules)
	8535 30 18	Disconnectors and switches for rated current less than or equal to 1,600 amps and others with automatic actuation device except for contacts immersed in liquid medium
	8535 30 19	Other disconnectors and switches for rated current less than or equal to 1,600 amps
	8535 30 27	Switches for rated current greater than 1,600 amps and others with non-automatic actuation device
	8535 30 28	Switches for rated current greater than 1,600 amps and others with automatic actuation device except for contacts immersed in liquid medium
		Electrical apparatus for switching, protecting or making connections for a voltage exceeding 1,000 volts
	8535 90 04	Starter relays
	8535 90 05	Thermal or induction relays
	8535 90 06	High sensitivity relays, with laminated core, inverting monopole, as exclusively designed for telephone equipment
	8535 90 13	Secondary electromagnetic relays, powered exclusively through current and / or voltage transformers
	8535 90 14	Automatic differential relays, up to 60 amps with differential protection up to 300 milliamps
	8535 90 22	Relays other than those included in subheadings 8535.90.04, 8535.90.05, 8535.90.06, 8535.90.13 and 8535.90.14.
		Relays for a voltage not exceeding 60 volts
	8536 41 01	For speakers
	8536 41 02	6- and 12-volt solenoids, for automotive starter motors
	8536 41 03	Thermal or induction
	8536 41 04	Certified for aircraft
	8536 41 05	High sensitivity, with laminated core, inverter monopole, designed and certified for telephone equipment
	8536 41 06	Electromagnetic secondaries, powered exclusively through current and / or voltage transformers
	8536 41 07	Automatic differential, up to 60 amps with differential protection up to 300 milliamps
	8536 41 08	Photoelectric relays
	8536 41 09	Directional indicators for maneuvering indicator lights, for automotive use
	8536 41 10	For start-up functions, other than those included in section 8536.41.02
	8536 41 11	Manual or electrical reset multiple contact lockout auxiliary relays rated less than or equal to 60 amps
	8536 41 99	Other
		Relays for a voltage greater than 60 volts and not exceeding 1,000 volts
	8536 49 01	For start-up functions
	8536 49 02	Thermal or induction
	8536 49 03	Electromagnetic secondaries, powered exclusively through current and / or voltage transformers Automatic differential, up to 60 amps with differential protection up to 300 milliamps
	8536 49 04	Multi-contact block auxiliary relays, manual or electrical reset, rated less than or equal to 60 amps and 480 volts maximum voltage
	8536 49 05	Other

		Switches, for a voltage not exceeding 1,000 volts
	8536 49 99	Switches other than those included in subheadings 8536.50.05, 8536.50.06, 8536.50.07, 8536.50.10, 8536.50.11 and 8536.50.15
	8536 50 01	Certified for aircraft
	8536 50 05	Switches, by pressure of liquids for level controls in washing machines for domestic use
	8536 50 06	Thermoelectric automatic switches for priming the discharge in fluorescent lamps or tubes
	8536 50 07	Switches designed and certified exclusively for radio or television, other than those included in
	8536 50 10	section 8536.50.15
	8536 50 11	Loose or grouped switches, actuated by buttons, weighing up to 250 grams, or single or multiple push-button or keyboard switches, designed and certified exclusively for electronics, other than those included in section 8536.50.15
	8536 50 15	Dual, foot or pull-type light switches; start button; designed and certified exclusively for automotive use
		Thermostats
	9032 10 20	Electronic thermostats
	9032 10 80	Other thermostats
Lamps		

Photo 39: Energy saving fluorescent lamps
Also called CFLs or compact fluorescent lamps
Source: Mercury in Compact Fluorescent Lamps (CFLs) (dpic.org)

Figure 10: Schematic overview of a compact fluorescent lamp. Source: https://www.energystar.gov/products/lighting_fans/light_bulbs/learn_about_cfls).

