UNITED NATIONS
ENVIRONMENT PROGRAMME
CHEMICALS

Guide for Reducing Major Uses and Releases of Mercury

June 2006

IOMC INTER-ORGANIZATION PROGRAMME FOR THE SOUND MANAGEMENT OF CHEMICALS
A cooperative agreement among UNEP, ILO, FAO, WHO, UNIDO, UNITAR and OECD

Disclaimer

This publication is intended to serve as a guide. While all reasonable precautions have been taken to verify the information contained in this publication, this published material is being distributed without warranty of any kind, either expressed or implied. UNEP disclaims any responsibility for possible inaccuracies or omissions and consequences that may flow from them. The responsibility for the interpretation and use of the material lies with the reader. Neither UNEP nor any individual involved in the preparation shall be liable for any injury, loss, damage or prejudice of any kind that may be caused by persons who have acted based on their interpretation and understanding of the information contained in this publication.

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the United Nations or UNEP concerning the legal status of any country, territory, city or area of its authorities, or concerning the delimitation of its frontiers or boundaries.

The mention of specific companies or of certain manufacturers' products does not imply that they are endorsed or recommended by UNEP, nor preferred compared to others of a similar nature that are not mentioned. The use of information from this publication concerning proprietary products for publicity or advertising is not permitted.

TABLE OF CONTENTS

1.0 Introduction

Background

The UNEP *Global Mercury Assessment*[1], completed in December 2002 by a UNEP working group representing a wide range of stakeholders, showed that environmental mercury levels have increased considerably since the beginning of the industrial era. Mercury is now present in various media and food, especially fish, all over the globe at levels that adversely affect humans and wildlife. Widespread exposures are occurring due to human-generated sources. Even regions with no significant mercury releases, such as the Arctic, are adversely affected due to long-range transport of mercury.

At its session in February 2003, the UNEP Governing Council concluded, after considering the key findings of the Global Mercury Assessment report, that there is sufficient evidence of significant global adverse impacts from mercury to warrant further international action to reduce the risks to humans and wildlife from the release of mercury to the environment. The Council decided that further national, regional and global actions should be initiated as soon as possible, and urged all countries to adopt goals and take actions, as appropriate, to identify populations at risk and to reduce human-generated releases.

The Council requested UNEP, in cooperation and consultation with other appropriate organizations, to facilitate and conduct technical assistance and capacity building activities to support the efforts of countries to take action regarding mercury pollution. This request was reinforced by the Governing Council at its 23rd session in February 2005.

In response to the Governing Council's request, UNEP has established a mercury programme within UNEP Chemicals, with the immediate objective of encouraging all countries to adopt goals and take actions, as appropriate, to identify exposed populations, to minimize exposures through outreach efforts, and to reduce anthropogenic mercury releases.

Among the priorities of the programme are to assist countries in assessing their own situation with regard to mercury pollution, and identifying possible ways of dealing with any adverse impacts, such as developing tools and strategies to mitigate problems, increasing awareness and promoting mercury-free products or responsible use of mercury, where appropriate, and developing strategies for enhanced communication to reach at-risk populations.

Purpose, scope and organization of this document

This document is intended to assist countries to strengthen their knowledge base, to identify sources of possible mercury exposure and to readily assess the viability of the main methods of reducing mercury exposures and risks to their people. The information provided reflects approaches that have been considered and/or

---

[1] The Global Mercury Assessment (UNEP, 2002), a comprehensive report covering most issues relevant to mercury pollution, can be accessed online at the UNEP Chemicals website in English, French and Spanish. The Global Mercury Assessment is used throughout this document as an information source.
(URL: http://www.chem.unep.ch/mercury/Report/Final%20Assessment%20report.htm).

implemented in some countries/industries/products to reduce or eliminate mercury releases. However, they may not be applicable in all situations. Whether or not they are applied in different countries depends upon government and local priorities, information and education about possible risks, the legal framework, enforcement, implementation costs, perceived benefits and other factors.

It must be recognised that in a relatively brief document covering so many applications the scope of the *Guide* is seriously limited. In such cases the *Toolkit*, for example, is an excellent source of a more detailed understanding of the mercury life cycle from raw materials through products and processes. Likewise, the EIPPCB BREF documents on best available techniques, and various other documents referenced in the different sections of the *Guide*, are also quite valuable in providing an appreciation of the details of the techniques involved, and the range of emission reduction measures possible.

Acknowledgements

In order to ensure consistency with existing UNEP mercury documents, the *Guide* relies heavily on the UNEP *Global Mercury Assessment*, as well as the *Toolkit for identification and quantification of mercury releases*,[2] to provide a general overview of most of the major product and process applications of mercury. The *Guide* also brings in a range of other sources in order to summarise the main methods for reducing exposures and risks, including examples from various parts of the world.

This *Guide* was produced by Concorde East/West Sprl, and the main author was Mr. Peter Maxson, who has previously been involved in a number of UNEP and other publications on mercury issues, both at national and international level. Within UNEP Chemicals, the Mercury and Other Metals Team contributed to the structure, editing and finalization of the document.

---

[2] Toolit for identification and quantification of mercury releases is a key training and guidance material that is of use to Governments and others in their efforts to evaluate and address mercury pollution. See website (URL: http://www.chem.unep.ch/mercury/Toolkit/default.htm)

2.0 General Best Practices

Even before consulting the more specific information provided in the *Guide*, it must be mentioned that there are a number of more general measures (implemented in virtually all successful industries) that can be extremely effective in greatly reducing mercury emissions of all kinds, and at very low cost:

1. *Training, education and motivation of staff and operators.* Industrial processes are overseen by people. Therefore, appropriate and focused training of staff can be a very cost-effective way of reducing discharges of harmful substances.

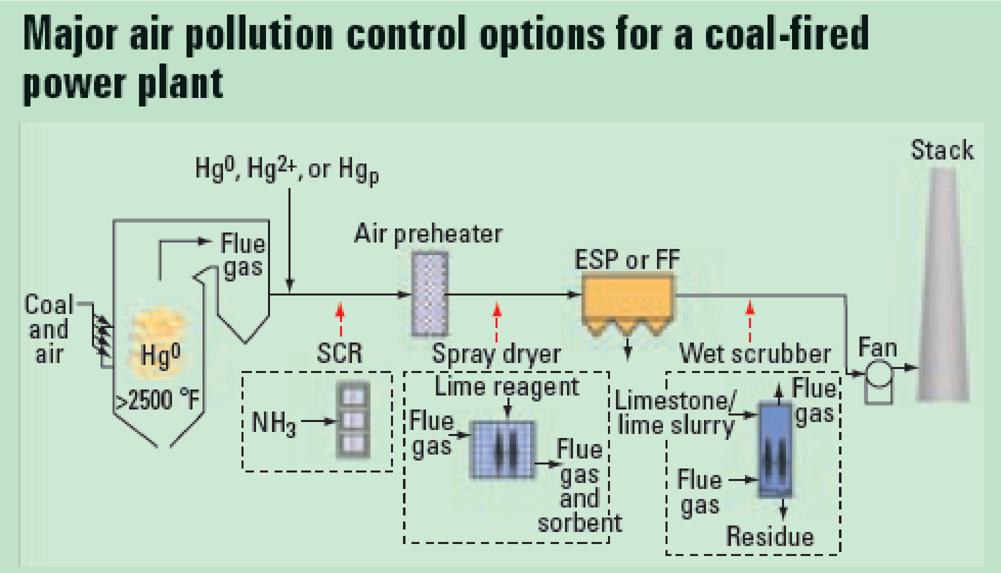
2. *Process control optimisation.* To be able to reduce different pollutants simultaneously, and to maintain low emissions, strict attention to process control is required.

3. *Regular maintenance.* To maintain the efficiency of the technical units of industrial processes, and the keep the associated abatement systems operating at a high level, sufficient and routine maintenance has to be ensured.

4. *An operational awareness of the importance of environmental management.* An environmental management system that clearly defines the responsibilities for environmentally relevant operations is a necessary tool of responsible management. It raises awareness while including goals and measures, process and job instructions, check lists and other relevant documentation, as necessary.

3.0 Power & Heat Production and Refinement and Use of Oil & Gas

3.1 Coal fired power plants and other coal combustion sources

Description	This summary covers large combustion plants (typically with thermal boiler capacity above 300 MW). Most such plants are large-scale electricity production plants, some of which also supply heat (district heating, etc.). The reason for presenting such large coal-fired power plants separately from smaller ones is that in many countries they represent a large part of the national coal consumption, and that they may be equipped with sophisticated, custom-designed emission reduction systems. Such equipment captures part of the mercury emissions, which reduces direct release to the atmosphere. Smaller coal combustion plants are not normally equipped with emission reduction devices that are so sophisticated, and many are not equipped with any emission reduction device at all.
Main mercury releases (air, water, soil, production, use, disposal)	The mining of coal is not identified with particular mercury releases, although coal combustion is. The major pathways for mercury releases from coal use and combustion are via air and in wastes/residues, and to a lesser extent in water (in the case of coal washing, for example) and soil – sometimes many years after waste disposal. For coal combustion plants with no emission reduction equipment, or with retention of larger particles only (ESP retention), all or most of the mercury inputs will be released directly to the atmosphere. This is because, contrary to most other heavy metals, the majority of the mercury in the exhaust gas remains in the gas phase (or adsorbed to small particles, if temperatures are lowered sufficiently during transport through the exhaust gas system).
Mercury reduction options (alternative technologies, other mercury reduction strategies)	 Major air pollution control options for a coal-fired power plant Srivastava *et al.* (2006) © 2006 American Chemical Society Pre-combustion coal wash, used in some countries (which was originally introduced to remove part of the sulphur in the coal), can remove part of the mercury in the coal and requires adequate cleaning/retention systems to retain the washed out mercury. Another common strategy is a special emission reduction system. Post-combustion equipment for flue gas desulphurization, de-NO$_x$ and particle retention, today applied widely in industrialized countries, retain some of the otherwise emitted mercury. The retention varies not only among main filter types, but also among individual

combustion plants with the same filter configurations. Filter configurations designed for optimal mercury retention are still not common, but are in development or advanced testing phases in a few countries (e.g. Sweden and USA).

The combustion technology and coal types also influence the efficiency of the flue gas cleaning systems, and thereby the direct releases. For example, for coal types with high chloride content, and combustion conditions favouring oxidation of mercury in the exhaust gas, mercury is more effectively removed with flue gas desulphurisation systems commonly used in industrialized countries. On the other hand, for units burning bituminous coal, or with high residual carbon in the flue gas, mercury is more effectively removed with particle filters and scrubbers (UNEP, 2002). For more detailed information on different combustion principles in coal combustion plants, see for example (US EPA, 1997a) and (US EPA, 2002a).

For further detail on options especially relevant to smaller combustion facilities, i.e., less than 50 MW thermal, see AEA/NILU (2005).

Assessment of options (feasibility, costs, benefits, advantages, disadvantages)

The US EPA (1997a) reported a mean mercury removal value of 21% for coal pre-wash for plants in the USA.

The following table summarizes results from US EPA's investigation of the mercury retention in different emission reduction systems. It shows the average mercury capture in % of mercury input to each reduction device (US EPA, 2002a).

Post-combustion control strategy	Post-combustion emission control device configuration	Average mercury capture across all installed control devices (no. of tests in parentheses)		
		Coal burned in pulverized-coal-fired boiler unit		
		Bituminous coal	Sub-bituminous coal	Lignite
PM Control Only	CS-ESP	36 % (7)	3 % (5)	- 4 % (1)
	HS-ESP	9 % (4)	6 % (4)	Not tested
	FF	90 % (4)	72 % (2)	Not tested
	PS	Not tested	9 % (1)	Not tested
PM Control and Spray Dryer Adsorber	SDA+ESP	Not tested	35 % (3)	Not tested
	SDA+FF	98 % (3)	24 % (3)	0 % (2)
	SDA+FF+SCR	98 % (1?)	Not tested	Not tested
PM Control and Wet FGD System	PS+FGD	12 % (1)	-8 % (4)	33 % (1)
	CS-ESP+FGD	74 % (1)	29 % (3)	44 % (2)
	HS-ESP+FGD	50 % (1)	29 % (5)	Not tested
	FF+FGD	98 % (2)	Not tested	Not tested

SCR - Selective catalytic reduction

CS-ESP - Cold-side electrostatic precipitator

HS-ESP - Hot-side electrostatic precipitator

FF - Fabric filter

PS - Particle scrubber

SDA - Spray dryer adsorber system

FGD – Flue gas desulphurization.

With regard to the cost of these systems, David Foerter, executive director of the Institute of Clean Air Companies, a trade group representing the makers of pollution control devices, said mercury controls cost far less than those for other pollutants – about $US 1 million to install and about $2 million annually to maintain.

More detailed (current and projected) cost estimates of specific retrofit mercury control systems are summarised in the table below (UNECE, 2002).

Coal Type (sulphur content)	Existing air pollution control device [a]	Retrofit mercury control [b]	Current cost (cents/kWh)	Projected cost (cents/kWh)
Bituminous (3% S)	CS-ESP+FGD	PAC	0.07 - 0.12	0.04 - 0.07
	FF+FGD	PAC	0.03 - 0.05	0.02 - 0.03
	HS-ESP+FGD	PAC+PFF	0.15 – NA [c]	0.09 – NA [c]
Bituminous (0,6% S)	CS-ESP	SC+PAC	0.1 - 0.18	0.06 - 0.1
	FF	SC+PAC	0.04 - 0.08	0.03 - 0.05
	HESP	SC+PAC+PFF	0.18 - 0.38	0.1 - 0.23
Sub-bituminous (0,5% S)	CS-ESP	SC+PAC	0.12 - 0.19	0.07 - 0.11
	FF	SC+PAC	0.04 - 0.11	0.03 - 0.07
	HESP	SC+PAC+PFF	0.14 - 0.27	0.09 - 0.16

a) CS-ESP = cold-side electrostatic precipitator; HS-ESP and HESP = hot-side electrostatic precipitator; FF = fabric filter; FGD = flue gas desulphurization

b) PAC = powdered activated carbon; SC = spray cooling; PFF = polishing fabric filter

c) NA = not available

Actual cases, examples	In actual operating plants, Lehigh University's Energy Research Center (ERC) carried out extensive testing of their system for reducing mercury emissions. Testing at three coal-fired units burning bituminous coals was performed: - Site #1 was a 108 MW, T-fired boiler. Cold-and hot-ESP, and tubular APH. Conventional burners. Unit burns low-sulphur Eastern U.S. bituminous coal. - Site #2 was a 250 MW, T-fired boiler. Rotating APH with two cold ESP’s in series. LNCFS-III low-NOx firing system. Unit burns U.S. bituminous and imported coals. - Site #3 was a 650 MW, opposed wall-fired boiler. Rotating APH with two cold ESP’s in series. DRB-XCL low-NOx burners with OFA. Unit burns U.S. bituminous and imported coals. ERC confirmed a 50-75% reduction of total mercury in the flue gas by optimising mercury residence time in flue gases (in-flight capture), flue gas temperature, and fly ash size and unburned carbon level. These mercury reductions were achieved with minimal to modest impact on thermal performance and fuel cost.
Waste management issues, options	For the general situation in North America and Western Europe, about half of the mercury input is released with air emissions, while the other half is retained in flue gas cleaning residues, and only a minor part is generally retained in bottom ashes/slags. Depending on the flue gas cleaning systems applied, the residues and by-products that may contain mercury include fly ash, solid sulphur reaction product for disposal (from dry or wet scrubbers), gypsum wallboards (sold commercially) and sulphuric acid (also sold commercially).
Implementation and enforcement, costs, barriers	The efficiency of emission reduction systems to retain mercury from the exhaust gases of coal-fired power plants has been investigated in many operating facilities and on many different equipment configurations. Generally operators prefer to rely on equipment installed for other pollutants to also remove mercury from flue gases. The efficiency of mercury removal may vary considerably even among similar units due to the great range of variables associated with coal type and chlorine content, coal particle size, oxygen “trim,” etc., not to mention other installed pollution-control devices. Therefore, a mercury control system must be specially adapted to unit design and operating characteristics, and specific measurements of the control efficiency at various stages of the process are necessary to optimise mercury emissions reduction.
Information sources, references, websites	BREF Large Combustion Plants (2005), *Reference Document on Best Available Techniques for Large Combustion Plants*, European Integrated Pollution Prevention and Control (IPPC) Bureau, IPTS, Sevilla, May 2005. Available at http://eippcb.jrc.es/pages/Fmembers.htm

	US EPA (1997a): Locating and estimating air emissions from sources of mercury and mercury compounds. Report EPA-454/R-97-012, (NTIS PB98- 117054), Office of Air Quality Planning and Standards, Research Triangle Park, NC. Available at: http://www.epa.gov/ttn/chief/le/index.html. US EPA (2002a): Control of Mercury Emissions from Coal-fired Electric Utility Boilers, Interim Report Including errata Data 3-21-02. EPA-600/R-01-109, National Risk Management Research Laboratory, Research Triangle Park, NC, April 2002. Available at http://www.epa.gov/appcdwww/aptb/EPA-600-R-01-109corrected.pdf. AEA/NILU (2005). “Costs and environmental effectiveness of options for reducing mercury emissions to air from small-scale combustion installations,” Final report (Version 2), AEA Technology Environment & NILU-Polska, for the European Commission DG Environment, Harwell, Oxon, UK, December 2005. Available at: http://europa.eu.int/comm/environment/chemicals/mercury/pdf/sci_final_report.pdf Lehigh University's Energy Research Center (ERC), http://www.lehigh.edu/~inenr/research/researchactivities.htm University of North Dakota Energy & Environmental Research Center (EERC), Center for Air Toxic Metals, 2002, Development of mercury control technologies, Available at: http://www.eerc.und.nodak.edu/catm/pdf/SJM_2002.pdf Northeast States for Coordinated Air Use Management (NESCAUM), 2003. Mercury Emissions from Coal-Fired Power Plants: The Case for Regulatory Action, October 2003. Available at: http://bronze.nescaum.org/newsroom/rpt031104mercury.pdf Clean Air Task Force et al., 2004. Comprehensive Comments on Proposed Emission Standards for Hazardous Air Pollutants; and Alternative Proposed Standards of Performance for New and Existing Sources: Electric Utility Steam Generating Units, submitted to U.S. EPA on June 29, 2004. Available at EPA docket (http://docket.epa.gov/edkpub/index.jsp) Docket No. OAR-2002-0056. Srivastava RK, N Hutson, B Martin, F Princiotta (U.S. EPA National Risk Management Research Laboratory), J Staudt (Andover Technology Partners), “Control of Mercury Emissions from Coal-Fired Electric Utility Boilers: An overview of the status of mercury control technologies,” *Environmental Science & Technology 1385,* 1 March 2006. UNECE (2002). “Control of Mercury Emissions from Coal-Fired Electric Utility Boilers.” Note prepared by the Secretariat based on information submitted by the US delegation. p14. Available at http://www.unece.org/env/documents/2002/eb/wg5/eb.air.wg.5.2002.6.e.pdf

3.2 Biomass fired power and heat production

Description	Many countries and regions rely heavily on the combustion of biomass for power and heat production. This includes the use of wood, including twigs, bark, sawdust and wood shavings; peat; and/or agricultural residues (such as straw, bagasse, citrus pellets, coconut shells, poultry litter and animal dung) (UNEP, 2003). Wood and agricultural wastes are used in wood-fired boilers and biomass-fired boilers in industry, which is the main focus of this entry. The combustion of biomass for power generation takes place predominantly in two types of boilers (stokers and fluidized bed boilers), which are distinguished by the way the fuel is fed to the system (UNEP, 2003).
Main mercury releases (air, water, soil, production, use, disposal)	The major pathways for mercury releases are via air and, and to a lesser extent, in water, soil and in wastes/residues. Stokers use a stationary, vibrating or travelling grate on which the biomass is transported through the furnace while combusted. Primary combustion air is injected through the biomass fuel from the bottom of the grate. Such firing systems burn biomass in a highly efficient manner, leaving the majority of the ash as a dry residue at the bottom of the boiler (UNEP, 2003). Fluidized bed boilers use a bed of inert material (*e.g.,* sand and/or ash), which is fluidized by injecting primary combustion air. The biomass is shredded and added to the fluidized bed, where it is combusted. The fluidized ash, which is carried out with the flue gas, is commonly collected in a (multi-) cyclone followed by an electrostatic precipitator (ESP) or baghouse, and re-injected into the boiler. Little or no bottom ash leaves the boiler, since all the larger ash particles either remain within the fluidized bed or are collected by the cyclone separator. Thus, most of the ash is collected as fly ash in the ESP or baghouse (UNEP, 2003). Mercury releases from wood combustion and other biofuels may be significant in some countries (COWI, 2002). Most of the mercury in the biomass is expected released to the air from the combustion process. A smaller amount of mercury may be released to the ashes or residues, the extent of which depends on the specific material burned, type of combustion device, and any emission controls present.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The most important factors determining releases are the mercury levels in the biomass, and the amount of biomass burned. Mercury in biomass originates from both naturally present mercury, and mercury deposited from anthropogenic emissions (COWI, 2002). For example, trees (especially needles and leaves) absorb mercury from the atmosphere over time. This mercury is readily released (mostly to air) when the wood and other biomass are burned (Friedli, H.R. *et al*., 2001). Currently, the four most common control devices used in the USA to reduce PM emissions from wood-fired boilers are mechanical collectors, fabric filters, wet scrubbers, and electrostatic precipitators (ESP's). Of these controls, the last three have the potential for significant capture of mercury (US EPA, 1997a, US EPA, 2002a and US EPA, 1996).
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	The most widely used wet scrubbers for wood-fired boilers in the USA are venturi scrubbers. No data is available on the control efficiency of these devices for mercury emissions on wood boilers. However, some control is expected. Fabric filters (FFs) and ESP's are also employed on some wood boilers. No data is available for the control efficiencies of these devices on wood fired boilers. However, based on data from coal combustion plants, reduction of mercury emissions by FFs may be 50% or more, and efficiencies for ESP's are likely to be somewhat lower, probably 50% or less (US EPA, 1997a and US EPA, 2002a).
Actual cases, examples	The data on mercury releases from biomass combustion are limited. A report by the National Council of the Paper Industry for Air and Stream Improvement (NCASI) in the USA provided a range of emissions for boilers with and without ESP's (NCASI, 1995, as cited in US EPA, 1997a). The average mercury emission reported for boilers with ESP's was 1.3×10^{-6} kg/metric ton of dry wood burned. The boilers without ESP's had a variety of other control devices including cyclones, multiclones,

	and various wet scrubbers. The average mercury emission reported for boilers without ESP's was 3.5 x 10^{-6} kg/metric ton of dry wood burned. For combustion of wood scraps in boilers without emission controls, the US EPA established an average emission factor for mercury emissions (based on four emission tests) of 2.6 x 10^{-6} kg/metric ton of wood burned (U.S EPA 1997a).
Waste management issues, options	No special issues other than those noted above.
Implementation and enforcement, costs, barriers	Since there is no available information on control devices specifically installed and operated for the purpose of reducing mercury emissions, no further discussion is possible here.
Information sources, references, websites	UNEP (2003): Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases, 1st edition, May 2003, UNEP Chemicals, Geneva, Switzerland. COWI (2002): ACAP and Danish EPA Reduction of Atmospheric mercury emissions from Arctic countries – questionnaire on emissions and elated topics. November 2002. Friedli, H.R., Radke, L.F. and Lu, J.Y. (2001): Mercury in Smoke from Biomass Fires. Geophysical Research Letter, 28: 3223-3226. Available at: http://www.mindfully.org/Air/Mercury-Smoke-Biomass.htm. US EPA (1997a): Locating and estimating air emissions from sources of mercury and mercury compounds. Report EPA-454/R-97-012, (NTIS PB98- 117054), Office of Air Quality Planning and Standards, Research Triangle Park, NC. Available at: http://www.epa.gov/ttn/chief/le/index.html. US EPA (2002a): Control of Mercury Emissions from Coal-fired Electric Utility Boilers, Interim Report Including errata Data 3-21-02. EPA-600/R-01-109, National Risk Management Research Laboratory, Research Triangle Park, NC, April 2002. Available at http://www.epa.gov/appcdwww/aptb/EPA-600-R-01-109corrected.pdf. US EPA (1996): Emission Factor Documentation for AP-42, Section 1.6, Wood Waste Combustion in Boilers, Research Triangle Park, NC. NCASI (1995): Compilation of Air Toxic and Total Hydrocarbon Emissions Data for Sources at Chemical Wood Pulp Mills. National Council of the Paper Industry for Air and Stream Improvement, Inc. *NCASI Technical Bulletin* No. 701. October 1995.

3.3 Extraction, refining and use of mineral oil

Description	Extraction, refining, and use of mineral oil (also called “petroleum oil” or “oil”) includes the combustion of oil to provide power, heat, and transportation, and other uses such as for example road asphalt (bitumen), synthesis of chemicals, polymer production, lubricants and carbon black production (black pigments). Like other natural materials, mineral oil contains small amounts of natural mercury impurities, which are mobilised to the biosphere by extraction and use. Mercury concentrations in oil may vary extensively depending on the local geology. Pirrone *et al.* (2001) reported a general average concentration of 10 ppb in crude oil, but with some values as high as 30,000 ppb.
Main mercury releases (air, water, soil, production, use, disposal)	Oil extraction is known to potentially cause significant releases of mercury and focus has increased on mercury releases from this sector in recent years. Mercury may be released to air, land or water during refining as well as through refinery products or by-products and various process wastes and sludges. Combustion of oil releases mercury primarily to air in the form of air emissions. However, a very small percent of the mercury may be released to other media, such as incineration residues. Generally, only large combustion units designed for oil use have emission reduction equipment.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The most important factors determining releases from oil combustion sources are the mercury levels in the oil and amount of fuel burned. Based on a comparison of the mercury content of crude oil to some refined oil products, it appears that mercury emissions from petroleum refineries may be significant. However, there are as yet no measures in place to address these emissions. With regard to oil combustion, the only measures currently taken that may affect mercury emissions are fuel substitution and flue gas cleaning systems. The primary aim of fuel substitution is to reduce sulphur dioxide (SO_2) and nitrogen oxide (NO_x) emissions, but this may also imply the use of a fuel with lower mercury content. Larger oil-fired boilers in some countries may clean flue gases with mechanical collectors, electrostatic precipitators (ESP’s), or scrubbing systems. It is believed such systems contribute some modest control of mercury emissions, but insufficient data are available on the percent of mercury removed.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	Due to the lack of widespread emissions control of oil-fired combustion units, and the lack of data on any mercury control, it is reasonable to assume that nearly 100% of the mercury in the fuel will be released to air through the combustion stacks.
Actual cases, examples	There are no examples of oil-fired combustion units in which controls have been installed especially to address mercury emissions.
Waste management issues, options	As mentioned, mercury may be released through various process wastes and sludges. At present, there are no known efforts to treat such wastes specially because of any mercury content.
Implementation and enforcement, costs, barriers	Not applicable.
Information sources, references,	BREF Oil & Gas (2003), *Reference Document on Best Available Techniques for Mineral Oil and Gas Refineries*, European Integrated Pollution Prevention and Control (IPPC) Bureau, IPTS, Sevilla, February

websites	2003. Available at http://eippcb.jrc.es/pages/Fmembers.htm Pirrone, N., Munthe, J., Barregård, L., Ehrlich, H.C., Petersen, G., Fernandez, R., Hansen, J.C., Grandjean, P., Horvat, M., Steinnes, E., Ahrens, R., Pacyna, J.M., Borowiak, A., Boffetta, P. and Wichmann-Fiebig, M. (2001): EU Ambient Air Pollution by Mercury (Hg) - Position Paper. Office for Official Publications of the European Communities, 2001. Available on http://europa.eu.int/comm/environment/air/background.htm#mercury). NESCAUM (1998): The Northeast States and Eastern Canadian Provinces Mercury Study, February 1998. Available on internet at: http://www.cciw.ca/ca/eman-temp/reports/publications/mercury/

3.4 Extraction, refining and use of natural gas

Description	Natural gas is a fossil fuel extracted, refined and used for various purposes, especially combustion to produce electricity and heat, but also transportation, synthesis of chemicals and polymers, production of carbon black, etc. Like many other natural materials, natural gas contains small amounts of natural mercury impurities, which are mobilized to the biosphere during extraction, refining and combustion. In some regions of the world, depending on geology, such as the North Sea, Algeria, Croatia, etc., natural gas is known to have significant mercury concentrations which may cause serious equipment problems during processing if it is not removed.
Main mercury releases (air, water, soil, production, use, disposal)	Mercury releases may occur during extraction, refining, gas cleaning and use (COWI, 2002 and US EPA, 1997b). The major pathways for mercury releases are via air, water, soil and in wastes/residues, and to a lesser extent in products that may be fabricated using mercury recovered during gas cleaning or other mercury reduction measures. For off-shore gas extraction, initial gas cleaning steps may take place off-shore, and may involve the use of cleaning water, which may be discharged on site.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	Most of the mercury in the raw natural gas may be removed during the extraction and/or refining process, including during the removal of hydrogen sulphide. Pirrone *et al*. (2001) reported that “a reduction of mercury to below 10 $\mu g/m^3$ has to be obtained before the gas can be used” (Pirrone *et al.*, 2001). Therefore, natural gas is generally considered a clean burning fuel that usually has very low mercury concentrations at the point of combustion. Also, little or no ash is produced during the combustion process (US EPA, 1997b). Since the entire fuel supply is exposed to high flame temperatures, essentially all of the mercury remaining in the natural gas will be volatilized and exit the furnace with the combustion gases through the emissions stack. Gas-fired plants usually have no emissions control devices that would reduce mercury emissions (US EPA, 1997a).
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	The major part of the mercury content of the raw natural gas may generally be separated from the gas into the different gas cleaning wastewaters or condensates. The term “gas condensate” refers to liquids that can originate at several locations in a gas processing scheme (Wilhelm, 2001). According to BREF Oil & Gas (2003), mercury is removed from the gas in a 'cold trap' (e.g. by gas expansion) and recovered as a mercury containing sludge. A mercury recycling company later processes this sludge by treatment in a vacuum distillation unit.
Actual cases, examples	It may be assumed that all significant producers of natural gas already take the necessary measures to remove mercury from natural gas supplies. Otherwise they would experience significant and sometimes dangerous equipment problems.
Waste management issues, options	In some countries, mercury in gas cleaning residues ("condensate" and possibly other media) is recovered and marketed as a by-product. In other countries, these residues are collected and treated as hazardous waste.
Implementation and enforcement, costs, barriers	Not applicable.
Information sources, references, websites	BREF Oil & Gas (2003), *Reference Document on Best Available Techniques for Mineral Oil and Gas Refineries*, European Integrated Pollution Prevention and Control (IPPC) Bureau, IPTS, Sevilla, February 2003. Available at http://eippcb.jrc.es/pages/Fmembers.htm COWI (2002): ACAP and Danish EPA Reduction of Atmospheric mercury emissions from Arctic countries – questionnaire on emissions and elated topics. November 2002. US EPA (1997a): Locating and estimating air emissions from sources of mercury and mercury compounds. Report EPA-454/R-97-012, (NTIS PB98- 117054), Office of Air Quality Planning and Standards, Research Triangle Park, NC. Available at:

	http://www.epa.gov/ttn/chief/le/index.html. US EPA (1997b): Mercury Study Report to Congress. US EPA, Dec. 1997. Available at: http://www.epa.gov/mercury/report.htm. Pirrone, N., Munthe, J., Barregård, L., Ehrlich, H.C., Petersen, G., Fernandez, R., Hansen, J.C., Grandjean, P., Horvat, M., Steinnes, E., Ahrens, R., Pacyna, J.M., Borowiak, A., Boffetta, P. and Wichmann-Fiebig, M. (2001): EU Ambient Air Pollution by Mercury (Hg) - Position Paper. Office for Official Publications of the European Communities, 2001. Available on http://europa.eu.int/comm/environment/air/background.htm#mercury). Wilhelm, S.M. (2001): Mercury in petroleum and natural gas: Estimation of emissions from production, processing, and combustion. US Environmental Protection Agency, Office of Research and Development, Washington. Available at: http://www.epa.gov/ORD/NRMRL/pubs/600r01066/600r01066.pdf.

