

ANNEX XV RESTRICTION REPORT

PROPOSAL FOR A RESTRICTION

SUBSTANCE NAME: MERCURY

IUPAC NAME: MERCURY

EC NUMBER: 231-106-7

CAS NUMBER: 7439-97-6

SUBMITTED BY: EUROPEAN CHEMICALS AGENCY (ECHA)

VERSION 1

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Preface

The existing restriction in Entry 18a of Annex XVII to the REACH Regulation on mercury in measuring devices includes a review clause. According to the clause, the Commission was to carry out a review of the availability of reliable safer alternatives that are technically and economically feasible for mercury containing measuring devices and where such alternatives are available present, if appropriate, a proposal to extent the existing restriction. The Commission sent its review report to ECHA on 20 November 2009 and requested ECHA to prepare a corresponding Annex XV restriction report.

This Annex XV report concerns the industrial and professional uses of mercury in measuring devices as the existing entry in Annex XVII already restricts the placing on the market of mercury containing measuring devices for general public. The following measuring devices are covered:

- Barometers
- Mercury electrodes (used in voltammetry)
- Manometers (including tensiometers)
- Metering devices for the determination of softening point
- Porosimeters
- Pycnometers
- Sphygmomanometers
- Strain gauges (used with plethysmographs)
- Thermometers (including hygrometers)

Barometers, manometers, sphygmomanometers and strain gauges are used to measure pressure and thermometers temperature. Porosimeters, pycnometers and metering devices for determination of softening point measure different parameters related to the structure and porosity of a sample. Mercury electrodes are used with specific devices like polarographs, for instance to determine trace elements in the environment and in biological fluids.

Barometers, manometers, sphygmomanometers, strain gauges and thermometers contain mercury as an integral part of the device whereas metering devices (for determination of softening point), polarographs (using mercury electrodes), porosimeters and pycnometers use mercury during the measurement. This difference has an effect on the assessment of the devices as will be described later in this report. The devices included in the Annex XV report are also significantly different with regard to other factors, such as number of devices in the EU, the amount of mercury involved, the type of users (private practitioners, laboratories and research institutions, meteorological stations, airfields, ships, different industries etc), and reasons for the continued use.

The main focus of this report is on the assessment of the technical and economic feasibility of alternatives for the mercury devices. This emphasis on possibilities to transfer to alternatives stems from the review clause in the existing restriction. Furthermore, extensive amount of work has already been carried out on the hazard properties, fate, emissions of and exposures to mercury at international, EU and

national levels and there is a wide agreement on the human health and the environmental concerns related to mercury and on the need for further actions where technically and economically possible. Based on this, the hazard profile is discussed only briefly. Furthermore, a qualitative approach is taken to the emission and exposure assessment. The approach taken to describe the hazard, emissions and exposure in this report is presented and justified in Section B.2. Based on this approach taken, Part B of the report deviates from the standard format for an Annex XV restriction report, as published by ECHA (2009).

Furthermore, the number and different nature of the devices covered in this report have led to the development of device specific annexes that discuss the following information:

- Technical description of the device
- Description of release and exposure
- Available information on the alternatives (Part C)
- Justification why the proposed restriction is the most appropriate Community-wide measure (Part E).

Consequently, Part E in the main document is in practise a summary of the proposed restrictions and provides a short justification for proposed actions / non-actions on different devices while Part C in the main document is reduced to a general introduction.

The main information source used for the assessments of the technical and economic feasibility of alternatives to mercury measuring devices is Lassen et al. (2008). This report called “*Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society*” was commissioned by the European Commission (DG Environment). Lassen et al. (2008) and other information sources have an extensive amount of data on mercury in measuring devices, but still there were some data gaps for the remaining specific uses. Therefore, ECHA complemented this information by commissioning a consultant for the preparation of this restriction report. The results from the additional work are referred to as Lassen et al. (2010) in this report and can be found as Appendix 3. In addition, ECHA staff carried out literature and internet searches. These are reported in the relevant sections as well as in Appendix 2. To keep the workload proportionate, the efforts were targeted to gather data that could support the conclusion as to whether technically and economically feasible alternatives exist.

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A. Proposal

A.1 Proposed restriction(s)

A.1.1 The identity of the substance(s)

- Substance name: Mercury
- IUPAC name: Mercury
- EC number: 231-106-7
- CAS number: 7439-97-6
- Index number: 080-001-00-0

A.1.2 Scope and conditions of restriction(s)

Based on the justifications summarised in Section A.2 and discussed in the report, the following restrictions with derogations are suggested for mercury measuring devices in professional and industrial uses¹:

1. Barometers, hygrometers, manometers, sphygmomanometers, tensiometers, thermometers and other non-electrical thermometric applications containing mercury shall not be placed on the market. This applies also to measuring devices placed on the market empty intended to be filled with mercury.

It is suggested that the placing on the market of devices containing mercury for the following uses are derogated from the restriction described above:

- (a) Sphygmomanometers that are used (i) in long-term, epidemiological studies which are on-going at entry into force; (ii) as reference standards in clinical validation studies of mercury-free sphygmomanometers.
 - (b) Mercury-in-glass thermometers used in industrial applications for temperature measurements above 200°C as demonstrated by the reading scale.
 - (c) Thermometers exclusively intended to perform tests according to standards that require the use of mercury thermometers. It is suggested that this derogation will be valid until five years after the date of the adoption of this restriction.
 - (d) Mercury triple point cells that are used for the calibration of platinum resistance thermometers.
2. Plethysmographs designed to be used with mercury strain gauges, mercury pycnometers and mercury metering devices for determination of the softening point shall not be placed on the market.

It is suggested that the restrictions mentioned under paragraphs 1 and 2 will apply 18 months after the adoption of the respective Commission proposal.

¹ These suggested restrictions and related derogations concern only professional and industrial uses of the devices. They do not affect the existing restriction on mercury in measuring devices intended for sale to general public and on mercury in fever thermometers established in entry 18a of Annex XVII to the REACH Regulation.

Furthermore, it is suggested that these restrictions would not apply to measuring devices mentioned above that are more than 50 years old.

A.2 Summary of the justification

Identified hazard and risk

Mercury and its compounds are highly toxic to humans, ecosystems and wildlife, with amongst others serious chronic irreversible adverse neurotoxic and neurodevelopmental effects.

It is estimated that 3.5 to 7.6 tonnes of mercury is placed on the market in mercury containing measuring devices in 2010 (see Table 1). These amounts are used to describe the maximum potential for mercury emissions to the environment that might ultimately occur. This is considered appropriate for the purpose of this restriction report as the low separate collection rate and resulting inadequate waste treatment of a substantial part of the devices, leads in the long term to a relatively high share of mercury used in these devices being released to the environment.

Table 1: The amount of mercury estimated to be placed on the market in the EU in mercury containing measuring devices in 2010

Measuring device <u>containing</u> mercury	Amount of Hg placed on the market in the EU in 2010 (t/y)
Barometers	0.1-0.5
Manometers (including tensiometers)	0.04-0.4
Sphygmomanometers	2.6-5.1
Strain gauges (used with plethysmographs)	0.014
Thermometers (including hygrometers)	0.7-1.6
Total	3.5-7.6

Source: Lassen et al. (2008) as updated in device specific annexes 1 – 5.

In addition, around 5-15 tonnes of mercury is supplied annually to be used with porosimeters, pycnometers, devices using mercury electrodes in voltammetry and metering devices for determining the softening point (see Table 2).

The annual amounts presented (in Tables 1 and 2) are not comparable. The figures in Table 2 are the amount of mercury the laboratories purchase and cannot be used to estimate maximum potential for emission as is the case in Table 1. To estimate emissions several additional factors need to be considered. These include number of measurements carried out, practices to purify and regenerate used mercury and the

risk management measures and operational conditions applied to control the emissions and exposures. Furthermore, available information indicates that the hazardous waste legislation requirements are generally complied with when handling the mercury contaminated waste generated during these measurements.

Table 2: The amount of mercury estimated to be purchased in the EU to be used with measuring devices in 2010

Measuring device <u>using</u> mercury	Amount of Hg purchased to be used for measurements (t/y)
Mercury electrodes (used in voltammetry)	0.1-0.5
Metering devices for the softening point determination	not available
Porosimeters	5-14
Pycnometers	not available
Total	5-15

Source: Lassen et al. (2008), device specific annexes 6-9

Once released to the environment, mercury persists in the environment, where it circulates between air, water, sediments, soil and biota in various forms. Mercury can be transformed to methylmercury, the most toxic form, which biomagnifies especially in the aquatic food chain, making populations and wildlife with a high intake of fish and seafood particularly vulnerable.

Several existing pieces of legislation abate the risks arising from mercury in different stages of the life-cycle of measuring devices. However, none of the measures currently in place is sufficient to remove the concern fully, although there is a difference between their observed effectiveness with regard to measuring devices containing mercury and measuring devices using mercury.

The emissions from mercury measuring devices, although relatively small, contribute to the overall emissions of mercury to the environment and thereby also to the exposure of species and of humans via the environment. Therefore, measuring devices containing or using mercury are of concern.

Justification that action is required on a Community-wide basis

The main reason to act on a Community-wide basis is the cross boundary human health and environmental problem. Furthermore, the fact that the goods need to circulate freely within the EU stresses the importance of the Community-wide action. Thus, the use of mercury in these devices needs to be controlled at the EU level. In addition, acting at Community level strengthens the possibilities to address the adverse impacts of mercury at worldwide level.