Photo 40: Example of a general purpose linear fluorescent lamp (LFL).Source: el-grossisten.dk

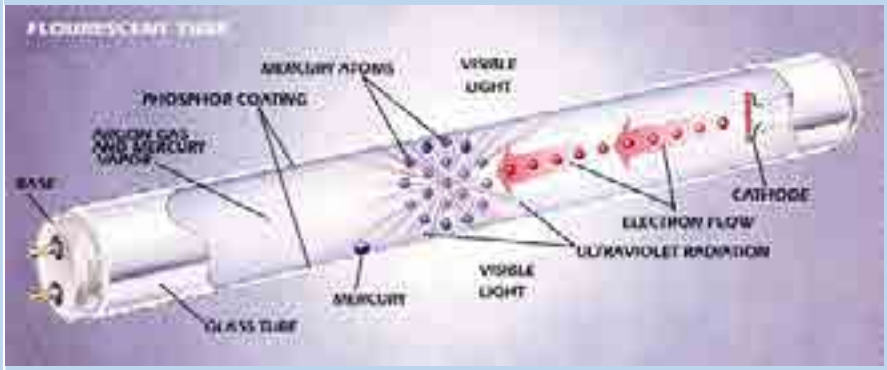


Figure 11: Schematic overview mercury containing fluorescent tube lamp. A typical fluorescent tube is filled with inert gas and a small amount of mercury that creates vapor. Generating fluorescent light occurs in two stages. First, electrons emitted from cathodes create an electrical arc through mercury vapor. Then, resultant ultraviolet radiation strikes phosphor coating which then gives off visible light. Bi-pin bases are necessary for preheat and rapid-start fixture designs.
Source: http://www.piclist.com/images/net/ustr/www/http/electronics/fluorescent.shtml.ht

Photo 41: LCD screen backlight (cold cathode fluorescent lamp).
Source: https://eeb.org/call-to-action-tell-the-eu-to-eliminate-mercury-in-light-bulbs/

Photo 42: Probably a high-pressure discharge (HID) lamp.

Photo 43: Pen-ray lamp.

Photos 42 and 43 were obtained from KMK Metals Recycling Ltd. Ireland. KMK Metals Recycling is the industry leader in certified resource recovery solutions and plays a crucial role in achieving Ireland's recycling targets.

Photo 44: High pressure mercury vapour (HPMV) lamp.
Source: https://www.industricals.com/hpmv-lamps.

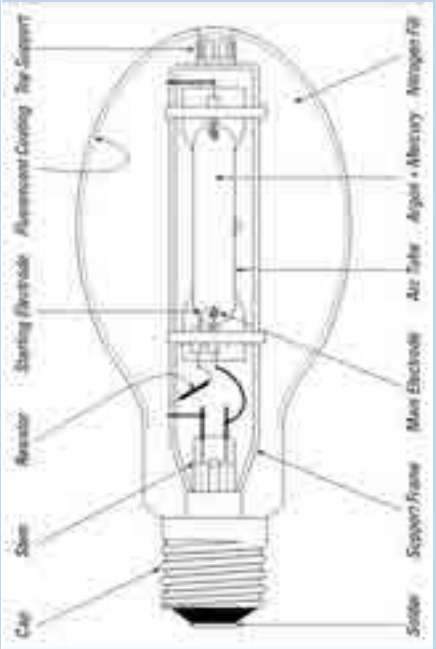
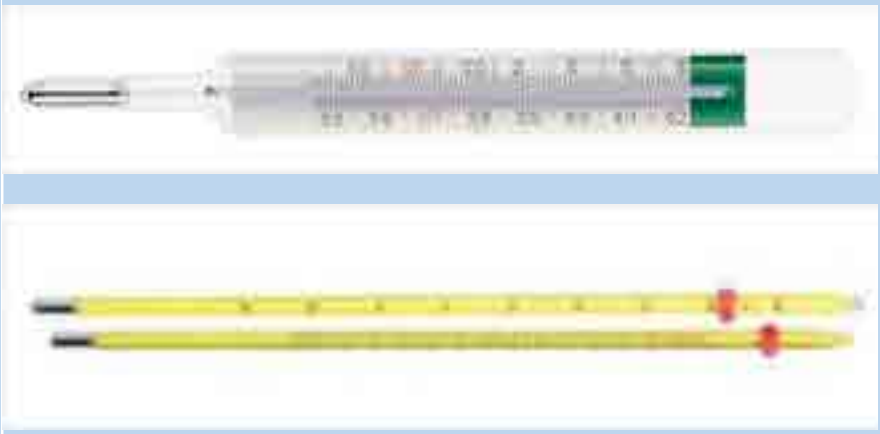


Figure 12: Schematic overview of a high-pressure mercury vapour (HPMV) lamp. Source: http://lamptech.co.uk/Documents/M1%20Introduction.htm.