4.0 Primary (virgin) Metal Production

4.1 Primary extraction and processing of mercury

Description	Primary extraction and processing of mercury, i.e. dedicated primary mercury mining on an industrial scale, continues in 2005 in China, the Kyrgyz Republic, and Algeria, with informal mercury mining operations in Mexico, China, and a number of other countries. Mercury mining is known to have caused extensive mercury releases to terrestrial, atmospheric and aquatic environments, with both local and regional/global pollution as a consequence. Even those countries that have terminated their mercury mining activities – including the US, Spain, Slovenia, Ukraine, Italy, etc. – continue a range of efforts to manage the residual pollution many years after the mining activities have ceased.
Main mercury releases (air, water, soil, production, use, disposal)	Mercury is extracted, typically from cinnabar ore, by the use of pyrometallurgical processes. For a description of processes involved, see European Commission (2001). The major pathways for mercury releases include air, water, soil, wastes/residues, and eventually products made from mercury. Most mercury mines have operated since long before any controls were considered necessary. The Almadén mine in Spain had operated almost continuously since Roman times until its closure in 2003. Not surprisingly, mercury releases have typically been enormous. At the Idrija mines in Slovenia, which were closed in 1995, it has been calculated that during the period 1961-1995, 9777 metric tons of mercury were extracted from 4.2 million metric tons of ore. During the same period, an estimated 243 metric tons of mercury were lost to the environment, of which 168 metric tons were deposited in landfills as smelting residue, 60 tons were emitted to the atmosphere with flue gases, and 15 tons were released to the Idrijca river with condensation water (Kotnik *et al.*, 2004). As mentioned above, even after these mines have closed, the tailings, residues and other deposits from mercury mining may be a significant ongoing source of mercury emissions to the air, water and soil.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	Mercury may be lost during various steps in the mining and refining process. Furthermore, because most mercury mining facilities are quite old, the level of emissions is only as good as the attention and resources devoted to reducing them. A highly efficient and well-operated condenser will clearly lead to decreased mercury emissions to all three main media – landfills, the atmosphere and the water. Next flue gas and wastewater controls are able to remove nearly all mercury from these waste streams. Finally, reprocessing and recovery of all possible sludges and wastes will further decrease total mercury emissions to the environment.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	As in the example of Idrija above, some 2.5% of the available mercury was lost to the environment during processing between 1961 and 1995. Mercury condenser losses at the last primary mercury mine in operation in the USA were less than 1% (Jasinski, 1994). Before it was closed, it was estimated that losses at Almadén were approximately 0.5-1.0% (Ferrara et al., 1998). Apart from whatever environmental regulations are in force, the various

	waste treatment and recovery options are strongly influenced by world mercury prices. The global mercury market is known for gradually decreasing demand. However, due to tight supplies starting in 2004, mercury prices have increased from $100-200/flask (34.5 kg) to $700-800/flask at the end of 2005. At this level, it is economically attractive to recover mercury from a variety of wastes and sludges that might have been send to disposal in the past. Two key factors may be expected to influence prices in the near future. First, significant amounts of mercury will emerge from the chlor-alkali industry as facilities convert to a mercury-free process, depressing prices. Second, the EU mercury export ban is scheduled to take effect in 2010 or 2011, once again tightening supplies and probably sending the mercury price up again.
Actual cases, examples	At Almadén, over the years, associated with the gradual phase-out of mining operations, funds have been allocated and strategies developed for identifying alternative areas of business and employment, promoting pilot projects, restoring some degraded sites, promoting public awareness, developing contaminated site inventories, developing waste management regimes, supporting regional information exchange, etc.
Waste management issues, options	The heavily contaminated former mercury mining sites serve as continuous sources of mercury to the atmosphere, due to evaporation/volatilization, and runoff to surface waters (rivers and lakes) as well as coastal areas. At the Idrija mercury mine in Slovenia, an estimated 40 000 t of mercury have accumulated in waste (Miklavcic, 1998). In another case in the Philippines in the 1960s, more than one million tonnes of mercury mine tailings and roasting plant wastes were used for the construction of a breakwater, which continues to leach mercury into the sea (Williams et al, 1999). In other cases of industrial pollution, some countries have made a comprehensive inventory of such areas (such as Superfund in the US), in which the emissions and other key characteristics are assessed so that the sites may be classified and prioritised for attention. Especially with regard to rehabilitating former mining sites, in some cases the benefits have been justified in economic and social terms, as well as environmental qualities and health. Only such a “self-sustaining” approach will guarantee economic vitality of the measures/policy through longer term perspectives. A tool which can support such an approach is a type of strategic environmental assessment (SEA), in which environmental impacts are considered inseparably with economic and social considerations.
Implementation and enforcement, costs, barriers	These are site specific and political issues for the Chinese, Kyrgyz Republic, and Algerian governments that still operate mercury mines.
Information sources, references, websites	BREF Non-Ferrous Metals (2001), *Reference Document on Best Available Techniques in the Non Ferrous Metals Industries*, European Integrated Pollution Prevention and Control (IPPC) Bureau, IPTS, Sevilla, December 2001. Available at http://eippcb.jrc.es/pages/Fmembers.htm Jasinski SM. *The materials flow of mercury in the United States*. US Bureau of Mines Information Circular 9412, Version 1.0, 1994, http://greenwood.cr.usgs.gov/pub/min-info-pubs/usbm-ic/ic-9412/mercury.pdf Ferrara R, Maserti BE, Andersson M, Edner H, Ragnarson P, Svanberg S, Hernandez A. Atmospheric mercury concentrations and fluxes in the Almadén district (Spain).Atmos Environ 1998;32:3897 –3904. Miklavcic, V. Mercury in the Idrija region, in *Idrija as a natural and anthropogenic laboratory: Mercury as a major pollutant*, Proceedings of

	the meeting of researchers, May 24–25, 1996, Miklavcic, V., ed., Mercury Mine, Idrija, Slovenia, 6-9, 1998. Williams, T.M., Weeks, J.M., Apostol, Jr., A.N., and Miranda, C.R. Assessment of mercury contamination and human exposure associated with coastal disposal of waste from a cinnabar mining operation, Palawan, Philippines, *Environmental Geology* 39, 51, 1999.

4.2 Gold and silver extraction with the mercury-amalgamation process

Description	Please note that this entry discusses the (generally artisanal or small-scale) extraction of gold and silver using a mercury amalgamation process, as opposed to other gold and silver extraction processes. Since Roman times mercury has been used in artisanal and small-scale mining (ASM) operations to recover gold and silver from ores. Generally, this mining process involves the following: the wet ore (or mud or ore concentrate) is mixed with metallic (liquid) mercury; the mercury amalgamates (dissolves) with the gold or silver in the wet ore; the remaining ore is washed away, leaving a mercury-gold (or mercury-silver) amalgam; and the amalgam is then heated to evaporate the mercury, leaving behind a gold and/or silver *doré* or “sponge,” which still contains some mercury as well. With the invention in Spanish colonial America of the "patio" process where mercury-wetted copper plates are used instead of liquid mercury, silver and gold were produced on an even larger scale in America as well as in Australia, Southeast Asia and even in England. The amount of mercury released per unit of gold (or silver) extracted varies according to the methods and equipment used, and various other factors. For example (UNIDO, 2003) has made the following estimates: - If mercury is used to extract gold from the whole ore, and no recovery devices are utilized, the ratio of mercury released to gold extracted is likely greater than 3-to-1 (i.e., more than 3 kg of mercury released per 1 kg of gold obtained). - If mercury is used on ore concentrates (instead of whole ores), the ratio may be close to 1-to-1. - If ore concentrates are used in a retorting system for mercury recovery, the amount of mercury released may be as low as 0.001-to-1, although it may be significantly higher than this as well, depending on the type of retort, and how it is used. Lacerda (1997) reviewed literature on mercury consumed per kg of gold produced with the amalgamation process, and reported that while estimates varied widely, the average appeared to be 1-2 kg of mercury consumed per 1 kg of gold produced
Main mercury releases (air, water, soil, production, use, disposal)	Mercury is released directly from ASM activities to the air, water, sediments and soils. The mercury-gold amalgam from the extraction process releases mercury as vapour to the air when heated in one of the steps in the purification. The evaporation is often done with no retention of the evaporated mercury. Sometimes the evaporation step is done in semi-closed "retorts", in which parts of the evaporated mercury are condensed and re-used. This gold extraction process is simple and cheap, but not very efficient in terms of gold recovery, and even less so with regard to mercury retention. Mercury is also present in mine tailings, which can lead to future releases to land, water and air. Mercury is found at extraction sites, trading posts, and in soil, plants, sediments and waterways in the area of ASM operations. The amalgamation process has led to intense mercury pollution of the terrestrial, aquatic and atmospheric environment in large areas around these operations, and has also contributed significantly to the levels of mercury in the global environment (COWI, 2002).
Mercury reduction options (alternative technologies, other	Mercury emissions depend fundamentally on the mining and processing methods used by artisanal and small-scale mining (ASM). As noted above, the use of mercury on concentrates rather than the whole ore, or

mercury reduction strategies)	eventually combined with a retorting system, can greatly reduce mercury losses. Due to the economic and social circumstances of most ASM workers, alternative low-mercury or mercury-free techniques must be inexpensive, relatively simple and easy to adapt, while allowing a rapid rate of return. In fact, there are numerous alternatives available, but the educational, cultural and other barriers to implementation must not be underestimated. However, due to the scale of the mercury pollution from ASM activities, a range of efforts are underway to introduce such alternatives. Among others, UNIDO is presently carrying out an extensive programme that seeks to greatly reduce ASM use of mercury, initially in six key countries (ref. UNIDO Global Mercury Project). Likewise, encouraged by the ban on the use of mercury from January 2006 in French Guiana, WWF has prepared an excellent brochure on mercury-free alternatives (WWF, 2005). As key alternatives, WWF lists gravity concentration, sluice boxes, the Cleangold sluice, the Gemini table, centrifuges, and processing with chlorine.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	Despite a range of promising results during on-site testing, it must be noted that most of the above technologies are 1) relatively expensive, and/or 2) not locally produced or available to ASM workers. The lack of availability in the mining communities has been one of the recent conclusions of the UNIDO Global Mercury Project. Such challenges make it all the more important to develop local capacities. Meanwhile, alternative approaches are receiving increasing attention, especially as mercury prices increased several-fold during 2005.
Actual cases, examples	Recently, UNIDO demonstrated very cost-effective mercury-reduction techniques using basic kitchen bowls and pipes that allow miners to contain mercury emissions and recycle as much of 95% of the mercury from the vaporization process (Spiegel and Veiga 2005). Still, such a system requires that that the retort be properly operated in order to optimally reduce emissions and limit human exposure. Some miners have been seen to open retorts while they are still hot, effectively releasing much of the mercury vapour that could have been recovered. Elsewhere it has been written that retorts introduced at some mining sites to reduce mercury emissions have not reduced the emissions of mercury to an acceptable level (Oliveira et al, 2004). See UNIDO Global Mercury Project website (below).
Waste management issues, options	At abandoned ASM sites, the cleanup and/or even containment challenges may be quite difficult. There are no known cases of extensive cleanup efforts specifically focused on an ASM site.
Implementation and enforcement, costs, barriers	In numerous low-income countries around the world, a combination of high gold prices and persistent poverty is contributing to a proliferation of small-scale gold mining that uses mercury amalgamation to concentrate gold (ILO 1999; Hilson 2005) About 10 to 15 million miners in over 50 developing countries currently depend on this activity for their livelihood (Veiga and Baker 2004). In some countries the use of mercury in ASM activities has been banned. Tradition and mentality as precursors for the continued use of the amalgamation method can be overcome by economic incentives, e.g. an increased mercury price, by legislation with enforcement, and by training and technical support. Technical support could be mining engineers, specialized in topics relevant for small-scale gold mining, being paid jointly by public authorities and the miners, eventually via mining cooperatives. Strategies to eliminate the negative environmental and health impacts of mercury include both community capacity-building to target

	emissions, exposures and the economics of mercury use in gold production and regulations to limit mercury accessibility. mercury accessibility is easiest limited by reduced mercury exports from producer countries and the European Union agreed ban on the export of mercury is a relevant policy, which should be joined by other mercury exporting countries.
Information sources, references, websites	UNIDO Global Mercury Project at http://www.globalmercury.org UNIDO (2003): Marcello M. Veiga and Randy Baker. Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-scale Miners. April 2003. WWF, 2005. “Mercury-Free Gold mining Technologies: Possibilities for Adoption in the Guianas,” prepared by R Vieira, WWF Guianas Regional Program Office Technical Paper series #1. www.wwfguianas.org Spiegel SJ, and Veiga MM (2005) Building Capacity in Small-Scale Mining Communities: Health, Ecosystem Sustainability, and the Global Mercury Project. *EcoHealth*, 2, Issue 4 (forthcoming). Published online October 19, 2005. DOI: 10.1007/s10393-005-8389-9 International Labour Organization (ILO) (1999) *Social and Labour Issues in Small-scale Mines*. Report for discussion at the Tripartite Meeting on Social and Labour Issues in Small-scale Mines, ILO, Geneva Hilson G (2005) Abatement of mercury pollution in the small-scale gold mining industry: restructuring the policy and research agendas. *Science of the Total Environment* (in press) Veiga MM, Baker R (2004) *Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small Scale Miners*, Report to the Global Mercury Project: removal of barriers to introduction of cleaner artisanal gold mining and extraction technologies, GEF/UNDP/UNIDO, 170 p. http://www.globalmercury.org Veiga MM, Maxson P, and Hylander LD (2006). Origin of mercury in artisanal and small-scale gold mining. *J. of Cleaner Production. 14*: 436-447. Oliveira L, Hylander LD and Silva EC. Mercury behavior in a tropical environment—the case of small scale gold mining in Poconé, Brazil, *Environmental Practice* 6, 13, 2004.

4.3 Extraction and initial processing of other non-ferrous metals, including zinc, copper, lead, gold (other than amalgamation with mercury), and aluminium

Description	This entry describes the extraction and processing of non-ferrous metal ores where mercury impurities are present in the ores or other feedstock materials. In the process of extracting the metal from the ore, processes are used which release this mercury from the rock material. This mercury may evaporate and follow the gaseous streams in the extraction processes (in most cases) or follow wet (liquid) process streams, depending on the extraction technology used. Unless the mercury is captured by process steps dedicated to this purpose, much of it may be released to the atmosphere, land and aquatic environments. Captured mercury may be sold in the form of "calomel" (Hg_2Cl_2), or it may be stored or disposed as solid or sludge residues (Environment Canada, 2002). In general, as primary (mined) mercury production decreases worldwide, the demand for mercury is increasingly met by mercury obtained as a by-product during the production of other metals such as zinc, lead, copper, gold, etc. This is especially the case when these metals are extracted from sulphide ores, where mercury is often found as a trace element due to its affinity for sulphur (Hylander 2005).
Main mercury releases (air, water, soil, production, use, disposal)	The major pathways for mercury releases during extraction and initial processing for all of these non-ferrous metals (except aluminium) include air, water, soil, wastes/residues, and eventually certain products. For example, part of the mercury input (presumably a minor fraction) follows co-produced sulphuric acid at trace concentrations (European Commission, 2001). Sintering and roasting take place at high temperatures (roasting at up to 1000 °C; Rentz *et al.*, 1996), and most of the mercury present in the concentrate is expected to be evaporated in this oxidation step. If the production plant is equipped with a sulphuric acid production plant (which may often be the case), most of the mercury initially follows the gas stream to the acid plant. Schwarz (1997) estimated that global zinc production mobilises several hundred metric tons of mercury per year - a conservative estimate for 1995 was 600 metric tons - ranking zinc production among the largest sources of by-product mercury, as well as potential releases. Emissions to the atmosphere from non-ferrous metal production, however, may be reduced significantly, and has been in some countries during the last decades (Environment Canada, 2002; UNEP, 2002). In the case of aluminium, the major pathway for mercury releases is via air, and to a lesser extent to soil and in wastes/residues. The Australian emissions guide for alumina production (NPI, 1999a) suggests that the fuels used for heat production for the process are major sources of mercury. Likewise, NPI (2004) gives general mercury concentration data for bauxite (<0,03 g/metric ton) and "red mud" (<0,05 g/metric ton), the solid residue formed from alumina production.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	Dust generating processes, including breaking of sinters and roasted material, may be equipped with fabric filters or other filters (Rentz *et al.*, 1996) retaining (part of) the dust, which may possibly contain a minor portion of the mercury inputs. Recovering mercury from the acidic flue gases during ore roasting (or “sintering”) requires a separate removal stage in addition to the stage for removing other impurities. Such installations have been applied in some countries in response to environmental regulations. When mercury is removed from a gas phase of the refining process, the gas is passed through a sequence of particle filters, typically cyclones

<table>
<tr>
<td></td>
<td>(retaining larger particles), hot electrostatic precipitators (ESP’s) for removing fine particles, and wet ESP's. Moisture and particles may also be controlled by the use of scrubbers. Cyclones and hot ESP’s generate dry solid wastes, which may contain mercury, and wet ESP's and scrubbers generate sludges, which may likely contain more mercury than the initial residues due to lowered temperatures and content of fine particles.
Mercury may also be recovered from the cyanide leaching of gold bearing ores, which results in about 100 t by-product mercury annually in Peru. Chile exported 75 t mercury to the USA in 2002, much of it presumed to be by-product of copper and other mineral production. Australia exported 107 t mercury to the USA in 2002, but has no mercury mine. Other countries are believed to recover mercury from copper electro-refining processes, but few details are available (Hylander 2005).</td>
</tr>
<tr>
<td>Assessment of options (feasibility, costs, benefits, advantages, disadvantages)</td>
<td>There are so many competing mercury reduction options for these various non-ferrous metal ores, each deposit of which may have significantly different characteristics, that it is virtually impossible to generalise about feasibility, costs, etc. It is suggested that the reader refer to (European Commission, 2001) for a much fuller treatment of such issues. To take only a small example, UNEP (2002) cited Pirrone *et al.* (2001) for the efficiencies shown in the table below of selected mercury removal techniques, of which several are employed in the non-ferrous metal smelters.
Efficiency of flue gas mercury removal techniques (Pirrone et al., 2001)
<table>
<tr><th>Control technique</th><th>Typical mercury removal efficiency</th><th>Measured Hg content downstream (µg/m^3)</th></tr>
<tr><td>Selenium filter</td><td>> 90%</td><td>< 10</td></tr>
<tr><td>Selenium scrubber</td><td>90-95%</td><td>200</td></tr>
<tr><td>Carbon filter</td><td>90-95%</td><td>10</td></tr>
<tr><td>Odda chloride process</td><td>n.a.</td><td>50-100</td></tr>
<tr><td>Lead sulphide process</td><td>90-99%</td><td>10-50</td></tr>
</table>
In general , the main factors determining releases and feasibility of mercury reduction options from non-ferrous metal mining and extraction are the following:
The concentration of mercury in the ore/concentrate, and the amount of ore/concentrates used are important factors determining mercury releases. As indicated below, the first aspect can - in principle - be controlled to some degree through the choice of types of ore and concentrates applied.
The presence of a dedicated mercury removal step will influence the distribution between output pathways considerably. Releases to the atmosphere will be converted to by-product outputs and releases to land, waste deposition and water. In case sulphuric acid is produced, releases to sulphuric acid (a marketed by-product) will also be converted to the same output pathways, if a mercury removal step is present. The presence of a mercury removal step is likely partly driven by the technical need to purify the gases prior to the conversion of sulphur dioxide gases to sulphuric acid, so if an acid plant is present, a mercury removal step may be present too.
Since part of the mercury input may be retained with particles in exhaust gas particle filters, the presence of high efficiency ESP's and fabric filters may also reduce atmospheric mercury releases somewhat - if filter dust is not recycled back into the process - and convert the retained mercury to</td>
</tr>
</table>

<table>
<tr>
<td></td>
<td>solid, suspended and/or liquid residues.

Wastewater from different process steps can contain mercury. The extent of releases of mercury with the discharge water to aquatic environments depends on how well the wastes are treated and managed.

The extent of releases to the environment from waste material deposition, including waste rock, tailings from concentration steps, extraction process residues, exhaust gas cleaning residues and wastewater treatment residues, is very dependent on how carefully the waste deposits are managed. Poorly managed deposits may result in releases to air, water and land.</td>
</tr>
<tr>
<td>Actual cases, examples</td>
<td><i>Example of mercury distribution in outputs from production of concentrates, from Uchalinsky zinc works, Russian Federation (Kutliakhmetov, 2002)</i>
<table>
<tr><th>Ore, concentrate, waste</th><th>Average, grams Hg/metric ton</th><th>Relative quantity of mercury in %</th></tr>
<tr><td>Ore</td><td>10-25</td><td>100</td></tr>
<tr><td>Pyrite concentrate</td><td>5-15</td><td>36-50</td></tr>
<tr><td>Copper concentrate</td><td>28-41</td><td>10-14</td></tr>
<tr><td>Zinc concentrate</td><td>76-123</td><td>35-48</td></tr>
<tr><td>Reject materials</td><td>1-9</td><td>2-3</td></tr>
</table></td>
</tr>
<tr>
<td>Waste management issues, options</td>
<td>Processing of mercury wastes, which may otherwise go directly to disposal, has been driven primarily by market conditions, i.e., when the mercury removed may be sold for more than the cost of removal. Production of by-product mercury from zinc ores in Finland has long been standard practice. Massive sulphide deposits in the Urals (former Soviet Union) and India also contain mercury that is, however, probably released to the atmosphere rather than recovered during the smelting process (Hylander 2005).

Even after extraction and processing operations have finished, the tailings, residues and other wastes may be a significant ongoing source of mercury emissions to the air, water and soil. This material is much more susceptible to weathering than the original deposits, due to the reduced particle sizes and higher accessibility for air and precipitation. See also the above discussion.</td>
</tr>
<tr>
<td>Implementation and enforcement, costs, barriers</td>
<td>It should be pointed out that in most countries the recovery of mercury from non-ferrous metal ore processing is driven primarily by environmental regulations and the possibility of marketing the recovered by-product mercury.</td>
</tr>
<tr>
<td>Information sources, references, websites</td>
<td>European Commission (2001): Integrated pollution prevention and control (IPPC) - Reference document on best available techniques in the non ferrous metals industry. Available at: http://eippcb.jrc.es/pages/Fmembers.htm.

Hylander, L. D. and Meili, M. (2005): The rise and fall of mercury: converting a resource to refuse after 500 years of mining and pollution. <i>Crit. Rev. Environ. Sci. Technol. 34</i>:1-36.

Environment Canada (2002): Environment Canada, Minerals and Metals Division, National Office of Pollution Prevention: Multi-pollutant emission reduction analysis foundation (MERAF) for the base metal smelter sector. Prepared for Environment Canada and The Canadian Council of Ministers of Environment (CCME), Canada. Available at http://www.ccme.ca/assets/pdf/bms_final_meraf_e.pdf (accessed October 2003).

Rentz, O., Sasse, H., Karl, U., Schleff, H.J. and Dorn, R. (1996): Emission control at stationary sources in the Federal Republic of Germany - Volume II, Heavy metal emission control. French-German Institute for Environmental Research (DFIU), University of Karlsruhe, 1996 (see</td>
</tr>
</table>

	German submissions to the UNEP Global Mercury Assessment. Pirrone, N., Munthe, J., Barregård, L., Ehrlich, H.C., Petersen, G., Fernandez, R., Hansen, J.C., Grandjean, P., Horvat, M., Steinnes, E., Ahrens, R., Pacyna, J.M., Borowiak, A., Boffetta, P. and Wichmann-Fiebig, M. (2001): EU Ambient Air Pollution by Mercury (Hg) - Position Paper. Office for Official Publications of the European Communities, 2001. See http://europa.eu.int/comm/environment/air/background.htm#mercury). Kutliakhmetov, A.N. (2002): Mercury contamination of landscapes by mining enterprises of Bashkirian East-of-Ural Region (in Russian). Autoref. thesis of Cand. Geogr. Sc. - Yekaterinburg. NPI (1999a): Emission Estimation Technique Manual for Alumina Refining, Environment Australia, 1999. NPI (2004): National Pollution Inventory (NPI), data extracted from the NPI database.

4.4 Primary ferrous metal production

Description	The iron and steel industry is highly material- and energy-intensive. Considerable amounts of the mass input become outputs in the form of off-gases, wastes and residues. This industry's primarily activities include smelting iron ore to produce pig iron in molten or solid form; converting pig iron into steel by the removal, through combustion in furnaces, of the carbon in the iron. Various processors may cast ingots only, or also produce iron and steel basic shapes, such as plates, sheets, strips, rods and bars, and other fabricated products. Sinter plants are associated with iron production, often in integrated iron and steel works. The sintering process is a pre-treatment step in the production of iron, where fine particles of metal ores are agglomerated by combustion. The agglomerated product (sinter) is then used to fuel the blast furnace. Sinter, as a product of an agglomeration process of iron-containing materials, represents a major part of the environmental burden of blast furnaces.
Main mercury releases (air, water, soil, production, use, disposal)	Mercury may be emitted from various locations in an integrated iron and steel facility, including the sinter plant, the blast furnace that produce iron, the basic oxygen process (BOP) furnaces that produce steel, etc. The major pathway for mercury releases is via air, and to a lesser extent in wastes/residues. The most relevant environmental issues with regard to the sinter plant are the off-gas emissions from the sinter strand, which contains a wide range of pollutants such as dust, heavy metals, SO_2, HCl, HF, PAHs and organochlorine compounds. An assessment of all raw materials for pig iron production in the Russian Federation (Lassen *et al*., 2004) revealed that 20% of the mercury originated from limestone (with an average content of 0.05 mg Hg/kg), 75% from the concentrate (average content of 0.06 mg Hg/kg) and the remaining 5% from other raw materials. The resulting emission was estimated at 0.04 g per metric ton pig iron produced, assuming that 99% of the mercury was released to the air. According to Berndt (2003), the mercury that is emitted to the air from the sintering process is predominantly in elemental form. A study conducted at one of the plants in Minnesota indicated that an average of 93.3% of mercury emissions were in Hg(0) form, with almost all of the remainder emitted as oxidized mercury Hg(II) (HTC, 2000). The content of mercury (which may vary considerably) in the iron ore/concentrates, and the amount of ore/concentrates used, are important factors determining mercury releases. During concentration of the ore, a significant part of the mercury ends up in tailings that are landfilled.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	Since integrated facilities may consist of many plants, including raw material handling, sinter plants, pelletisation plants, coke oven plants, blast furnaces, basic oxygen processes, electric processes, and/or various others, it is virtually impossible in a brief summary to do justice to the great range of mercury reduction options. A couple of cases are mentioned below, but the reader is advised to consult the valuable document prepared by EIPPCB (BREF Iron & Steel, 2001) for a treatment of the entire field. For sinter plants, for example, the following techniques or combination of techniques are considered as BAT for minimising heavy metal emissions: Use of fine wet scrubbing systems in order to remove water-soluble heavy metal chlorides, especially lead chloride(s) with an efficiency of > 90% or a bag filter with lime addition; Exclusion of dust from last ESP field from recycling to the sinter strand,

	dumping it on a secure landfill (watertight sealing, collection and treatment of leachate), possibly after water extraction with subsequent precipitation of heavy metals in order to minimise the quantity to dump. In the case described by Berndt (2003) above, 70-80% of the oxidized mercury was being collected by the wet scrubber, corresponding to about 5% of the total. (Benner, 2001) has said that some emission control may be obtained by modifying the current practice in Minnesota of recycling the dust from wet scrubbers into the indurating furnaces (thermal treatment process, consisting of drying, heating and cooling). Benner found that this dust contains extremely high mercury concentrations, and when this material, particularly the fine fraction, was channelled into the waste stream (rather than recycled to the indurator), mercury emissions were reduced. The reported decrease in mercury emission by this measure was about 10-20%.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	There are so many mercury reduction options for the various plants in an integrated facility, and different raw materials may have significantly different characteristics, that it is virtually impossible to generalise about feasibility, costs, etc. It is suggested, once again, that the reader refer to the summary document prepared by EIPPCB (BREF Iron & Steel, 2001) for an adequate treatment of such issues. With regard only to sinter plants, the most commonly used abatement devices for treating the large volumes of waste gases in sinter plants in the EU are dry, electrostatic precipitators with three or four fields arranged in series. Already several years ago (BREF Iron & Steel, 2001) a few types of ESP were in use: Moving Electrode Electrostatic Precipitator (MEEP), energy pulse superimposition, and Electrostatic Space Cleaner Super (ESCS). BREF Iron & Steel (2001) reported that ESP reduces particulate matter concentrations with an efficiency of >95%. In some cases efficiency of 99% is achievable. Operational data for sinter plants are in the range of 20 to 160 mg/Nm^3. Emission values for MEEP and ESCS may achieve < 40 mg/Nm^3. ESP with energy pulse superimposition may achieve 20 to 30 mg/Nm^3. Moreover, electrostatic precipitators can be installed at both new and existing plants. To take a single example with regard to the sintering process, mercury enters the gas phase directly. Emission levels depend on the mercury content of the sinter feed, but emissions are normally low. In the case of iron ore which contains higher amounts of mercury, however, emissions may be significant. In such a case, emissions of 15-54 µg Hg/Nm^3 or 38-136 mg Hg/t sinter have been reported when a well-designed and well-operated ESP, together with a fine wet scrubbing system, were applied as abatement techniques (Linz, 1996).
Actual cases, examples	BREF Iron & Steel (2001), which is in the process of being updated, reported already some years ago: that nearly all sinter plants in Europe applied electrostatic precipitators. UBA also reported that all German sinter plants applied dry ESP. MEEP has been installed at two sinter plants in Japan and at two sinter plants in Germany, one at Krupp Hoesch Stahl, Dortmund and one at EKO Stahl, Eisenhüttenstadt. Energy pulse superimposition has been installed at four sinter plants at Kwangyang Works, Posco in South-Korea and at two strands at Thyssen Krupp Stahl, Duisburg, Germany. ESCS has been installed in the sinter plant of Nippon Steel Corporation, Wakamatsu/Yawata Works, Japan.
Waste	A solid waste flow is generated by an ESP in a sinter plant. In some

management issues, options	cases, this waste flow can be recycled into the sintering process. Whenever the concentration of heavy metals and/or alkali compounds is too high, reuse may be hampered. Furthermore, energy consumption is increased.
Implementation and enforcement, costs, barriers	Due to the emerging importance of this source category, the US Environmental Protection Agency recently published a rule requiring the removal of mercury switches before smelting at iron and steel foundries, and is moving forward on a similar requirement for electric arc furnaces (US Fed. Reg. 2004). See also BREF Iron & Steel (2001).
Information sources, references, websites	BREF Iron & Steel (2001), *Best Available Techniques Reference Document on the Production of Iron and Steel*, European Integrated Pollution Prevention and Control (IPPC) Bureau, IPTS, Sevilla, December 2001. Available at http://eippcb.jrc.es/pages/Fmembers.htm BREF Ferrous Metals (2001), *Reference Document on Best Available Techniques in the Ferrous Metals Processing Industry*, European Integrated Pollution Prevention and Control (IPPC) Bureau, IPTS, Sevilla, December 2001. Available at http://eippcb.jrc.es/pages/Fmembers.htm Lassen, C. (Ed.), Treger, Y.A., Yanin, E.P., Revich, B.A., Shenfeld, B.E., Dutchak, S.V., Ozorova, N.A., Laperdina, T.G. and Kubasov, V.L. (2004): Assessment of mercury releases from the Russian Federation. Ministry of Natural Resources of the Russian Federation, Danish Environment Protection agency, Arctic Council. Draft, 2004. HTC (2000): Hibbing Taconite Company. Voluntary mercury reduction agreement. Berndt, M.E. (2003): Mercury and Mining in Minnesota. Minerals Coordinating Committee. Final Report. Minnesota Department of Natural Resources, St. Paul, Minnesota. Available at: http://files.dnr.state.mn.us/lands_minerals/mercuryandmining.pdf Benner, B. R. (2001): Mercury removal from induration off-gas by wet scrubbers. Coleraine Minerals Research Laboratory Draft Report. (quoted in Berndt, 2003) Linz (1996), City of Linz – Office for Environmental Protection, W. Medinger and G. Utri, *Bilanz der Quecksilbermissionen aus Quellen im Linzer Stadtgebiet* (Balancing the emissions of mercury in the area of the city of Linz), Report No. 1/96 (1996). US Fed. Reg. (2004). 69 Fed. Reg. 21906, 21918-21919 (April 22, 2004).