Justification that the proposed restriction is the most appropriate Community-wide measure

Tables 3 and 4 summarise the justifications for the proposed restriction as well as the justification for not proposing any regulatory action for each device. The main purpose of the proposed restrictions is to reduce the mercury pool in the society, thus avoiding negative impacts on human health and environment. Nevertheless, based on the review clause, the justification is focused on the technical and economic feasibility of the alternatives.

Table 3: Proposed restrictions and summary of justification for measuring devices containing mercury

Measuring device containing mercury	Proposed restriction	Summary of justification
Barometers	Restriction on the placing on the market of mercury barometers.	Technically and economically feasible alternatives are available.
Manometers (including tensiometers)	Restriction on the placing on the market of mercury manometers and tensiometers.	Technically and economically feasible alternatives are available.
Sphygmomanometers	Restriction on the placing on the market of mercury sphygmomanometers <u>with limited derogations</u> .	Technically and economically feasible alternatives are available in most applications.
Strain gauges (used with plethysmographs)	Restriction on the placing on the market of plethysmographs designed to be used with mercury strain gauges.	Technically and economically feasible alternatives are available.
Thermometers (including hygrometers)	Restriction on the placing on the market of mercury thermometers with derogations for i) mercury-in-glass thermometers used in industry to measure temperatures above 200°C, ii) thermometers to perform specific analytical tests according to established standards and iii) mercury triple point cells that are used for the calibration of platinum resistance thermometers	Technically feasible alternatives are available for majority of applications. Reasons for derogations: i) the alternatives are not economically feasible, ii) some current standards refer to mercury thermometers and time is needed to revise them iii) mercury is one of the reference points needed in the International Temperature Scale (ITS-90)

Table 4: Proposed restrictions and summary of justification for measuring devices using mercury

Measuring device <u>using</u> mercury	Proposed restriction	Summary of justification
Mercury electrodes (used in voltammetry)	No restriction proposed	Technically feasible alternatives are not available in all applications. In addition, two main alternatives seem not to be economically feasible.
Metering devices for the softening point determination	Restriction on the placing on the market of mercury metering devices for the softening point determination	Technically feasible alternatives are available and in use. The alternatives also seem to be economically feasible.
Porosimeters	No restriction proposed	High uncertainties in the technical feasibility of the alternatives. Consequently the economic feasibility was not assessed in detail.
Pycnometers	Restriction on the placing on the market of mercury pycnometers.	Technically feasible alternatives are available and in use. The alternatives also seem to be economically feasible.

B. Information on hazard and risk

B.1 Name and other identifiers of the substance

Name of a substance: Mercury

EC Number: 231-106-7

CAS Number: 7439-97-6

B.2 Scope and approach

Scope

The existing restriction in Entry 18a of Annex XVII to the REACH Regulation for mercury in measuring devices includes a review clause². According to that clause, the Commission was to carry out a review of the availability of reliable safer alternatives that are technically and economically feasible for mercury containing measuring devices and where such alternatives are available to present, if appropriate, a proposal to extend the existing restriction. The Commission services have collected a significant amount of new information from stakeholders on measuring devices and have received the SCENIHR opinion on the safety, availability and quality of alternative methods for blood pressure measurements (SCENIHR, 2009). The Commission has sent ECHA its review report (see Appendix 5) and requested the European Chemicals Agency to prepare an Annex XV dossier as foreseen by Article 69 of REACH.

Regulation (EC) No 1102/2008 bans the export of metallic mercury and certain mercury compounds from 15 March 2011. Furthermore, this Regulation calls for examining the need to extend the export ban to products containing mercury naming in particular thermometers, barometers and sphygmomanometers. For reasons of consistency it is not considered whether there is a need to ban the export of mercury in measuring devices in the framework of the REACH Regulation. Consequently, this Annex XV report does not further address the need or possibilities to limit export of mercury in measuring devices.

Several mercury containing measuring devices are dependent on electric currents in order to work properly, and thus fall under the definition of ‘electrical and electronic equipment’ in the RoHS Directive³. For reasons explained in Appendix 4, they are not

² Paragraph 4 of Entry 18a of Annex XVII of the REACH Regulation as amended by Commission Regulation (EC) No 552/2009

“By 3 October 2009 the Commission shall carry out a review of the availability of reliable safer alternatives that are technically and economically feasible for mercury containing sphygmomanometers and other measuring devices in healthcare and in other professional and industrial uses. On the basis of this review or as soon as new information on reliable safer alternatives for sphygmomanometers and other measuring devices containing mercury becomes available, the Commission shall, if appropriate, present a legislative proposal to extend the restrictions in paragraph 1 to sphygmomanometers and other measuring devices in healthcare and in other professional and industrial uses, so that mercury in measuring devices is phased out whenever technically and economically feasible.”

³ ‘*electrical and electronic equipment*’ or ‘*EEE*’ means equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields falling under the categories set out in Annex IA to

covered by this restriction report. This is in line with recital 1 of the Directive 2007/51/EC that introduced the restriction on mercury in measuring devices, now subject to revision and reads: *“The Commission communication of 28 January 2005 on the Community strategy concerning mercury, which considered all uses of mercury, concluded that it would be appropriate to introduce Community-level marketing restrictions on certain **non-electrical or non-electronic** measuring and control equipment containing mercury, which is the main mercury product group not covered by Community action so far.”* (emphasis added).

In summary, this Annex XV restriction report covers placing on the market and use of mercury for non-electrical or non-electronic measuring devices. The need for marketing or use restrictions for other uses of metallic mercury or other mercury compounds is not within the scope of this report.

Background

Several international governance bodies have undertaken action to address the global human health and environmental concerns related to emissions of and exposure to mercury. The existing restriction on mercury in measuring devices, and the current restriction proposal to extend this restriction, is part of this overall action.

United Nations

The UNEP mercury programme has been established and strengthened by a series of Governing Council decisions. In February 2003, the UNEP Governing Council decided that *“national, regional and global actions, both immediate and long-term, should be initiated as soon as possible to protect human health and the environment through measures that will reduce or eliminate releases of mercury and its compounds to the environment”*, and urged *“all countries to adopt goals and take national actions, as appropriate, with the objective of identifying exposed populations and ecosystems, and reducing anthropogenic mercury releases that impact human health and the environment”* (UNEP, 2003).

In February 2009 the UNEP Governing Council adopted a decision, where it recalled the findings of the 2002 global mercury assessment that mercury is a substance of global concern due to its long-range atmospheric transport, its persistence in the environment once anthropogenically introduced, its ability to bioaccumulate in ecosystems and its significant negative effects on human health and the environment. The Governing Council further requested to continue and enhance, as part of the international action on mercury, the existing work in reducing mercury use in products and processes and raising awareness of mercury free-alternatives.

The organisation of activities concerning mercury at the United Nations level is described in the following quotes:

“The UNEP mercury programme has been established and strengthened by a series of Governing Council decisions since decision 21/5 in 2001. The UNEP mercury programme delivers activities on mercury through the UNEP Global Mercury

Directive 2002/96/EC (WEEE) and designed for use with a voltage rating not exceeding 1 000 volts for alternating current and 1 500 volts for direct current (Article 3(a) of Directive 2002/95/EC).

Partnership, and will also support the negotiations of an internationally legal instrument for control of mercury.” (UNEP, 2010)

“The overall goal of the UNEP Global Mercury Partnership is to protect human health and the global environment from the release of mercury and its compounds by minimizing and, where feasible, ultimately eliminating global, anthropogenic mercury releases to air, water and land.” (UNEP, 2010)

One of the Partnership Areas focuses specifically on products containing mercury, also covering measuring devices:

“The goal of the Mercury-Containing Products Partnership Area is to phase out and eventually eliminate mercury in products and to eliminate releases during manufacturing and other industrial processes via environmentally sound production, transportation, storage, and disposal procedures. Key product areas identified under this partnership area include: batteries, dental amalgams, measuring and control (largely medical sector), electric and electronic switches, fluorescent lamps, cosmetics.” (UNEP, 2010)

The UNEP Governing Council agreed to elaborate a legally binding instrument on mercury and gave a mandate to an intergovernmental negotiating committee (INC) to prepare this. The first session of this committee will be held in Stockholm, Sweden, from 7 to 11 June 2010. (UNEP, 2010)

European Community

In the EU, mercury has been under different policy actions. The Community Strategy Concerning Mercury (COM(2005) 20 final) has 20 action points with the aim to reduce mercury levels in the environment and human exposure, especially from methylmercury in fish.

In October 2007, the Commission adopted a restriction for mercury in all fever thermometers and in other measuring devices intended for sale to the general public (Directive 2007/51/EC, current Entry 18a of Annex XVII to REACH). This restriction established that as soon as new information on reliable safer alternatives for sphygmomanometers and other measuring devices becomes available, the Commission shall consider to extend the restriction.

Other regional and global actions

In addition to the described actions on the UN and EU-level, several other regional and global initiatives are active in identifying sources of mercury emissions and exposures, monitoring concentrations of mercury in the environment, defining protection objectives and recommending measures to address the mercury problem. Examples are the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP); the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic; the Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area; the UNEP Mediterranean Action Plan (MAP); the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal; the Rotterdam Convention on the Prior Informed Consent (PIC) Procedure for Certain Hazardous Chemicals and Pesticides in International

Trade; The Arctic Council Action Plan to Eliminate Pollution of the Arctic (working groups ACAP and AMAP); and Nordic Co-operation.