	 **Photo 45: High-intensity discharge (HID) bulbs.**  **Photo 46: Metal parts from HID bulbs.**
	Photos 45 and 46 are obtained from ELEKTRO RECYCLING, s.r.o. Slovakia. ELEKTRO RECYCLING recycles waste from electric and electronic equipment's (WEEE). It includes not only processing but also accredited collection of WEEE and transport in the whole region of Slovakia.
	 **Photo 47: Mercury containing fluorescent powder. The powder is separated from other materials during the recycling of the different types of mercury lamps. Material originates from Indaver Antwerp Belgium. Indaver provides Total Waste Management (TWM) Services and Services for Industrial waste. Photo: NFI.**
Type of material *Visual* *Chemical*	Products. Divers types, more examples can be found in (Asia-Pacific Economic Cooperation (APEC), June 2020) Elemental mercury and mercury salts in concentrations between 3 and 30 mg mercury per lamp. During the recyling process mercury bearing fluorescent powder is separated (see photo 47). The material shown on photo 47 contained 1331 mg/kg mercury measured with mobile XRF (see table 5).
Other characteristics *Wastes generated*	- Spent lamps, fluorescent powder, contaminated metal, and glass parts.
Options for classification	WFD Chapter 20 01 *Separately collected fractions* with code 20 01 21* *fluorescent tubes and other mercury-containing waste* (AH). Relevant codes from the Basel Convention are Y29 *Wastes having as constituents mercury, mercury compounds* and A1030 *Wastes having as constituents or contaminants any of the following: mercury, mercury compounds.* This group is covered by Minamata Convention and EU mercury regulation for some sub-types only.

Examples of customs codes		**Linear fluorescent lamps**
		Fluorescent, hot cathode discharge lamps, other than ultraviolet lamps
	8539 31 00 10 Hg	Linear fluorescent lamps (LFLs) for general lighting purposes
	8539 31 00 90 Hg	Other
		Compact fluorescent lamps
	8539 31 00 Hg	Discharge lamps, fluorescent and hot cathode
	8539 31 10 Hg	Compact fluorescent lamps (CFLs) for general lighting purposes
		High-pressure mercury vapour lamps
	8539 32 00	Mercury or sodium vapour lamps; metal halide lamps
	8539 32 20	Mercury or sodium vapour lamps (CN)
		Cold cathode and external electrode fluorescent lamps
	8539 39 00	Electrical discharge lamps, other than fluorescent (hot cathode), mercury or sodium vapour, metal halide or ultraviolet lamps
		Discharge lamps scrap
	CN 8549 21 00	CN 8549 21 00 – – Electrical and electronic waste and scrap: Containing primary cells, primary batteries, electric accumulators, mercury switches, glass from cathode-ray tubes or other activated glass, or electrical or electronic components containing cadmium, mercury, lead or polychlorinated biphenyls (PCBs).
	CN 8549 31 00	CN 8549 31 00 – – Electrical and electronic waste and scrap: Other electrical and electronic assemblies and printed circuit boards: Containing primary cells, primary batteries, electric accumulators, mercury switches, glass from cathode-ray tubes or other activated glass, or electrical or electronic components containing cadmium, mercury, lead or polychlorinated biphenyls (PCB).
	CN 8549 91 00	CN 8549 91 00 – – Electrical and electronic waste and scrap; Other: Containing primary cells, primary batteries, electric accumulators, mercury switches, glass from cathode-ray tubes or other activated glass, or electrical or electronic components containing cadmium, mercury, lead or polychlorinated biphenyls (PCBs).
	HS (not CN) 8548 10	HS (not CN) 8548 10- - Waste and scrap of primary cells, primary batteries and electric accumulators; spent primary cells; spent primary batteries and spent electric accumulators; electric parts of machinery and apparatus; n.e.s. or included elsewhere in chapter 85.