5.0 Production of recycled metals ‘secondary production’

5.1 Production of recycled mercury (“secondary” production)

Description	There are two basic types of secondary mercury production: 1) recovery of liquid mercury from dismantled equipment, and 2) mercury recovery from scrap products using extractive processes. In the USA (and probably many other countries), the total quantity of mercury recovered as liquid mercury is much greater than that recovered by extractive processes. Three areas that comprise a large proportion of the liquid mercury recovered are: 1) decommissioning of chlor-alkali facilities; 2) recovery from mercury meters used in natural gas pipelines; and 3) recovery from manometers, thermometers, and other equipment. In each of these processes, the liquid mercury is drained from the dismantled equipment into containers. The second type of mercury recovery involves the processing of scrapped mercury-containing products (dental amalgams, lamps and switches, batteries, etc.) and industrial wastes and sludges (scrap mercury from instrument and electrical manufacturers, wastes and sludges from research laboratories and electrolytic refining plants, etc.) using thermal or chemical extractive processes (US EPA, 1997a and COWI, 2002). The similar recovery of mercury from mineral wastes and concentrates from mining and primary processing of zinc or other ores, and from sludges resulting from pre-distribution cleaning of natural gas are often referred to as “by-product” mercury recovery, as opposed to post-consumer recycling. Countries without recycling programs may export waste with high mercury concentrations to recycling facilities abroad (COWI, 2002).
Main mercury releases (air, water, soil, production, use, disposal)	Mercury recycling/recovery activities may lead to substantial releases of mercury to the atmosphere, to aquatic and terrestrial environments. The amounts lost depend very much on how carefully the process releases are managed. The major pathways for mercury releases include air, water, soil, wastes/residues, or eventually products made from this recycled mercury. Likewise, even after reprocessing or recycling operations have finished, the residues and other wastes contaminating the site and surroundings may be a significant ongoing source of mercury emissions to the air, water and soil.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	During extraction of mercury from waste materials, emissions may vary considerably from one type of process to another. Emissions may potentially occur from the following sources: retort or furnace operations, distillation, and discharge to the atmosphere from the charcoal filters. The major mercury emission sources are due to condenser exhaust and vapour emissions that occur during unloading of the retort chamber, which should have its own activated-charcoal filtered exhaust system. Mercury emissions also can occur in the filling area during the bottling process, or if a flask overflows. If a scrubber is used, mercury vapour or droplets in the exhaust gas may be captured in the spray. Concentrations in the workroom air due to mercury vapour emissions (such as from the hot retort process) may be reduced by containment, local exhaust ventilation, dilution, isolation, and/or personal protective equipment. Vapour emissions due to mercury transfer during the distillation or filling stages may be reduced by

<table>
<tr><td></td><td>containment, ventilation (local exhaust or ventilation), or temperature control (US EPA, 1997a).</td></tr>
<tr><td>Assessment of options (feasibility, costs, benefits, advantages, disadvantages)</td><td>In the USA (and probably many other countries) information on the performance of specific emission control measures is largely dependent on the specific processing equipment and methods, which are very site specific.
For reference, one company in the USA (Mercury Refining Company) in 1973 estimated emissions of 20 kg per metric ton of mercury processed due to uncontrolled emissions over the entire recycling process (Anderson, 1973, as cited in US EPA, 1997a). The same facility reported results from two emission test studies conducted in 1994 and 1995 that showed average mercury emissions of 0.85 kg per metric ton of mercury recovered (MRC, 1997, as cited in US EPA, 1997a).</td></tr>
<tr><td>Actual cases, examples</td><td>Weight of processed mercury containing waste and weight of the commercial mercury recovered from the waste in a Russian mercury recycling facility is shown in the table below. The facility employs a tubular rotary oven for the recovery. The oven is a metal cylinder body with the diameter 1.6 m and the length 14 m, installed at a gradient of 3-4° and lined with refractory bricks. The total reported mercury release from the process was 120 kg broken down into 52 kg with off-gas, 65 kg with wastewater, 3 kg with cinders, and 0.5 kg unaccounted losses. The average emission to air from the process was 2 kg/metric ton mercury processed whereas the release to wastewater corresponds to and 2.5 kg per metric tons mercury processed. The previous years the releases were significantly higher and the mercury emission to air decreased from 1999 to 2001 for 20 g/metric ton processed mercury to 2 g/metric ton. During the same period the releases to water increased from 0.5 - 2.5 g/metric ton processed mercury.
Processing of mercury-containing waste at a recycling facility in Russia in 2001 (Lassen et al., 2004)
<table>
<tr><th>Type of waste</th><th>Weight of waste, kg</th><th>Commercial Hg, kg</th></tr>
<tr><td>Catalyst, sorbent, sludge (from VCM production)</td><td>244,312</td><td>9,793</td></tr>
<tr><td>Unconditioned mercury</td><td>16,113</td><td>16,097</td></tr>
<tr><td>Mercury lamps</td><td>20,610</td><td>7</td></tr>
<tr><td>Mercury-containing devices</td><td>1,784</td><td>131</td></tr>
<tr><td>Luminophor concentrate</td><td>23,700</td><td>78</td></tr>
<tr><td>Other (galvanic elements, mercury-contaminated construction waste and soils, proper production waste, etc.)</td><td>54,800</td><td>343</td></tr>
<tr><td>Total</td><td>361,319</td><td>26,449</td></tr>
</table></td></tr>
<tr><td>Waste management issues, options</td><td>As in other sectors, release reduction technology yields additional solid or fluid residues, which also have to be managed to prevent or reduce additional releases (COWI, 2002).</td></tr>
<tr><td>Implementation and enforcement, costs, barriers</td><td>The most reliable manner of reducing mercury emissions in this industry is to record the weight of all mercury products and wastes entering the facility, and to carefully measure mercury amounts in all output streams.</td></tr>
<tr><td>Information sources, references, websites</td><td>COWI (2002): ACAP and Danish EPA Reduction of Atmospheric mercury emissions from Arctic countries – questionnaire on emissions and elated topics. November 2002.
BREF Non-Ferrous Metals (2001), *Reference Document on Best Available Techniques in the Non Ferrous Metals Industries*, European Integrated Pollution Prevention and Control (IPPC) Bureau, IPTS,</td></tr>
</table>

	Sevilla, December 2001. Available at http://eippcb.jrc.es/pages/Fmembers.htm US EPA (1997a): Locating and estimating air emissions from sources of mercury and mercury compounds. Report EPA-454/R-97-012, (NTIS PB98- 117054), Office of Air Quality Planning and Standards, Research Triangle Park, NC. Available at: http://www.epa.gov/ttn/chief/le/index.html. MRC (1997): Mercury Refining Company. Excerpts from emission source test reports conducted by General Testing Corporation in September 1994 and Galson Corporation in June 1995, Submitted to Midwest Research Institute, Cary, NC, September 3, 1997.

5.2 Production of recycled ferrous metals (iron and steel)

Description	Recycled iron and steel are produced from scrap metal using various high temperature processes. For example, many facilities produce steel by melting scrap in electric arc furnaces. Others produce cast iron by melting scrap in furnaces called “cupolas.” Mercury may be present in recycled metals/materials as a result of the presence of natural mercury impurities in the original materials, as well as the presence of mercury contamination originating from intentional use of mercury in certain products (e.g. mercury switches in cars) that end up in iron/steel recycling. Since the previous section on Primary Ferrous Metal Production has addressed emissions during thermal processes, reference should be made to that section as well. It has been estimated that 15-22 metric tons of mercury from automobiles enters the scrap processing system each year in the US (NJMTF, 2002). This quantity is probably decreasing since mercury use in car switches has declined roughly 60-80% between 1996 and 2000 in the USA. However, the use of mercury in anti-lock braking systems (ABS) actually increased by 130-180% over the same period (NJMTF, 2002). It should be noted that mercury switches were substituted earlier in European cars than in American cars, and therefore contribute much less to scrap steel emissions. Mercury is also found extensively in gas pressure regulators, other switches, relays and flame sensors in appliances, etc., that also become scrap for iron and steel production (Cain, 2000, as cited in NJ MTF, 2002).
Main mercury releases (air, water, soil, production, use, disposal)	Ferrous scrap is processed by different industries and types of facilities, and involves various process steps. For example, some automobiles are sent to dismantlers initially, where valuable components are removed. The rest of the automobile is usually crushed and then shipped to a shredder. Some older automobiles with few components of value are sent directly to the shredder. Other scrap items, such as waste metals from demolished building structures, may enter the recycling process at various stages of the processing system. Mercury may be released to air, water or soil during various points in the process of storage, shredding, dismantling (NJ MTF, 2002) and eventually smelting (see also Primary Ferrous Metal Production). Electric arc furnaces need considerable amounts of electric energy, and cause substantial emissions to air and solid wastes/by-products – mainly filter dust and slags. The emissions to air from the furnace consist of a wide range of inorganic compounds (iron oxide dust and heavy metals) and organic compounds.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	Because scrap preparation is crucial with regard to mercury, mercury emissions can greatly vary from charge to charge depending on scrap composition/quality. The most cost-effective way to greatly reduce eventual mercury emissions at all points of the recycling process is to identify the mercury components in the scrap metal supply chain, and to physically remove the switches and other mercury sources before they are crushed, shredded, or otherwise get to the point where they can no longer be easily removed. If mercury is not removed at an early stage, it becomes rather more expensive to remove at a later phase of scrap treatment or emissions control – if at all. The primary off-gas contains about 10-20 kg dust per tonne of steel, which is typically collected in the bag filters or electrostatic precipitators (ESP). Mercury, however, which may be significantly present in some

	scrap and then in the gas phase, is not much captured by filtration or ESP. In the EU, there is little evidence that the off-gases are treated specifically to remove mercury. In some cases the off-gases are treated in a wet scrubber. There is no information available on applied treatment techniques or eventual emissions (BREF Iron & Steel, 2001).
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	Several techniques are proposed in BREF Iron & Steel (2001) for general off-gas treatment: In a hood system, one or more hoods over the furnace indirectly collect fumes escaping from the furnace during charging, melting, slag-off, and tapping steps (up to 90% of primary emissions and also secondary emissions) Furnace enclosures, also called dog-houses (see Figure 9.6), usually encapsulate the furnace, its swinging roof, and also leave some working space in front of the furnace door. Typically, waste gases are extracted near the top of one of the walls of the enclosure, and makeup air enters through openings in the operating floor. Another way to collect secondary emissions from the furnace, as well as preceding and succeeding installations, is a complete enclosure of all plants in one sealed building. It can be regarded, roughly speaking, as just a larger type of furnace enclosure, mainly containing more process steps.
Actual cases, examples	Many plants in Europe have a combination of direct off-gas extraction and hoods. The following German plants are equipped with dog-house systems, among other emission controls: Benteler AG, Lingen; Krupp Thyssen Nirosta, Bochum; Krupp Thyssen Nirosta, Krefeld; etc. (BREF Iron & Steel, 2001). A North Carolina (USA) bill requires auto manufacturers to pay a "bounty" of US $5.00 per mercury switch removed by auto recyclers and scrap dealers. Mercury switches are commonly found in hood and trunk lights, among other equipment, in US-made cars. The bill is expected to cut mercury emissions from steel mills in North Carolina, which recycle scrap cars, by 50% (NCCN 2005).
Waste management issues, options	See BREF Iron & Steel (2001) for further details.
Implementation and enforcement, costs, barriers	Due to the emerging importance of this source category, the US Environmental Protection Agency recently published a rule requiring the removal of mercury switches before smelting at iron and steel foundries, and is moving forward on a similar requirement for electric arc furnaces (US Fed. Reg. 2004). The cost of some off-gas extraction systems, especially sophisticated hoods and full enclosures, may be high. The US federal Environmental Protection Agency is expected to soon restrict mercury emissions from scrap steel plants, which will help steel recycling stay competitive (NCCN 2005).
Information sources, references, websites	BREF Iron & Steel (2001), *Best Available Techniques Reference Document on the Production of Iron and Steel*, European Integrated Pollution Prevention and Control (IPPC) Bureau, IPTS, Sevilla, December 2001. Available at http://eippcb.jrc.es/pages/Fmembers.htm BREF Ferrous Metals (2001), *Reference Document on Best Available Techniques in the Ferrous Metals Processing Industry*, European Integrated Pollution Prevention and Control (IPPC) Bureau, IPTS, Sevilla, December 2001. Available at http://eippcb.jrc.es/pages/Fmembers.htm NJ MTF (2002): New Jersey Mercury Task Force Report. Volume III.

	Sources of Mercury in New Jersey. January 2002. Available at website: http://www.state.nj.us/dep/dsr/Vol3-chapter1.pdf US Fed. Reg. (2004). 69 Fed. Reg. 21906, 21918-21919 (April 22, 2004). NCCN (2005), “Mercury switch recycling bill passes House,” North Carolina Conservation Network, 24 May 2005.

5.3 *Production of other recycled (non-ferrous) metals*

Description	It has been observed that aluminium, copper, zinc and other recycled metals may contain mercury. Since for most non-ferrous metals, any mercury found in the raw ores is generally removed during the original manufacturing process, it is concluded that if mercury appears during recycling, it must originate from other mercury-containing materials or products/components. As in the case of recycled steel, the most obvious contributors are mercury switches, relays, thermostats and similar devices. Based on the typical uses of mercury in components and products, it may be assumed that non-ferrous metals fed to recycling processes may typically be less contaminated with mercury than ferrous scrap. One exception may be aluminium. Mercury tends to amalgamate with aluminium more readily than with ferrous metals. Therefore, in the recycled metals stream, mercury contamination may be even more associated with aluminium than with ferrous metals. It is possible that aluminium recycling facilities using a thermal process release some mercury to the air and other media.
Main mercury releases (air, water, soil, production, use, disposal)	The major pathway for mercury releases is to the air, and to a lesser extent, to the water, soil and wastes/residues. The NJ MTF (2002) assumed that releases from aluminium recycling facilities would be similar in amount to the releases from facilities that produce recycled ferrous metals (iron and steel) described above, and that the emissions go mostly to the air. Releases from the recycling of these other non-ferrous metals cannot be generalised. They are extremely dependent on the nature and source of any mercury-containing components in scrap metal products.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	If it is determined that significant mercury is being released during scrap processing, there are various methods for removing it from the gas stream. Two of these methods are described. The Boliden-Norzink process is the most widely used technique for removing mercury from emissions to air. This is based on a wet scrubber using the reaction between mercuric chloride and mercury vapour to form mercurous chloride (calomel), which precipitates from the liquor. The subsequent recovery of mercury from the calomel may be inhibited by a low mercury market price, if it is not required by legislation. This process is capable of achieving emissions in the range 0.05 – 0.1 mg/Nm^3 of mercury in air, and is reported to have the lowest capital and operating costs. However, mercuric chloride is a very toxic compound, and great care must be taken when operating this process Alternatively, an adsorption filter using activated carbon is frequently used to remove mercury vapour from the gas stream, as in a number of industries. The "break-through" of mercury (exhaustion of the filter) is not easy to predict, and consequently a double filter is normally used to contain the mercury when the first filter is exhausted. After use, the carbon can be regenerated and the mercury recovered. Activated carbon filters are capable of reducing mercury concentrations to 0.002–0.007 mg/Nm^3 provided the double filter arrangement is used.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	Various processes are in use around the world, depending on the type of scrap and the mercury content. The Boliden-Norzink process is reported to have the lowest capital and operating costs, despite some energy cost of operating the scrubber.
Actual cases, examples	The Boliden-Norzink process is in use, for example, in plants in Germany, Finland and Sweden. Activated carbon systems are in use

	widely as well.
Waste management issues, options	Mercury is generally removed from wastewater, when necessary, by precipitation. Sodium sulphide is used as the reagent, and the pH of the effluent is controlled. Mercury sulphide, which is not soluble, and is then precipitated from the solution. Activated carbon may also be used to remove final traces of mercury from effluents. Emissions to water may easily be reduced to 0.05 mg/l, provided that solids are removed during the process; in some cases sand filters are used for this purpose.
Implementation and enforcement, costs, barriers	See BREF Non-Ferrous Metals (2001) for further details.
Information sources, references, websites	BREF Non-Ferrous Metals (2001), *Reference Document on Best Available Techniques in the Non Ferrous Metals Industries*, European Integrated Pollution Prevention and Control (IPPC) Bureau, IPTS, Sevilla, December 2001. Available at http://eippcb.jrc.es/pages/Fmembers.htm NJ MTF (2002): New Jersey Mercury Task Force Report. Volume III. Sources of Mercury in New Jersey. January 2002. Available at website: http://www.state.nj.us/dep/dsr/Vol3-chapter1.pdf

6.0 Production of other minerals and materials with Hg impurities

6.1 Cement Production

Description	The raw materials used for the production of cement contain trace concentrations of mercury. This mercury originates from three basic sources: there is mercury naturally present in virgin raw materials (lime, coal, oil etc.), there is mercury in solid residues from other sectors (e.g. fly-ashes and gypsum from combustion of coal) often used as raw materials for cement production, and there may be mercury in wastes sometimes used as fuels in cement manufacturing. Depending upon the materials, the last two sources may significantly increase the total input of mercury to cement production. Cement production is a good example of a source of mercury releases due to the use of materials with very low mercury concentrations, but consumed in very great quantities. A typical, but not the only, process for the manufacture of cement is the Portland cement manufacturing process. This involves: 1) drying or preheating the raw materials; 2) calcination, a heating process in which calcium oxide is formed from calcium carbonate; and 3) sintering, in which lime reacts with various oxides to form silicates, aluminates, and ferrites of calcium, also known as "clinker". As the hot clinker comes from the kiln, it is rapidly cooled. Finally, the cooled clinker is ground or milled together with gypsum ($CaSO_4$), making a fine powder that is then mixed with other additives to produce the final cement product.
Main mercury releases (air, water, soil, production, use, disposal)	The major pathway for mercury releases from cement production is to the air, and to a lesser extent to the soil, in wastes and residues, as well as in the cement product itself. Important factors for mercury releases include: the amount and type of raw materials processed (for example, the use of waste products like fly ash or pyrite ash as raw materials may significantly increase the mercury input), mercury concentration in the raw materials, amount of clinker and cement produced, amounts and types of fuel burned, and concentrations of mercury in each of the fuels burned at the facility. The principal emissions of mercury to the air are from the kiln. Much lower emissions would be expected from the raw material processing and mixing steps.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	Depending on the flue gas cleaning technology employed, a part of the mercury is captured by the dust removal systems, e.g. fabric filters and ESP's. The efficiency of mercury capture depends on the actual filters used, and the temperature at the filter inlet. The lower the exhaust gas temperature at the filter inlet, the higher the proportion of particulate mercury that can be removed from the exhaust gas (Cembureau, 1999). Information on the mercury removal efficiency of different emission reduction systems for cement plants is scarce, but compared to other heavy metals (e.g. lead and cadmium) removed by these systems, the efficiency of the removal of mercury is relatively low. The EMEP/CORINAIR emission guidebook estimates average atmospheric mercury emissions of 0.1 g/metric ton cement produced (EMEP/CORINAIR, 2001).
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	In the United States and Canada, the kiln emissions are typically reduced with either fabric filters (FFs) or ESP's, but only limited information is available on the efficiency of these devices with respect to mercury removal. One source indicates (US EPA, 1993, cited by Pirrone *et al*., 2001) that ESP's capture about 25%, and FFs may capture up to 50% of the potential mercury emissions as particulate matter. In general, it is assumed that the mercury removal efficiency in kilns is comparable to

	the efficiency of mercury removal by the same devices employed in combustion plants. However, if the captured dust is mixed with the raw materials and recycled into the kiln, any mercury that might have been removed with the dust will, in this case, be ultimately emitted to the air (VDZ, 2001).
Actual cases, examples	In a study of mercury releases in the Russian Federation, an average emission factor of 0.045 g/metric ton of cement was derived from information on mercury in raw materials and an assumption that 80% of the mercury in the raw materials was emitted to the air (Lassen *et al.,* 2004).
Waste management issues, options	The mercury concentration of gypsum waste produced from acid flue gas cleaning residues, e.g. from coal-fired power plants, may significantly exceed the mercury concentration of natural gypsum. Therefore, if gypsum waste from acid flue gas cleaning is used as a raw material for cement production, it may significantly increase the mercury content of the final cement. The mercury concentration of 418 samples of cement produced in Germany in 1999 ranged from <0.02 mg/kg (detection limit) to 0.3 mg/kg.
Implementation and enforcement, costs, barriers	In most countries the issue of controlling mercury emissions from cement plants has not yet become a high priority, although plant operators are required to report them under the Toxic Release Inventory (US) and European Polluting Emissions Register (EU).
Information sources, references, websites	BREF Cement & Lime (2001), *Reference Document on Best Available Techniques in the Cement and Lime Manufacturing Industries*, European Integrated Pollution Prevention and Control (IPPC) Bureau, IPTS, Sevilla, December 2001. Available at http://eippcb.jrc.es/pages/Fmembers.htm Cembureau (1999): Best available techniques for the cement industry. European Cement Association, Brussels. Available at: http://www.cembureau.be/Documents/Publications/CEMBUREAU_BAT_Reference_Document_2000-03.pdf EMEP/ CORINAIR (2001): EMEP/CORINAIR Emission Inventory Guidebook - 3rd edition, 2001, Technical report No 30. Available at http://reports.eea.eu.int/technical_report_2001_3/en#TOC Pirrone, N., Munthe, J., Barregård, L., Ehrlich, H.C., Petersen, G., Fernandez, R., Hansen, J.C., Grandjean, P., Horvat, M., Steinnes, E., Ahrens, R., Pacyna, J.M., Borowiak, A., Boffetta, P. and Wichmann-Fiebig, M. (2001): EU Ambient Air Pollution by Mercury (Hg) - Position Paper. Office for Official Publications of the European Communities, 2001. Available at http://europa.eu.int/comm/environment/air/background.htm#mercury) VDZ (2001): Activity Report 1999-2001. Verein Deustcher Zementwerke e. V., Forshungsinstitut der Zementindustrie, Dusseldorf, Germany. Available at: http://www.vdz-online.de/daten/tb_99_01/en/script/start.htm. Lassen, C. (Ed.), Treger, Y.A., Yanin, E.P., Revich, B.A., Shenfeld, B.E., Dutchak, S.V., Ozorova, N.A., Laperdina, T.G. and Kubasov, V.L. (2004): Assessment of mercury releases from the Russian Federation. Ministry of Natural Resources of the Russian Federation, Danish Environment Protection agency, Arctic Council. Draft, 2004

6.2 Pulp and paper production

Description

In the pulp and paper industry, wood pulp is produced from raw wood via chemical or mechanical means or a combination of both. Four principal chemical wood pulping processes are currently in use: (1) kraft, (2) soda, (3) sulphite, and (4) semichemical (US EPA, 1997a). The four processes are mostly similar, but also have some important differences. Therefore, any pollution reduction options have to specifically take account of the characteristics of a given process.

In the kraft pulping process, for example, wood chips are "cooked" under pressure in a digester in a solution of sodium hydroxide ($NaOH$) and sodium sulphide (NaS). Various other steps take place and a washed pulp is produced. The washed pulp may then enter a bleaching sequence before being pressed and dried to yield the finished paper product.

The sources of input mercury may include trace levels of mercury in the wood raw material, in fuels used for energy production, and in the chemicals used in the various production processes (sodium hydroxide, chlorine, and often others). Likewise, the use of mercury-compound slimicides has long contributed to mercury releases from pulp and paper production. This use has been much reduced in the West, but likely continues in many parts of the world.

Main mercury releases (air, water, soil, production, use, disposal)

The major pathways for mercury releases from the pulp and paper industry include atmospheric emissions from combustion (fossil fuels, bark and other wood wastes), or with solid wastes and wastewater. If mercury is not purged from the process in the wastewater or solid wastes, it can accumulate in the chemical recovery area and subsequently be emitted during the chemical recovery combustion process. The amount of mercury emitted may depend on how tightly closed the pulping process is (such as the degree to which process waters are recycled and reused) (US EPA, 1997a).

In the USA, mercury emissions data are only available from combustion units at kraft pulp mills, at which nearly all of the mercury emissions from pulp and paper manufacturing are from kraft and soda recovery processes (US EPA, 1997a).

Releases of mercury and mercury compounds from kraft and paper production in the USA, 2002 (TRI, 2004)

Release path	Mercury compounds		Mercury (elemental)	
	kg/year	%	kg/year	%
Air	2,098	71	319	39
Surface water	36	1	19	2
Land treatment and surface impoundments	217	7	20	2
Off-site wastewater treatment	3	0	0	0
Off-site solid waste disposal	594	20	451	56
TOTAL	2,948	100	809	100

The pulp and paper industry is another example of a source of mercury releases due to the use of materials with mostly very low mercury concentrations, but consumed in great quantities.

It should also be kept in mind that closed or abandoned pulp and paper

	manufacturing sites (especially those with integrated mercury-based chlor-alkali production, or those that used mercury-based slimicides) may be significant sources of ongoing mercury releases to the air, water, and soil.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	There are no examples of emission reduction options implemented specifically for the purpose of reducing potential mercury emissions. However, the actual case described below is instructive in terms of what can be done.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	Not applicable.
Actual cases, examples	SCA Packaging Industriepapier GmbH, Aschaffenburg, Germany, has implemented a process of co-incineration of solid wastes from a recycled fibre (RCF) mill. Because of their inhomogeneous composition, rejects from RCF mills without de-inking are commonly dumped in landfill sites. However, due to their high heating value in the range of 22–24 MJ/kg dry substance due by the high proportion of plastics, rejects may be suitable for energy recovery, replacing fossil fuels. In paper mills firing solid fuels such as coal (in Europe, this is mostly the smaller and/or older mills), the co-incineration of rejects is feasible. The installation of a drying and gasification chamber connected with the combustion chamber of the power plant is necessary. In the drying and gasification chamber, the rejects are gasified by oxidation of the carbon-containing material with air. The gases generated during gasification are after-burned in the combustion chamber of the power plant. Proper combustion conditions have to be ensured to avoid problems with VOC and soot. Of course, co-incineration of rejects in existing combustion facilities requires additional measures for flue gas purification. Among other measures, the waste gases are treated in a an electrostatic precipitator and additionally in a fabric filter. The removal of dioxins and mercury from the flue gas is achieved with activated carbon (BREF Pulp & Paper 2001).
Waste management issues, options	Incineration of rejects saves landfill space. The resulting ashes are suitable for reutilization, e.g. for use in road construction. Fossil fuels for energy generation can be substituted. Emissions to air are released from the incinerator and have to be treated. In contrast, potential emissions from landfill gases are reduced. Wastewater is generated when wet scrubbers are used for waste gas treatment (BREF Pulp & Paper 2001).
Implementation and enforcement, costs, barriers	In the example described above, investment costs for a recycled fibre (RCF) mill co-incineration plant, including facilities for solid waste (“reject”) pretreatment, drying and the gasification chamber for a reject volume of maximum 3 tonnes/h, are in the range of about 2.5 million euro. Assuming costs for landfilling of 50 euro/t, the annual saving due to avoided landfilling is about 0.6 million euro. The eventual substitution of brown coal would save an extra 0.3 million euro per year. Costs for maintenance are not available (BREF Pulp & Paper 2001).
Information sources, references, websites	US EPA (1997a): Locating and estimating air emissions from sources of mercury and mercury compounds. Report EPA-454/R-97-012, (NTIS PB98- 117054), Office of Air Quality Planning and Standards, Research Triangle Park, NC. Available at: http://www.epa.gov/ttn/chief/le/index.html.