Approach

As mentioned above, Entry 18a of Annex XVII requests the Commission to present a legislative proposal to extend the restrictions where reliable safer alternative substances or technologies that are technically and economically feasible are available for mercury containing sphygmomanometers and other measuring devices in healthcare and in other professional and industrial uses. Based on this entry, the Commission prepared a review report on the technical and economic feasibility of alternatives (see Appendix 5) and requested ECHA “*to evaluate new scientific evidence concerning the availability of reliable safer alternatives that are technically and economically feasible for mercury-containing sphygmomanometers and other measuring devices in healthcare and in other professional and industrial uses*”, and to present the outcome in an Annex XV restriction report.

Therefore, the focus of the report is on the technical and economic feasibility of the alternatives, while the hazards and exposure are described in general and qualitative terms.

The risks related to the use of mercury measuring devices cannot be assessed in isolation, and further restrictions related to these devices has to be seen as one of the means in the Community Strategy Concerning Mercury to reduce the overall mercury emissions.

Hazard

The hazardous properties and risks of mercury and methylmercury have been extensively studied and described in different scientific reports and have been acknowledged at high policy levels. A systematic literature survey would be unlikely to deliver new information that would change the consensus at the EU and international level on this hazard profile and the need for reduction of the mercury pool in the society. Hence, since a comprehensive description of the hazardous properties of mercury would mean duplicating the extensive work already carried out and agreed upon and taking into account the fact that the focus of the dossier is on the technical and economic feasibility of alternatives, the hazard assessment in this report is brief and qualitative, and the technical dossier (IUCLID 5 –file) does not contain robust study summaries.

Exposure

Annex XV of REACH calls for the assessment of risks in accordance with the relevant parts of Annex I. Mercury as an element is persistent and has extremely complex processes of bioaccumulation and biomagnification that involve complicated biogeochemical cycles and ecological interactions (see section B.3 and UNEP, 2002). Therefore, it is not possible to carry out a quantitative exposure estimation with sufficient reliability, and a qualitative characterisation of risks in accordance with section 6.5 of Annex I to REACH is considered appropriate.

Since release estimates would not serve a quantitative exposure assessment or risk characterisation and would have to be expressed in exceedingly broad ranges to take

into account all accumulated uncertainties (see section B.4), no quantitative release estimates are made either. The focus of the exposure assessment is on the minimisation of mercury emissions to the environment, which is also supported by the objectives in the Community Strategy Concerning Mercury to '*reduce mercury emissions*' and '*reduce the entry into circulation of mercury in society by cutting demand*' and the agreement on the UN-level to '*eliminate releases of mercury and its compounds to the environment*'.

As described above the main focus of this report is on the technical and economical feasibility of the alternatives. The estimated amounts of mercury placed on the market in different devices are used to illustrate the risk reduction capacity of the restriction options. Where available, the risk reduction capacity is expressed as amount of mercury (kg Hg) which would not be placed on the market per year. This is then used when assessing the proportionality of the restriction options. Where technical or economic feasibility of alternatives cannot be established and consequently restrictions are not proposed in this report the estimated amounts together with other considerations can be used to describe the remaining concern related to mercury included in or used with measuring devices.

Measuring devices covered by this report can be divided to two categories i) devices containing mercury as an integral part of the device (barometers, manometers, sphygmomanometers, strain gauges and thermometers) and ii) devices using mercury during the measurements (porosimeters, pycnometers, mercury electrodes used in voltammetry and metering devices). This difference is crucial for the description of releases and emissions in this report as explained below and in Section B.4.

Release from measuring device containing mercury

The total estimated amount of mercury placed on the market in measuring devices containing mercury is used to describe the maximum potential for mercury emissions to the environment that might ultimately occur.

Mercury is an integral part of these devices and they normally operate without a need to handle mercury. Mercury is disposed of together with the devices at the end of their service life. Therefore, the emission estimation related to measuring devices containing mercury concentrates on the release of mercury to the environment during the waste stage. Also the existing restriction covering mercury containing devices focused on the waste stage as described in recital 2 of Directive 2007/51/EEC which states: '*(2) There would be benefits for the environment and, in the long term, for human health, through **preventing mercury from entering the waste stream**, if restrictions on the marketing of measuring devices containing mercury were introduced*'. (emphasis added). Nevertheless, it is recognised - and shortly described - that direct exposure of humans to elemental mercury may occur during the production and service-life of the devices.

In addition to the amounts placed on the market also the dispersiveness of use, proportion of proper waste collection and disposal of and other factors described in the report are taken into account when illustrating the emissions and exposures related to different devices. This estimation is obviously not to be confused with a quantitative estimate of actual emissions which would require in particular detailed

information on the current waste management practices and emissions resulting from the waste stage (see section B.4.1).

Release from measuring devices using mercury

The situation is more complex for devices using mercury during the measurements. The amount of mercury placed on the market cannot be used for these devices as a proxy for maximum potential for emissions in a similar way as it is used for mercury containing devices. The annual amount of mercury purchased by the laboratories to be used in the measurements is given to illustrate the volumes involved. However, for reasons given in section B.4.2 this amount alone does not describe the potential releases and exposures related to the measuring devices using mercury. Further parameters and qualitative descriptions are used to give a more complete picture.

Proportionality

The total amount of mercury placed on the market in the measuring devices is used to assess the proportionality of the restriction options. The cost-effectiveness (€/kg Hg) of avoiding mercury is calculated for different devices by dividing the cost of using an alternative device by the amount of mercury that is avoided (for details, see Annexes 3b and 5b). The cost-effectiveness estimates are compared with the estimates of compliance costs and human health benefits of reduced mercury emissions, as well as with restoration costs in the EU and elsewhere. The details are provided in Appendix 2.

Summary

In summary, considering that this Annex XV report supports the extension of the existing restriction on mercury in measuring devices where technically and economically feasible alternatives are available, considering the common understanding on the hazardous properties of mercury and its transformation products and considering it would not be possible to perform a reliable quantitative estimation of releases, and especially of the resulting exposure levels this approach to describe hazard in brief and to focus the exposure assessment on the minimisation of emissions was deemed warranted.

Information sources for hazard and risk

The hazard and fate of mercury and its compounds are described in numerous peer-reviewed reports. The following reports were considered key documents:

- *'Global Mercury Assessment'*, published by UNEP in 2002 (and UNEP 2008a and b).
- *'Methylmercury'* (WHO, 1990) ;
- *'Risks to Health and the Environment Related to the Use of Mercury Products'* prepared for the Commission by RPA in 2002;

It is noted that references used and cited in these key documents are not explicitly referred to in this restriction report.

For the qualitative description of potential releases and exposure, amounts of mercury included in or used with the measuring devices are mainly taken from Lassen et al. (2008). Additional information on release and exposure situations for porosimeters is gathered during the preparation of this dossier (Lassen et al., 2010 in Appendix 3).

B.3 General description of hazard and fate

Fate

Elemental mercury (Hg(0)) is a shiny, silver-white metal that is a liquid at room temperature. At room temperature some of the metallic mercury will evaporate and form mercury vapours. Mercury vapours are colourless and odourless.

After release, mercury persists in the environment, where it circulates between air, water, sediments, soil and biota in various forms (UNEP, 2002).

Elemental mercury vapour is transported on a hemispherical/global scale making mercury emissions a global concern. Elemental mercury in the atmosphere can undergo transformation into inorganic mercury forms⁴, providing a significant pathway for deposition of emitted elemental mercury. Mercury vapour has an atmospheric residence time that is between 0,4 and 3 years (WHO, 1990). Emitted mercury vapour is converted to soluble forms, these soluble forms have residence times of a few weeks (WHO, 1990). Soluble forms of mercury are deposited by rain into soil and water.

Mercury in soil is mostly bound to bulk organic matter and is susceptible to wash out in runoff only when attached to suspended soil or humus. Mercury has a long retention time in soil and as a result, the mercury accumulated in soil may continue to be released to surface waters and other media for long periods of time, possibly hundreds of years.

Various chemical reactions can return mercury to the elemental form which can be readily re-emitted. Thus, mercury that has been deposited can be re-emitted and continue travelling through the atmosphere from source regions to receptor regions in a series of 'hops' (so called grasshopper effect). Mercury may be accumulated in polar regions, where colder conditions may be less favourable to re-emissions (UNEP, 2008b).

A portion of the inorganic mercury is methylated (particularly within sediments) to methylmercury, which enters the water column (RPA, 2002). Methylmercury is by far the most common organic mercury compound in the environment (UNEP, 2002). The rate of mercury methylation depends on factors such as the activity of mercury methylating bacteria (e.g. sulphate reducers), concentration of bioavailable mercury (UNEP, 2002). These factors in turn are influenced by parameters such as temperature, pH, redox potential and the presence of inorganic and organic complexing agents (UNEP, 2002). Chemical methylation of mercury is also possible,

⁴ Oxidation states +I and +II

and biotic demethylation occurs as well (UNEP, 2002). Methylation and demethylation processes are in fact determining the actual methylmercury concentrations in the environment (UNEP, 2002).

Although all forms of mercury can accumulate to some degree, methylmercury is absorbed and accumulates to a greater extent than other forms (UNEP, 2002)⁵. Marine and freshwater fish, as well as marine mammals, bioaccumulate⁶ methylmercury in their muscle tissue (UNEP, 2008). Fish bind methylmercury strongly, and elimination of methylmercury from fish is very slow, which causes fish to accumulate methylmercury over time (UNEP, 2002).