Thermometers		
	 **Photo 48: Elemental mercury in glass thermometers. Upper picture: fever (medical) thermometer. Source: Geratherm on amazon.com. Lower picture : Mercury laboratory thermometer (actually longer then the fever thermometer). Source: https://www.globalgilson.com/general-lab-thermometers.**	
	 **Photo 49: Double ambient air thermometers with elemental mercury. Photo: KMK Metals Recycling LTd. Ireland. KMK Metals Recycling is the industry leader in certified resource recovery solutions and plays a crucial role in achieving Ireland's recycling targets.**	
Type of material *Visual* *Chemical*	Product. Elemental mercury is visible as a thick silver fluid. Pure elemental mercury.	
Other *Wastes generated*	Size and shape may vary considerably for different purposes. Mercury thermometers are also used in various apparatus. Examples are devices for measuring air humidity (hygrometers and psycrometers), and for the measuring of the softening point of fats, waxes, bitumen, etc. Product, whole or broken.	
Options for classification	WFD code 20 01 21* *fluorescent tubes and other mercury containing waste AH* or Basel convention codes Y29 *Wastes having as constituents: mercury, mercury compounds* or A1030 Wastes having as constituents or contaminants any of the following: *mercury; mercury compounds.*	
Examples of customs codes	9025 11 10 9025 11 40 9025 80 02	Clinical thermometers, liquid filled, for direct reading Liquid-filled thermometers, for direct reading, not combined with other instruments, other than clinical thermometers Other instruments: hygrometers

Barometers, manometers, sphygmomanometers (blood pressure gauges)		
	 **Photo 50: Mercury blood pressure gauge. Source: https://www.dreamstime.com/photos-images/.**	 **Photo 51: Barometer with elemental mercury. Photo: NFI.**
	 **Photo 52: Manometer with elemental mercury. Used to measure pressure/vacuum in monitoring of production processes; here for a vacuum milking machine system. Source: http://www.newmoa.org/prevention/mercury/projects/legacy/measdev.cfm:.**	
Type of material	This category includes a variety of manometers, barometers, sphygmomanometers (also called blood pressure gauges) using mercury and that are not powered by batteries or electric current.	
Visual	Elemental mercury may be visible in a glass tube.	
Chemical	-	
Other	-	
Wastes generated	Intact and broken products, with free elemental mercury.	

Options for classification	WFD code 20 01 21* *Fluorescent tubes and other mercury containing waste* is relevant or Basel convention codes Y29 *Wastes having as constituents: mercury, mercury compounds* or A1030 Wastes having as constituents or contaminants any of the following: *mercury; mercury compounds.*	
Examples of customs codes	9018 90 92 9025 80 01 9026 20 10	Devices for measuring blood pressure Other instruments, including barometers Instruments and apparatus for pressure measurement or control, manometers
Paints		
	 **Photo 53: Mercury containing paint. Material was obtained from ATM BV Moerdijk The Netherlands. ATM is one of Europe's largest professional processors of contaminated soil and TAG (tar asphalt granulate), wastewater and oily sludge. Photo: NFI.**	
Type of material *Visual* *Chemical*	Mercury in paint or paint solvent serves as an preserving agent in for example antifouling paint. Thick, dark fluid, in the example of photo 53. Mercury was used however as a preservative in different paint types including indoor lataex paint and the example given is probably not representative (Agocs, et al., 1990). Check the label in case the original packaging is present. 10 ppm mercury is measured with XRF in the example of photo 53. Phenyl mercuric acetate and similar mercury compounds were widely used in the past (Asia-Pacific Economic Cooperation (APEC), June 2020).	
Other *Wastes generated*	In case of the material of photo 53: strong smell. Remaining remnants.	
Options for classification	Chapter 8 of the WFD code 08 01 11* *Waste paint and varnish containing organic solvents or other hazardous substances* (MH) may be relevant, another option is 20 01 27* *Paint, inks, adhesives, and resins containing hazardous substances (*MH) or the (MNH) variant 20 01 28. Based on the mercury concentration this material is not expected to be hazardous waste. Relevant codes from the Basel Convention may be Y12 and A4070 *Wastes from the production, formulation and use of inks, dyes, pigments, paints, lacquers, varnish*.	
Examples of customs codes	3208 00 3209 00	Paints and varnishes, including enamels and lacquers, based on synthetic polymers, dispersed or dissolved in a non-aqueous medium (excluding those based on polyesters and acrylic or vinyl polymers) Paints and varnishes, including enamels and lacquers, based on synthetic polymers or chemically modified natural polymers, dispersed or dissolved in an aqueous medium