	TRI (2004): Toxics Release Inventory (TRI) Program. US Environmental Protection Agency. Available at: http://www.epa.gov/triexplorer/ BREF Pulp & Paper (2001), *Reference Document on Best Available Techniques in the Pulp and Paper Industry*, European Integrated Pollution Prevention and Control (IPPC) Bureau, IPTS, Sevilla, December 2001. Available at http://eippcb.jrc.es/pages/Fmembers.htm

7.0 Intentional use of Mercury as an auxiliary or catalyst in industrial processes

7.1 Chlor-alkali production with mercury-technology

Description	At a mercury cell chlor-alkali facility, elemental mercury is used as a fluid electrode in an electrolytic process (referred to as the "mercury cell" process) used for production of chlorine and sodium hydroxide (NaOH) or potassium hydroxide (KOH) from salt brine. Hydrogen is also produced as a by-product. As the electrolytic process involves breaking the molecular bonds in salt (NaCl) and water molecules, massive amounts or electricity are required. Each mercury cell production loop includes an elongated electrolysis cell, a decomposer, a mercury pump, piping, and connections to other systems. The electrolyser produces chlorine gas, and the decomposer produces hydrogen gas and caustic solution (NaOH or KOH). The electrolyser is usually an elongated steel trough enclosed by side panels and a top cover, containing (at the bottom) typically 2-4 metric tons of mercury. The decomposer is a cylindrical vessel located at the outlet of the electrolyser. The electrolyser and decomposer are typically linked by an inlet end box and an outlet end box. Brine and a shallow stream of liquid elemental mercury flow continuously between the electrolyser and the decomposer. While each cell is an independent production unit, numerous cells are connected electrically in series. A plant usually has many electrolysis cells. In light of the tendency nearly everywhere to move away from mercury products and processes, it should be mentioned that two mercury-free chlor-alkali processes are also widely used: the membrane process and the diaphragm process. While the prevalence of the mercury-cell process is generally decreasing in many countries, it is still used widely, e.g. the mercury-cell process is used for about 50% of chlor-alkali production in Europe, less than 10% in the US and less than 25% in India.
Main mercury releases (air, water, soil, production, use, disposal)	The major pathways for mercury releases include air, water, soil, wastes/residues, and to a lesser extent to the chlorine and caustic products, which contain varying amounts of mercury, depending on the specifics of the raw materials and the production process, and the care taken in mercury removal. These releases can occur at various stages of the process. The specific releases are highly dependent on the level of controls present, workplace/management practices, waste treatment/disposal procedures, and other factors. Closed or abandoned chlor-alkali production sites may be significant sources of ongoing mercury releases to the air, water, and soil.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	As mentioned, two alternative mercury-free technologies are quite viable, of which the membrane process has been determined to represent “best available techniques” (BREF Chlor-alkali, 2001). With regard to the mercury-cell process, most mercury releases are to the air from the cell room. Preventive measures and good management practices can significantly reduce these emissions. The primary mercury emissions to air occur during virtually any maintenance procedure that opens the system, as well as from the end-box ventilation system and the hydrogen gas vent. Several control techniques may be employed to reduce mercury levels in the hydrogen streams and in the end box ventilation systems. The most common techniques are (1) gas stream cooling, (2) mist eliminators, (3) scrubbers, and (4) adsorption on

	activated carbon or molecular sieves. Gas stream cooling may be used as the main mercury control technique, or as a preliminary step to be followed by a more efficient control device.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	The investment cost of converting from the mercury-cell process to membrane is typically on the order of $US 400-600 per metric ton of chlorine production capacity, but could be lower or higher based on specific plant considerations, such as the extent of site clean-up required. At the same time, significant operating cost savings are realised, especially a 20-30% reduction in electricity requirements, but also reduced waste disposal costs, etc. Dozens of mercury-cell plants, especially in Europe and the US, have converted to mercury-free during the last 15 years (BREF Chlor-alkali, 2001). Within a mercury-cell plant, a great number of measures can be taken, in addition to vigilance and "good housekeeping" measures, to reduce mercury emissions. An **end box ventilation system** is used at most plants to vent the end boxes, and sometimes other equipment as well. The collected gases are most often cooled and then treated with control equipment. The extent of releases from this system is highly dependent on the type of controls used. Hydrogen gas exiting the **decomposer** contains high concentrations of mercury vapour (as high as 3,500 mg/m^3). In most situations, each decomposer is equipped with an adjacent cooler through which the hydrogen gas stream is routed to condense some of the mercury and return it to the mercury cell. Mercury vapour from **fugitive emissions** can be detected by commercially available vapour analyzers. In addition, when liquid elemental mercury is accessible to open air, it will give off some vapour, at rates depending on temperature and other factors. Therefore, visual inspection for visible mercury is one effective work practice for curtailing air emissions. However, mercury vapour can also be generated from leaks in pressurized equipment, maintenance work and malfunction, absent of any visual appearance of liquid mercury. Thus, another work practice is visual inspection for vapour leaks from production equipment by means of ultra-violet spectrum lights. When vapour leaks are identified, workers can take remedial steps to correct them (See reference for Fugitive emissions – website). Although mercury is released as a contaminant in **products** – chlorine, caustic and hydrogen, the levels appear to be low in the US and EU (US EPA, 1997b). However, the levels in these products could be higher in other countries if similar purification and cleaning steps are not employed.
Actual cases, examples	As mentioned, many mercury-cell facilities have already converted to the membrane process (some with government aid, but most without), and there is a wealth of literature about how this is done, costs incurred, etc. In a recent press release, "The European Commission has authorised, under EU state aid rules, subsidies to two chlorine producers in Italy to set up new plants allowing for mercury-free chlorine production. Solvay Rosignano is due to receive €13.5 million aid to promote a €48 million investment, and Altair Chimica is due to receive about €5 million for a planned €13.5 million investment. The companies will end production based on mercury technology and introduce so-called membrane technology for which no mercury is needed." (EU Press release, 2005). For those facilities not yet ready to convert, all of the information sources provided below describe actual cases of mercury-cell plants substantially reducing mercury releases through a great variety of measures. Most striking are the cases in which a very modest investment, or merely operator training, have improved plant management and "good housekeeping" to the extent that mercury emissions have been reduced

	by many tons. At the chlor-alkali plant at ECI Ibbenbüren (Germany), for example, in addition to a very observant and experienced management culture, four continuous mercury monitors are strategically positioned to monitor emissions, and there are also manual weekly measurements of hydrogen emissions, indicative of system leaks.
Waste management issues, options	At a mercury-cell plant, various solid wastes are produced that are contaminated with mercury. The management of solid wastes varies by site and may include treatment on-site with mercury recovery processes (generally “retorts”), use of hazardous waste landfills, or disposal on-site or at general waste landfills, depending on the mercury content. Some of the solid wastes generated include: wastewater treatment sludge, as well as various non-specific wastes including graphite from decomposers, cell room sump sludges, and spent carbon adsorption devices. Also, various other mercury-contaminated items are disposed of, including hardware, protective gear, piping, and equipment. In the USA, virtually all mercury-cell plants have retorting systems to remove mercury from wastes, which is then reused in the mercury cells. The best performing units treat the off-gases with a wet scrubber and condenser, followed by an activated carbon adsorber.
Implementation and enforcement, costs, barriers	Many countries (Portugal, Canada, Japan, Norway, Ireland, etc.) have already phased out the mercury-cell process – some through legislation and others through voluntary agreements. Other countries (Belgium, the Netherlands, Sweden, etc.) will use it no longer after 2010. Still others (Germany, France, Italy, Spain, etc.) have committed to phase out the mercury-cell process by 2020.
Information sources, references, websites	BREF Chlor-alkali (2001), *Reference Document on Best Available Techniques in the Chlor-Alkali Manufacturing Industry*, European Integrated Pollution Prevention and Control (IPPC) Bureau, IPTS, Sevilla, December 2001. Available at http://eippcb.jrc.es/pages/Fmembers.htm Euro Chlor website http://www.eurochlor.org US EPA (1997b): Mercury Study Report to Congress. US EPA, Dec. 1997. Available at: http://www.epa.gov/mercury/report.htm. Fugitive emissions (website). Detailed operational methods for prevention of fugitive air emissions have been developed by US chlor-alkali firms. Their procedures are available at http://www.usepa.gov/Region5/air/mercury/hgcontrolguidance-final.pdf. EU Press release (2005). European Commission Press release IP/05/303, “State aid: Commission endorses €18.5 million of aid to reduce mercury emissions in Italy,” Brussels, 16 March 2005

7.2 Vinyl chloride monomer (VCM) production with mercury process

<table>
<tr>
<td>Description</td>
<td>Two processes are used to manufacture vinyl chloride. The choice of process in the past depended mostly on the source and availability of raw materials (e.g. calcium carbide), as well as other local conditions such as energy supply, etc. One process (acetylene process) uses mercuric chloride on carbon pellets as a catalyst, and the other (mercury-free) is based on the oxychlorination of ethylene.
One facility in the USA used the mercuric chloride process (US EPA, 1997a) until 2001, but is now closed. In Russia four enterprises were identified by Lassen et al. (2004) that still use the mercuric chloride process. In China many facilities are known to use the same process, consuming some 6 thousand metric tons of mercuric chloride catalyst (containing an estimated 600 t of mercury) in 2004 – and the number continues to increase. It is believed that some facilities in other parts of the world continue to use the mercuric chloride process as well.</td>
</tr>
<tr>
<td>Main mercury releases (air, water, soil, production, use, disposal)</td>
<td>Intrinsically, the mercuric chloride process is not necessarily highly polluting because the catalyst can be recycled and the hydrochloric acid product can be cleaned. In practice, however, there are various places in the system where mercury is released, and if the spent catalyst is not recycled (as routinely happened when world mercury prices were lower), large quantities of mercury are disposed of. The major pathway for mercury releases is therefore via wastes/residues, and to a lesser extent, emissions to the air and water. The following table is reproduced from the Toolkit, and gives some indications of mercury releases.
Estimated mass balance of VCM production with mercury catalysts in 2002 in Russia (Lassen et al., 2004)
<table>
<tr><td>Inputs</td><td></td></tr>
<tr><td>Annual Hg consumption with catalyst, metric tons/year</td><td>16</td></tr>
<tr><td>Annual VCM production, metric tons/year</td><td>130,000</td></tr>
<tr><td>Calculated g Hg input per metric ton of VCM produced, rounded</td><td>120</td></tr>
<tr><td>Output distribution</td><td>Share</td></tr>
<tr><td>Spent catalyst for external recycling</td><td>0,62</td></tr>
<tr><td>Low grade hydrochloric acid product</td><td>0,37</td></tr>
<tr><td>Direct releases to air</td><td>0,003</td></tr>
<tr><td>Direct releases to wastewater</td><td>0,003</td></tr>
</table>
An OSPAR Convention decision in 1985 (Decision 85/1) defined recommended thresholds for mercury releases to the aquatic environment from VCM production with mercury catalysts at 0,05 mg Hg/l effluent, and 0,1 g Hg/metric ton VCM production capacity. These values may indicate the approximate mercury releases to air and water from this sector around 1985 in Western Europe, which roughly correspond to the 2002 level presented for Russian VCM production above.
It should also be kept in mind that closed or abandoned VCM/PVC production, as well as catalyst production or recycling sites, may be significant sources of ongoing mercury releases to the air, water, and soil.</td>
</tr>
<tr>
<td>Mercury reduction options (alternative</td>
<td>As mentioned above, there is an economically and technically viable option to the mercuric chloride process, although the choice of process has traditionally had more to do with a variety of other factors.
Mercuric chloride catalyst wastes, especially in China, are large. Normally, the</td>
</tr>
</table>

technologies, other mercury reduction strategies)	amount of catalyst consumed will be the amount that goes to waste. In addition, during vinyl chloride refining, activated carbon is often used to adsorb minor mercuric chloride remaining in VCM. The mercury-containing wastewater produced in the production process is also treated by using activated carbon as adsorbent. This activated carbon waste is mixed into the waste mercury catalysts for joint treatment.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	The Chinese government is now dealing with the environmental and other impacts of permitting the mercuric chloride process to continue and even to expand without adequate controls and limitations (see "Implementation and enforcement" below). If it is not disposed of, mercuric chloride catalyst may be recycled. A lime or caustic soda solution reacts with the mercuric chloride catalyst when heated to boiling. The reaction generates mercury vapour and water vapour inside the distillation column. The flue gases should also be treated with an activated carbon filter. Mercury-saturated activated carbon from all sources may be regenerated and the mercury distilled off. Mercury recovered from the condensation process has a purity of 99.9%.
Actual cases, examples	Experience in China has determined that 95% of the mercury in waste catalysts can be recovered under the right operating conditions.
Waste management issues, options	The recent recycling of mercury catalysts in China seems to be due largely to the world market price for mercury. There is a general desire in China, for environmental reasons, to recycle all spent catalysts, no matter the market price for mercury.
Implementation and enforcement, costs, barriers	The VCM/PVC production process using acetylene generates a large amount of calcium carbide slag and waste mercury catalysts, as well as mercury-containing sludges, flue gas wastes, etc. Their proper treatment and disposal remains a heavy burden, and has resulted in serious environmental pollution. Meanwhile, calcium carbide production requires high energy consumption and inefficient use of other resources, all of which inhibits enterprises from investing in environmental protection.
Information sources, references, websites	US EPA (1997a): Locating and estimating air emissions from sources of mercury and mercury compounds. Report EPA-454/R-97-012, (NTIS PB98-117054), Office of Air Quality Planning and Standards, Research Triangle Park, NC. Available at: http://www.epa.gov/ttn/chief/le/index.html. Lassen, C. (Ed.), Treger, Y.A., Yanin, E.P., Revich, B.A., Shenfeld, B.E., Dutchak, S.V., Ozorova, N.A., Laperdina, T.G. and Kubasov, V.L. (2004): Assessment of mercury releases from the Russian Federation. Ministry of Natural Resources of the Russian Federation, Danish Environment Protection agency, Arctic Council. Draft, 2004. CRC (2005). Information from Chemical Research Centre, Beijing. *China Chemical Industry Yearbook* Editorial Department, *China Chemical Industry Yearbook* 2003/2004. Beijing: China Chemical Industry Information Center, 2004. China Non-Ferrous Metal Industry Yearbook, 2004.

8.0 Production, use and disposal of consumer products with intentional use of mercury

8.1 Thermometers with mercury

Description	Mercury thermometers have traditionally been used for most medium-range temperature measurements. Today they are increasingly substituted by electronic and other thermometer types, but the degree of substitution varies considerably from one country to another. Major types of mercury thermometers that remain in widespread use include medical thermometers (e.g. to measure body temperature in hospitals, households, etc.), ambient air temperature thermometers, thermometers used in chemical laboratories and educational establishments, as well as in the controls of some machines (e.g. large diesel engines) and industrial equipment. Mercury thermometers may contain less than one gram of mercury, or up to several hundred grams of mercury per unit, depending on the size and use (COWI, 2002 and US EPA, 1997a).
Main mercury releases (air, water, soil, production, use, disposal)	Mercury releases from thermometers may take place: during production of mercury thermometers (emissions to air, water and soil) depending on how closed the manufacturing systems are, and depending on the handling and workplace procedures in the individual production units; by breakage or loss of thermometers (emissions to air, water, soil) during use; and during disposal of thermometers after use (emissions directly to soil or landfill, and subsequently to water and air), closely depending on types and efficiency of waste collection and handling procedures. Even after thermometer production has stopped, closed or abandoned thermometer production sites may be significant sources of ongoing mercury releases to the air, water, and soil.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	In some countries there are efforts to collect mercury thermometers to ensure safe handling of the mercury, and sometimes recycling. However, the main way to reduce mercury emissions and exposures due to thermometers is by substituting this mercury use with a mercury-free alternative. There are many alternatives to clinical mercury-thermometers, including electrical and electronic thermometers, “disposables” designed for a single use, glass thermometers containing a Ga/In/Sn “alloy”, etc. With regard to non-medical thermometers, alternatives to mercury as the measuring medium include other liquids as above, gas, electrical and electronic (probably the most common) sensors. The choice of alternative depends on the temperature range, the specific application, and the need for precision. For temperature readings in buildings, a bimetal device is often used, or a Pt-100 or thermocouple is used when a temperature signal needs to be transmitted to a controller or recorder. For a very small number of precision applications, mercury thermometers are still preferred for technical reasons, e.g. for calibration of other thermometer types, for international standards, etc.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	Thermometers have been extensively analysed, alternatives have been identified and costs have been examined and shown comparable. There are non-mercury alternatives which are commercially available for practically all sub-categories of thermometer. This has enabled a near phase-out of mercury use in these devices in some countries. Where the costs of alternatives are not comparable, the alternatives often outperform the mercury-containing devices in terms of longevity and faster performance (e.g. digital electronic thermometers). Moreover, the costs of

	alternatives always decrease once the alternatives become more commonly used. There is such a great range of mercury alternatives and applications that it can only be said that prices of mercury-free thermometers vary widely, but are not necessarily more expensive. Electronic alternatives have several advantages over mercury. One thermometer can be adjusted to several different measuring ranges, thereby substituting for several mercury thermometers. Further, it is possible to read temperatures digitally and record them remotely. This can reduce the chance of human error, as well as reduce operating costs. It should also be noted that, while the initial cost of some mercury thermometers may be lower than an electronic device, the frequency of broken mercury thermometers is higher, and one electronic thermometer may replace several mercury ones. If an annual cost is calculated, the price of an electronic measuring device is probably no higher than the mercury device it replaces. Moreover, mercury thermometers are worthless at temperatures below –39°C, when mercury turns solid.
Actual cases, examples	Individual countries in Europe have already taken action to ban or restrict the use of some or all products containing mercury. Countries such as Denmark, France, the Netherlands, Sweden, Norway, Canada and the US (some states are much more progressive than others in this respect) have done so, while permitting specific exemptions for specialized uses where adequate alternatives do not yet exist. The experiences of Sweden and Denmark, in particular, where such restrictions are more comprehensive than most, and have been in place for many years; the experience of the United States, where mercury fever thermometers are essentially unavailable due to voluntary phase-outs by most pharmacies, as well as laws prohibiting sales by many states and local governments; and detailed studies comparing the cost and functionality of mercury and non-mercury products all demonstrate the feasibility of halting the sales of most mercury-containing measuring devices and instruments.
Waste management issues, options	The fact of initially producing a product that contains mercury means that the product must forever be managed in a responsible manner. If a mercury product is broken, it becomes a hazard not only to people close to that accident, but also, if the mercury is not properly cleaned up, to people who may live or work in that area in the future. And even if the cleanup is adequate, the mercury waste may be put in the municipal waste rather than hazardous waste. If mercury products go to municipal waste incineration, much of the mercury goes into the atmosphere, depending on the type of flue gas controls. If mercury products go to landfill, the mercury will eventually go into the air, water or soil. If mercury products are collected separately, there is still a considerable cost of collection, as well as hazardous waste disposal or recycling, and related emissions, after which (in the case of recycling) the mercury will likely appear once again on the market. Moreover, since many mercury-containing products have long technical lives, it should be kept in mind that even if a country decides to ban the marketing and use of mercury in most products, it may take decades before most of the mercury in use is collected and removed from human circulation.
Implementation and enforcement, costs, barriers	European Parliament resolution on the European Environment & Health Action Plan 2004-2010 - Article 6, declared that, consistent with the “opinion of the relevant Scientific Committee, urgent consideration should be given to restricting the marketing and/or the use of mercury used in … non-electrical or non-electronic measuring and monitoring devices … to which newborn babies, children, pregnant women, elderly persons, workers and other high-risk sections of the population are heavily exposed, as safer alternatives become available” (European Parliament, 2005).
Information sources, references, websites	http://www.newmoa.org/prevention/topichub/toc.cfm?hub=101&subsec=7&nav=7 US EPA (1997a): Locating and estimating air emissions from sources of mercury and mercury compounds. Report EPA-454/R-97-012, (NTIS PB98- 117054), Office of Air

	Quality Planning and Standards, Research Triangle Park, NC. Available at: http://www.epa.gov/ttn/chief/le/index.html. COWI (2002). ACAP and Danish EPA, Reduction of Atmospheric mercury emissions from Arctic countries – questionnaire on emissions and related topics. November 2002. LCSP (2003). An Investigation of Alternatives to Mercury Containing Products, Lowell Centre for Sustainable Production, 22 January 2003, available at http://mainegov-images.informe.org/dep/mercury/lcspfinal.pdf NWF (2002). Mercury Products Guide, Todd Kuiken and Felice Stadler, National Wildlife Federation, Ann Arbor, Michigan, August 2002. Nordic Council (2002). Nordic Council of Ministers, “Mercury – a global pollutant requiring global initiatives”, Copenhagen 2002. INFORM. http://www.informinc.org/fsmercalts.pdf and http://www.informinc.org/fsmerchealth.pdf HCWH. See Health Care Without Harm websites www.noharm.org/mercury/mercuryFree for a list of pharmacies no longer selling mercury fever thermometers and www.noharm.org/mercury/ordinances for a list of laws prohibiting mercury fever thermometer sales in the United States Maine DEP. See a detailed comparison of mercury and non-mercury measuring devices and instruments performed for the Maine Department of Environmental Protection at www.maine.gov/dep/mercury/lcspfinal.pdf and the proposed strategy based on that report at www.maine.gov/dep/mercury/productsweb.pdf. Following the submission of this strategy, the Maine Legislature enacted a prohibition on the sale of most mercury measuring devices and instruments effective July 2006. Appendix B to the report contains some examples of substantial cleanup expenditures resulting from measuring instrument breakage. European Parliament (2005). http://www2.europarl.eu.int/omk/sipade2?PUBREF=-//EP//TEXT+TA+P6-TA-2005-0045+0+DOC+XML+V0//EN&LEVEL=3&NAV=X

8.2 Electrical and electronic switches, contacts and relays with mercury

<table>
<tr><td>Description</td><td>Electrical and electronic switches, contacts and relays with mercury are used in many applications, such as:
• level or “tilt” switches in thermostats, car boot or bonnet lids (lighting), car ride-control systems, freezer or washing machine lids, “fall alarms” for the elderly, railway signals, sewer pumps, water pumps, car ABS sensors, light-activators in children's shoes, etc.,
• multiple-pole level switches in excavation machines,
• mercury-wetted contacts (in electronics),
• data transmission relays or "reed relays",
• thermo-switches, etc.
In some countries mercury in electrical components have been under substitution for nearly two decades, and mercury-free substitutes are being used for most or all of these applications. However, while there is increasing awareness of mercury-free substitutes, the status and extent of substitution varies considerably from one country to another.</td></tr>
<tr><td>Main mercury releases (air, water, soil, production, use, disposal)</td><td>The major pathways for mercury releases during the product life-cycle include air, soil, wastes/residues, as well as during product use, in the event of breakage, and to a lesser extent, releases to water.
Also, closed or abandoned production sites for this type of equipment may be significant sources of ongoing mercury releases to the air, water, and soil.</td></tr>
<tr><td>Mercury reduction options (alternative technologies, other mercury reduction strategies)</td><td>The most effective means to reduce mercury emissions and exposures related to these products is by substituting these products with a mercury-free alternative.
With very few exceptions, there are no technical obstacles to replacing electrical components, conventional relays and other contacts (even when these are contained in level switches, pressure switches, thermostats, etc.) with equivalent mercury-free components. A number of examples are given below.
<table>
<tr><th>Mercury component</th><th>Alternative component</th><th>Typical application</th></tr>
<tr><td>Tilt-switch
(“silent switch”)</td><td>Manual/mechanical (rolling steel ball, alternative conducting fluid), micro-switch, etc.</td><td>Circuit control, thermostats, communications</td></tr>
<tr><td>Electronic-switch</td><td>Solid state-switch, optical switch</td><td>Circuit control, thermostats, communications</td></tr>
<tr><td>Reed-switch
(“mercury-wetted”)</td><td>Solid-state-switch, electro-optical-switch, semi-conductor</td><td>Communications, circuit control in sensitive electronic devices</td></tr>
<tr><td>Proximity sensor or proximity switch
(“non-touch contact”)</td><td>1-inductive sensor
2-capacitive sensor
3-photoelectric sensor
4-ultrasonic</td><td>1-shaft rotation, conveyors
2-conveyors
3-conveyors
4-conveyors</td></tr>
</table></td></tr>
<tr><td>Assessment of options (feasibility, costs, benefits, advantages, disadvantages)</td><td>There are no significant price differences between conventional mercury and mercury-free relays and contacts, except for very specific applications. There are also various examples of mercury-free alternatives that are less expensive than the mercury components they replace (UNEP 2002).</td></tr>
<tr><td>Actual cases,</td><td>Individual countries in Europe have already taken action to ban or restrict the use of</td></tr>
</table>

examples	some or all products containing mercury. Countries such as Denmark, France, the Netherlands, Sweden, Norway, Canada and the US (some states are much more progressive than others in this respect) have done so, while permitting specific exemptions for specialized uses where adequate alternatives do not yet exist. The experiences of Sweden and Denmark, in particular, where such restrictions are more comprehensive than most, and have been in place for many years; and many detailed studies comparing the cost and functionality of mercury and non-mercury products all demonstrate the feasibility of banning the sales of most mercury-containing products. Based on these experiences, the European Union has developed and passed two pieces of legislation regulating the content and disposition of electrical and electronic equipment (EEE). Directive 2002/96/EC (WEEE) mainly ensures separate collection and recycling of EEE, while Directive 2002/95/EC (RoHS) bans the use of certain hazardous chemicals – including mercury or any components containing mercury – in new equipment marketed after 1 July 2006. The RoHS directive presently includes such EEE as large household appliances, small household appliances, information and communications technology equipment, consumer devices, lighting equipment, electrical and electronic tools, etc.
Waste management issues, options	The fact of initially producing a product that contains mercury means that the product must forever be managed in a responsible manner. If a mercury product is broken, it becomes a hazard not only to people close to that incident, but also, if the mercury is not properly cleaned up, to people who may live or work in that area in the future. And even if the cleanup is adequate, the mercury waste may be put in the municipal waste rather than hazardous waste. If mercury products go to municipal waste incineration, much of the mercury goes into the atmosphere, depending on the type of flue gas controls. If mercury products go to landfill, the mercury will eventually go into the air, water or soil. If mercury products are collected separately, there is still a considerable cost of collection, as well as hazardous waste disposal or recycling, and related emissions, after which (in the case of recycling) the mercury will likely appear once again on the market. Moreover, since many mercury-containing products have long technical lives (even after it is no longer used, much EEE is kept in storage), it should be kept in mind that even if a country decides to ban the marketing and use of mercury in most products, it may take decades before most of the mercury in use is collected and removed from human circulation.
Implementation and enforcement, costs, barriers	During the implementation of the Swedish ban on mercury in products (except those few products with an exemption), an investigation of substitutes for mercury-containing measuring instruments and electrical components was carried out. It was discovered that while many applications of mercury were being phased out, some new applications, surprisingly, were appearing, e.g. in electronic equipment, even though alternative technologies were available. It became clear that an appropriate programme of information and incentives should ideally accompany any broad-based efforts to promote or legislate mercury-free products.
Information sources, references, websites	http://www.newmoa.org/prevention/topichub/toc.cfm?hub=101&subsec=7&nav=7 LCSP (2003). An Investigation of Alternatives to Mercury Containing Products, Lowell Centre for Sustainable Production, 22 January 2003, available at http://mainegov-images.informe.org/dep/mercury/lcspfinal.pdf NWF (2002). Mercury Products Guide, Todd Kuiken and Felice Stadler, National Wildlife Federation, Ann Arbor, Michigan, August 2002. Nordic Council (2002). Nordic Council of Ministers, “Mercury – a global pollutant requiring global initiatives”, Copenhagen 2002. INFORM. http://www.informinc.org/fsmercalts.pdf and http://www.informinc.org/fsmerchealth.pdf Maine DEP. See a detailed comparison of mercury and non-mercury measuring

	devices and instruments performed for the Maine Department of Environmental Protection at www.maine.gov/dep/mercury/lcspfinal.pdf and the proposed strategy based on that report at www.maine.gov/dep/mercury/productsweb.pdf. Following the submission of this strategy, the Maine Legislature enacted a prohibition on the sale of most mercury measuring devices and instruments effective July 2006. Appendix B to the report contains some examples of substantial cleanup expenditures resulting from measuring instrument breakage. RoHS (2003). Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003. (RoHS), OJ L37, 13.2.2003 http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_037/l_03720030213en00190023.pdf COWI (2005). E Hansen, C Lassen, P Maxson, *RoHS substances (Hg, Pb, Cr(VI), Cd, PBB and PBDE) in electrical and electronic equipment – Belgium*, Final Report, COWI & Concorde East/West report for the Belgian Federal Public Service Health, Food Chain Safety and Environment, Directorate-General Environment, Brussels, October 2005.

8.3 Light sources with mercury

Description	Mercury is used in small amounts in a number of different types of discharge lamps, with fluorescent tubes and compact fluorescent lamps (CFLs) as the most common types (COWI, 2002). Over 70% of the mercury-containing lamps sold in Europe and the USA are linear fluorescent tubes (NESCAUM, 1998; COWI, 2005). The remainder are compact fluorescent or specialty lamps (such as metal halide, mercury vapour, high-pressure sodium, and neon lamps) that are produced for commercial or municipal use, such as street lighting (NJ MTF, 2002). Significant progress has been made by some producers to reduce the amount of mercury used per lamp, with reductions of about a factor of 10 achieved in newer mercury lamps as compared to earlier types. Lamps with high mercury content are, however, still on the market, and may still be sold in large quantities as they are generally cheaper than low-mercury lamps. Non-mercury alternatives for these lamps, with similar energy saving specifications, are not yet widely available on the market, although some (e.g. ultra-bright LEDs) are available for specific applications, and others are under development. Other light sources containing mercury include special lamps for photographic purposes, chemical analyses (atomic absorption spectrometry lamps), ultraviolet sterilisation, and back-lighting for flat-screen displays of computers and televisions (COWI, 2002).
Main mercury releases (air, water, soil, production, use, disposal)	The major pathways for mercury releases during the lamp life-cycle include air, soil, wastes/residues, as well as during product use, in the event of breakage, and to a lesser extent, releases to water. Likewise, closed or abandoned (mercury) lamp production sites may be significant sources of ongoing mercury releases to the air, water, and soil.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The most direct way to reduce mercury emissions and exposures in this case is by substituting this mercury use with a mercury-free alternative, when available. For example, LEDs are already used in digital clocks, mobile phones, traffic lights, auto rear/brake lights (e.g., high performance LEDs combined with prism rods), emergency exit signs, some scanners and printers, etc. They can also provide backlighting for small LCD panels. There are also reports of a high-efficiency non-mercury lamp based on the field-emission effect, which is said to be starting production in China (Lightlab, 2005), and a lamp based on diode technology is in research. Lacking broadly available alternatives to mercury lamps, one can only prescribe production/use of energy-efficient lamps with a minimum mercury-content, combined with separate collection and treatment of spent lamps. According to European Commission Decision 1999/568/EC (amended 9 September 2002), for a manufacturer to be allowed to use the European Ecolabel on a single-ended compact fluorescent lamp, the mercury content must not exceed 4 mg, and the life of the lamp must exceed 10,000 hours.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	Low-mercury lamps tend to be more expensive than those with higher amounts of mercury. Incandescent and some other alternative lamps are generally less expensive than energy-efficient lamps, but they have a much higher energy/operating cost.
Actual cases, examples	The European Union has developed and passed two pieces of legislation regulating the content and disposition of electrical and electronic equipment (EEE). Directive 2002/96/EC (WEEE) mainly ensures separate collection and recycling of EEE, while Directive 2002/95/EC (RoHS) bans the use of certain hazardous chemicals –

	including mercury or any components containing mercury – in new equipment marketed after 1 July 2006. The RoHS directive presently includes such EEE as large household appliances, small household appliances, information and communications technology equipment, consumer devices, lighting equipment, electrical and electronic tools, etc. At present, however, due to the lack of widely available energy-efficient alternatives, the EU has specifically permitted continued use of fluorescent lamps with a generally low mercury content, as well as all specialty mercury lamps (see the RoHS Directive for specifics).
Waste management issues, options	The fact of initially producing a product that contains mercury means that the product must forever be managed in a responsible manner. If a mercury product is broken, it becomes a hazard not only to people close to that accident, but also, if the mercury is not properly cleaned up, to people who may live or work in that area in the future. And even if the cleanup is adequate, the mercury waste may be put in the municipal waste rather than hazardous waste. If mercury products go to municipal waste incineration, much of the mercury goes into the atmosphere, depending on the type of flue gas controls. If mercury products go to landfill, the mercury will eventually go into the air, water or soil. If mercury products are collected separately, there is still a considerable cost of collection, as well as hazardous waste disposal or recycling, and related emissions, after which (in the case of recycling) the mercury will likely appear once again on the market. Moreover, since many mercury-containing products have long technical lives, it should be kept in mind that even if a country decides to ban the marketing and use of mercury in most products, it may take decades before most of the mercury in use is collected and removed from human circulation.
Implementation and enforcement, costs, barriers	The cost of separate collection of mercury lamps is high, relative to the amount of mercury releases avoided, and the collection rate is not high in most countries. In order to achieve a rate of collection even above 20%, significant resources must be devoted to public awareness and incentives.
Information sources, references, websites	COWI (2002). ACAP and Danish EPA, Reduction of Atmospheric mercury emissions from Arctic countries – questionnaire on emissions and related topics. November 2002. NESCAUM (1998): The Northeast States and Eastern Canadian Provinces Mercury Study, February 1998. Available on internet at: http://www.cciw.ca/ca/eman-temp/reports/publications/mercury/. NJ MTF (2002): New Jersey Mercury Task Force Report. Volume III. Sources of Mercury in New Jersey. January 2002. Available at website: http://www.state.nj.us/dep/dsr/Vol3-chapter1.pdf. LCSP (2003). An Investigation of Alternatives to Mercury Containing Products, Lowell Centre for Sustainable Production, 22 January 2003, available at http://mainegov-images.informe.org/dep/mercury/lcspfinal.pdf NWF (2002). Mercury Products Guide, Todd Kuiken and Felice Stadler, National Wildlife Federation, Ann Arbor, Michigan, August 2002. Nordic Council (2002). Nordic Council of Ministers, “Mercury – a global pollutant requiring global initiatives”, Copenhagen 2002. Lightlab (2005). See http://www.lightlab.se/english/products/index.htm INFORM. http://www.informinc.org/fsmercalts.pdf and http://www.informinc.org/fsmerchealth.pdf

	COWI (2005). E Hansen, C Lassen, P Maxson, *RoHS substances (Hg, Pb, Cr(VI), Cd, PBB and PBDE) in electrical and electronic equipment – Belgium*, Final Report, COWI & Concorde East/West report for the Belgian Federal Public Service Health, Food Chain Safety and Environment, Directorate-General Environment, Brussels, October 2005.