Moreover, methylmercury biomagnifies⁷ throughout the many aquatic trophic levels (UNEP, 2002). The highest levels in the aquatic food web are found in fish that are apical predators of older age (such as king mackerel, pike, shark, swordfish, walleye, barracuda, large tuna, scabbard, and marlin) and fish-consuming mammals such as seals and toothed whales (UNEP, 2008a). Other fish-eating species, such as seabirds, but also humans are situated at top level of the trophic chain through eating (predator) fish and other seafood (UNEP, 2002).⁸

On a global scale, the Arctic region and its species has been in focus because of the tendency of mercury to be transported over a long-range. However, the impacts of mercury are by no means restricted to the Arctic region. The same food web characteristics and similar dependence on mercury contaminated food sources are found in specific ecosystems and human communities in many countries around the world, particularly where a fish diet is predominant. (UNEP, 2002)

The bioaccumulation factor⁹ for methylmercury in edible freshwater and saltwater fish and marine mammals can mount to many thousands (UNEP, 2002), and can even be well above one million (SCHER, 2008). In other words, low concentrations in the

⁵ Inorganic mercury can also be taken up, but generally at a lower rate and with lower efficiency compared to methylmercury (UNEP, 2002).

⁶ Bioaccumulation refers to uptake from all environmental sources including water, food and sediment. UNEP (2002) gives the following description: “The term bioaccumulation refers to the net accumulation over time of metals within an organism from both biotic (other organisms) and abiotic (soil, air, and water) sources.”

⁷ Biomagnification refers to accumulation via the food chain. UNEP (2002) gives the following description: “The term biomagnification refers to the progressive build up of some heavy metals (and some other persistent substances) by successive trophic levels – meaning that it relates to the concentration ratio in a tissue of a predator organism as compared to that in its prey (AMAP, 1998).”

⁸ In EU the maximum levels for mercury in fishery products, in muscle meat of fish and in crustacea are given in the Commission Regulation (EC) No 1881/2006, amended No 629/2008. In addition, the Joint FAO/WHO Expert Committee on Food Additives (JECFA), established a provisional tolerable weekly intake (PTWI) of 1.6µg/kg bw, and the US National Research Council (NRC) established an intake limit of 0.7µg/kg bw (EFSA, 2004). According to EFSA, estimated intakes of mercury in Europe varied by country, depending on the amount and the type of fish consumed. The mean intakes in some countries exceeded the NRC-limit, and high intakes may also exceed the JECFA-limit (EFSA, 2004). Several EU Member States have issued advice to vulnerable populations to avoid or limit the frequency of intake of certain fish species (COM, 2008). The Commission advises that women who might become pregnant, woman who are pregnant or women who are breastfeeding, as well as young children, should not eat more than 100g per week of large predatory fish, such as swordfish, shark, marlin and pike (COM, 2008).

⁹ The overall bioaccumulation factor is the ratio between the concentration in the organisms and the concentration in water (SCHER, 2008).

environment can still lead to high dietary exposure. Much is known about mercury bioaccumulation and biomagnification, but because of the complexity of the processes involved, the extent of mercury biomagnification in fish is not easily predicted (UNEP, 2002).

Hazard

Each form of mercury has its own toxicological profile, although, in general terms, the organic mercury compounds have the highest toxicity, followed by elemental mercury and inorganic mercury compounds. The focus is on the description of the hazards of methylmercury, since it is the most toxic form and, as described earlier, is of highest concern since it biomagnifies in food webs (UNEP, 2008). Elemental mercury is described in brief since mercury in measuring devices might result in direct human exposure to elemental mercury. Inorganic mercury compounds are not described here, since they are of less relevance.

Methylmercury

Humans

Methylmercury is highly toxic especially to the nervous system. Methylmercury toxicity has been demonstrated at low exposure levels (EFSA, 2004). In adults, the first effects at the lowest doses are non-specific symptoms, such as paresthesia, malaise and blurred vision. This may progress to cerebellar ataxia (clumsiness or unsteadiness), dysarthria (speech disorder), constriction of the visual fields and loss of hearing. With increasing exposure there are signs such as constriction of the visual field, deafness, dysarthria and ataxia, and ultimately leading to coma and death (UNEP, 2002).

Methylmercury exhibits severe neurodevelopmental effects. It passes both the placental barrier and the blood-brain barrier. The developing nervous system in unborn and newborn children is the most sensitive target organ. The effects can take place even at exposure levels where the mother remains healthy or suffers only minor symptoms due to mercury exposure. At lower exposure levels, the effects may only become apparent later during the development as psychomotor and mental impairment and persistent pathological reflexes. In infants exposed to high levels of methylmercury during mothers pregnancy, the clinical picture can be indistinguishable from cerebral palsy caused by other factors, the main pattern being microcephaly, hyperreflexia and gross motor and mental impairment, and in rare cases, blindness or deafness (UNEP, 2002). Some studies suggest even small increases in methylmercury exposures may cause adverse effects on the cardiovascular system, thereby leading to increased mortality (UNEP, 2002).

The examples of mercury poisoning in Japan and Iraq have shown on a population scale the severe neurological effects of methylmercury to humans. At first the poisoning in Minamata, Japan, was regarded as an epidemiological disease of unidentified causes (Minamata Disease), first seen in abnormal behaviour in animals, and in 1956 reported first in humans. In 1959 the cause was officially recognized as being methylmercury foodpoisoning. The methylmercury originated from discharged mercury containing wastewater from an acetaldehyde production factory into

Minamata bay. According to the National Institute for Minamata Disease, there are 2955 legally recognized patients. (National Institute for Minamata Disease, 2010).

In Iraq, the poisoning incidents in 1956 and 1959-1960 and in 1971-1972 were due to the consumption of seed grain that had been treated with fungicides containing methyl- and ethylmercury. After the incident in 1971-1972 it was reported severe damage to the central nervous system in infants prenatally exposed to methylmercury (WHO, 1990 and UNEP, 2002). In adults the symptom was paresthesia and in more severe cases ataxia, blurred vision, slurred speech and hearing difficulties (UNEP, 2002).

In addition there are number of other epidemiological studies with pregnant women having marine diets and their children which provide some supporting evidence to the previous findings related to the neurological effects (WHO, 2007).

Environment

As in humans, mercury exposure of animals may result in severe neurological effects. These effects were clearly seen in the Minamata poisoning, where birds experienced severe difficulties in flying, and domestic animals, especially cats, showed signs of severe neurological intoxication. (UNEP, 2002)

In birds, methylmercury has been associated with eggshell thinning in the 1950's and 1960's. Methylmercury was used as a fungicidal seed dressing, and severe poisoning of wildlife was observed in Scandinavia and North America. Populations of pheasants and other seed-eating birds, as well as birds of prey were drastically reduced and in some areas nearly disappeared. Adverse effects of mercury on reproduction can occur at egg concentrations as low as 0.05 to 2.0 mg/kg (wet weight). UNEP (2002), reported eggs of certain Canadian species to be in this range, and concentrations in the eggs of several other Canadian species were said to continue to increase and are approaching these levels.(UNEP, 2002)

To adult fish, direct exposure to methylmercury from the surrounding water is generally not a serious concern. However evidence suggests that mercury exposure to early life stages of some fish can affect growth, development and hormonal status at levels within a factor of 10 of levels encountered in “pristine” lakes. Effects from indirect exposure via dietary uptake and maternal transfer of methylmercury to eggs and developing embryos might be of concern. (UNEP, 2002)

Mercury is toxic to micro-organisms and has long been used to inhibit the growth of bacteria in laboratory experiments. Evidence suggests that mercury is responsible for a reduction of micro-biological activity vital to the terrestrial food chain in soils over large parts of Europe – and potentially in many other places in the world with similar soil characteristics. (UNEP, 2002)

Elemental mercury

Elemental mercury is very toxic to humans via inhalation. About 80 percent of inhaled vapours are absorbed by the lung tissues. This vapour easily penetrates the blood-brain barrier and is a well documented neurotoxicant causing neurological and

behavioural disorders in humans when inhaled. Specific symptoms include tremors, emotional lability, insomnia, memory loss, neuromuscular changes, and headaches. Intestinal absorption of elemental mercury is low.

The EU harmonised classification and labelling of mercury is described in Appendix 1.

B.4 General qualitative description of potential release and exposure

More than 60 different applications for mercury have been identified in the EU. Lassen et al. (2008) estimated that in 2007 between 320 and 530 tonnes of mercury was used in industrial processes and products in the EU27+2. The biggest annual tonnages are used in chlor-alkali production and in dental amalgams representing 47 % and 27 % of the total amount of mercury used in the EU for all applications. The demand of mercury for chlor-alkali production is steadily declining as a result of a phase-out of the mercury-cell process¹⁰. The Figure 1 presents the shares of each application areas, including measuring devices, from the total annual use of mercury in products and industrial processes in the EU.

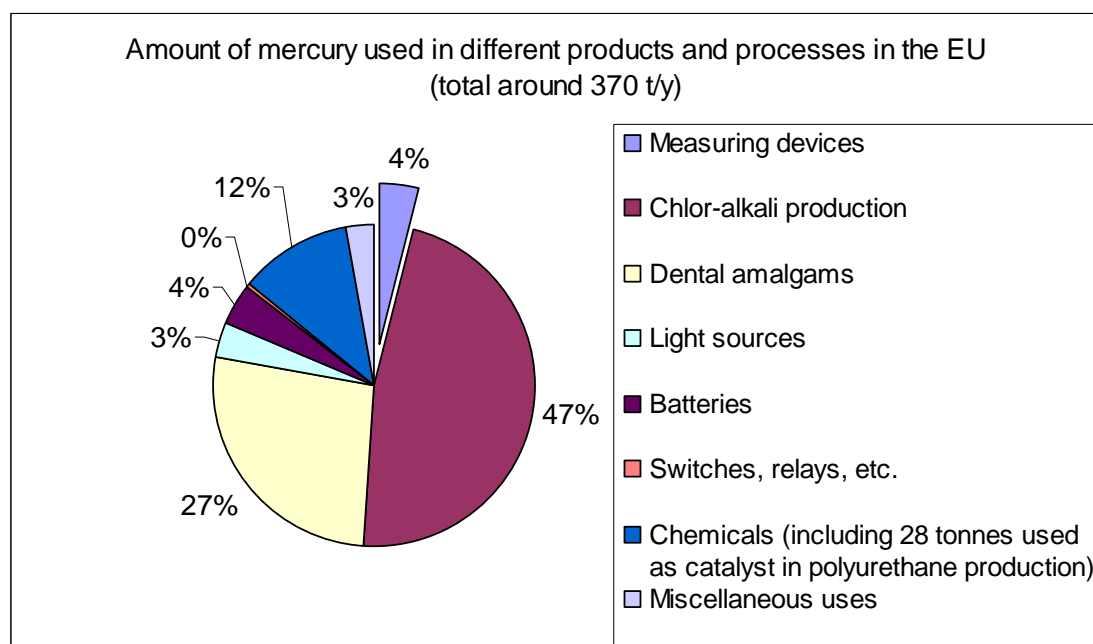


Figure 1: The amount of mercury used in products and industrial processes in the EU annually. Source: Figures based on Lassen et al. (2008) and updated for measuring devices as described in device specific Annexes.