Pesticides		
	 **Figure 13: Label of mercury containing pesticide. Source: internet (Australian Government, 2017).**	
Type of material *Visual* *Chemical*	Product. Check label for information. Divers.	
Other Wastes generated	No use is known within the European Union. -	
Options for classification	WFD 20 01 19* *Pesticides* AH may be aplicable or Basel Convention code A4030 *Wastes from the production, formulation and use of biocides and phytopharmaceutical, including waste pesticides and herbicides which are off-specification, outdated, or unfit for their originally intended use.*	
Examples of customs codes	3808.50.01 3808.50.10 3808.50.50	Goods containing a range of substances as specified in Subheading Note 1 to Chapter 38, of which one is mercury compounds Specified goods containing any aromatic or modified aromatic pesticide Other pesticides
Pharmaceuticals (EC, Revision 1, 29 April 2019)		
	 **Photo 54: Pharmaceutical products containing merbromin (adhesive plaster). Used as merbromin solution. Source: (Asia-Pacific Economic Cooperation (APEC), June 2020).**	
Type of material *Visual* *Chemical*	Product. Check label for "*merbromin*". Products may contain mercury(II)chloride.	

Other	-	
Wastes generated	Unused products.	
Options for classification	WFD chapter 18 01 *wastes from natal care, diagnosis, treatment or prvention of diseare in humans* is applicable. Relevant code may be 18 01 06 *medicines other than those mentioned in 18 01 08* MNH[B] or 20 01 32 *Medicines other than those mentioned in 20 01 31* MNH[B]. Basel Convention code A4010 *Wastes from the production, prepartion and use of pharmaceutical products.*	
Examples of customs codes	3808.50.01	Goods containing a range of substances as specified in Subheading Note 1 to Chapter 38, of which one is mercury compounds
	3808.50.10	Specified goods containing any aromatic or modified aromatic pesticide
	3808.50.50	Other pesticides
	3808.91.00	Insecticides
	3808.92.00	Fungicides
	3808.93.00	Herbicides, anti-sprouting products and plant-growth regulators
	3808.99.00	Other

Traditional medicine

Photo 55: Traditional Chinese medicine with a cinnabar (mercury sulphide) coating. Photo: NFI.

Type of material	Products, mercury sulphide or cinnabar.
Visual	Products may have the characteristic red colour of mercury sulphide.
Chemical	The outer red shell of this product shown contained 18927.38 mg/kg mercury (measured with mobile XRF). In this situation a Raman was used to determine that the chemical mercury form is cinnabar (HgS) (see figure 3).
Other	Cinnabar (HgS) is a component in traditional Chinese Medicine. Mercury or its compounds are also traditionally used in some Ayurvedic medicines. Labels may in some cases be an important source of information.
Wastes generated	Waste products. When consumed, most mercury will be released to waste water.
Options for classification	Material is no waste, neither is it to be expected hazardous waste.

Table 10: Mercury containing wastes

Materials of table 10 are generated by industrial processes that use mercury containing raw materials and generate mercury contaminated wastes and waste treatment residues. Most of these materials have no specific outstanding visual characteristics that indicate the presence of mercury. Mercury contents of the wastes are variable.

Fly ash	 **Photo 56: Fly ash. Material originates from ATM Moerdijk, The Netherlands. ATM is one of Europe's largest professional processors of contaminated soil and TAG (tar asphalt granulate), wastewater and oily sludge. Photo: NFI.**
Type of material *Visual* *Chemical*	Fly ash, residue from combustion processes carried along with flue gases. Fine dark gray, black material, not recognisable by visual aspects alone. Material of photo 56 contained 60.60 mg/kg mercury determined with mobile XRF. In the air above the sample 7399 ng/m^3 was measured with a Lumex mercury analyzer (see also table 5).
Other characteristics	-
Options for classification	Depending on the origin WFD codes 10 01 02 coal fly ash (ANH), 10 01 16* fly ash from co-incineration containing hazardous substances (MH), 19 01 013* fly ash containing hazardous substances (MH) or 19 04 02* fly ash and other flue-gas treatment wastes (AH), 10 14 wastes from crematoria, 10 14 01* waste from gas cleaning containing mercury (AH) may be relevant. Note that the mercury concentrations in the fly ash of photo 56 are too low to fulfill the hazardous waste criteria of the WFD. A1030 Basel Convention *Wastes having as constituents or contaminants mercury; mercury compounds.* Note that concentrations in this specific waste are too low to fulfill criteria of Basel convention Annex III codes H6.1. *toxic* and code H11 *delayed toxicity.*
Examples of customs codes	2620 60 00_ _Slag, ash and residues (other than from the manufacture of iron or steel), containing metals, arsenic or their compounds: – Containing arsenic, mercury, thallium or their mixtures, of a kind used for the extraction of arsenic or those metals or for the manufacture of their chemical compounds.