8.4 Batteries containing mercury

Description	The use of mercury in various types of batteries is decreasing now, but has been extensive; it has been among the largest product uses of mercury in recent decades. Mercury has mainly been used in primary (non-rechargeable) batteries, of which the main ones are described below. Mercury is used in high concentrations (about 30-32% by weight) in mercury oxide batteries (sometimes called zinc-mercury batteries). In the West these have mostly been sold as button cells, but there have also been significant markets for larger cylindrical and other shapes. The sale of mercury oxide batteries is now severely restricted in many countries, while some specific uses (e.g. military applications) may still be exempted, and trade statistics appear to indicate significant ongoing demand (Maxson, 2004). In other battery types the mercury content has been much lower. Previously, alkaline cylindrical cells on the European market had mercury concentrations of around 1%. Due to environmental restrictions, however, the mercury content of cylindrical alkaline batteries has been greatly reduced, and most global battery brands are now produced without intentionally added mercury content. However, some nationally or regionally traded brands of alkaline batteries with mercury added still exist, and may be significant. China, for example, produced some 5 billion mercury-added cylindrical alkaline-manganese batteries in 2004, as well as over 9 billion mercury-added paste-type cylindrical zinc-manganese batteries. Button cell shaped batteries of alkaline, silver oxide and zinc/air types still contain mercury in most cases (at concentrations up to or sometimes exceeding 1% mercury by weight). China may have also produced as many as 10 billion of these batteries in 2004. Note that in addition to plain battery sales, batteries may be imported and exported in substantial amounts enclosed in other products like electronics, toys, greeting cards with sounds, etc.
Main mercury releases (air, water, soil, production, use, disposal)	The major pathways for mercury releases from batteries during the life-cycle include air, soil, wastes/residues, as well as during product use, in the event of damage or corrosion, and to a lesser extent, releases to water. Likewise, closed or abandoned (mercury) battery production sites may be significant sources of ongoing mercury releases to the air, water, and soil.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The primary means to reduce mercury emissions and exposures in this case is by substituting mercury batteries with mercury-free alternatives. With regard to mercury oxide and mercury-zinc (medical) “button cell” batteries, virtually mercury-free zinc-air batteries and other button-cell alternatives (actually still containing less than 10 mg of mercury) have been available for several years. Many manufacturers no longer produce mercury-oxide and mercury-zinc batteries, but they remain a significant problem in the municipal waste stream of most countries. Manufacturers are also beginning to market mercury-free versions of silver oxide, alkaline manganese dioxide (“alkaline”), and zinc air miniature batteries. Some of these batteries seem to be targeted for the European market, but most are intended for worldwide use. The performance characteristics appear to be comparable to the mercury cells. The National Electrical Manufacturers Association (NEMA) of the USA has committed itself to market only mercury-free batteries in the US by 2011. This association does not represent the entire US market, but its

	decisions are influential.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	The costs of the mercury-free batteries mentioned above are not readily available; however, based on pricing provided by one manufacturer, there seems to be a 24-30% premium for the mercury-free miniature batteries compared to the mercury containing batteries. It is expected that this cost difference will gradually disappear as sales volumes and competition increase for mercury-free miniature batteries (COWI, 2005). With regard to mercuric-oxide and mercury-zinc (medical) "button cell" batteries, the cost of alternatives may still be higher than the original mercuric-oxide and mercury-zinc batteries, but municipalities can avoid expensive collection and disposal schemes at the same time. With regard to other types of batteries, while comparisons are difficult across a broad range of batteries (and as battery capacities increase), standard mercury-free batteries generally cost about the same as the batteries they replace.
Actual cases, examples	In the EU, Directives 91/157 and 98/101 set maximum mercury limits for alkaline and button cell batteries, and prohibit the marketing of mercury oxide batteries, although there may still be significant quantities of the latter that transit the EU in trade flows. Likewise, China prohibits the manufacture of mercury oxide batteries, although there is evidence that some production continues (Maxson, 2004). In the USA, the sale of mercury-oxide batteries is now prohibited, but they were previously used in transistorised equipment, hearing aids, watches, calculators, computers, smoke detectors, tape recorders, regulated power supplies, radiation detection meters, scientific equipment, pagers, oxygen and metal monitors, and portable electrocardiogram monitors (US EPA, 1997a).
Waste management issues, options	The fact of initially producing a product that contains mercury means that the product must forever be managed in a responsible manner. Even if a product does not release mercury during its normal lifetime, it must be disposed of properly. If mercury products go to municipal waste incineration, much of the mercury goes into the atmosphere, depending on the type of flue gas controls. If mercury products go to landfill, the mercury will eventually go into the air, water or soil. If mercury products are collected separately, there is still a considerable cost of collection, as well as hazardous waste disposal or recycling, and related emissions, after which (in the case of recycling) the mercury will likely appear once again on the market. Moreover, since many mercury-containing products have long technical lives, it should be kept in mind that even if a country decides to ban the marketing and use of mercury in most products, it may take decades before most of the mercury in use is collected and removed from human circulation.
Implementation and enforcement, costs, barriers	Separate collection of batteries is improving in many countries but still problematic, as well as expensive. Even in the best case, no more than 30% of button cells are collected, and perhaps 50% of larger batteries. The decision to mandate mercury-free batteries is no longer, effectively, a technical decision as much as a political decision. Such a decision requires a major industrial shift which is, however, already well underway in most countries.
Information sources, references, websites	Maxson (2004). Mercury Flows in Europe and the World, 2004. LCSP (2003). An Investigation of Alternatives to Mercury Containing Products, Lowell Centre for Sustainable Production, 22 January 2003, available at http://mainegov-

	images.informe.org/dep/mercury/lcspfinal.pdf NWF (2002). Mercury Products Guide, Todd Kuiken and Felice Stadler, National Wildlife Federation, Ann Arbor, Michigan, August 2002. Nordic Council (2002). Nordic Council of Ministers, “Mercury – a global pollutant requiring global initiatives”, Copenhagen 2002. CRC (2005). Information from Chemical Research Centre, Beijing. INFORM. http://www.informinc.org/fsmercalts.pdf and http://www.informinc.org/fsmerchealth.pdf US EPA (1997a): Locating and estimating air emissions from sources of mercury and mercury compounds. Report EPA-454/R-97-012, (NTIS PB98- 117054), Office of Air Quality Planning and Standards, Research Triangle Park, NC. Available at: http://www.epa.gov/ttn/chief/le/index.html. COWI (2005). E Hansen, C Lassen, P Maxson, *RoHS substances (Hg, Pb, Cr(VI), Cd, PBB and PBDE) in electrical and electronic equipment – Belgium*, Final Report, COWI & Concorde East/West report for the Belgian Federal Public Service Health, Food Chain Safety and Environment, Directorate-General Environment, Brussels, October 2005.

8.5 Pesticides and biocides

Description	Many mercury compounds are toxic to micro-organisms, and mercury compounds have been used as biocides (slimicides) in the paper industry during production, in paints (discussed separately), and on seed grain and other agricultural applications. One of the major uses of mercury compounds as biocides was as seed dressing. These uses have been discontinued or banned in many countries (UNEP, 2002). In the former Soviet Union the production of organomercurial pesticides was initiated in 1955 with a production that reached 200 metric tons/year by 1960. The main compound used was ethyl mercury chloride, but 14 different compounds are known to have used as pesticides in the country. Production of organomercurial pesticides in the Russian Federation has ceased, but it is estimated that in recent years 20-40 metric tons has annually been used from stocks (Lassen et al., 2004). In Australia, a liquid fungicide product containing methoxy-ethyl mercuric chloride is used to control pineapple disease in sugarcane sett (UNEP, 2002). In India the use of organomercurial pesticides in 1999-2000 reported by the Directorate of Plant Protection was 85 metric tons, although production seems to have ceased (Wankhade, 2003). Formerly a number of mercury-based pesticides were used in India, but today most are banned.
Main mercury releases (air, water, soil, production, use, disposal)	While the majority of the product in use will end up on land, some will likely end up in water through disposal of unused amounts, washing of the equipment used, leaching to groundwater, and runoff with surface water. Unused product, including stocks of obsolete pesticides, may be lost or disposed of with normal waste or through special disposal programs.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The main way to reduce mercury emissions and exposures in this case is by replacing this mercury use with a mercury-free alternative. The use of mercury in pesticides and biocides has been discontinued or banned in many countries. Two main alternatives have been promoted in their place: 1) Use of processes not requiring chemical pesticides/biocides, and 2) Easily degradable, narrow-targeted substances with minimal environmental impact.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	Various alternatives have long been in use in many countries. The range of products and applications is too diverse to permit definitive cost comparisons, although it is likely that in the majority of cases the costs of alternatives are roughly comparable, while environmental benefits of substitution are considerable.
Actual cases, examples	The sale and use of pesticides containing mercury for plant protection purposes, and as a seed dressing, have been severely restricted or prohibited/discontinued in a large number of countries throughout the world, although certain limited uses remain in some countries. Lesotho reported that two mercury-based pesticides, used as a dip for potatoes and as a seed dressing for seed-borne diseases in grain crops, have been discontinued. In Colombia, registration of fungicides based on mercury compounds for agricultural use has been cancelled; presently, no registration is active for any mercury-based pesticide (UNEP, 2002). In the EU, the sale and use of pesticides based on mercury compounds for plant protection are prohibited by Directive 79/117/EEU and its

	amendments. This also applies to seed treatment. On the other hand, the export of such preparations to countries outside the European Community is not specifically prohibited by the Directive.
Waste management issues, options	In some countries significant amounts of obsolete pesticides are stored in farmhouses and warehouses under inadequate conditions. In the Russian Federation, for example, the quantity of mercury containing pesticides stored in warehouses, and requiring destruction or storage at special landfills, is estimated to exceed 1,000 metric tons, containing about 20 metric tons of mercury (Lassen et al., 2004).
Implementation and enforcement, costs, barriers	In most cases appropriate legislation is in place to ban the use of mercury compounds for most pesticide and biocide uses. Only adequate enforcement is required.
Information sources, references, websites	Lassen, C. (Ed.), Treger, Y.A., Yanin, E.P., Revich, B.A., Shenfeld, B.E., Dutchak, S.V., Ozorova, N.A., Laperdina, T.G. and Kubasov, V.L. (2004): Assessment of mercury releases from the Russian Federation. Ministry of Natural Resources of the Russian Federation, Danish Environment Protection agency, Arctic Council. Draft, 2004. Wankhade, K.K. (2003): Mercury in India. Toxic pathways. Toxics Link, New Delhi. Available at: http://www.toxicslink.org/pub-view.php?pubnum=35.

8.6 Paints

Description	Phenyl mercuric acetate (PMA) and similar mercury compounds have been widely used as water-based paint additives, and may still be used in some countries. These compounds were used as “in-can” preservatives to extend the shelf life by controlling bacterial fermentation in the can (biocides), as well as to retard fungus attacks on painted surfaces under damp conditions (fungicides). During the Global Mercury Assessment (UNEP, 2002) Thailand reported that less than 25% of the paint factories in Thailand still use mercury compounds as additives, and in quantities of not more than 0.5% of total weight. In Costa Rica, the regulation on the content of lead and mercury in paints sets a maximum limit of 50 ppm (0.005 %) mercury. Australia, Ghana, Guinea, India, Ireland, Samoa and Trinidad and Tobago (mostly discontinued now) have also indicated recent or continued use of mercury in paints (UNEP, 2002), although there is little further information available. In the USA the use of mercury biocides in paint officially ended in 1991. Prior to that, mercury compounds were used in 25 to 30% of all interior latex paints (it was not used in oil-based paints), and in 20 to 35% of outdoor latex paints (Heier, 1990). An estimated 227 metric tons per year of PMA and other mercury compounds were used in paints in the USA between the mid 1960s and 1991 (NJ MTF, 2002). Inorganic mercury compounds of very low solubility have also been used as additives in marine coatings and paints to impede bacteria formation and to hinder the development of marine organisms. This use is believed to have been largely discontinued by the mid-1970s (US DOC, as cited in NJ MTF, 2002).
Main mercury releases (air, water, soil, production, use, disposal)	The major pathways for mercury releases during the paint life-cycle include air and wastes/residues, and to a lesser extent, to the water and soil. Bass (2001) estimated that about 5% of mercury is discharged with wastewater, 3% ends up in municipal solid waste and the remaining 92% is emitted to air from the paint after application. The half-life of mercury on painted surfaces has been estimated to be about one year, i.e., half of the remaining mercury content is released each year (NJMTF, 2002). Therefore, ongoing releases from this source in the USA are now expected to be rather low.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The best means to reduce mercury emissions and exposures from paints is by substituting this mercury use with a mercury-free alternative. There are many alternative formulations available, and they have been in use for many years.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	Alternative paint formulations have long been in use in most countries. Their feasibility and effectiveness have been proven, and their cost is competitive.
Actual cases, examples	In a reported incident of mercury poisoning in 1989 in the US, the walls were painted with latex paint containing 930-955 ppm mercury (MMWR, 1990). The use of mercury in paints has now been substantially reduced or eliminated in a large number of countries. Among others, Mauritius, Cameroon, Costa Rica, Japan, Norway, the USA and Switzerland have

	all discontinued this use (UNEP, 2002). Some paint industries in Thailand have no mercury in their processes or paints since 1991, and are certified as “green label.” The European Union directive 76/769/EEU restricts the marketing and use of certain dangerous substances and preparations, and includes a prohibition of the use of mercury substances in marine anti-fouling paints, wood preservatives, etc.
Waste management issues, options	There is little information about any restrictions or guidelines on the removal or disposal of mercury-based paints. The issues are rather different from those related to lead-based paints, which are mostly concerned with inhalation or ingestion of paint dust and flakes.
Implementation and enforcement, costs, barriers	No further information is available besides that presented above.
Information sources, references, websites	Heier, A. (1990): Use of mercury compounds in indoor latex paint to be eliminated. US EPA Environmental News, JUNE 29, 1990. At: http://www.paint.org/protocol/app-d.cfm). NJ MTF (2002): New Jersey Mercury Task Force Report. Volume III. Sources of Mercury in New Jersey. January 2002. Available at website: http://www.state.nj.us/dep/dsr/Vol3-chapter1.pdf. MMWR (1990): Mercury exposure from interior latex paint -- Michigan. Morbidity and Mortality Weekly report March 1990. Available at: http://www.cdc.gov/mmwr/preview/mmwrhtml/00001566.htm

8.7 Pharmaceuticals for human and veterinary uses

Description	Mercury has been used in various pharmaceuticals such as vaccines, eye drops, some herbal medicines, disinfectants and other products, mainly as a preservative, but also significantly over the years with mercury as the active ingredient. The mercury-added substance could include phenyl mercuric acetate, ethyl thiosalicylate, phenyl mercuric nitrate, ammoniated mercury, mercuric chloride, mercurous chloride, mercuric oxide and other preparations. For a list of hundreds of pharmaceuticals containing mercury, see Premier (2005). For example, thimerosal (ethyl thiosalicylate, also known as thiomersal) has been used for decades in (mostly multi-dose) vaccines to prevent growth of various pathogens after the seal is broken. The use of mercury compounds in vaccines may be more prevalent in countries where vaccines are supplied in multiple-dose units, and where the need for preservatives may therefore be higher. The quantities of mercury are very small compared to other mercury uses such as dental fillings, thermometers, blood pressure gauges, batteries, etc. Nevertheless, the fact that this ethyl mercury compound is injected directly in the human body concerns many people, and there remains significant controversy over whether or not thimerosal in vaccines causes health effects in humans. Based on the precautionary principle, and the goal of reducing human exposure to mercury, some countries are taking steps to reduce mercury in various pharmaceutical products. The use of mercury in vaccines, eye drops and other pharmaceuticals has decreased significantly in recent years (UNEP, 2002). However, production and/or use still occurs in most countries around the world. With regard to veterinary uses, the Australian government reported that a "counter irritant" medication used on horses contains mercuric chloride at 3 g/litre, and is used topically to treat leg injuries, soreness and musculo-skeletal conditions (UNEP, 2002).
Main mercury releases (air, water, soil, production, use, disposal)	The primary pathways for mercury releases from pharmaceuticals are through the body to wastewater or land. Also, unused products may be disposed of as general or hazardous waste depending on customary waste management practices.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The main way to reduce mercury emissions and exposures related to pharmaceuticals is by substituting, reducing or eliminating this mercury use, which could imply an alternative mercury-free chemical used as preservative, a significantly reduced level of thimerosal, or no preservative of any kind. A further option, particular to the use of mercury in cases such as this, where the risk may be more significant for a certain age group or population, is to reduce or eliminate the mercury content of pharmaceuticals used with infants and children. This could be done in combination with a warning label.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	Single-dose vaccines are generally produced without preservatives, but they are typically about 50% more expensive than multi-dose vaccines. According to WHO, there are other chemicals such as 2-phenoxy-ethanol also used as vaccine preservatives; however, WHO believes that thimerosal is better than the alternative preservatives.
Actual cases, examples	In the United States, under the Food and Drug Administration Modernization Act of 1997, FDA is required to assess the risk of all mercury containing food and drugs. Under this provision, FDA in 1999 asked vaccine manufacturers to provide information about the thimerosal

	content of vaccines. Based on this information, the Public Health Service, the American Academy of Pediatrics, and vaccine manufacturers agreed that thimerosal would be phased out of vaccines administered to infants and children as soon as possible (US FDA). According to its Immunization Safety Office, WHO continues to recommend the use of thimerosal-containing vaccines. According to WHO, these vaccines have been used safely throughout the world for decades, helping to save many millions of children's lives. The potential levels of exposure to mercury via thimerosal, and therefore any health risks, will differ in different countries based on the recommended immunization schedule and the specific vaccines used in each country. (WHO, 2001). In the EU, the EMEA completed an 18-month inquiry into the risks and benefits of using thimerosal in vaccines in June 1999. The EMEA concluded that: "Although there is no evidence of harm caused by the level of exposure from vaccines, it would be prudent to promote the general use of vaccines without thimerosal within the shortest possible time-frame" (EMEA, 1999). The EMEA updated its advice on use of thimerosal in vaccines in March 2004. While it rejected any possible connection between thimerosal and "specific neurodevelopmental disorders," it continues to promote the development of vaccines without thimerosal, or with the lowest possible levels of thimerosal. A labelling requirement for thimerosal-containing vaccines was also included, containing a warning with regard to sensitisation to thimerosal (EMEA, 2004). In Denmark, the National Central Laboratory of the Danish Health System has not used thimerosal in vaccines for children since 1992 (Denmark, 2004).
Waste management issues, options	The mercury content in pharmaceuticals is typically at a level that they should be considered as hazardous medical waste and disposed of properly.
Implementation and enforcement, costs, barriers	The issue of mercury in vaccines, especially, has proven to be a contentious and emotional one, including claims, for example, that there may be a link to the rise in cases of autism in children. This should be kept in mind during any stakeholder discussion of the issue.
Information sources, references, websites	Premier (2005). List of pharmaceuticals containing mercury available at http://www.premierinc.com/safety/publications/10-02_downloads/02_HG_drug_list_08-22-02_public.xls US FDA. United States Food and Drug Administration. Thimerosal in Vaccines. http://www.fda.gov/cber/vaccine/thimerosal.htm WHO (2001): Thiomersal in Vaccines – Questions and answers, Department of Vaccines and Biologicals, WHO - http://www.who.int/vaccines-surveillance/ISPP/hotQAthiomersal.shtml EMEA (1999). European Agency for the Evaluation of Medicinal Products, "EMEA Public Statement on Thiomersal Containing Medicinal Products", London, 8 July 1999, Doc. Ref: EMEA/20962/99 http://www.emea.eu.int/pdfs/human/press/pus/2096299EN.pdf EMEA (2004). European Agency for the Evaluation of Medicinal Products, "EMEA Public Statement on Thiomersal in Vaccines for Human Use – Recent Evidence Supports Safety of Thiomersal-Containing Vaccines", London, 24 March 2004, Doc. Ref: EMEA/CPMP/Veg/1194/04/Adopted http://www.emea.eu.int/pdfs/human/press/pus/119404en.pdf Denmark (2004). Indikation 14 July 2004 http://www.dkma.dk/1024/visUKLSArtikel.asp?artikelID=3551

8.8 Cosmetics and related products

Description	Mercury has been used for many years in skin lightening creams, soaps, and as preservatives in some eye cosmetics. The mercury used in skin lightening soaps and creams is inorganic mercury (Hg++). It is combined with iodide or sometimes chloride and becomes a salt. This type of mercury will be absorbed from the skin. The production and use of mercury containing cosmetics has decreased significantly in the West over the past decades. However, several countries around the world continue production and use (UNEP, 2002 and COWI, 2002). This use of mercury is disturbing not only for the health implications, but also because the product is completely diffused to the environment on use. The use of skin lightening cosmetics is reported to be widespread in many African and Asian countries and other parts of the world. Approximately 25% of 210 questioned women in Bamako, Mali, used skin bleaching agents (Mahe *et al*., 1993). Among these, 11% used mercury containing products; whereas 16% used agents of unknown composition. In Dakar, Senegal, 53% of 425 questioned women were current users of a skin bleaching agent that contained 10% mercury iodide (Guidice and Yve, 2002). In Lagos, Nigeria, 77% of 440 interviewed traders (women and men) used skin lightening cosmetics (Adebajo, 2002). Mercury based preparations were not the most prevalent, but they were widely used. And there have been similar surveys and findings in Togo, Kenya, Tanzania, etc. New York newspapers reported in January 2005 a case of mercury poisoning by a person who used a product called Recetas de la Farmacia - Crema Blanqueadora, which was manufactured in the Dominican Republic. Likewise, a sample of Mekako soap purchased in the US in 2004 was found in an NRDC survey to contain nearly 1% mercury. In April 2005 Hong Kong newspapers reported a 39-year-old woman who suffered from mercury poisoning after using Whitening Sunblock Cream bought in South China's Shenzhen city. The Indonesian Food and Drug Control Agency's (BPOM) latest public warning was issued in 2004, when it identified 51 beauty care products containing mercury and Rhodamin B colour additive that were being sold in markets across the country, mostly in Jakarta and Riau provinces. Many of the products were whitening lotions and creams, imported from China and Thailand for consumers seeking fairer complexions. Only three were registered with the agency (Jakarta Post, 2006). The use of mercury containing skin-lightening soap also takes place in European countries, despite an EU-wide ban on their use. In 2000 the Danish EPA found seven types of mercury-containing soaps marketed in Denmark (Danish EPA, 2000). These soaps contained 1-3% mercury iodide. Not long ago a significant amount of mercury was consumed in Europe for production of mercury containing cosmetics which were then exported to other parts of the world. For example, Ireland imported 17 metric tons of mercury in 1999 for use in soaps, which were subsequently exported from the EU (Maxson, 2004).
Main mercury releases (air, water, soil, production, use,	Mercury releases from cosmetics and soaps may occur during production, use and/or disposal of these products. The main pathway for mercury releases is assumed to be to wastewater when the cosmetics are removed by washing. Likewise, whatever is left

disposal)	in pots, tubes and other containers may be disposed of with general waste.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The main way to reduce mercury emissions and exposures from cosmetics is by stopping their use, or substituting this mercury use with a mercury-free alternative. Merely reducing the mercury content is not a viable solution. The use of mercury-containing cosmetics has in recent years been banned in many countries, and their widespread use may no longer take place, for example, in some of the African countries mentioned above. Tanzania now forbids imports, as do South Africa, Cameroon and others (NRDC, 2004). The most common alternative to mercury as an active ingredient in skin lightening soaps and cosmetics is hydroquinone, although corticosteroids are also widely used.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	While hydroquinone and corticosteroids are widely used as active ingredients in skin-lightening preparations, these alternative ingredients are not without risk as well, although their health impacts are different from those associated with mercury. Hydroquinone can cause ochronosis (a blue-black skin discoloration), hyperchromia (when red blood cells have too much haemoglobin), hypochromia (when red blood cells have too little haemoglobin), and/or neuropathy (a disease of the nervous system). Topical steroids, on the other hand, may cause eczema, bacterial and fungal infections, Cushing syndrome, acne, skin atrophy, and pigmentation disorders (NRDC, 2004).
Actual cases, examples	Legislation exists in many countries limiting or prohibiting mercury in cosmetic products. According to Directive76/768/EEU (and its amendments 2000/6/EU and 2000/11/EC) relating to cosmetic products, mercury and its compounds may not be present as ingredients in cosmetics, including soaps, lotions, shampoos, skin bleaching products, etc. (except for phenyl mercuric salts as a preservative in eye make-up, and in products for removal of eye make-up, in concentrations not exceeding 0.007 percent by weight) that are marketed within the European Community. The production (e.g. for export) in the EU of mercury containing cosmetics was also banned in 2003 under Annex 5 of the EU Regulation implementing the Rotterdam Convention. In Cameroon, an Inter-Ministerial Order bans the importation, marketing and use of cosmetic products containing more than 2 percent mercury. Under this order, twelve soaps and thirteen creams were banned (UNEP, 2002).
Waste management issues, options	The mercury content in many of these cosmetic preparations is typically at a level where they should be considered as hazardous waste and disposed of as such.
Implementation and enforcement, costs, barriers	Implementation of restrictions on the mercury content of cosmetic preparations has long been a particular challenge, and requires periodic inspections, testing, etc. It is not only a problem of shopkeepers attempting to circumvent the restrictions. In some cases, the ingredients are not listed on a cosmetic product, or the ingredients are not properly listed. Moreover, even when the ingredients are listed, many or most consumers (and shopkeepers) do not look carefully at the content, or they are not aware of the possible health effects of a mercury ingredient. In Jakarta, Indonesian Consumer Foundation research department head Ida Marlinda recommended that the Food and Drug Control Agency (BPOM) strengthen coordination with other government agencies to overcome the problem. "The agency should also ask Customs and Excise officials to inspect cosmetics that are carried by individuals into the country," she said. “Courts also must hand down tough sentences for

	those guilty of producing or distributing the products," she added. Consumer protection and health laws stipulate people responsible for producing and distributing harmful products face a minimum five years imprisonment or two billion rupee fine if found guilty. "Up to now, I have never heard of any court handing down heavy punishment to the perpetrators," she said. The BPOM argues that its efforts have been successful through the National Food and Drugs Monitoring System, known as SISPOM, that involves producers, the government and the public. "We all need to work together because this problem inflicts losses on everyone. However, public monitoring is the most vital because the people should be empowered to protect themselves," said the agency's director of traditional medicines, cosmetics and complementary products, Mufrihatu Hayatie Amal (Jakarta Post, 2006).
Information sources, references, websites	COWI (2002). ACAP and Danish EPA, Reduction of Atmospheric mercury emissions from Arctic countries – questionnaire on emissions and related topics. November 2002. Mahe et al. (1993). Mahe, A., Blanc, L., Halna, J.M., Keita, S., Sanogo, T. and Bobin, P. (1993): An epidemiologic survey on the cosmetic use of bleaching agents by the women of Bamako (Mali). *Ann. Dermatol. Vernereol* 120: 870-873. (In French) Guidice and Yve (2002). Del Guidice, P and Yves, P. (2002): The widespread use of skin lightening creams in Senegal: a persistent public health problem in West Africa. *The International Journal of Dermatology* 41: 69-72. Adebajo (2002). Adebajo S.B. (2002): An epidemiological survey of the use of cosmetic skin lightening cosmetics among traders in Lagos, Nigeria. *West African Journal of Medicine* 21: 51-55. Danish EPA (2000): Warning: Sale of mercury soaps is banned. Danish Environmental Protection Agency. Available at. http://www.mst.dk/news/02010000.htm. Maxson (2004). Mercury Flows in Europe and the World, 2004. NRDC (2004). "Mercury in Soaps and Cosmetics for Skin Lightening," presentation by L. Greer Ph.D. (NRDC, Washington, D.C.) at the Regional Awareness-Raising Workshop On Mercury Pollution: A global problem that needs to be addressed, Pretoria, South Africa, 1-4 June 2004. Available at http://www.chem.unep.ch/mercury/ Jakarta Post (2006). Tb. Arie Rukmantara, "Risky cosmetics still on store shelves," *The Jakarta Post*, 15 April 2006. http://www.thejakartapost.com/misc/PrinterFriendly.asp

9.0 Other intentional products/process uses

9.1 Dental mercury amalgam fillings

Description	Dental amalgam fillings consist of an alloy of mercury, silver, copper and tin (typically just under 50% mercury by weight). The alloy is usually supplied to dentists either 1) as pure mercury along with a powder mix of the other metals, which are weighed and mixed in the clinic; or 2) as small capsules where mercury and the metal powder are present in the right proportions and need only to be mixed (in the capsule before opening) in the clinic, prior to filling the cavity in the tooth (COWI, 2002).
Main mercury releases (air, water, soil, production, use, disposal)	Mercury is released to air, water, and wastes during the production, use and disposal of amalgam fillings (especially during the placing of fillings and the removal of fillings or teeth containing fillings, but also a low level of mercury vapour is released from fillings during normal wear). Also, releases can occur after the death of a person with fillings, e.g. dental amalgams are a major source of mercury releases to air from cremation (see section on cremation).
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The primary methods to reduce mercury emissions and exposures from dental fillings are by taking various measures to reduce wastes during dental treatment, and by substituting mercury amalgams with a mercury-free alternative. Mercury releases from dental practices may be reduced by preparing mercury amalgams more efficiently, and by installing appropriate traps in the wastewater system. As a result of technological advances in recent years, various newer alternatives (cold silver, gallium, ceramic, porcelain, polymers, composites, glass ionomers, etc.) to mercury amalgam fillings are commercially available. However, the Danish National Board of Health does not consider the alternatives capable of substituting for mercury amalgam in all cases (e.g. fillings in adult molars), and this is also the current Swedish position. On the other hand, even the substitutes that may be routinely used are not yet widely known or accepted in many countries, as dental practitioners generally find it easier to continue using the techniques with which they are most familiar.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	With regard to reducing mercury emissions through waste, there are available modern high-efficiency amalgam filters that are placed in the dental clinic wastewater system. If properly maintained, they may collect over 90% of the amalgam in the clinic wastewater. If only the coarse mesh filters (strainers) are used, most of the amalgam - perhaps 80-90% based on the Danish studies - is lost to the public wastewater system or released to the environment. Amalgam waste (excess amalgam from new fillings, in collected filter material and in extracted or lost teeth) may be collected separately for recycling or other treatment as hazardous/medical waste, or it may be disposed of with general waste to landfills, incineration or other waste treatment. The amount of mercury discharged by a dentist office is dependent on various factors, including whether filters (or “chairside traps”) are used. One study reported that an average of 2g mercury per dentist per day may be discharged if no filtration is used (Drummond *et al*., 1995, as cited in NJ MTF, 2002). If chairside traps are used, 60-70% of the mercury may be captured before getting to the wastewater (NJ MTF, 2002). Some facilities also use additional filter systems such as vacuum filters or air/water separators that collect additional, smaller mercury particles (NJ MTF, 2002). The cost is not high for professional dentists. Modifications required in dental offices to reduce mercury emissions are straightforward to install and operate, and are relatively inexpensive. For example, it costs dentists between $US37 and $100 per month to prevent mercury releases down the drain (MPP, 2006).