¹⁰ The OSPAR Decision 90/3 of 14 June 1990 on reducing atmospheric emissions from existing chlor-alkali plants recommended that “existing mercury cell chlor-alkali plants be phased out as soon as practicable. The objective is that they should be phased out completely by 2010”.

Euro Chlor and its members state that they continue implementing a voluntary agreement on the gradual conversion to membrane technology. According to Eurochlor, the final phase out for the chlor-alkali production should be completed by 2020. (<http://www.eurochlor.org/news/detail/index.asp?id=272>) The chlor-alkali industry is also covered by the IPPC Directive, which requires installations to have permit conditions based on best available techniques (BAT). The mercury-cell process is not considered to be BAT for the chlor-alkali sector.

The following subsections describe the potential mercury releases and exposure during the life-cycle of mercury containing measuring devices and devices using mercury. Details for specific devices are given in Annexes 1 to 9.

B.4.1 Mercury emissions from measuring devices containing mercury

The amount of mercury placed on the market in the EU in different measuring devices containing mercury is estimated to be between 3.5 and 7.6 tonnes in 2010. Device specific figures are summarised in Table 5. The service-life of the measuring devices containing mercury is usually longer than 1 year, and consequently the accumulated pool of mercury in measuring devices in use is higher than the amount placed on the market annually. The estimates on the accumulated pool are also presented in Table 5.

Table 5: The amount of mercury estimated to be placed on the market in the EU in mercury containing measuring devices in 2010

Measuring device containing mercury	Amount of Hg placed on the market in the EU in 2010 (t/y)	The estimated accumulated pool of Hg in the devices in 2010 (t)
Barometers	0.1-0.5	3
Manometers (including tensiometers)	0.04-0.4	4
Sphygmomanometers	2.6-5.1	39
Strain gauges (used with plethysmographs)	0.014	0.014
Thermometers (including hygrometers)	0.7-1.6	88
Total	3.5-7.6	134

Source: Lassen et al. (2008)¹¹ as updated in device specific Annexes 1 – 5.

Mercury emissions to the environment and direct human exposure may occur during all life-cycle stages of mercury containing measuring devices, but in particular emissions to the environment from the waste stage are of concern. Figure 2 shows the life cycle of mercury containing devices and indicates the relative size of mercury losses from different life cycle stages.

¹¹ Lassen et al. (2008) estimated the amount of mercury placed on the EU market in measuring devices containing mercury to be between 7 and 17 tonnes in 2007 (this amount included also devices for consumer use). Of this amount, 3 – 8 tonnes per year are covered by the existing restriction on the placing on the market of mercury containing measuring devices for sale to general public and placing on the market of fever thermometers and therefore not anymore available on the EU market (the measures in entry 18a of Annex XVII of REACH apply since 3 April 2009). Based on these figures the amount of mercury placed on the market in mercury containing measuring devices not covered by the existing restriction is roughly estimated to have been between 4 and 9 tonnes per year in 2007.

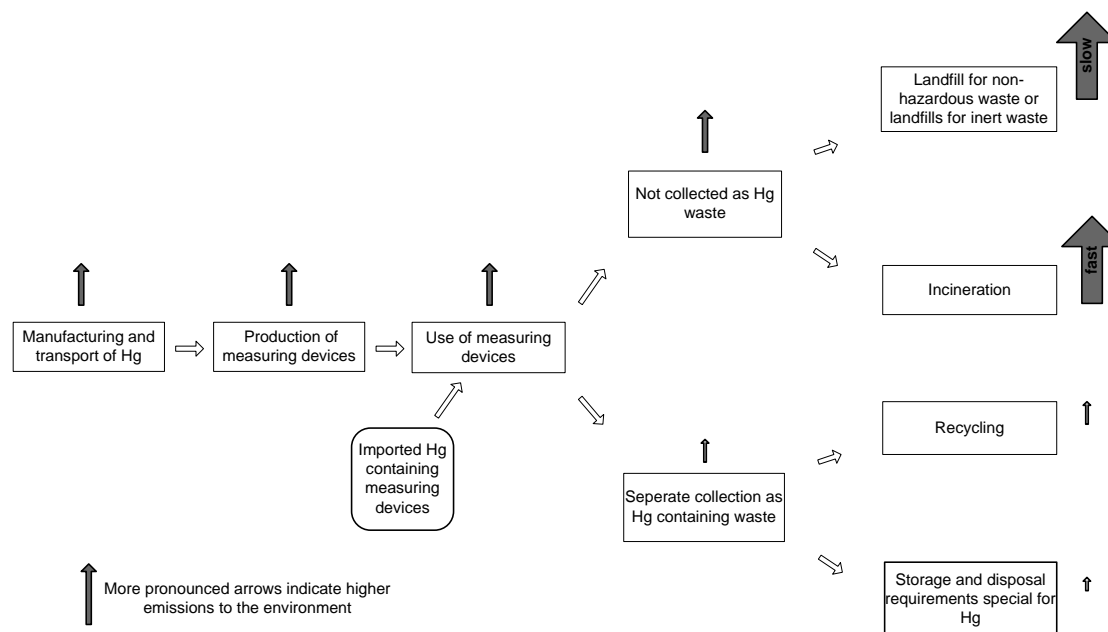


Figure 2 Scheme of the life-cycle of mercury in measuring devices

Production and service-life of measuring devices

In the production phase of mercury containing devices occupational exposure and emissions to the environment may occur during the handling of mercury, filling of the devices, and the handling of mercury contaminated waste.

During the service-life of the devices emissions of and exposure to mercury may occur during maintenance and breakage of devices.

Waste stage of measuring devices

Mercury containing measuring devices are legally required to be collected separately from other (hazardous and non-hazardous) waste streams at the end of their service life (see also section on waste legislation in B.5).

Typically, after separate collection, the mercury containing waste has to undergo pretreatment (which can consist of sorting out, breaking of glass devices, etc). Subsequently the mercury can be separated from the other waste material and concentrated by vacuum distillation. The off gases can be treated with dust filters and activated carbon filters. The dust and the contaminated carbon from the gas treatment can be returned into the process used to isolate the mercury from the other parts of the devices (BREF Waste Treatments Industries, 2006). The resulting mercury can be refined and used as a secondary material or disposed of in compliance with amongst others the very specific rules for mercury waste storage in Regulation No 1102/2008.

Proper separate collection of mercury containing devices is the best way to avoid emissions, but is challenging and costly, especially for devices where discarding is not very regular (e.g. as a result of a long life-time) and where devices are geographically widely spread. Promoting and organising collection is very dependant on priorities in individual Member States (Lassen et al., 2008). As a rough figure, collection

efficiencies of mercury in measuring devices in accordance with requirements set out in the hazardous waste legislation are estimated to be as low as approximately 20%. Collection efficiencies above 50% should in general not be expected (Lassen et al., 2008).

If not collected and treated in accordance with hazardous waste legislation, mercury containing waste is fed to landfill or incineration, which results in higher emissions compared to treatment according to hazardous waste legislation as described above. So called 'secondary techniques' for the abatement of mercury emissions from installations for incineration and landfills are briefly described in Box 1.

The low separate collection rate and resulting inappropriate waste treatment of a substantial part of measuring devices, leads in the long term to a relatively high share of mercury in measuring devices being released to the environment. Figure 2 represents the possible routes of mercury release to environment from measuring devices. The size of the arrows illustrates the importance of emissions in the different stages.

In principle it would be possible to make release estimates for the incinerated and landfilled waste fraction by estimating the mass flows going to the different fractions and by applying release factors to those estimates. However, the mercury volumes placed on the EU market in measuring devices and the fraction that is not specifically treated as mercury containing hazardous waste are rather uncertain. Also, it is unknown what fractions are incinerated and what fractions are landfilled. In addition, the reported release factors¹² are very variable and entailed with high uncertainty. To sufficiently remove all these uncertainties, very extensive surveys on the market for all mercury devices, and on the compliance rate with the hazardous waste legislation in all Member States and on country-specific waste management practises would have to be carried out, without guarantee of success.