Industrial filters	 **Photo 57: Mercury contaminated filter. Material was obtained from BMT The Netherlands. BMT is specialized in developing practical Total Mercury management solutions for mercury containing wastes. Photo: NFI.**
Type of material *Visual* *Chemical*	Used industrial filters. Elemental mercury is visible as small silvery bulbs. Filter of photo 57 contained 30,4359.90 mg/kg mercury measured with mobile XRF and in the air above the sample 12,908 ng/m^3 mercury measured with a Lumex mercury analyser (see table 5).
Other characteristics	-
Options for classification	WFD codes 15 02 02* *absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by hazardous substances (MH) or 05 07 01* wastes from natural gas purification and transportation 05 07 01* wastes containing mercury (AH)* may relevant. Basel convention code Y29 *wastes having as constituents' mercury; mercury compounds* (A1030*).* The mercury concentration in the material of photo 57 is high enough to meet criterium H11 *Delayed toxicity* of the Basel convention based on GLP H-phrase 360D reproductive toxicity (more than 0.3%).
Examples of customs codes (pellets recycled for metals/chemicals recovery)	2620 60 00_ _Slag, ash and residues (other than from the manufacture of iron or steel), containing metals, arsenic or their compounds: – Containing arsenic, mercury, thallium or their mixtures, of a kind used for the extraction of arsenic or those metals or for the manufacture of their chemical compounds.

Spent activated carbon	 **Photo 58: Spent activated carbon. Material was obtained from BMT The Netherlands. BMT is specialized in developing practical Total Mercury management solutions for mercury containing wastes. Photo: NFI.**
Type of material	Used activated carbon, may originate from different chemical production processes, or from activated carbon filters used for example to clean exhaust air from production processes like manufacture of mercury-added products, mercury recycling facilities, large scale industrial gold production, etc.
Visual	-
Chemical	The materials of photo 58 contained 180 mg/kg mercury measured with mobile XRF. In the air above the sample 12498 ng/m^3 mercury was measured with a Lumex mercury analyser (see table 5).
Other characteristics	-
Options for classification	The WFD has several entrees for spent activated carbon not specially related to a mercury contamination, like 06 07 02* *activated carbon from chlorine production (AH), 06 13 02* spent activated carbon (AH), 19 01 10* spent activated carbon from flue-gas treatment (AH) and 19 09 04 spent activated carbon (*ANH). *Basel convention A4160 spent activated carbon not included on list B (note the related entry on list B2060).* The concentration mercury in the material of photo 58 is not high enough to meet criterium H11 delayed toxicity of the Basel convention based on GLP H-phrase 360D reproductive toxicity (more than 0.3%).
Examples of customs codes	2620 60 00_ _Slag, ash and residues (other than from the manufacture of iron or steel), containing metals, arsenic or their compounds: – Containing arsenic, mercury, thallium or their mixtures, of a kind used for the extraction of arsenic or those metals or for the manufacture of their chemical compounds.

Pyrolysis residue	 **Photo 59: Pyrolysis residue. Material originates from ATM Moerdijk, The Netherlands. ATM is one of Europe's largest professional processors of contaminated soil and TAG (tar asphalt granulate), wastewater and oily sludge. Photo: NFI.**
Type of material *Visual* *Chemical*	Remains of pyrolysis oven, the mercury contamination may have diferent origins. Fine black material. The material of photo 59 contained 5.93 mg/kg mercruy measured by mobile XRF and in air above the sample 2471 ng/m^3 was measured with a Lumex mercury analyser (see table 5).
Other characteristics	-
Options for classification	Options for a WFD code are 19 01 17* *pyrolysis wastes containing hazardous substances* (MH) or 19 01 18 *pyrolysis wastes other than those mentioned in 19 01 17** (MNH). Note that based on the mercury concentration there is no indication that the material of photo 59 should be classified as hazardous.
Examples of customs codes	2620 60 00 _Slag, ash and residues (other than from the manufacture of iron or steel), containing metals, arsenic or their compounds: – Containing arsenic, mercury, thallium or their mixtures, of a kind used for the extraction of arsenic or those metals or for the manufacture of their chemical compounds.
Contaminated metal	 **Photo 60: Mercury contaminated metal used for natural gas extraction. Mercury condenses as liquid mercury on the inside of piping and equipment, or it forms amalgamates. Use of a handheld XRF offers the opportunity**