	With regard to amalgam substitutes, some alternatives are less expensive and some are more expensive than mercury amalgams, some are as easy to apply and others are more difficult, but none of the alternatives require the specialized wastewater treatment equipment that dental professionals need to meet environmental regulations in many countries. The shares of dental filling materials, estimated recently by weight, in Sweden, are approximately: composites (78%), glass ionomers (13%), amalgam (6%), compomers (3%) and ceramic (1%) (KEMI, 2005). Since composites are lighter than amalgam, one kilo of composites represents many more teeth repaired than one kilo of amalgam. The American Dental Association has estimated that when the initial price and longevity of the two filling types are compared, composites cost 1.7 to 3.5 times more than amalgam (HSER, 2005). This comparison does not consider, however, the "bigger picture" of mercury costs, e.g. possible health effects related to dental mercury, the cost of filters or other equipment to remove mercury from wastewater, etc.
Actual cases, examples	In New Jersey (USA), the mercury-contaminated material captured by traps and other control devices is generally sent to municipal solid waste or recycled (NJ MTF, 2002). Regarding amalgam wastes in the wastewater, an estimated 80% of the dental clinics in Denmark have high-efficiency central filters which may retain up to 95% of the amalgam waste in the wastewater, while the remaining 20% of clinics are assumed to not have these filters. For the clinics that have coarse mesh filters only, and do not have high efficiency filters, it is estimated that only 20-50% of the mercury in the wastewater is retained in the filters and disposed of to hazardous waste, municipal waste or recycling (Skårup *et al.*, 2003). A recent study in Sweden reveals that dental amalgam has been replaced almost totally by other materials during the last six to seven years (KEMI, 2005).
Waste management issues, options	The amounts of dental amalgam used per person reflect both the general dental care standard in the population, and the extent of use of alternative dental filling materials (plastic composites, ceramics or cast gold crowns). In the dental clinic some of the mixed amalgam filling is placed in the cavity, but there is always some waste, which is often collected for waste disposal or recycling (especially due to the silver value). Normally the filling needs a final adjustment, which releases amalgam particles to the wastewater system. Also during routine renewal of amalgam fillings, the old filling is drilled out and amalgam particles go to the wastewater system – with or without screens, traps, etc. In addition, teeth with amalgam fillings may be removed in the clinic, and disposed of as general waste or separately collected hazardous waste, or sent for recycling. In Denmark, and surely in other countries, a substantial number of extracted teeth are sent to dental schools for use in practical dentist teaching (Maag *et al.*, 1996; Skårup *et al.*, 2003). The fact of initially placing in someone's tooth an amalgam that contains mercury means that, completely apart from any health implications, the mercury must later be managed in a responsible manner. If an amalgam is removed, it becomes hazardous waste, which should be properly collected, but which is often flushed to wastewater. If mercury amalgam waste goes to municipal waste incineration, much of the mercury goes into the atmosphere, depending on the sophistication of flue gas controls. If mercury amalgam waste goes to landfill, the mercury will eventually go into the air, water or soil. If mercury amalgam waste is collected separately, there is still a considerable cost of collection, as well as hazardous waste disposal or recycling, and related emissions, after which (in the case of recycling) the mercury will likely appear once again on the market. Moreover, since amalgams may last 10-20 years, it should be kept in mind that even if a country decides to phase out the use of mercury in dental amalgam, it

	will be decades before most of the mercury in use is removed from human circulation.
Implementation and enforcement, costs, barriers	A number of countries have put in place measures to reduce or even phase out the use of mercury in the dental sector. In addition to the use of amalgam separators to substantially reduce the amount of mercury discharges through wastewater from dental clinics (combined with appropriate service to maintain the effectiveness of these systems), some countries are also promoting the substitution of mercury-containing amalgam fillings, especially among sensitive populations including pregnant women, children and those with impaired kidney functions. Denmark and Sweden are perhaps the countries that have gone farthest in eliminating the use of mercury-containing amalgam. The Swedish Government's overall goal to phase out mercury also includes dental amalgam. In Sweden, where dental amalgam has been subject primarily to voluntary phasing out measures, the consumption of mercury for dental use has decreased significantly after a policy decision by the Parliament in 1994 to phase out the use of dental amalgam. In Denmark, dental amalgam is allowed only in molar teeth where the filling is subject to wear, but the Government is ready to ban the remaining use of dental amalgam as soon as the Danish National Board of Health is satisfied that the non-mercury alternatives are adequate for all requirements. Norway has also developed a directive (from 1 January 2003) on the use of dental filling materials, which encourages dentists to reduce the use of amalgam as much as possible. The directive is expected to take effect. The European Parliament resolution on the European Environment & Health Action Plan 2004-2010 - Article 6, declared that, consistent with the "opinion of the relevant Scientific Committee, urgent consideration should be given to restricting the marketing and/or the use of mercury used in dental amalgams … to which newborn babies, children, pregnant women, elderly persons, workers and other high-risk sections of the population are heavily exposed, as safer alternatives become available" (European Parliament, 2005). In New Zealand, a "Practice guideline - controlling dental amalgam waste and wastewater discharges" has been adopted. It recommended that amalgam waste should be collected, stored and sent for recycling, or for disposal at an approved landfill when collection for recycling is not available. Also, amalgam scrap and contaminated particulate amalgam waste should not be disposed of in any medical waste to be incinerated. Dental surgeries should use systems to reduce amalgam discharge to wastewater, including amalgam separators where local authorities require. It has issued precautionary advice for dentists and pregnant women. It recommended that amalgam should be used with informed consent of patients (UNEP, 2002).
Information sources, references, websites	http://www.newmoa.org/prevention/topichub/toc.cfm?hub=103&subsec=7&nav=7 COWI (2002). ACAP and Danish EPA, Reduction of Atmospheric mercury emissions from Arctic countries – questionnaire on emissions and related topics. November 2002. NJ MTF (2002): New Jersey Mercury Task Force Report. Volume III. Sources of Mercury in New Jersey. January 2002. Available at website: http://www.state.nj.us/dep/dsr/Vol3-chapter1.pdf. KEMI (1998), Submission from the Nordic Council of Ministers, Gustafsson (2001), US EPA (1997) LCSP (2003). An Investigation of Alternatives to Mercury Containing Products, Lowell Centre for Sustainable Production, 22 January 2003, available at http://mainegov-images.informe.org/dep/mercury/lcspfinal.pdf NWF (2002). Mercury Products Guide, Todd Kuiken and Felice Stadler, National Wildlife Federation, Ann Arbor, Michigan, August 2002. Nordic Council (2002). Nordic Council of Ministers, "Mercury – a global pollutant

	requiring global initiatives", Copenhagen 2002. INFORM. http://www.informinc.org/fsmercalts.pdf and http://www.informinc.org/fsmerchealth.pdf HCWH. See Health Care Without Harm websites www.noharm.org/mercury/mercuryFree for a list of pharmacies no longer selling mercury fever thermometers and www.noharm.org/mercury/ordinances for a list of laws prohibiting mercury fever thermometer sales in the United States Maine DEP. See a detailed comparison of mercury and non-mercury measuring devices and instruments performed for the Maine Department of Environmental Protection at www.maine.gov/dep/mercury/lcspfinal.pdf and the proposed strategy based on that report at www.maine.gov/dep/mercury/productsweb.pdf. Following the submission of this strategy, the Maine Legislature enacted a prohibition on the sale of most mercury measuring devices and instruments effective July 2006. Appendix B to the report contains some examples of substantial cleanup expenditures resulting from measuring instrument breakage. MPP (2006). What Patients Don't Know: Dentists' Sweet Tooth for Mercury, Mercury Policy Project, Consumers for Dental Choice, New England Zero Mercury Campaign, Sierra Club California, Clean Water Action California, 14 February 2006. Available at www.mercurypolicy.org HSER (2005). State Considers Ban On Use Of Mercury In Dental Fillings - Little Or No Health Risk Seen But Ban May Help Remove Element From Environment, by JUDY BENSON, Health/Science/Environment Reporter, published 5/9/2005. KEMI (2004). KEMI - Swedish Chemical Inspectorate. Mercury – Investigation of a general ban. http://www.kemi.se/upload/Trycksaker/Pdf/Rapporter/Rapport4_04.pdf KEMI (2005). KEMI – Swedish Chemical Inspectorate, Nr.9/05 Mercury-free Dental Fillings; Phase out of amalgam in Sweden, December 2005. Skårup, S., Christensen, C.L., Maag, J. and Jensen, S.H. (2003): Substance Flow Analysis for Mercury. Environmental project no. 808, The Danish EPA, 2003(in Danish with summary in English). Available at www.mst.dk. Since 2004 also available in English at same website. Maag, J., Lassen, C. and Hansen, E. (1996): Massestrømsanalyse for kviksølv (substance flow assessment for mercury). *Miljøproject* no. 344, 1996, Danish Environmental Protection Agency, Copenhagen (in Danish with summary in English). Available at www.mst.dk; publikationer European Parliament (2005). http://www2.europarl.eu.int/omk/sipade2?PUBREF=-//EP//TEXT+TA+P6-TA-2005-0045+0+DOC+XML+V0//EN&LEVEL=3&NAV=X

9.2 Manometers and pressure gauges

Description	Mercury is used in a variety of blood pressure gauges, industrial and meteorological manometers, and pressure valves (UNEP, 2002). Blood pressure gauges marketed by suppliers are still mostly mercury models, although mercury-free devices exist. For pressure valves in district heating and educational uses, metallic mercury is often supplied separately rather than together with the product. For all mercury pressure devices, mercury may be added at different times during use. In the same manner, the mercury may eventually be disposed of with the apparatus or separately. Non-mercury alternatives exist for all of these devices and are gradually substituting for them in an increasing number of countries (Maag *et al.*, 1996, as cited in COWI, 2002).
Main mercury releases (air, water, soil, production, use, disposal)	Like for other products containing mercury, releases may take place: 1) from production of gauges/manometers supplied with mercury (to air, water and soil), depending on how well isolated the manufacturing systems are, and on the relevant workplace practices; 2) by damage to or loss of mercury from gauges/manometers (to air, water/wastewater, soil) during use, and; 3) during disposal of the mercury with or without manometers/gauges/valves after use (releases directly to soil or landfill, and subsequently to water and air), depending on the type and efficiency of the waste handling procedures (COWI, 2002). Mercury may be released from manometers and valves during use, as it is often necessary to top up the mercury. Mercury may also be released from valves in district heating plants, where each valve may contain several hundred kilograms of mercury. These have been shown to be significant sources of mercury to municipal waste treatment plants in Denmark (Markmann *et al*., 2001).
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The principal way to reduce mercury emissions and exposures from manometers and pressure gauges is by substituting this application with mercury-free alternatives. The product group is very diverse, including many different types of device. Nevertheless these devices can be roughly viewed as two main types: 1) Applications where mercury is used as a “heavy liquid” in pressure gauges, pressure switches and pressure transmitters. All of these may be substituted without any loss of accuracy or reliability. Three main technologies are used: • flexible membranes; • piezoelectric crystals and other sensors in which some physical property changes when the pressure changes; and • fibre-optic pressure sensors, based on light transmission. 2) Applications where mercury is used to continuously indicate pressure differentials, such as U-tube meters, barometers, and manometers. In these devices mercury can be replaced by another liquid, by gas or by other techniques. For example: mercury pressure switches can be used to measure pressure or vacuum differentials. They can be replaced by the same techniques as for pressure gauges (above), but they are also equipped with a non-mercury breaker switch; and for remote transmission of measurement readings, a pressure transmitter is often used. A special (mercury) pressure transmitter is a circular tube which may contain up to 8 kg of mercury. Substitutes include a potentiometer or a differential transformer to measure pressure changes and to transmit an electronic signal. The most common alternative device is a diaphragm sensor.
Assessment of	Pressure measuring devices have been extensively analysed, mercury-

options (feasibility, costs, benefits, advantages, disadvantages)	free alternatives have been identified and costs have been examined and shown comparable. There are mercury-free alternatives which are commercially available for practically all sub-categories of manometer. This has enabled a near phase-out of mercury use in these devices in some countries. Where the costs of alternatives are not comparable, the alternatives often outperform the mercury-containing devices in terms of longevity and faster performance. Moreover, the costs of alternatives always decrease once the alternatives become more commonly used. Alternatives based on gas, other liquids or a mechanical spring show no significant differences in price, compared to mercury devices. Alternatives in the form of electric and electronic instruments are only slightly more expensive, but have several advantages over mercury (UNEP, 2002).
Actual cases, examples	There is an impressive track record of medical institutions that have made the transition to non-mercury equipment. There is also considerable information readily available in the public domain that demonstrates that the obstacles to this transition are more often a matter of education and training, than availability and functionality of non-mercury equipment (see websites below for “Healthcare initiatives”). Individual countries in Europe have already taken action to ban or restrict the use of some or all products containing mercury. Countries such as Denmark, France, the Netherlands, Sweden, Norway, Canada and the US (some states in the US are more progressive than others in this respect) have done so, while permitting specific exemptions for specialized uses where adequate alternatives do not yet exist. The experiences of Sweden and Denmark, in particular, where such restrictions are more comprehensive than most, and have been in place for many years; the experience of the United States, where many hospitals have shifted very seriously to a mercury-free policy; and detailed studies comparing the cost and functionality of mercury and non-mercury products all demonstrate the feasibility of halting the sales of most mercury-containing measuring devices and instruments.
Waste management issues, options	The fact of initially producing a product that contains mercury means that the product must forever be managed in a responsible manner. If a mercury product is broken, it becomes a hazard not only to people close to that incident, but also, if the mercury is not properly cleaned up, to people who may live or work in that area in the future. And even if the cleanup is adequate, the mercury waste may be put in the municipal waste rather than hazardous waste. If mercury products go to municipal waste incineration, much of the mercury goes into the atmosphere, depending on the type of flue gas controls. If mercury products go to landfill, the mercury will eventually go into the air, water or soil. If mercury products are collected separately, there is still a considerable cost of collection, as well as hazardous waste disposal or recycling, and related emissions, after which (in the case of recycling) the mercury will likely appear once again on the market. Moreover, since many mercury-containing products have long technical lives, it should be kept in mind that even if government authorities decide to ban the marketing and use of mercury in most products, it may take decades before most of the mercury in use is collected and removed from human circulation.
Implementation and enforcement, costs, barriers	The European Parliament resolution on the European Environment & Health Action Plan 2004-2010 - Article 6, declared that, consistent with the “opinion of the relevant Scientific Committee, urgent consideration should be given to restricting the marketing and/or the use of mercury

	used in … non-electrical or non-electronic measuring and monitoring devices … to which newborn babies, children, pregnant women, elderly persons, workers and other high-risk sections of the population are heavily exposed, as safer alternatives become available" (European Parliament, 2005).
Information sources, references, websites	COWI (2002). ACAP and Danish EPA, Reduction of Atmospheric mercury emissions from Arctic countries – questionnaire on emissions and related topics. November 2002. Maag, J., Lassen, C. and Hansen, E. (1996): Massestrømsanalyse for kviksølv (substance flow assessment for mercury). Miljøproject no. 344, 1996, Danish Environmental Protection Agency, Copenhagen (in Danish with summary in English). Available at www.mst.dk; publikationer Markmann P. N., Jensen, P. and Abildgård, J. (2001): Old heating plants still cause mercury pollution. NyViden from the Danish EPA. Available at: http://www.mst.dk/project/NyViden/2001/11230000.htm. LCSP (2003). An Investigation of Alternatives to Mercury Containing Products, Lowell Centre for Sustainable Production, 22 January 2003, available at http://mainegov-images.informe.org/dep/mercury/lcspfinal.pdf NWF (2002). Mercury Products Guide, Todd Kuiken and Felice Stadler, National Wildlife Federation, Ann Arbor, Michigan, August 2002. Nordic Council (2002). Nordic Council of Ministers, "Mercury – a global pollutant requiring global initiatives", Copenhagen 2002. UNEP (2002). Global Mercury Assessment, UNEP, December 2002. INFORM. http://www.informinc.org/fsmercalts.pdf and http://www.informinc.org/fsmerchealth.pdf Maine DEP. See a detailed comparison of mercury and non-mercury measuring devices and instruments carried out for the Maine Department of Environmental Protection at www.maine.gov/dep/mercury/lcspfinal.pdf, and the proposed strategy based on that report at www.maine.gov/dep/mercury/productsweb.pdf. Following the submission of this strategy, the Maine Legislature enacted a prohibition on the sale of most mercury measuring devices and instruments effective July 2006. Appendix B to the report contains some examples of substantial cleanup expenditures resulting from measuring instrument breakage Healthcare initiatives. See www.sustainablehospitals.org, www.inform.org and www.h2e-online.org for detailed information regarding non-mercury alternatives in the health-care setting European Parliament (2005). http://www2.europarl.eu.int/omk/sipade2?PUBREF=-//EP//TEXT+TA+P6-TA-2005-0045+0+DOC+XML+V0//EN&LEVEL=3&NAV=X

9.3 Laboratory chemicals and equipment

<table>
<tr>
<td>Description</td>
<td>In addition to the thermometers, manometers, etc., discussed previously, mercury and mercury compounds are used in laboratories in instruments that include the blood gas analyser, mercury electrodes (calomel), blood lead analyser, mercury drop electrode, Coulter counter, centrifuge, electron microscope, not to mention thermostats, thermometers, and other measuring devices, as well as mercury-containing lamps for atomic absorption spectroscopy and various other applications.
Mercury and mercury compounds are used in laboratories as reagents, preservatives, and catalysts in a great variety of applications such as:
<table>
<tr><td>Mercuric sulphate, $HgSO_4$</td><td>Chemical oxygen demand (COD) analysis.
In laboratory electrochemistry for creation of electrochemical chains.
Flame photometer.</td></tr>
<tr><td>Mercuric chloride, $HgCl_2$</td><td>Ingredient of Zenker's solution (72 g Hg/L) and B5 (37 g Hg/L), a tissue fixative for pathology, histology.
Ingredient of Hayem's Solution for red blood cell count.</td></tr>
<tr><td>Mercurous chloride, Hg_2Cl_2, calomel</td><td>For preparation of reference electrodes.</td></tr>
<tr><td>Mercuric oxide, HgO</td><td>Catalyst for detection of nitrogen in organic compounds using Kjeldahl method (other catalysts may be used as well).</td></tr>
<tr><td>Metallic mercury</td><td>Determining fluoride purity and its concentration in gases.
Creation of new superconducting materials.
Development of new gas-discharge devices.
Laboratory electrochemistry.</td></tr>
<tr><td>Mercury fluoride, Hg_2F_2</td><td>For preparation of reference electrodes.</td></tr>
<tr><td>Mercury bromide, Hg_2Br_2</td><td>For preparation of electrolytes.</td></tr>
<tr><td>Mercuric nitrate, $Hg(NO_3)_2$</td><td>Determination of chlorides in blood, etc.</td></tr>
</table>
</td>
</tr>
<tr>
<td>Main mercury releases (air, water, soil, production, use, disposal)</td>
<td>A small percentage of the mercury from lab equipment and chemicals (except in the event of breakage or spills) may be emitted to the air in laboratories, and released to the surroundings though air exhausts from fume hoods. The majority of the mercury in lab equipment will not be released until the equipment is disposed of, while most mercury in laboratory chemicals will be disposed of with used reagents. The fate of mercury waste depends on the systems for management of laboratory waste in different countries or regions. The waste may be disposed of properly as hazardous waste, or it may be sent to municipal waste, landfill or discharged though wastewater (treated or untreated) to the sewer.</td>
</tr>
<tr>
<td>Mercury reduction options (alternative technologies, other mercury reduction strategies)</td>
<td>The best way to reduce mercury emissions and exposures from these sources is by substituting these mercury uses, to the extent possible, with mercury-free alternatives. Most suppliers who sell mercury equipment for lab use also sell mercury free alternatives.
For example, the mercury column of various pressure measuring devices may be replaced with a gallium-indium-tin mixture or other “proprietary” formulas, among others. Alternatively, mercury containing pressure measuring devices may be replaced by mechanical devices using a piston, diaphragm, bellows, or combination piston/diaphragm as the pressure sensor. Or they may be replaced by solid-state devices containing one or more strain gauge pressure sensors, a transmitter, and one or more switches – all in a compact package.
Likewise, there are infrared and other electronic temperature measuring devices, etc.
In the case of mercury containing chemicals, while some standard uses of mercury may be difficult to substitute in practice, it is generally possible to restrict mercury use in school and university laboratories to a few specific, controllable uses (mainly</td>
</tr>
</table>

	references and standard reagents). For example, B-5 fixative or Zenker's Solution may be replaced by Acetic Zinc Formalin Working Solution or another formula containing formaldehyde and zinc (which may have their own disposal requirements), zinc chloride solution, etc., depending on the application. Likewise, Hayem's Solution may be replaced by an alcohol, acetic acid, aluminium-ammonium sulphate, and/or sodium iodate solution. If such substitutions are not possible, for some reason, there are various methods for removing mercury from exhaust and wastewater systems. A number of manufacturers, for example, provide mercury removal equipment for clinical laboratories, histology laboratories, pathology laboratories and research laboratories.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	As in the case of thermometers, manometers and other equipment discussed in previous sections, not only is the cost of mercury-free substitutes nearly always competitive, but there are other savings to be gained as well, such as reduced employee safety training and precautions, reduced cleanup costs in the event of breakage, reduced equipment and disposal costs, etc. With regard to the mercury compounds typically used in labs, although the total consumption of mercury is rather low, and most uses may be substituted, the barriers to change may be significant. Some of the present standards were developed around the use of certain mercury compounds, and they are sometimes considered necessary in order to reliably reproduce certain analyses. In addition, technicians tend to favour the procedures they know well and have long used.
Actual cases, examples	The Health Care Without Harm website gives a long list of mercury-free laboratory and medical equipment, as well as laboratory chemicals (HCWH, 2006). Measures designed to greatly reduce the use of mercury in laboratory equipment and chemicals have already been implemented in Swedish and Danish legislation. The alternatives are generally no more expensive, and the need for control of mercury sources in the laboratory is greatly reduced. Specifically, in Denmark the use of mercury with laboratory chemicals has decreased from about 510 kg/year in 1982/83 (Hansen, 1985) to 20-40 kg/year in 2001 (Skårup *et al.*, 2003). The main reason for the decrease is the substitution of mercury for nitrogen analysis in organics using the Kjeldahl method, which formerly accounted for much of the total. In 2001, mercury sulphate used for chemical oxygen demand (COD) analyses accounted for most of the mercury used with laboratory chemicals. Kaiser Permanente, America's largest not-for-profit health maintenance organization, estimated that based on the percentage of mercuric chloride in average volumes of solution, their substitution of Z-5 and other mercury-free solutions has eliminated roughly 10 pounds (nearly 5 kg) of soluble mercury disposed of in California each year. Further, the company has reported that the cost of disposal of Z-5 (in accordance with California regulations) is about 10% of the cost of disposing of mercuric chloride (HCWH, 2006).
Waste management issues, options	In the Russian Federation, laboratories are obliged to neutralize their mercury-containing wastes. In general, the wastes are then transported to landfills, but small laboratories may, after neutralization, heavily dilute the reagent wastes and then discharge them to the sewerage system (Lassen *et al*., 2004). The practice of dilution of wastes is not permitted in the US or the EU, among other countries.
Implementation and enforcement, costs, barriers	As mentioned above, some standard analyses are difficult to substitute in practice, even though substitutes are often available. Effective change may require a gradual transition in the scientific culture, a concrete shift to parallel or new testing protocols, as well as changes in some testing standards or public regulations that may specifically mandate mercury-based testing equipment or reagents.
Information sources, references, websites	HCWH (2006). See website http://www.sustainablehospitals.org/cgi-bin/DB_Report.cgi?px=W&rpt=Haz&id=2 Hansen, E. (1985): Forbrug og forurening med kviksølv i Danmark [Consumption of and pollution with mercury in Denmark]. Danish Environmental Protection Agency, Copenhagen. (In Danish) Skårup, S., Christensen, C.L., Maag, J. and Jensen, S.H. (2003): Substance Flow Analysis for Mercury. Environmental project no. 808, The Danish EPA, 2003.

	Available at www.mst.dk. Lassen, C. (Ed.), Treger, Y.A., Yanin, E.P., Revich, B.A., Shenfeld, B.E., Dutchak, S.V., Ozorova, N.A., Laperdina, T.G. and Kubasov, V.L. (2004): Assessment of mercury releases from the Russian Federation. Ministry of Natural Resources of the Russian Federation, Danish Environment Protection agency, Arctic Council. Draft, 2004.

9.4 Mercury metal use in religious, cultural rituals and folklore medicine

Description	In many urban areas of the United States, stores known as *botánicas* (stores that sell remedies and religious items) sell a variety of herbal remedies, cultural and religious items used in certain Latino and Afro-Caribbean traditions, including *Santería*, *Palo*, *Voodoo*, and *Espiritismo*. These traditions mostly evolved from native faiths brought to the US, the Caribbean and Latin America by African slaves. It is important to note that these practices were vigorously suppressed by slave owners over hundreds of years, and their survival was only assured by disguising them in European religious traditions. Thus, many of the figures were renamed for Catholic saints, and there often considerable sensitivity to any external scrutiny (USEPA, 2002). In these traditions, metallic mercury, often sold under the name *"azogue"* in capsules containing 8-9 grams of mercury, is used to attract luck, love, good health or money; to protect against evil; or to speed the action of spells through a variety of recommended uses, including carrying mercury in a sealed pouch prepared by a spiritual leader, wearing it as an amulet, sprinkling it on the floor or in an automobile, mixing it with perfumes or adding it to devotional candles or oil lamps. For pharmaceutical purposes it is also sometimes taken internally to treat gastrointestinal disorders, or added to bath water, detergent or cosmetic products (NJ MTF, 2002). Surveys in Massachusetts, New York, and Chicago (all cities in the USA) found that about 20-40 percent of Hispanic respondents reported sometimes using mercury for magic or religious purposes. Researchers estimated that this use of mercury is likely to cause long-term contamination of more than 13,000 homes or apartment buildings in New York City each year, where toxic vapours can linger for months or even years, leading to possible neurological and respiratory symptoms in apartment residents (NRDC, 2004). In India and Pakistan, and among some expatriate communities, the science of mercury is known as Rasa Vidya in Ayurveda. Ayurveda contends that various minerals such as mercury, some of them toxic, can by certain procedures be made into medicines. In 2004, a medical researcher purchased 70 traditional Ayurvedic preparations imported from India and Pakistan at Boston-area (USA) South-Asian grocery stores. 14 of the preparations were found to contain potentially toxic levels of mercury, lead and/or arsenic. These preparations were marketed to treat illnesses ranging from colic in children to urinary tract infections (reported by *Reuters News Service*, 15 December 2004). Likewise, in Hindu scriptures, *parad* (mercury) is regarded as the best of all metals. The opportunity to touch and worship a *parad Shivalinga* (statue or icon) is believed by some to reward one's holy and good deeds done in the previous and present life. If one meditates beside a *parad Shivalinga*, it is believed the mind naturally gets concentrated. Mercury is used in such statues, objects and amulets throughout Hindu areas of India for a range of health-related, ceremonial and religious purposes. Mercury is also used in many Asian (especially Chinese) medicines. Ernst and Coon (2001) reported that dozens of Chinese medicines contain Cinnabaris – a complex of sulphides that contain mainly mercuric sulphide; Calomelas – mercurous chloride (calomel); or Hydrargyri oxydum rubrum – red mercuric oxide. (See also Guangdong, 1997.) No doubt these are among the approximately 1000 homeopathic products identified by the US Food & Drug Administration to contain mercury in varying amounts (Maxson, 2004).