In other words, the release estimates would have to be expressed in exceedingly broad ranges to take into account all the accumulated uncertainty. Since such estimates would not serve any quantitative exposure assessment or risk characterisation¹³, it was not judged useful to attempt to quantify emissions entailed with such high uncertainty, whereas the actual aim is to minimise exposure and emissions. The total estimated amount of mercury included in the measuring devices (see Table 5) was considered to be more useful to describe what emissions to the environment might ultimately occur,

¹² Kindbom and Munthe (2007) assumed a release factor of 0.5 to air for mercury in measuring devices that are incinerated in municipal solid waste **incineration**. A tenfold lower default release factor of 0.05 is suggested for municipal solid waste incineration in the draft ECHA Guidance on information requirements and chemical safety assessment, Chapter R.18 (ECHA, 2010). The guidance however also notes that metals are not destroyed and could be emitted to a rather high extent to air, even if flue gas is cleaned.

Kindbom and Munthe (2007) assumed an emission factor of 0.05 to air for the 1st year for mercury measuring devices in **landfills**, and a factor of 0.001 for the 9 consecutive years. Emissions for the years after were not estimated, but assumed to be very low as the waste will be covered with more layers. It is not clear whether the authors take into account emissions through flaming of gasses. The draft ECHA Guidance on information requirements and chemical safety assessment, Chapter R.18 (ECHA, 2010) does not report a specific release factor for mercury.

¹³ As described in section B.2, it is not possible to carry out a quantitative exposure estimation for mercury with sufficient reliability because of the properties of mercury.

and therefore in what follows only a qualitative description of releases and risk management measures is given.

It is assumed that releases from waste incineration and landfills will at least be significant, and mercury measuring devices ending up in incineration are assumed to contribute to peaks that overload flue-gas cleaning system capacities for mercury removal (see also Box 1).

Virtually all handling of mercury can lead to emissions. To some limited extent this will also be the case during the management of properly collected mercury containing measuring devices according to the hazardous waste requirements (see section B.5). However due to all the provisions and requirements for treatment of hazardous waste, these emissions are in magnitude incomparable to the emissions that may occur when mercury containing measuring devices go to installations for incineration or disposal of non-hazardous waste.

Box 1 Abatement of mercury emissions

Waste incineration

(source: *BREF Waste Incineration, 2006*)

There is a direct linear relationship between the amount of mercury in the *raw* flue-gases and the amount of mercury in the waste. Typical concentrations for municipal waste incineration plants are 0.05 – 0.5 mg/m³ in crude flue-gas. There are two ways to satisfy the mercury emission limit of 0.05 mg/m³ in the waste incineration Directive (Directive 2000/76/EC). The most important means is limiting the input of mercury in the installation by proper collection, the other being an efficient mercury removal.

The majority of installations need special gas cleaning measures in order to meet the mercury emission limit value for air (but note that continuous monitoring of mercury emission levels is not required by Directive 2000/76/EC). Especially when the waste stream contains significant amounts of metallic mercury emissions are more difficult to control, since removal of metallic mercury is more challenging compared to ionic mercury. The precise abatement performance and technique required will depend on the levels and distribution of mercury in the waste. Under certain conditions such as a high input rate of mercury, the removal capacity limits of a flue gas cleaning systems may be exceeded, leading to temporarily elevated mercury emissions. Some short-term high loads have been noted in municipal solid waste. These are generally associated with the presence of batteries, electrical switches, thermometers, laboratory wastes, etc.

At high enough chlorine contents, mercury in the crude fluegas will be increasingly in the ionic form which can be deposited in wet scrubbers. Volatile mercury compounds, such as HgCl₂, will condense when flue-gas is cooled, and dissolve in the scrubber effluent. To maintain scrubbing efficiency and prevent clogging in the wet scrubber system, a portion of the scrubber liquor must be removed from the circuit as waste water. This waste water must be subjected to special treatment (neutralisation, precipitation of heavy metals), before discharge or use internally.

Many waste streams contain relatively high amounts of mercury in metallic form, and therefore generally require adsorption by the use of carbon based reagents to achieve the emission levels, or alternatively by transformation into ionic mercury by adding oxidants that are subsequently deposited in the wet scrubber. Injected activated carbon is filtered from the gas flow using bag filters, and when saturated, the used activated carbon is often landfilled as hazardous waste. However, saturated active carbon is sometimes burnt in the incinerator in order to further remove dioxins (PCDD/F), what might lead to re-circulation of metallic mercury.

Landfill

According to recital 8 of Directive 1999/31/EC on the landfill of waste, both the quantity and hazardous nature of waste intended for landfill should be reduced where appropriate. This can only be achieved by proper collection. Mercury measuring devices that end up in landfills will result in emissions to air, soil and water.

Certain general requirements for landfills in respect to location, water control, leachate management, bottom and surface sealing and stability can to a certain extent limit the release rate for mercury emissions from landfills. Due to its properties it is nevertheless likely that in the course of time the mercury will be slowly emitted to the environment.

B.4.2 Mercury emissions from measuring devices using mercury

Around 5-15 tonnes of mercury is annually purchased by laboratories to be used with porosimeters, pycnometers, devices using mercury electrodes in voltammetry and metering devices for determining the softening point. These devices do not contain mercury, but mercury is used during the measurements and consequently the devices need to be refilled with mercury regularly. The estimated amount of mercury purchased for the use with measuring devices is presented in Table 6. It is stressed that these amounts are not comparable to the amounts placed on the market in mercury containing measuring devices (Table 5). Below, it is explained how the amounts in Table 6 as well as other parameters, are used to describe the mercury cycle related to these measurements.

Table 6: The amount of mercury estimated to be purchased in the EU to be used with measuring devices in 2010

Measuring devices <u>using</u> mercury	Amount of Hg purchased to be used in the measurement (t/y)
Mercury electrodes (used in voltammetry)	0.1-0.5
Metering devices for the softening point determination	not available
Porosimeters	5-14
Pycnometers	not available
Total	5-15

Source: Lassen et al. (2008), device specific Annexes 6-9

The devices described in this section use mercury as ‘an analytical chemical’ for their functioning. They have to be filled with mercury regularly and mercury is not an integral part of these measuring devices. Without rigorous risk management measures and use conditions, mercury emissions and exposure of workers and environment occur when carrying out measurements with porosimeters and similar devices, when handling the used mercury (including its regeneration or purification for reuse) and as a result of handling of mercury contaminated waste. Therefore, risk management measures and operational conditions recommended by the producers of the devices and reported to be used by the laboratories performing the measurements are used to qualitatively describe the minimisation of releases.

There is no single parameter to describe the potential release and exposure from the measuring devices using mercury. Therefore, several parameters are used in device specific annexes. The amount of mercury purchased by the users is used to describe the flow of mercury between the users and the suppliers of mercury (including companies offering regeneration or purification services).

As the same mercury can be used several times (after in-house or outsourced regeneration or purification) the amount of mercury used annually in the measurements is reported to describe the magnitude of the mercury involved in the use phase of devices. The available information suggests that the emissions to the environment during the use phase are likely to be low. The same applies to exposure of workers. It is stressed that the laboratories concerned will have to ensure that the newly established occupational exposure limit value for mercury and the requirements of hazardous waste legislation will be complied with (see section B.5).

The amount of mercury containing waste disposed of annually is estimated where possible. These amounts are considerably lower than the amount purchased by the users. This is because the purchased amount includes also mercury purified and regenerated by specialised companies and resold to the users. The available information (see Annex 7, and Lassen et al. 2010), suggests that compliance with the hazardous waste legislation is considerably higher for devices using mercury than for devices containing mercury. The main reason for this difference in compliance would be that handling of mercury and mercury waste is part of normal use of porosimeters

and other similar devices. Consequently the standard operation procedures of laboratories performing measurements with these devices should cover treatment of mercury containing wastes.

It is stressed that the main focus of this restriction report is on the assessment of technical and economic feasibility of alternatives. The potential releases and exposures are described primarily to illustrate the risk reduction capacity of the restriction options. Although the releases and exposures related to the use of mercury with these four types of measuring devices appear to be relatively low, it is stressed that the objective expressed in the Community mercury strategy to reduce the entry into circulation of mercury into society still applies. Consequently the use of mercury with the remaining measuring devices should be phased out as soon as technically and economically feasible alternatives are available.

B.5 Summary of existing legal requirements and their effectiveness

Several existing pieces of legislation aim to reduce or control risks arising from chemicals in their different life-cycle phases. In the following sections the effectiveness of this legislation to specifically address the concerns with mercury in measuring devices is assessed.

Waste legislation

Mercury-containing measuring devices are classified as dangerous according to the European List of Waste (Commission Decision 2000/532/EC)¹⁴, and should be handled according to the rules under Directive 91/689/EEC on hazardous waste (the directive will be repealed by the Waste Framework Directive 2008/98/EC with effect from 12 December 2010). These rules in both the old and new framework, relate to amongst others a ban for mixing hazardous waste with other waste streams and record keeping and permit requirements for waste treatment establishments.

Landfill of mercury containing waste has to be dealt with according to the requirements for the 'hazardous waste' class in Directive 1999/31/EC on the landfill of waste, and according to the acceptance criteria for landfills in Decision 2003/33/EC. Some specific rules for mercury waste are laid down in Regulation No 1102/2008. The Regulation contains rules on the safe storage of metallic mercury. Until special requirements and acceptance criteria are adopted under a Comitology procedure, only temporary above-ground storage is permitted. The concern is that eventually mercury in landfills may slowly be remobilised over time (UNEP, 2008b). These concerns for remobilisation are in particular related to the indefinite persistence of mercury, but also to the liquid status of mercury, high vapour pressure, and solubility in water. Storage in salt mines, and storage in deep underground, hard rock formations are under assessment as options for final disposal.