	to examine large parts of the surface fast and efficient for the presence of mercury. Material is obtained via the NAM (Nederlandse Aardolie Maatschappij). NAM is a Dutch exploration and production company and responsible for unlocking two of the Netherlands' most important resources: gas and oil. The material originates from their waste processing plant. Photo: NFI.
Type of material *Visual* *Chemical*	Different types of metal piping and equipment made from aluminum, copper, or other non-ferrous metal are capable of amalgamating with mercury. Corrosion. Although mercury was not measurable with mobile XRF in the material of photo 60, it is a fact of common knowledge that mercury forms amalgams with metal equipment in direct contacts with mercury bearing natural gas or raw mineral oil (Kibogy, May 25th 2010) (Finster, Raymond, Scofield, & Smith, 2015) (Thermo Scientific, 2014). The mercury concentrations in the metal can be variable at short distances in the metal. Reported concentrations are 1- 300 ppm (Finster, Raymond, Scofield, & Smith, 2015) (Walraven)).
Other characteristics	-
Options for classification	WFD code 05 07 01* (AH) Wastes *from natural gas purification and transportation, wastes containing mercury* may be applicable. Basel Convention code A1030 W*astes having as constituents or contaminants mercury; mercury compounds* may be applicable. Note that based on the mercury concentration there is no indication that the material of photo 60 should be classified as hazardous.
Gas condensates	 **Photo 61: Gas condensate. Material is obtained via the NAM (Nederlandse Aardolie Maatschappij). NAM is a Dutch exploration and production company and responsible for unlocking two of the Netherlands' most important resources: gas and oil. The material originates from their waste processing plant. Photo: NFI.**
Type of material *Visual* *Chemical*	Gas cleaning residue (or condensate). Condensates may originate from various steps in the cleaning process or wastewaters and may be recovered and marketed as a byproduct. Black fluid, not recognisable by visual aspects alone. The material of photo 61 contained 573 mg/kg mercury measured with mobile XRF.
Other characteristics	-
Options for classification	Chapter 5 WFD *Wastes from petroleum refining, natural gas purification and pyrolytic treatment of coal*, code 05 07 01* *Wastes containing mercury* (AH) or Basel Convention code A4060 W*aste oils/water, hydrocarbons/water mixtures, emulsions.*

Examples of customs codes	2620 60 00_ _Slag, ash and residues (other than from the manufacture of iron or steel), containing metals, arsenic or their compounds: – Containing arsenic, mercury, thallium or their mixtures, of a kind used for the extraction of arsenic or those metals or for the manufacture of their chemical compounds.

Sludges

Photo 62: Dry sludge.

Photo 63: Wet sludge.

Materials of photos 62 and 63 were obtained from BMT The Netherlands. BMT is specialized in developing practical Total Mercury management solutions for mercury containing wastes. Photos: NFI.

Photo 64: Solid waste sludge.

Photo 65: Decanter sludge; remains from a separation technique with a centrifuge.

	 **Photo 66: Dewatered week sample.**
	Materials of photos 64, 65 and 66 originate from ATM Moerdijk, The Netherlands. ATM is one of Europe's largest professional processors of contaminated soil and TAG (tar asphalt granulate), wastewater and oily sludge. Photos: NFI.
Type of material *Visual* *Chemical*	Different types of sludges originating from waste management facilities. - Composition of these materials is variable, depending on the original waste treated, the waste treatment process and the treatment step within the process. The materials collected during the STRiKE project contained in between 9 and 783 mg/kg mercury measured by mobile XRF. In the air above the materials mercury concentrations between 792 and 3257 ng/m^3 were measured with a Lumex mercury analyzer (see also tables 5 and 6).
Other characteristics	-
Options for classification	Chapter 19 WFD *Wastes from waste management facilities, off-site wastewater treatment plants and the preparation of water intended for human consumption and water for industrial use* is relevant. One of the codes under 19 02 *Wastes from physico/chemical treatments of waste* or 19 03 *Stabilized/solidified wastes* may apply.