Main mercury releases (air, water, soil, production, use, disposal)	Mercury used in these practices could ultimately be released to air, wastewater, or to municipal solid waste. Mercury vapours are released if the mercury is not contained in sealed containers. Such practices as sprinkling it in homes and automobiles, and especially burning it in candles and oil lamps, increase the rate of vaporization. Persons using some of these folk medicines, or participating in certain religious or ethnic practices, may expose themselves and their families to the effects of metallic mercury. Because it vaporizes into the air at room temperature, mercury presents a health risk to anyone spending a significant amount of time in a room where metallic mercury has been sprinkled or spilled onto the floor, where opened containers of metallic mercury are present, or even where mercury-amalgam icons or statues are present. Very small amounts of metallic mercury (for example, a few drops) can raise air concentrations to levels that may be harmful to health (NRDC, 2004).
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The main way to reduce mercury emissions and exposures in religious, cultural and medicinal uses is, first, to avoid using metallic mercury or mercury-containing preparations or objects, and second, to reduce any uses as much as possible. The special problem here is that many of these uses are not rational choices, but rather traditional customs, religious obligations, etc. In such cases, if one cannot eliminate the uses of mercury, one must at least try to limit the health and environmental effects. Apart from these cultural and religious uses of mercury, alternatives are available for virtually all of the medicinal preparations. Therefore, in light of possible health and environmental effects, one should carefully question the purpose and need for using mercury in these ways. If a substitute is considered adequate, one should make arrangements to safely dispose of whatever mercury one might have. If one is convinced of the need to use mercury in whatever form, one must use only the minimum necessary, one must make sure it is properly used and safely stored in a leak-proof container. Under no circumstances should mercury be strewn on the floor, in a car, or elsewhere in an uncontrolled manner. One should keep it in a secure place (e.g., a locked closet) so that others cannot easily get access to it. If mercury must be used, use of the smallest possible amounts of mercury in a controlled environment is the best way to reduce the risk that contamination will occur.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	In the case of medicinal uses of mercury, one must be careful that substitutes do not also contain hazardous heavy metals (see above). Otherwise, there can only be advantages for human health and the environment as mercury-containing medicines are replaced by mercury-free preparations.
Actual cases, examples	NRDC (2004) pointed out that some *azogue* users realize that touching or eating mercury may be harmful, but they are generally unaware that mercury is highly volatile, and that inhalation is a dangerous route of mercury exposure. NRDC suggested that a culturally sensitive educational campaign that involves *Santeros* (i.e., *Santería* priests), local groups, and local government could help to reduce this mercury problem.
Waste management issues, options	New York's Bureau of Wastewater Treatment has been unable to identify the source of about 68 pounds (31 kg) per year of mercury entering one of its plants from a region that contains the city's largest Latino population (NRDC, 2004). With regard to overall disposal methods, one study (Johnson, 1999, as cited in NJ MTF, 2002) found that 64% of Latino mercury users reported throwing mercury in the garbage, 27% flushed it down the toilet, and 9% threw it outdoors. These cases illustrate the formidable challenges inherent in making sure

	that mercury waste is disposed of properly, not to mention the even greater challenges of reducing the amounts of waste and releases from these uses.
Implementation and enforcement, costs, barriers	As noted above, the main barriers to progress in reducing mercury releases from these uses will be cultural. This implies the need for a strong cultural component in any program that intends to address these issues.
Information sources, references, websites	NRDC (2004). *Hidden Danger: Environmental Health Threats in the Latino Community,* A. Quintero-Somaini and M. Quirindongo, Natural Resources Defense Council, October 2004. Tamrakar, B.P. & Pandey R.S. Pharmacæutics of Metals in Ayurveda. ISBN 81-86782-22-2. Publication Scheme, Jaipur, India, 1998. NJ MTF (2002): New Jersey Mercury Task Force Report. Volume III. Sources of Mercury in New Jersey. January 2002. Available at website: http://www.state.nj.us/dep/dsr/Vol3-chapter1.pdf USEPA (2002). Task Force on Ritualistic Uses of Mercury Report, United States Environmental Protection Agency, Office of Emergency and Remedial Response, OSWER 9285.4-07 EPA/540-R-01-005, Washington, DC, December 2002. Ernst, E., and J. Thompson Coon, “Heavy metals in traditional Chinese medicines: A systematic review,” American Society for Clinical Pharmacology & Therapeutics, *Clin Pharmacol Ther 2001;70*:497-504. Guangdong (1997). The Chinese Pharmacopoeia Commission of the Ministry of Public Health. *Pharmacopoeia of the People’s Republic of China*, 1997 edition, vol. 1, Guangdong Technology and Chemical Industries, Guangdong, 1997. Maxson, P. (2004): Mercury flows in Europe and the world: The impact of decommissioned chlor-alkali plants. European Commission, Brussels. Available at: europa.eu.int/comm/environment/chemicals/mercury/pdf/report.pdf. New York City Department of Health, “Metallic Mercury Exposure: A Guide for Health-Care Providers.” Available online at http://www.ci.nyc.ny.us/html/doh/pdf/eode/mercury1.pdf

10.0 Waste Incineration

10.1 Incineration of municipal/general waste

Description	The mercury content in the general waste stream originates from three main groups of inputs: 1) intentionally used mercury in discarded products; 2) natural mercury impurities in high-volume materials (plastics, paper, etc.) and minerals; and 3) mercury as a human-generated trace pollutant in high-volume (e.g. recycled) materials. The mercury concentrations in the waste stream are directly dependent on the inputs of mercury to the waste, and will therefore likely vary greatly between different countries and circumstances. Municipal solid waste (MSW) consists of household garbage and other mostly non-hazardous commercial, institutional, and non-manufacturing industrial solid waste. MSW is generally incinerated (under controlled conditions) or landfilled, while waste fractions dominated by mineral materials are generally deposited in landfills. The quantitative split between incineration and other treatments of combustible waste vary greatly between countries. In some countries, sewage sludge and pathogenic medical waste are incinerated along with municipal waste. The mercury content of MSW will depend on the prevalence of mercury containing products in the waste, as well as the extent of specific collection systems for mercury containing waste products. Typical sources of mercury in MSW include, among others, batteries, discarded electrical equipment, fluorescent lamps, dental waste, paint residues, etc. Depending on the life-time of the various products, the sources of mercury in the waste will reflect the use of mercury in different products a number of years before the mercury enters the waste stream.
Main mercury releases (air, water, soil, production, use, disposal)	Important factors determining releases of mercury from MSW are the concentration of mercury in the wastes, and the efficiency of any control devices that may reduce mercury emissions. MSW may be burned without pretreatment, or it may be treated or processed to varying degrees: from the removal of large, bulky and non-combustible items, to extensive processing to produce a well separated fuel suitable for co-firing in, e.g., pulverized coal-fired boilers. Processing of MSW generally raises the heating value of the waste because many of the non-combustible items are removed (US EPA, 1997a). In some types of incinerators, part of the mercury may remain in waste that is not fully incinerated; this mercury will leave the incinerator with the grate ash. Generally, however, virtually all of the mercury present in the waste is converted to mercury vapour because of the high temperature of the combustion process. This mercury is then released with the exhaust gas, and the share of mercury that is released as air emissions through the stack will depend largely on the control devices in place. In well controlled facilities, most mercury will end up in the flue gas residues. The incineration technology, and particularly the flue gas cleaning systems, determine the repartition of mercury among air emissions, accumulation in solid incineration residues (grate ash) and gas cleaning residues, and sometimes releases to water (via some flue gas cleaning technologies). Post-combustion equipment for flue gas cleaning, applied widely in many countries, retains part of the mercury in these gases.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The flue gas cleaning systems used for MSW emissions are similar to those used for large coal combustion plants, with the occasional addition of activated carbon injection in some countries, e.g. the USA, Germany, Sweden, Denmark and Austria. Atmospheric mercury emissions from MSW combustors can, to some extent, be reduced by removing mercury adsorbed to particles from the flue gas using electrostatic precipitators (ESP's) and fabric filters (FFs). The particulate control devices most frequently used in the USA are ESP's. Simple ESP's sometimes only have very low mercury removal efficiencies. Wet scrubbers or spray absorbents using limestone for acid gas removal achieve mercury removal efficiencies of 55-65% and

<table>
<tr><td></td><td>44-52%, respectively.
To achieve higher mercury removal, reducing the flue gas temperature at the inlet to the control device is beneficial. Typically, newer MSW emission control systems use a combination of gas cooling and duct sorbent injection (DSI) or spray dryer (SD) systems upstream of the particle removal device to reduce temperatures and provide a mechanism for acid gas control (US EPA, 1997a). For obtaining a mercury removal efficiency >90%, the addition of special absorbents/adsorbents, most often activated carbon, is requisite.</td></tr>
<tr><td>Assessment of options (feasibility, costs, benefits, advantages, disadvantages)</td><td>Some examples of the distribution of mercury emissions from municipal waste incinerators are presented in the table below. Compared to other ESP systems, the ESP’s of these incinerators have relatively high removal efficiencies, through the retention of a greater proportion of the small-size particles.
<table>
<tr><td></td><td colspan="6">Percentage of total mercury emitted to:</td><td></td></tr>
<tr><td></td><td>Emissions to air</td><td>Grate ash</td><td>ESP and FF dust</td><td>Acid gas cleaning filter cake</td><td>Carbon adsorber residue</td><td>Waste-water</td><td>Flue gas cleaning system</td></tr>
<tr><td>Schachermayer *et al*., 1995 (Austria)</td><td><1</td><td>5</td><td>30</td><td>65</td><td></td><td><1</td><td>ESP, wet scrubber, denox</td></tr>
<tr><td>Amagerforbrænding, 2000 (Denmark)</td><td>7</td><td>1</td><td colspan="3">92</td><td><0.01</td><td>ESP, semi-dry flue gas cleaning process</td></tr>
<tr><td>Achtenbosch and Richers, 2002, (Germany)</td><td>0.4</td><td>-</td><td>44.3</td><td>54.6</td><td>0.7</td><td></td><td>ESP, spray dryer/ESP, wet scrubber, carbon adsorber</td></tr>
<tr><td>Shin Chan-Ki *et al*., 2000 (Korea)</td><td>7.3</td><td>1.8</td><td>13.9</td><td></td><td></td><td>77</td><td>ESP, wet scrubber</td></tr>
</table>
Some indications of mercury control costs are presented in UNEP (2002). Activated carbon injection seems to lead the field in overall cost effectiveness, although its ability to remove other pollutants from the flue gas is greatly limited. It is therefore generally combined with an electrostatic precipitator or a fabric filter.</td></tr>
<tr><td>Actual cases, examples</td><td>According to compliance tests recently conducted at 115 of the 167 large municipal solid waste incinerators in the USA, the average mercury control efficiencies for large municipal incineration plants was 91.5% (UNEP, 2002).
Continuous measurement and recording of emissions of mercury and its compounds has been required by law for waste incineration installations in Germany since 1990, except those installations where it can be reliably proven that mercury levels are less than 20 % of the defined limits. The German legislation requires a daily average emission no greater than 30 µg/Nm^3 and a half-hour average emission no greater than 50 µg/Nm^3 (EIPPCB, 2003).
Current emission controls on New Jersey (USA) solid waste incinerators, which primarily consist of the injection of carbon into the particulate control device, remove an estimated 95% or more of the mercury from the exhaust gas. The carbon is eventually mixed with the ash, but it has been reported that the mercury remains adsorbed on the injected carbon, and mercury releases from this residue are thought to be low (NJ MTF, 2002).</td></tr>
<tr><td>Waste management issues, options</td><td>Many countries make an effort to separate products with high mercury content from the general waste stream, so they can be managed or recycled properly. Removing mercury from the waste stream is much more cost-effective than removing mercury from the emission streams. It has, however, proven difficult to reach high collection rates, particularly when the separation is done by consumers. A high degree of</td></tr>
</table>

	information and motivation is necessary to achieve a high level of separation by consumers, and the simplest possible separation system meeting one's requirements should therefore be preferred. Irrespective of the collection system, separate collection and treatment implies significant extra costs for society (UNEP, 2002), and it is not necessarily evident that the benefits to health and environment are commensurate. It is for this reason that an increasing effort in many countries is being devoted to phasing out the use of most mercury containing products and processes. The mercury eliminated from exhaust gases is retained in incineration residues and, for some types of filtering technology, in solid residues from wastewater treatment (from the scrubbing process). These residues are generally sent to landfills or – depending upon their content of hazardous materials and other characteristics – used for special construction purposes (gypsum wallboard, roadbeds or similar). In some cases these solid residues are stored in special deposits for hazardous waste, which are additionally secured with a membrane or other cover that eliminates or reduces releases by evaporation and leaching. Legislation restricting the use of solid incineration residues in road building, construction and other applications has been implemented in some countries.
Implementation and enforcement, costs, barriers	An example of typical legislation dealing with the incineration of waste is that of the European Community. The aim of this Directive is to prevent or limit, as far as possible, the negative effects on the environment, in particular pollution by emissions to air, soil, surface water and groundwater, and the resulting risks to human health, from the incineration and co-incineration of waste. The Directive sets out air emission limit values for waste incineration and co-incineration plants and for discharges of wastewater from the cleaning of exhaust gases. The provisions applied to new installations as from 28 December 2002 and for existing installations as from 28 December 2005. As in the case of other legislation, the existence of incineration emission legislation, while a necessary step toward significant incineration emission controls, is not sufficient to ensure compliance. A serious enforcement system must be in place as well, in which the enforcing authority not only has the power to adequately enforce the relevant legislation, but is also technically competent to understand the emission controls, measurement methods, etc.
Information sources, references, websites	EIPPCB (2003) Integrated Pollution Prevention and Control – Draft Reference Document on Best Available Techniques for Waste Incineration. European IPPC Bureau, Sevilla. March 2004. US EPA (1997a): Locating and estimating air emissions from sources of mercury and mercury compounds. Report EPA-454/R-97-012, (NTIS PB98- 117054), Office of Air Quality Planning and Standards, Research Triangle Park, NC. Available at: http://www.epa.gov/ttn/chief/le/index.html. US EPA Technical Report EPA/600/R-00/102. Schachermayer, E., Bauer, G. and Ritter, E. (1995): Messung der Güter- und Stoffbilanz einer Müllverbrennungsanlage. [Measurement of the material and substance balance of a municipal solid waste incineration plant]. Monographie; Band 56.Wien. (In German) Amagerforbrænding (2000): Miljøredegørelse 2000. [Environmental statement 2000]. I/S Amagerforbrændingen, Copenhagen. (In Danish) Achtenbosch, M. and Richers, U. (2002): Material flows and investment costs of flue gas cleaning systems of municipal solid waste incinerators. Institut für Technikfolgenabschätzung und Systemanalyse, Forschungszentrum Karlsruhe, Germany. Available at: http://www.itas.fzk.de/deu/Itaslit/acri00a.pdf. Shin Chan-Ki *et al*. (2000): A study on the proper treatment of incineration residues from MSW Incinerator (I) - on the basis of bottom ash. Waste Treatment Engineering Division of theNational Institute of Environmental Research, Korea. As cited in the submission from the Republic of Korea for the UNEP Global Mercury Assessment. Available at: http://www.chem.unep.ch/mercury/2001-gov-sub/sub76govatt2.pdf NJ MTF (2002): New Jersey Mercury Task Force Report. Volume III. Sources of

	Mercury in New Jersey. January 2002. Available at website: http://www.state.nj.us/dep/dsr/Vol3-chapter1.pdf Mukherjee, AB, R Zevenhoven, J Brodersen, LD Hylander and P Bhattacharya, "Mercury in waste in the European Union: sources, disposal methods and risks," *Resources, Conservation and Recycling 42* (2004) 155–182, Elsevier.

10.2 Incineration of hazardous waste

Description	The mercury content in the hazardous waste stream originates primarily from intentionally used mercury in discarded products and process waste. Some hazardous waste is incinerated as part of the treatment/disposal system. The mercury concentrations are directly dependent on the content of mercury in the waste, and will therefore likely vary greatly between different countries and facilities. Hazardous waste refers to residues and wastes which contain hazardous materials in significant quantities. It is important to note that generally such waste with high concentrations of mercury should not be incinerated, and should preferably be sorted (if at all possible) and treated separately. Practically, however, this is not always possible. Therefore, when hazardous waste containing mercury must be incinerated, emissions controls should be in place as this could be a significant source of mercury releases.
Main mercury releases (air, water, soil, production, use, disposal)	The mercury content in the waste determines the potential mercury releases. The incineration technology, and particularly the flue gas cleaning systems applied, determine the eventual releases of mercury as air emissions, as solid incinerator and flue gas cleaning residues, and as releases to water (only indirectly, via some flue gas cleaning technologies).
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The only relevant “primary” techniques for preventing emissions of mercury to air are those which prevent or control, if possible, the inclusion of mercury in the waste: • substitution of mercury containing products with mercury-free products • efficient separate collection of waste that may contain heavy metals e.g. button cells, batteries, dental amalgams, etc. • notification of waste producers of the need to segregate mercury identification and/or restriction of receipt of potential mercury contaminated wastes - by sampling and analysis of wastes where this is possible - by targeted sampling/testing campaigns • where such wastes are known to be received - controlled processing to avoid overloading the control system (EIPPCB, 2003). With regard to “secondary” control techniques, typically hazardous waste is burned either in special-technology incinerators or in rotary kiln type furnaces. Special-technology incinerators include drum type, grate type, or muffle type furnaces. Also, other technologies (such as supercritical water oxidation, and electric arc vitrification) which treat hazardous waste may be included in this group, although some of these are not always classified as “incineration”. Hazardous waste in some countries is also incinerated at cement plants, which should be equipped with appropriate emission controls. Incinerators are equipped with a wide variety of air pollution control devices that may range in complexity from no controls at all, to complex, state-of-the-art systems that control releases of several pollutants simultaneously. It is not surprising, since one is dealing with similar emissions, that the control techniques for hazardous waste emissions generally resemble those described previously for municipal waste incineration. Tests have shown that sulphur dioxide neutralisation in the furnace, by adding limestone, can reduce the proportion of metallic mercury, making overall mercury removal from the gas stream more efficient.

	When BAT is used for cleaning the flue gases, the concentration of mercury can be reduced to a range of 0.01 to 0.05 mg/m³ (normalized to 11% O_2) (UBA, 2004).
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	Atmospheric mercury emissions from hazardous waste incinerators can, to some extent, be reduced by removing mercury adsorbed to particles from the flue gas using electrostatic precipitators (ESP's) and fabric filters (FFs). Simple ESP's, however, sometimes have very low mercury removal efficiencies. Wet scrubbers or spray absorbents using limestone for acid gas removal may achieve mercury removal efficiencies on the order of 50%. To achieve higher mercury removal, reducing the flue gas temperature at the inlet to the control device is beneficial. Typically, more advanced emission control systems use a combination of gas cooling and duct sorbent injection (DSI) or spray dryer (SD) systems upstream of the particle removal device to reduce temperatures and provide a mechanism for acid gas control (US EPA, 1997a). For obtaining a mercury removal efficiency >90%, the addition of special absorbents/adsorbents, most often activated carbon, is requisite.
Actual cases, examples	In Austria, some batteries and other mercury containing waste are incinerated in a facility designed for the incineration of hazardous waste. This incinerator is fitted with a flue gas scrubber, followed by injection of activated coke. The wastewater from the scrubber is treated and the resulting filter cake is dewatered and disposed of properly. Filter dust arising from the treatment with activated coke is returned to the incineration plant. No metal mercury occurs (Austria, 2005). The US EPA estimated atmospheric emissions of mercury from hazardous waste incinerators for the year 1996. Total 1996 atmospheric mercury emissions from hazardous waste combustion in the USA were estimated to be 6.3 metric tons (US EPA, 1997a). No data were given for mercury outputs to solid residues or wastewater.
Waste management issues, options	In incineration plants for municipal and hazardous wastes, the chlorine content in the average waste is usually high enough, in normal operating states, to ensure that mercury is present mainly in the ionic form. However, specific types of high mercury content waste may change the situation, and metallic mercury may need to be deposited. For the incineration of waste with a high mercury content in hazardous waste incineration plants, mercury deposition of 99.9 % can only be ensured when highly chlorinated waste is also incinerated in an appropriate proportion to the mercury load. Multistage wet scrubbing processes are typical of this type of plant. High proportions of ionic mercury (e.g. >99.9 %) in the boiler crude flue-gas before wet gas cleaning are caused by including highly chlorinated waste. This assists total mercury removal from the flue-gas. High chlorine total loads (approx. 4 % w/w input) and a therefore high interim Cl_2 supply lead to high mercury chlorination levels and mercury deposition of close to 100 %. With lower chlorine loads, the mercury deposition degree reduces rapidly (EIPPCB, 2003).
Implementation and enforcement, costs, barriers	It is difficult to provide generally valid cost data because the relative costs of reducing emissions depend on a particularly wide range of site-specific variables, such as waste composition. The Protocol on Heavy Metals within the framework of the United Nations Economic Commission for Europe (UN-ECE) Convention on Long-Range Transboundary Air Pollution sets legally binding limit values for the emission of particulates of 10 mg/m³ for hazardous and medical waste incineration. For the emission of mercury, the legally binding limit value is 0.05 mg/m³ for hazardous waste incineration. As in the case of other legislation, the existence of incineration emission

	legislation, while a necessary step toward significant incineration emission controls, is not sufficient to ensure compliance. A serious enforcement system must be in place as well, in which the enforcing authority not only has the power to adequately enforce the relevant legislation, but is also technically competent to understand the emission controls, measurement methods, etc.
Information sources, references, websites	EIPPCB (2003) Integrated Pollution Prevention and Control – Draft Reference Document on Best Available Techniques for Waste Incineration. European IPPC Bureau, Sevilla. March 2004. US EPA Technical Report EPA/600/R-00/102. UBA (2004). *Materials for consideration in the discussion concerning the Protocol on Heavy Metals to the Convention on Long-range Transboundary Air Pollution*, O. Rentz, S. Wenzel, R. Deprost, U. Karl, French-German Institute for Environmental Research (DFIU-IFARE), Universität Karlsruhe (TH), for the German Federal Environmental Agency, Förderkennzeichen (UFOPLAN) 203 43 257/14, Second Draft Report (revised), 25. March 2004. US EPA (1997a): Locating and estimating air emissions from sources of mercury and mercury compounds. Report EPA-454/R-97-012, (NTIS PB98- 117054), Office of Air Quality Planning and Standards, Research Triangle Park, NC. Available at: http://www.epa.gov/ttn/chief/le/index.html. Austria (2005). Comments (Entwurf des Protokolls) submitted 1 September 2005 by Brigitte Winter (Umweltbundesamt) to the European Commission Mercury Strategy Stakeholder consultation meeting, convened 8 September 2005. Mukherjee, AB, R Zevenhoven, J Brodersen, LD Hylander and P Bhattacharya, “Mercury in waste in the European Union: sources, disposal methods and risks,” *Resources, Conservation and Recycling 42* (2004) 155–182, Elsevier.

10.3 Incineration of medical waste

Description	Medical waste is considered to be waste generated by a variety of medical and veterinary care facilities including hospitals, clinics, doctors' and dentists' offices, nursing homes, veterinary clinics, medical laboratories, and medical and veterinary schools and research units. The mercury content in the medical waste stream originates primarily from mercury in discarded products and chemicals, including thermometers, dental material with mercury amalgam, batteries, laboratory chemicals, pharmaceuticals, fluorescent lamps, high-intensity discharge lamps (mercury vapour, metal halide, and high-pressure sodium), special paper and film coatings, and pigments – most of which should preferably be separated from the waste stream before incineration, if possible. The waste generated during these activities includes a great variety of disposable bandages, blood, pharmaceuticals and other materials and equipment used for the medical treatment of people or animals. To reliably destroy viruses, bacteria, and pathogens, this waste is often destroyed by incineration (UNEP, 2003). Medical waste is sometimes incinerated in dedicated incinerators, and sometimes in selected municipal waste incinerators equipped for the purpose
Main mercury releases (air, water, soil, production, use, disposal)	Available information indicates that medical waste incinerators can be significant sources of mercury emissions. The mercury content in the waste determines the potential mercury releases. The incineration technology, and particularly the flue gas cleaning systems applied, determine the eventual releases of mercury as air emissions, as solid incinerator and flue gas cleaning residues, and sometimes as releases to water (via some flue gas cleaning technologies). Another issue of concern for both medical and municipal waste incinerators is the disposal of residual ash and the mercury that is captured by pollution control systems. According to US EPA (2004) there is up to 50 times more mercury in medical waste than in general municipal waste in the USA, and the amount of mercury emitted from general medical incinerators averages more than 60 times that from pathological waste incinerators.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The only relevant “primary” techniques for preventing emissions of mercury to air are those which prevent or control, if possible, the inclusion of mercury in the waste stream: • substitution of mercury containing products with mercury-free products • separate collection of waste that may contain mercury, e.g., batteries, dental amalgams, thermometers, etc. • notification of hospital staff of the need to avoid or segregate mercury contaminated wastes With regard to “secondary” control techniques, incinerators are equipped with a wide variety of air pollution control devices that may range in complexity from no controls at all, to complex, state-of-the-art systems that control releases of several pollutants simultaneously. It is not surprising, since one is dealing with similar emissions, that the control systems for medical waste incinerators generally resemble those described previously for municipal waste incineration.
Assessment of options (feasibility, costs, benefits, advantages,	A number of air pollution control system configurations have been used to control particulate material (PM) and gaseous emissions from medical waste incinerator combustion stacks. Most of these configurations fall within the general classes of “wet systems” and “dry systems.” Wet

disadvantages)	systems typically comprise a wet scrubber designed for particulate matter (PM) control (venturi scrubber or rotary atomizing scrubber) in series with a packed-bed scrubber for acid gas removal and a high-efficiency mist elimination system. Most dry systems use a fabric filter for PM removal, but ESP's have been installed on some larger medical waste incinerators. These dry systems may use sorbent injection via either dry injection or spray dryers upstream from the PM device to enhance acid gas control. Additionally, some systems incorporate a combination dry/wet system that comprises a dry sorbent injection/fabric filter system followed by a venturi scrubber. Because these systems are designed primarily for PM and acid gas control, they may have limited usefulness for mercury control unless activated carbon is added to the sorbent injection/fabric filtration systems (US EPA, 1997a).
Actual cases, examples	General medical waste contains significantly more mercury than pathological waste, and the average mercury content of general medical waste in the US is estimated to be slightly higher that 8.2 g mercury per metric ton (US EPA, 2004). At one time, many US healthcare facilities operated medical waste incinerators. Enough mercury found its way into the medical waste stream that hospital incinerators had become the fourth largest source of mercury emissions to the atmosphere. Increasing public awareness of the magnitude of mercury emissions from medical waste incinerators was a major factor in the drive to shut them down. In 1997, EPA finalized a National Environmental Standard for Hazardous Air Pollutants (NESHAP) for Hospital/Medical/Infectious Waste Incinerators (HMIWI). The NESHAP standard set strict limits on emissions for several compounds, including mercury. The number of medical waste incinerators had already been declining before the HMIWI NESHAP, but its effect was even more dramatic than anticipated. In 1997, there were approximately 2,400 incinerators burning medical waste nationwide, accounting for 8% of the national total of mercury emitted to the air. By 2004, the number of incinerators had declined to 111 (HERC, 2005)
Waste management issues, options	The Protocol on Heavy Metals within the framework of the United Nations Economic Commission for Europe (UN-ECE) Convention on Long-Range Transboundary Air Pollution sets legally binding limit values for waste incineration. For the emission of mercury, the legally binding limit value is 0.08 mg/m³ for medical waste incineration.
Implementation and enforcement, costs, barriers	As in the case of other legislation, the existence of incineration emission legislation, while a necessary step toward significant incineration emission controls, is not sufficient to ensure compliance. A serious enforcement system must be in place as well, in which the enforcing authority not only has the power to adequately enforce the relevant legislation, but is also technically competent to understand the emission controls, measurement methods, etc.
Information sources, references, websites	EIPPCB (2003) Integrated Pollution Prevention and Control – Draft Reference Document on Best Available Techniques for Waste Incineration. European IPPC Bureau, Sevilla. March 2004. US EPA Technical Report EPA/600/R-00/102. UNEP (2003): Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases, 1st edition, May 2003, UNEP Chemicals, Geneva, Switzerland. US EPA (2004): Mercury in medical waste. Available at: http://www.epa.gov/reg5oair/glakes/fact1.htm Mukherjee, AB, R Zevenhoven, J Brodersen, LD Hylander and P Bhattacharya, "Mercury in waste in the European Union: sources,

	disposal methods and risks,” *Resources, Conservation and Recycling 42* (2004) 155–182, Elsevier. US EPA (1997a): Locating and estimating air emissions from sources of mercury and mercury compounds. Report EPA-454/R-97-012, (NTIS PB98- 117054), Office of Air Quality Planning and Standards, Research Triangle Park, NC. Available at: http://www.epa.gov/ttn/chief/le/index.html. HERC (2005). Healthcare Environmental Resource Center. See http://www.hercenter.org http://www.sustainablehospitals.org/ http://www.informinc.org/fsmercalts.pdf

10.4 Sewage sludge incineration

<table>
<tr><td>Description</td><td>Much of the mercury in wastewater (originating from various sources, but often dominated by dental amalgam wastes) ends up in sewage sludge. Sewage sludge is the product of any wastewater treatment processes, regardless of their origin (e.g., wastewater from municipal, agricultural or industrial activities). The mercury concentrations are directly proportional to the inputs of mercury to the wastewater, and may therefore be expected to vary significantly among different countries and circumstances.
If the concentrations of hazardous substances are low enough, the sludge may be spread on farmland as fertilizer. Otherwise, the sludge can either be incinerated (separately or by co-combustion in power plants, municipal waste incinerators, cement kilns, etc.), be landfilled, or undergo other treatment like wet oxidation, pyrolysis, gasification, etc.</td></tr>
<tr><td>Main mercury releases (air, water, soil, production, use, disposal)</td><td>If not spread on farmland as fertiliser, sewage sludge may sometimes be incinerated in dedicated incinerators, sometimes in municipal waste incinerators. The major pathways for mercury releases are via the air, water and wastes/residues.
Because mercury and mercury compounds are relatively volatile, most mercury will leave the combustion chamber in the exhaust gas; concentrations in the ash residue are expected to be negligible (US EPA, 1997a).
The most important factors determining releases of mercury from sludge incineration are the concentration of mercury in the sludges that are incinerated, the type of control measures on the exhaust gases, and the fate of the incineration residues. If all incineration residues are fed back into the sludge incinerator, no mercury removal is achieved; a steady state situation will build up, and eventually mercury will be released to the atmosphere or to aquatic environments via the wastewater treatment system.</td></tr>
<tr><td>Mercury reduction options (alternative technologies, other mercury reduction strategies)</td><td>A variety of wet scrubbers are normally used to control pollutant emissions from sludge incinerators, including low pressure drop spray towers, wet cyclones, higher pressure drop venturi scrubbers, and venturi/impingement tray scrubber combinations (US EPA, 1997a).</td></tr>
<tr><td>Assessment of options (feasibility, costs, benefits, advantages, disadvantages)</td><td>Emissions estimates from US EPA (1997a), which have been developed for various control scenarios, are presented in the following table. However, since mercury concentration in sludge, and the effectiveness of control technologies vary widely, these emissions estimates should be regarded with some uncertainty.
<i>Atmospheric mercury emissions for sewage sludge incinerators in the USA</i>
<table>
<tr><th>Incinerator type</th><th>Control status</th><th>Estimated atmospheric mercury emissions (g/metric ton dry sludge)</th></tr>
<tr><td>Multiple hearth</td><td>Cyclone</td><td>2.3</td></tr>
<tr><td>Multiple hearth</td><td>Cyclone and venturi scrubber</td><td>1.6</td></tr>
<tr><td>Multiple hearth</td><td>Impingement scrubber</td><td>0.97</td></tr>
<tr><td>Multiple</td><td>Venturi scrubber and</td><td>0.005</td></tr>
</table></td></tr>
</table>