¹⁴ code 20 01 21 fluorescent tubes and other mercury-containing waste

Mercury in measuring devices that are not collected separately and are received in landfills for non-hazardous waste or for inert waste, will not be sufficiently contained. Certain general requirements for landfills in respect to location, water control, leachate management, bottom and surface sealing and stability do exist, and can to a certain extent abate mercury emissions from these landfills, although it is likely that eventually a significant proportion of the mercury slowly will be emitted - if not all in the course of time.

Similarly, mercury in measuring devices that are not collected properly and are incinerated, will lead to significant emissions. Nevertheless, according to the waste incineration Directive (Directive 2000/76/EC) both hazardous as non-hazardous waste incineration has to satisfy an air emission limit value of 0.05 Hg mg/m³¹⁵, and an emission limit value for mercury and its compounds in discharges of waste water of 0,03 mg/l (from the cleaning of exhaust gases). However, in contrast to continuous monitoring of dust, HCl, SO₂, CO, C_xH_y, NO_x, and HF, the waste incineration Directive only requires a minimum of two measurements each year for mercury compounds. Local authorities can require more frequent measurements, and in some Member States, such as Austria and Germany, continuous monitoring is required.

Despite these legal provisions, in particular because of low separate collection rates of mercury containing measuring devices, significant emissions occur in the waste phase from all mercury containing measuring devices covered by this report. The problems with regard to these emissions are described more in detail in the section B.4. It can be concluded that the risk management measures provided for in the waste legislation do not sufficiently address the concerns with mercury arising from the waste phase of mercury containing measuring devices. The efforts needed from the enforcement authorities to ensure that the existing requirements in the waste legislation are complied to are difficult to estimate and would vary between the Member States. However, taking into account the relatively high awareness with regard to the environmental and human health risks related to mercury (compared to many other hazardous wastes) and the fact that the requirements have been in place for a relatively long time it does not seem plausible to rely on better enforcement of waste legislation to address the issue.

With regard to measuring devices using mercury, the available information indicates that the hazardous waste legislation requirements are generally complied with to a substantially higher extent (see Annex 7 and Appendix 3).

Occupational health legislation

Several pieces of occupational health legislation are in place to manage the risks of the use of mercury in the working environment during the production of measuring devices containing mercury, filling of devices by the users, professional use of mercury with devices such as porosimeters, and during the treatment of mercury contaminated waste.

¹⁵ Average value over the sample period of a minimum of 30 minutes and a maximum of 8 hours

An 8-hour TWA for mercury and divalent inorganic mercury compounds of 0.02 mg/m³ is included in the 3rd list of IOELVs¹⁶ under the Chemical Agents at Work Directive (Directive 98/24/EC). Several Member States had already established national exposure limits before the Community-wide IOELV had been adopted (e.g., BE, IE, LT and UK). The IOELV will have to be implemented in all Member States by 18 December 2011 at the latest. The relevant biological monitoring techniques that complement the IOELV should be taken into account by MSs during health surveillance.

Finally, the Young People at Work Directive 94/33/EEC and the Pregnant Workers Directive 92/85/EEC apply to work with mercury (Repr. Cat. 2). They are targeted towards protection of vulnerable populations.

Although occupational health legislation has a crucial role to play in avoiding occupational exposure from mercury in general, measures such as IOELVs are not effective in preventing or reducing exposure resulting from certain events related to the measuring devices containing mercury, such as accidental breakage, spillage or leakage. With regard to measuring devices using mercury, based on available information, there are no reasons to assume that the newly established occupational exposure limits for mercury would be insufficient to protect workers.

Legislation controlling emissions to the environment during production

Production of mercury containing measuring devices does not seem to be covered by Community legislation specifically setting limits on mercury emissions to air or water. Production does not seem to be covered by the IPPC Directive (Directive 2008/1/EC) or the Council Directive 84/156/EEC on limit values and quality objectives for mercury discharges by sectors other than the chlor-alkali electrolysis industry.

Medical devices directive

Sphygmomanometers and strain gauges fall under the scope of the medical devices directive (Directive 93/42/EEC concerning medical devices). The directive foresees that devices must meet a series of “essential requirements”, such as for example a requirement to be designed and manufactured in such a way as to reduce to a minimum the risks posed by substances leaking from the device. However the existence of these requirements has not prevented that breakage and leakage still occurs in real-life, with emission, exposure and costs associated with cleaning the spills as consequences.

¹⁶ List of Indicative Occupational Exposure Limit Values established by the Commission Directive 2009/161/EU of 17 December 2009

National restrictions

Denmark, The Netherlands, Norway and Sweden have national restrictions on mercury in measuring devices. The following provides an overview of the information received from these Member States and Norway. An effort is made to summarise the elements of importance for mercury in measuring devices. For the full description of the restrictions, the national legislation should be consulted. The metering devices for the softening point determination are not mentioned in the national restrictions.

• Denmark

Denmark prohibits import, sale and export of mercury and mercury-containing products. The Danish restriction entered into force in 1994, was expanded in 1998 and 2003, was prolonged in 2008, and subsequently has been amended to take into account the entries 18 and 18a of Annex XVII to the REACH regulation. The legislation foresees a possibility for the Danish EPA to allow derogations, but according to information received from the Danish EPA this possibility has never been put to practise. The legislation foresees a list of exemptions to the general ban that are relevant to mercury measuring devices.

Thermometers for special applications, i.e. calibration of other thermometers and analysis equipment are exempted. According to the Danish EPA, in practise this can be translated to an exemption of thermometers for laboratory use. Manometers for calibration of other pressure gauges, barometers for calibration of other barometers, products for research, products for teaching, and products for the repair of existing mercury-containing equipment are exempted as well. Also an exemption is foreseen for 'mercury-containing chemicals for special applications'. According to the Danish EPA, mercury-intrusion porosimetry would, depending on the actual use, fall under one of the exemptions to the restriction.

The Danish EPA reported not to have experienced any particular problems introducing the national restriction.

• The Netherlands

The Netherlands restrict production and import of mercury containing products since 1 January 2000. Possession of a product containing mercury or use for trading (2nd hand market) or production purposes is restricted since 1 January 2003 (unless it was already in use before that date). The restriction is not applicable to antiques (>100 years old).

The restriction does not apply to pycnometers or porosimeters, a McLeod compression manometer meant for measuring absolute pressures lower than 20kPa, thermometers exclusively intended to perform specific analytical tests according to established standards, equipment for the calibration of platinum resistance thermometers using the triple point of mercury (the Netherlands would have only one such device).

- *Norway*

The sale of mercury thermometers is prohibited in Norway since 1 October 1998. Thermometers for professional use for meteorological, hydrological and oceanographical measurements and for control measurements and calibrations in laboratories were exempted until 1 January 2001.

Since 1 January 2008 there is a prohibition to manufacture, import, export and sell compounds and articles containing mercury. It is also prohibited to use compounds containing mercury. The restrictions do not apply to analysis and research purposes, but mercury thermometers for analysis and research purposes are specified not to be exempted from the prohibition, and polarographs are said to be exempted for analysis and research purposes only until 31 December 2010. According to information received from the Norwegian Climate and Pollution Agency (Klif), mercury used with porosimeters would fall under 'analysis and research', and thus is not restricted in Norway. Import and sales are however forbidden. Suppliers have to apply for an exemption in order to place mercury on the market for analysis and research.

Exemptions can be granted to the prohibitions. The most common cases with exemptions to buy mercury thermometers are for the following:

- Analyses according to ASTM¹⁷ in cases where mercury thermometers are specified
- Calibration thermometers (where very high precision is essential)
- Maximum thermometers to be placed inside older autoclaves (without thermocouples). The applicants claim that data loggers cannot stand the high temperatures.

According to Klif, Norway has received only very few such applications the last few years, less than ten a year. The ASTM standards referred to concerned all to testing of oil products (pour point, flash point open cup and closed cup, and possibly also cloud point were thought to be amongst these standards).

- *Sweden*

Sweden prohibits the placing on the market, use and export of mercury and chemical compounds and mixtures containing mercury. It is prohibited to place on the market or to export goods containing mercury. The Swedish Chemicals Agency (KemI) may issue regulations to derogate from the general restriction, and in addition can grant exemptions in individual cases. The original version of the restriction dates from 1991. In what follows is described how the Swedish mercury restriction affects individual mercury measuring devices (based on information received from KemI).

Thermometers

In Sweden, the production, sale and export of mercury thermometers is restricted since 1993. The granted exemptions concerning mercury containing thermometers are

- use for flash point determination according to standard method ASTM D93 (granted in 2006, expired);

¹⁷ ASTM International is one of the main standardisation organisations, see also section 3.3 of Annex 5a.

- import of two thermometers ASTM D97, which were then exported to be used according to 2381 Cloudpoint (granted in 2007, expired);
- export of 10 thermometers to be used for flash point determination according to dir. 67/548/EEG (granted in 2007, expired);
- export of thermometers to be used for flash point determination according to dir. 67/548/EEG (granted in 2007, will expire 30 June-2011).

KemI is not aware of any other problems to replace mercury containing thermometers and is not aware of particularly high costs when replacing them.

Porosimeters

The Swedish restriction applies to mercury containing devices as well as devices that make use of mercury. Until end of year 1995 there was an exemption to import, to manufacture and to place porosimeters on the market. According to an investigation made by a consultant 2004, commissioned by KemI, feasible alternative technology for pore sizes exceeding 2000 Å (0.2 µm) was not available at that time. There are further two exemptions granted in 2006 for two porosimeters sold to a company and to a university respectively. The intended uses were pore sizes exceeding 1000 Å mainly for research and development.