<table>
<tr><td></td><td><table><tr><td>hearth</td><td>impingement scrubber</td><td></td></tr><tr><td>Fluidized bed</td><td>Venturi scrubber and impingement scrubber</td><td>0.03</td></tr></table></td></tr>
<tr><td>Actual cases, examples</td><td>In Germany, studies have demonstrated that only 1-6 % of the mercury contained in the sludge is removed from the fly ash with electrostatic precipitators (Saenger et al., 1999a). On the other hand, in a fluidized bed sludge incinerator in Hamburg, Germany, the mercury concentration of the raw flue gas ranged between 500 and 950 $\mu g/m^3$ whereas in the cleaned gas it was below 40 $\mu g/m^3$ (Saenger et al., 1999b). This incinerator was equipped with an adsorber with injection of a mixture of activated carbon and lime hydrate. The adsorbent was removed in a fibrous filter, which was subsequently fed back into the incinerator.</td></tr>
<tr><td>Waste management issues, options</td><td>The unburned residual incinerator ash is removed from the incinerator, usually on a continuous basis, and is generally disposed of in a landfill or reused (i.e., in bricks, concrete, asphalt, etc.).</td></tr>
<tr><td>Implementation and enforcement, costs, barriers</td><td>As in the case of other legislation, the existence of incineration emission legislation, while a necessary step toward significant incineration emission controls, is not sufficient to ensure compliance. A serious enforcement system must be in place as well, in which the enforcing authority not only has the power to adequately enforce the relevant legislation, but is also technically competent to understand the emission controls, measurement methods, etc.</td></tr>
<tr><td>Information sources, references, websites</td><td>US EPA (1997a): Locating and estimating air emissions from sources of mercury and mercury compounds. Report EPA-454/R-97-012, (NTIS PB98- 117054), Office of Air Quality Planning and Standards, Research Triangle Park, NC. Available at: http://www.epa.gov/ttn/chief/le/index.html.
EIPPCB (2003) Integrated Pollution Prevention and Control – Draft Reference Document on Best Available Techniques for Waste Incineration. European IPPC Bureau, Sevilla. March 2004.
Saenger, M., Werther, J. and Lungwitz, H. (1999a): Mercury emissions from German fluidized bed sludge incinerators - A status report. Proceedings of the 15th International Conference on Fluidized Bed Combustion, May 16 - 19, 1999, Savannah, Georgia. Available at: http://www.portalenergy.com/balpyo/15icfbc/99-0042.pdf
Saenger, M., Werther, J. and Hanssen, H. (1999b): Concentrations and mass balance of mercury in a fluidized bed sewage sludge incineration plant. Proceedings of the 15th International Conference on Fluidized Bed Combustion, May 16 - 19, 1999, Savannah, Georgia.
US EPA Technical Report EPA/600/R-00/102.
Mukherjee, AB, R Zevenhoven, J Brodersen, LD Hylander and P Bhattacharya, “Mercury in waste in the European Union: sources, disposal methods and risks,” *Resources, Conservation and Recycling 42* (2004) 155–182, Elsevier.</td></tr>
</table>

11.0 Other Combustion Sources

11.1Crematoria/cremation

Description	Cremation, or the incineration of human corpses, is a common practice in many societies. Even in some societies where cremation has not been widely practiced for religious or other reasons, the authorities are considering the possibility due to limited space for cemeteries. Most of the mercury released during cremation is due to the vaporisation of dental amalgam fillings that contain mercury. The typical cremation process includes the charging of the coffin and corpse, incineration in the main combustion chamber and, where applicable, final treatment in the afterburning chamber. Most cremation furnaces are fired using oil or natural gas, although some operate on electricity. A large number of cremations occur throughout the world each year. For example, in 1995 in the USA, nearly 500 thousand cremations were performed at more than one thousand crematoria. In Germany there are 400-450,000 cremations/yr. Most of the flue gases in Germany are treated (Germany, 2005). In the UK there are a similar number of cremations (AEA, 2004). The UK has recently passed legislation to control emissions. Most crematoria around the world still have no controls on emissions, although legislation is increasing for reasons such as the following. In the Netherlands, the average number of fillings is expected to increase from 3.2 to 5.1 during the period 1995-2020 (OSPAR, 2002). This means that the emissions from cremations in the Netherlands will double between 2002 and 2020, unless abatement measures are introduced. In the UK it has been calculated that by 2020 crematoria will be by far the largest single contributor to mercury emissions (just over 25% of the UK mercury emissions to air) unless action is taken (AEA, 2004).
Main mercury releases (air, water, soil, production, use, disposal)	Crematoria are typically located within or close to residential areas, and normally gaseous emission stacks are not very tall (UNEP, 2003). Since cremations involve high temperatures, and since most crematoria have limited emission controls that would reduce mercury releases, the vast majority of the mercury in a corpse that is cremated is expected to be released to the air through the stack. In the crematoria that have effective emission controls, however, a significant part of the mercury will end up in fly ash and other residues (Reindl, 2003). (With regard to cemeteries, on the other hand, the major pathway for mercury releases from amalgam fillings is directly to the soil.)
Mercury reduction options (alternative technologies, other mercury reduction strategies)	The most effective measure to reduce mercury emissions and exposures from cremation is by substituting dental mercury use with mercury-free alternatives. Once mercury amalgams have been placed in the teeth, mercury emissions from crematoria may only be reduced by removing the amalgams before cremation,[3] which is not a common practice, or by treating the gaseous emissions from the crematoria. In some cases the combustion gases are made to pass through a dust separator. In more sophisticated systems, gas treatment controls are present. Gas cleaning by a dry sorbent and filter system or equivalent is recommended as the best available technique for the removal of mercury from crematoria emissions to air. The equipment is said to reduce mercury emissions by up to 99% (AEA, 2004).
Assessment of options (feasibility, costs, benefits,	National emission standards that require gas cleaning at new or large crematoria are in place in Austria, Belgium, Germany, the Netherlands, Norway, Sweden, Switzerland and the UK, among others. Gas cleaning systems are therefore clearly

---

[3] This measure was widely rejected during stakeholder consultations in the UK, but may be considered in other countries.

advantages, disadvantages)	"technically available". The Federation of British Cremation Authorities has said mercury emission abatement equipment costs £250,000 per crematorium. The National Association of Funeral Directors (NAFD) estimated this would add up to £100 to the price of cremation, which currently costs between £250 and £350. According to a UK government study, on the other hand, at publicly owned crematoria adult cremation ranged from £100 to £360 per cremation. Effluent gas cleaning has been estimated by the government at around £55 per cremation, and is therefore not expected to affect the economic viability of UK crematoria (AEA, 2004, citing public consultations, etc.). In any case, since flue gas cleaning does add to the cost of cremation, there remains a strong argument for preventing mercury emissions by substituting other materials for mercury amalgams during normal dental care.
Actual cases, examples	In Germany, the mercury emission from one cremation was calculated between 2 mg (based on a very efficient mercury removal system) and 100 mg (very conservative estimate of mercury removal) with the use of different BAT. The following were found in actual measurements of flue gases where different mercury removal techniques are employed: Actual measurements of mercury in clean flue gases of co-flow filters were recently performed in selected crematoria in 6 federal states of Germany. Mercury concentrations between 0.0001 mg/m³ and 0.03 mg/m³ were recorded. Investigations at another crematorium using an amalgator technique showed mercury concentrations in the clean flue gas between 0.01 and 0.02 mg/m³. At one crematorium with the same technique, a maximum concentration of 0.7 mg/m³ was found, while another amalgator cleaner resulted in an average mercury concentration of 0.028 mg/m³. Measurements at one installation using a catalytic adsorber showed mercury concentrations between 0.003 and 0.043 mg/m³ in the cleaned gas. Measurements at one crematorium using a solid bed filter with activated carbon showed average mercury concentrations of 0.039 mg/m³. Investigations of the efficiency of a tube filter with activated carbon (installed as end-of-pipe cleaning) showed mercury concentrations between 0.0009 and 0.33 mg/m³. As a result, the total annual mercury emissions from German crematoria are estimated at 0.036 tonne in treated flue gases. Approximately one-half is estimated to come from those 21 crematoria without adsorptive flue gas treatment systems (Germany, 2005).
Waste management issues, options	The accumulation of mercury in amalgams in cemeteries represents an intractable long-term hazardous substance management challenge. The only assured and cost-effective manner of dealing with this problem is by avoiding mercury amalgams in the first place.
Implementation and enforcement, costs, barriers	It has been estimated that amalgam fillings last approximately 10 years on average. If a serious effort were made in the near term (as Sweden has done) to phase out (virtually) all amalgam fillings, within 5-10 years crematoria emissions of mercury would be half of what they are now, and within 15 years crematoria emissions would be minimal. This would seem to be a more viable (and wiser) strategy than the plans to place controls on the mercury emissions of crematoria. Furthermore, this would also address the long-term problem posed by mercury amalgams in cemeteries.
Information sources, references, websites	Germany (2005). Answers to the Questions to be discussed at the stakeholder consultation meeting - 8 September 2005, Federal Republic of Germany. AEA (2004). Review of emission factors for mercury emitted from cremation, NR Passant, AEA Technology, June 2004. OSPAR (2002): Mercury emissions from crematoria and their control in the OSPAR Convention Area. OSPAR Commission, Paris. Available at: http://www.ospar.org/documents/dbase/publications/p00179_Mercury%20emissions%20from%20crematoria.pdf UNEP (2003): Standardized Toolkit for Identification and Quantification of Dioxin and

	Furan Releases, 1st edition, May 2003, UNEP Chemicals, Geneva, Switzerland. Reindl, J. (2003): Summary of References on Mercury Emissions from Crematoria - DRAFT. Dane County Department of Public Works. Madison Wisconsin. August 12, 2003.

12.0 Waste treatment, disposal, deposition/landfilling

12.1 Controlled landfills/deposits, deep underground disposal

Description	Controlled landfills/deposits are land areas where waste containing pollutants is deposited under controlled conditions (preferably based on risk assessments), including mainly: • Municipal (domestic and institutional) waste • Medical/hazardous waste • Solid combustion/incineration residue • Wastewater sludge Mercury is found in a variety of products, such as fluorescent and other lamps, batteries, electrical switches and relays, barometers, and thermometers, much of which end up in municipal landfills. Once buried, some of the inorganic mercury in the landfill is converted by bacteria into the more toxic organic or methylated mercury (NEWMOA, 2003). Deep underground disposal refers to the stabilization and encapsulation of mercury waste prior to its permanent disposal in an underground storage vault impervious to water incursion, earthquakes or other geological disturbance. The types of waste (and thereby the types of mercury content) allowed at landfills/deposits may vary between countries, and deposits receiving more hazardous waste fractions – for instance, chemicals or solid residues from waste incineration – should be designed to give better protection of the groundwater and other environmental media.
Main mercury releases (air, water, soil, production, use, disposal)	Throughout the lifetime of a typical landfill/deposit, relatively small amounts of mercury are released annually from the deposit with outputs of water (leaching water and surface run-off), and with air to the atmosphere, because some of the mercury is slowly evaporating from the waste. When products containing elemental mercury break in the waste stream, the mercury is released and begins to evaporate. Gaseous mercury can then be emitted at various stages of the solid waste disposal process, including: • on the way to a landfill or other waste management facility (from collection containers, transport vehicles, and transfer stations); • from the working face or active portion of the landfill, and during waste handling operations (i.e., transport, dumping, spreading, compacting and burial); • from landfill gas vents (many municipal sites collect the methane gas produced at landfills and either burn it, harness it as an energy source, or vent it to the atmosphere); • from the surface of covered, inactive portions of landfills. When rainwater infiltrates landfills, it dissolves organic and inorganic material, forming a toxic leachate that collects at the base of the landfill. Like all metals, mercury dissolves easily in the acidic leachate. Until the late 1980s, US landfills were not routinely lined and this leachate was allowed to seep slowly out of the landfill into the soil and groundwater. However, even liners and leachate collection systems are not fool proof.

	In addition to air and water emissions, the actual accumulation of mercury, over time, on the landfill site may possibly give rise to other long-term environmental impacts through excavation, urbanisation, etc. According to Lindberg *et al.* (2001), landfills are the only measured anthropogenic sources of dimethyl-mercury which, along with monomethyl-mercury, is the main mercury species responsible for mercury effects among the public through seafood consumption. Shunlin Tang *et al.* (2004) indicated a clear trend that mercury releases to the atmosphere (total gaseous mercury) from relatively recent waste were higher at daytime than during the night. This finding could suggest – as could perhaps be expected – that mercury releases to the atmosphere from landfills are influenced by ambient temperatures. If a deep underground disposal facility is properly designed, located and managed, it should not be a source of either air or groundwater emissions after the waste has been deposited.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	Researchers at the New Jersey (USA) Department of Environmental Protection have confirmed other research findings that 17 to 40 percent of mercury may be released from fluorescent lamps over a two-week period following breakage, with higher temperatures contributing to higher releases of mercury (Aucott, 2003). This sort of finding supports the increasing efforts of many countries to 1) encourage mercury-free products, and 2) separate mercury containing items from the waste stream before they reach the landfill. The most important waste products to substitute or to separate from the waste stream include thermometers, batteries, dental amalgam wastes, energy-saving lamps, switches, laboratory chemicals, etc. After these items are mostly removed, the mercury content of the waste stream is much less problematic. Once mercury has entered the landfill, the options are much more limited, and generally more expensive. With regard to air emissions, Lindberg *et al.* (2004) noted that mercury fluxes from landfills are dominated not by landfill gas, but by releases during routine waste handling operations at the working face of the landfill. Direct emissions of mercury in landfill gas were typically found to be less than 10% of the total mercury release from landfills. This argues for rapidly covering or sealing the working face with a soil layer or other vapour barrier when practicable. With regard to the actual landfill gas emissions, they are higher with active venting of landfill gases, rather than passive venting. Furthermore, “flaring” is the process of burning landfill gas before releasing it to the atmosphere. Flaring converts organic mercury to inorganic forms, but has no known effect on inorganic mercury. But many landfills do not use flaring. With regard to water emissions, the fate of the mercury released with water depends greatly on the presence and efficacy of the protective lining under the landfill, and associated wastewater management. If the water is not collected and sent to wastewater cleaning, the mercury (and other substances) may contaminate soil and groundwater under and around the deposit. If the water is sent to wastewater cleaning, the mercury will mainly follow the sludge fraction and go e.g. to land use, while the rest will follow the water discharge from the wastewater treatment system (COWI, 2002). Available data show that mercury in groundwater in the area of older, unlined landfills can exceed drinking water standards, but is less likely to leach into groundwater from landfills that are lined and use leachate collection systems. Newer landfills are lined with clay and flexible synthetic membranes to prevent leachate from escaping and contaminating the groundwater. The leachate is instead drained through

	a collection of horizontal perforated pipes, and collected by a sump for treatment via a leachate water cleaning system. After treatment it is discharged to surface water or a sewer system. However, even liners and leachate collection systems are not foolproof. Several researchers documented that many liners used in the 1980s eventually leak (Line and Miklas, 1989) (Bonaparte and Gross, 1990), (Gross et al., 1990). Furthermore, depending on how the leachate is treated, mercury may re-enter the environment. The only long-term sinks for removal of mercury from the biosphere are deep-sea sediments and, to a certain extent, controlled landfills or deep underground disposal, in which the mercury is physio-chemically immobilised and remains undisturbed by anthropogenic or natural activity (climatic and geological).
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	While precise figures depend on a great number of variables, substitution of mercury products and processes by mercury-free is generally a cost-effective way to avoid mercury getting into landfills, especially as the market demand for mercury-free products keeps increasing. If substitution is not feasible, then separate collection may also be a cost-effective method of reducing potential mercury emissions, especially for such waste streams as batteries, dental wastes, energy-efficient lamps, etc. Actual controls on landfill air and water emissions are more costly methods of reducing mercury releases than separating mercury products from the waste stream, but such controls are not practiced at many disposal sites around the world. Finally, deep underground disposal gives the best guarantee of minimal mercury releases, but at a significantly higher cost than the options described above.
Actual cases, examples	Based on measurements of mercury releases via landfill gas flares, landfill cover and the working face where the new waste is worked on and not yet covered, Lindberg (2004) estimated the total atmospheric releases from municipal landfill operations in the state of Florida, USA, to be in the order of 10-50 kg mercury per year. Mercury releases from the working face of the landfills were more than ten-fold higher than the mercury releases with flared landfill gas. A study of six landfills in Massachusetts found mercury in the leachate of lined landfills, but not in the groundwater (Massachusetts DEP, 1996). With regard to deep underground disposal, the Germans have deposited stabilised mercury wastes (mixed in concrete, etc.) in old salt mines for many years. In Sweden, the only legal disposal of mercury waste (containing >1% mercury) now consists of “final storage” of the treated waste deep underground, although some technical aspects of this method have yet to be agreed. As part of the proposed EU legislation to ban mercury exports and to store excess mercury after 2010-11, waste disposal experts are considering the possibility of deep underground disposal of liquid mercury, but this has not yet been authorized.
Waste management issues, options	Mercury waste management has become more complex as more mercury is collected from a greater variety of sources, including gas filtering products, sludges from the chlor-alkali industry, ashes, slags, and inert mineral residues, as well as used fluorescent tubes, batteries and other products that are often not recycled. Low concentrations of mercury in waste are generally permitted in normal landfills. In some countries, waste with higher mercury concentrations can only be

	deposited in landfills that incorporate enhanced control technologies to limit mercury leaching and evaporation. The cost of acceptable disposal of mercury (and other hazardous) waste is increasing in many countries to the extent that many waste generators now investigate whether alternatives exist in which they would not have to produce and deal with mercury waste. Mercury waste management, as it is most commonly done today, in accordance with national and local regulations, increasingly requires long-term oversight and investment.
Implementation and enforcement, costs, barriers	In many countries, establishing and properly managing a basic landfill area is already a significant challenge. There are many regions where the dumping of waste is carried out under informal conditions with no public control and no safeguards to minimise releases of pollutants to the surroundings. If mercury is present in the waste, it represents a potential for mercury releases to soil, air, groundwater and surface waters. Such informal waste disposal may pose an immediate risk to the local community in which it takes place, because mercury (and many other contaminants) may cause contamination of the local soil and groundwater.
Information sources, references, websites	Lindberg, S. E., Wallschlager, D., Prestbo, E. M., Bloom, N. S., Price, J. and Reinhart, D. (2001): Methylated mercury species in municipal waste landfill gas sampled in Florida, USA, *Atmospheric Environment* 35*,* 4011-4015. Shunlin Tang, Xinbin Feng, Zhonggen Li, Shaofeng Wang and Lian Liang (2004): “A preliminary study on mercury speciation in municipal waste landfill gas from Guizhou, China.” In “Mercury as a Global Pollutant,” part 1, *RMZ - Materials and Geoenvironment* - periodical for mining, metallurgy and geology, Ljubljana, Slovenia, 2004. NEWMOA (2003), “Summary of Research on Mercury Emissions from Municipal Landfills,” Northeast Waste Management Officials Association, Boston. http://www.newmoa.org. Aucott M, McLinden M, Winka M, 2003, “Release of Mercury from Broken Fluorescent Bulbs,” *Journal of the Air & Waste Management Association*, 53:143-151. Lindberg, S.E., Southworth, G., Prestbo, E.M., Wallschläger, D., Bogle, M.A., Price, J. (2004): “Gaseous methyl- and inorganic mercury in landfill gas from landfills in Florida, Minnesota, Delaware, and California.” *Atmospheric Environment 39* (2005) 249–258. COWI (2002): ACAP and Danish EPA Reduction of Atmospheric mercury emissions from Arctic countries – questionnaire on emissions and elated topics. November 2002. Line and Miklas (1989). Line, D.L., and Miklas, M.P., “Detection and Location of Leaks in Geomembrane Liners Using an Electrical Method: Case Histories,” 10th National Superfund Conference, November 27-29, 1989, Washington D.C. Bonaparte and Gross (1990). Bonaparte R. and Gross B.A., “Field Behavior of Double-Liner Systems in Waste Containment Systems: Construction, Regulation, and Performance.” ASCE Geotechnical Special Publication No. 26, November 1990, 52-83. Gross et al. (1990). Gross B.A., Bonaparte R., and J.P. Giroud, “Evaluation of Flow from Landfill Leakage Detection Layers.” Proceedings Fourth International Conference on Geotextiles, Volume 2, The Hague, June 1990, 481-486. Massachusetts Department of Environmental Protection, 1996, “Mercury in Massachusetts.” Swedish EPA (2003). *A Safe Mercury Repository*, a translation of the official report SOU 2001:58, Report 8105, translation by Maxwell Arding, Naturvårdsverket, ISBN 91-620-8105-5.pdf, ISSN 0282-7298,

	Digital publication only, Jan 2003.

12.2 Wastewater system/treatment

Description	Mercury in wastewater originates mainly from two sources: 1. mercury intentionally added to, and later released from, products and processes, such as dental amalgams, broken thermometers and other devices, industrial discharges, etc.; and 2. atmospheric mercury (originating from both anthropogenic and natural sources) washed out of the air by precipitation, which ends up in the wastewater system. A wastewater system is, in its simplest form, a network of drains, ditches, piping, channels and the like that receive wastewater from mostly domestic and industrial sources, and carry it to larger bodies of water or to treatment systems. In the first case, the untreated wastewater may be discharged directly to the sea or other waterways without any cleaning involved. In the second case, wastewater treatment systems receive wastewater from domestic and industrial sources and then clean it, filter it and treat it in various ways to remove harmful materials and to produce water clean enough to be discharged into local waterways, such as rivers or oceans. A typical wastewater treatment plant consists of a collection system, a series of processes that remove solids, organics and other pollutants from wastewater, and a series of processes for managing and treating the various sludges produced. In addition to such treatment processes, wastewater systems may also include “intercepting” sewers, outfall sewers, sewage collection systems, and/or equipment related to pumping, power and other requirements (US EPA, 1998). It should be mentioned that wastewater treatment systems that receive actual wastewater, rainwater runoff from roads, and other water runoff, are more prone to incidents during heavy rainfall in which the treatment plant is entirely bypassed due to the large volumes of water (COWI, 2002).
Main mercury releases (air, water, soil, production, use, disposal)	Wastewater treatment may be considered an intermediate step in the mercury life cycle, from which the mercury in the water inflow is distributed among one or more of the following output pathways: • water – through the treated water outflow, • land – through the application of sludge as fertiliser, or the disposal of sludge in a landfill, and • air – through sludge incineration or, to a lesser extent, sludge application to land. The split between the amount of wastewater that goes to a wastewater treatment system, and the amount discharged directly to aquatic environments varies greatly from one country to another, and may even vary greatly from one region to another within a country. The same may be said for the degree of mercury removal achieved by various treatment systems, depending on individual plant configurations and operating procedures. ICON (2001) concluded that in the EU-15, heavy metal releases from most major industries are now reasonably well controlled, and the primary targets for source control should include health establishments such as medical centres, small manufacturing industries, etc. The authors cited mercury as a specific case where compulsory use of dental amalgam separators, for example, and substituting mercury with alternative substances in thermometers, may significantly reduce discharges of mercury to the wastewater treatment system. On the other hand, even institutions that no longer use mercury, such as

	educational and research laboratories, have been found to be the source of continuing releases due to previous accumulations of mercury in drains and piping systems.
Mercury reduction options (alternative technologies, other mercury reduction strategies)	Many larger industries now have their own wastewater treatment facilities, which operate in a very similar manner to the facility described below. The advantage of an industry facility, of course, is that it has a much better idea of the composition of its typical wastewater, and is able to fine-tune its treatment system to the special characteristics of its wastewater stream. Urban wastewater (and sewage) treatment is comprised of a series of operations to separate, modify, remove and/or destroy objectionable, hazardous and pathogenic substances carried by wastewater in solution or in suspension, in order to render water fit and safe for downstream uses, or for discharge back into the environment. Stringent water quality and effluent standards in many countries require reductions in suspended solids, biochemical oxygen demand (BOD, related to biodegradable organic compounds), COD (chemical oxygen demand), and to some extent, coliform organisms (indicators of faecal pollution), control of pH and control of concentrations of certain organic compounds, as well as some potentially toxic elements and non-metals. Wastewater treatment may be preceded by a preliminary screening to remove any coarse solid particles, grit, sand and grease. Residues resulting from this pre-treatment are not normally referred to as sludges. Wastewater treatment sludge (or sewage sludge) consists of the residues from mechanical, biological, chemical and physical treatment of wastewater. The quantity and nature of the sludge may vary widely depending on the wastewater composition, the kind of wastewater purification process and the degree of purification. There are two main types of sewage sludge: • Primary sludge, which results from physical or chemical separation from wastewater during primary treatment; and • Secondary sludge, which results from the biological treatment phase (surplus activated sludge, sewage sludge from trickling filters) and tertiary treatment (often nutrient removal). Primary and secondary sludges are often combined to create a composite sludge, which may then go for further treatment in sludge digestion and dewatering (ICON, 2001). In activated sludge treatment systems, or other systems with a high retention of particulate matter, a large part of the mercury in wastewater (for example, roughly 50% in Denmark) will follow the sludge, meaning that the mercury concentration in the water outlets will be significantly reduced as compared to the inlet concentration.
Assessment of options (feasibility, costs, benefits, advantages, disadvantages)	There is such great variation among countries (and even within countries) in the design and operation of wastewater systems that cost estimates for mercury removal are impossible to provide. Wastewater systems are typically focussed little on mercury, and more on removing a variety of other solids and contaminants, and many operators do not even have a good idea of the level of mercury in the wastewater. Therefore, basic information on the average level of mercury in wastewater inlets and outlets, and how much of that mercury is retained in sludges, is the first step toward a better understanding of this problem. If the level of mercury in wastewater inlets is relatively high, this suggests there are municipal sources that are not being adequately controlled. If the level of mercury in wastewater outlets is not much lower, then the treatment system, as designed and operated, is not very effective at removing mercury.

	Once the level of mercury in wastewater and sludges is better known, it must be determined how the sludges are being disposed of in order to determine whether further accumulations or releases may result in health or environmental problems. In Denmark (in 1999) the average mercury concentration was 1.2 g mercury/metric ton of dry sludge (dry weight). About 41% of sludge was applied on agricultural or forest land, about 28% was incinerated and the remainder (about 31%) was landfilled or otherwise stored or treated. (Skårup *et al.*, 2003, based on Danish EPA, 2001). In the major cities of Russia (Moscow, St. Petersburg), the concentrations were recently 1-2 g mercury/metric ton of sludge (dry weight). Only a fraction of the sewage sludge in Russia was used as fertiliser (probably below 15%). After extended dewatering and settling in sludge ponds, the majority was landfilled or dumped in quarries (Lassen *et al.*, 2004). In Finland the average mercury concentration in sewage sludge was recently 0.5 g/metric ton (dry weight). 94% of the sludge was spread on land or added to soil in parks, gardens and agricultural land, while 6% was landfilled (Finnish Environment Institute, 2003).
Actual cases, examples	In Denmark, around 1993, average concentrations in inflows to a few major wastewater treatment plants were in the range of 1.1-3.4 µg mercury/l. By 2001, most mercury releases had been reduced very significantly so that the level of mercury entering municipal wastewater treatment plants averaged about 0.5 µg mercury/l (Maag *et al.*, 1996). Based on comprehensive data on mercury concentrations in municipal sewage sludge, it was calculated that about 50-70% of the mercury inflow to municipal wastewater treatment plants in Denmark in 2001 was retained in the sludge (based on Skårup *et al.*, 2003). Wastewater treatment plant designs in Denmark favour long retention times and very efficient activated sludge removal (necessary for the abatement of other pollutants). Therefore, the level of mercury retention with sludge in Denmark is likely among the highest in the world.
Waste management issues, options	In some countries, spreading wastewater or sewage sludge on farmland as fertiliser is the preferred method of "disposal." However, in this case it is obligatory that there be a threshold limit on the allowable mercury concentration in sludge used for agricultural purposes. If too much sludge with too much mercury is applied to agricultural land, the mercury will eventually accumulate to the point that it will contaminate certain crops. It is preferable that sludges containing mercury exceeding the thresholds be deposited in landfills or incinerated (see section, Sewage sludge incineration). Some wastewater treatment facilities have their own sludge incineration plant. Otherwise, sludge incineration usually takes place in municipal waste incineration plants.
Implementation and enforcement, costs, barriers	In many countries the basic water supplies for much of the population are becoming so polluted that the lack of adequate environmental controls and wastewater treatment systems are resulting in enormous social and economic costs. Mercury certainly plays a role in this larger problem, but its specific cost has not been widely calculated. The responsibility for proper implementation and enforcement of wastewater quality limits lies squarely with local and regional authorities. However, because sources of wastewater pollution are often difficult to identify, and resources for careful investigation are nearly always scarce, the problems are becoming worse, especially in those countries going through a process of rapid economic development.
Information sources, references,	US EPA (1998). National Emission Standards for Hazardous Air Pollutants: Publicly Owned Treatment Works MACT standard. *US Federal Register* Volume 63, No. 230. December 1, 1998. pages

websites	66084-66101. COWI (2002). ACAP and Danish EPA Reduction of Atmospheric mercury emissions from Arctic countries – questionnaire on emissions and elated topics. November 2002. ICON (2001). I Thornton *et al*., Pollutants in urban waste water and sewage sludge, prepared by ICON – IC Consultants Ltd, London, for the Directorate-General Environment of the European Commission, ISBN 92-894-1735-8, © European Communities, February 2001. Skårup, S., Christensen, C.L., Maag, J. and Jensen, S.H. (2003): *Substance Flow Analysis for Mercury*. Environmental project no. 808, The Danish EPA, 2003. Available at www.mst.dk. Lassen, C. (Ed.), Treger, Y.A., Yanin, E.P., Revich, B.A., Shenfeld, B.E., Dutchak, S.V., Ozorova, N.A., Laperdina, T.G. and Kubasov, V.L. (2004): *Assessment of mercury releases from the Russian Federation*. Ministry of Natural Resources of the Russian Federation, Danish Environment Protection agency, Arctic Council. Draft, 2004. Finnish Environment Institute (2003): Response to ACAP questionnaire on mercury releases, uses and wastes. Appendix to Maag (2004). Maag, J., Lassen, C. and Hansen, E. (1996): Massestrømsanalyse for kviksølv (substance flow assessment for mercury). *Miljøproject* no. 344, 1996, Danish Environmental Protection Agency, Copenhagen (in Danish with summary in English). Available at www.mst.dk; publikationer WRc (1994). *Diffuse sources of heavy metals to sewers*, final report to the Department of the Environment, DoE 3624, Swindon (UK), June 1994.