Strain gauges

The translation of the current exemption for strain gauges (2007) reads:

- “The applicant may manufacture and sell up to 150 mercury containing strain gauges each year and these must be used in already existing equipment*
- to measure blood flow in a muscle within clinical routine activities up to 2010-12-31*
 - for other uses within clinical routine activities up to 2009-12-31*
 - for research and development up to 2012-12-31 given that the project started prior to 2007-12-31. If the research concerns blood flow in a muscle the project may start not later than 2010-12-31.*
 - to validate mercury free alternatives up to 2010-12-31.*

The applicant has the duty to keep records on the uses.”

Manometers

KemI reports that there have not been any applications for exemptions to the restriction from 2005 up to now. As far as they are aware of, there have been no applications for exemption before 2005 either.

B.6 Summary of hazard and risk

Mercury and its compounds are highly toxic to humans, ecosystems and wildlife, with amongst others serious chronic irreversible adverse neurotoxic and neurodevelopmental effects.

It is estimated that 3.5 to 7.6 tonnes of mercury is placed on the market in mercury containing measuring devices in 2010 (see Table 7). These amounts are used to describe the maximum potential for mercury emissions to the environment that might

ultimately occur. This is considered appropriate for the purpose of this restriction report as the low separate collection rate and resulting inadequate waste treatment of a substantial part of the devices, leads in the long term to a relatively high share of mercury used in these devices being released to the environment.

Table 7: The amount of mercury estimated to be placed on the market in the EU in mercury containing measuring devices in 2010

Measuring device <u>containing</u> mercury	Amount of Hg placed on the market in the EU in 2010 (t/y)
Barometers	0.1-0.5
Manometers (including tensiometers)	0.04-0.4
Sphygmomanometers	2.6-5.1
Strain gauges (used with plethysmographs)	0.014
Thermometers (including hygrometers)	0.7-1.6
Total	3.5-7.6

Source: Lassen et al. (2008) as updated in device specific annexes 1 – 5.

In addition around 5-15 tonnes of mercury is supplied annually to be used with porosimeters, pycnometers, devices using mercury electrodes in voltammetry and metering devices for determining the softening point (see Table 8).

The annual amounts presented (in Tables 7 and 8) are not comparable. The figures in Table 8 are the amount of mercury the laboratories purchase and cannot be used to estimate maximum potential for emission as is the case in Table 7. To estimate emissions several additional factors need to be considered. These include number of measurements carried out, practices to purify and regenerated used mercury and the risk management measures and operational conditions applied to control the emissions and exposures. Furthermore, the available information indicates that the hazardous waste legislation requirements are generally complied with when handling the mercury contaminated waste generated during these measurements.

Table 8: The amount of mercury estimated to be purchased in the EU to be used with measuring devices in 2010

Measuring device <u>using</u> mercury	Amount of Hg purchased to be used for measurements (t/y)
Mercury electrodes (used in voltammetry)	0.1-0.5
Metering devices for the softening point determination	not available
Porosimeters	5-14
Pycnometers	not available
Total	5-15

Source: Lassen et al. (2008), device specific annexes 6-9

Once released to the environment, mercury persists in the environment, where it circulates between air, water, sediments, soil and biota in various forms. Mercury can be transformed to methylmercury, the most toxic form, which biomagnifies especially in the aquatic food chain, making populations and wildlife with a high intake of fish and seafood particularly vulnerable.

Several existing pieces of legislation abate the risks arising from mercury in different stages of the life-cycle of measuring devices. However, none of the measures currently in place is sufficient to remove the concern fully, although there is a difference between their observed effectiveness with regard to measuring devices containing mercury and measuring devices using mercury.

The emissions from mercury measuring devices, although relatively small, contribute to the overall emissions of mercury to the environment and thereby also to the exposure of species and of humans via the environment. Therefore, measuring devices containing or using mercury are of concern.

C. Available information on the alternatives

A deviation from the reporting format is made to improve the flow and readability of the text as several different measuring devices are assessed in this Annex XV restriction report. Thus the following issues are reported in device specific Annexes 1 to 9:

- Technical description of the device
- Description of release and exposure
- Available information on the alternatives (Part C)
- Justification that the proposed restriction is the most appropriate Community-wide measure (Part E).

The assessment of alternatives concentrates on the technical and economic feasibility, whereas the risks related to alternatives are described briefly. However, in most cases risks related to alternatives are considered to be minor compared to the risks related to mercury in measuring devices.

From the device specific information on alternatives it is concluded that technically and economically feasible alternatives are available for mercury barometers, hygrometers, manometers, metering devices (for determination of softening point), pycnometers, sphygmomanometers, strain gauges and tensiometers with very limited derogations. For thermometers technically feasible alternatives are available, but in specific applications it was not possible to firmly establish the economical feasibility of the alternatives. For mercury porosimeters and devices using mercury electrodes in voltammetry, the technical feasibility of alternatives could not be established and thus the economic feasibility was not fully assessed.

D. Justification for action on a Community-wide basis

As stated in part B of this report the need to consider the extension of the current restriction on mercury in measuring devices at Community level was already established in Directive 2007/51/EC.

D.1 Considerations related to human health and environmental risks

As explained in section B, the hazard properties of mercury and its transformation products are widely recognized. It is difficult for any Member State to act alone to effectively protect its environment or its population from mercury exposure, because the human health and environmental problem related to mercury is cross boundary. This is also well recognised by the Community mercury strategy and by the activities of UNEP and regional organisations.

As reported in Section B.5 mercury measuring devices are used throughout the EU, although some Member States have already established national restrictions. Consequently, the mercury emissions originating from the measuring devices, in particular their waste stage, take place in most of the Member States, even though the amount of emissions in different parts of the EU varies depending on the amounts of devices used and on disposed of and waste management practices.

Therefore, the risks need to be controlled on a Community-wide basis.

D.2 Considerations related to internal market

The proposed restrictions cover devices that are extensively traded among and used in all Member States most of which have not established national restrictions. The devices containing mercury are both produced in and imported to the EU as reported in Annexes 1 to 9. The justification to act on a Community-wide basis stems from the fact that the goods need to circulate freely within the EU. The proposed restriction would remove the potentially distorting effect that current national restrictions may have on the free circulation of goods. The second justification is that regulating mercury through Community-wide action ensures that the producers of the devices in different Member States are treated in an equitable manner. Furthermore, acting at Community level would ensure a 'level playing field' among all producers and importers of the devices.

D.3 Other considerations

The Community is currently promoting measures at international level¹⁸ that aim to address human health and environmental problems relating to mercury (see section B.2). Mercury is both a regional and a worldwide problem. Therefore, acting at

¹⁸ For instance, the Community is active in the United Nation's Environment Programme's Mercury Programme (see <http://www.chem.unep.ch/mercury/>).

Community level strengthens the Community's and its Member States' possibilities to cooperate constructively with other countries and relevant institutions.

D.4 Summary

The main reason to act on a Community-wide basis is the cross-boundary human health and environmental problem. Furthermore, the fact that the goods need to circulate freely within the EU stresses the importance of the Community-wide action, as some Member States have national restrictions for mercury measuring devices. Thus, the use of mercury in these devices needs to be controlled also at the EU level. In addition, acting at Community level strengthens the possibilities to address the adverse impacts of mercury at worldwide level.

E. Justification why the proposed restriction is the most appropriate Community-wide measure

A deviation from the reporting format is made to improve the flow of the restriction report as several different measuring devices are assessed in one report. Thus, the following issues are reported in device specific Annexes 1 to 9:

- Technical description of the device
- Description of release and exposure
- Available information on the alternatives (Part C)
- Justification why the proposed restriction is the most appropriate Community-wide measure (Part E).

This part provides a summary of the justifications why the proposed restrictions are the most appropriate Community-wide measure. It starts with an overview of the assessment of the proposed restrictions against their effectiveness, practicality and monitorability. This is followed by device specific summaries for the proposed restrictions as well as summaries for justifications for not proposing restrictions for certain devices. Finally, the justification for derogations and conditions common for all devices are provided.

Summary of the assessment of the proposed restrictions

While the major part of the assessment of the options and reasons for proposals can be found in the device specific annexes, some common issues and a summary are discussed below.¹⁹

The main purpose of the proposed restrictions is to reduce the mercury pool in the society, thus avoiding emissions and exposures causing negative impacts on human health and environment. While the main benefits of these restriction proposals result from the prevention of mercury from entering the waste stream, the proposed restrictions on the placing on the market would also result in additional other benefits related to reduction of possible exposure of workers during production and use of the devices. There may be also some further co-benefits (e.g. during waste handling).

Based on the review clause in the existing restriction on mercury in measuring devices, the justification for proposing further restrictions focuses on the technical and economic feasibility of the alternatives. The costs of avoiding mercury in euros per kilogramme (€/kg Hg) are presented to assess and conclude on the proportionality of the restriction options, when data exist to allow such estimation. For the purposes of this restriction report a literature review has been carried out of the compliance and other costs, as well as human health benefits of regulating mercury. This review has been used to support the assessment of the proportionality of restriction options. For details, see Appendix 2.

¹⁹ Note that it not has been considered appropriate to make a distinction between professional and industrial users for assessing possible restrictions on mercury measuring devices in this report. Nevertheless, the typical groups of users are described in the device specific annexes.

Assessment of effectiveness

The proposed restriction is estimated to reduce the amount of mercury placed on the EU market (in devices or to be used in measurements) by 57 tonnes for a 20 year period starting from 2015.

It is recognised that the time when the restriction becomes effective depends on the decision making process and the transitional periods after the decision is taken by the Commission. For the purpose of the risk reduction capacity and cost calculations of this report it is assumed that the restrictions would apply from the beginning of 2015.

The temporal scope of the analysis was selected in the following manner. Taking into account the uncertainties related to the available data and the assumed declining trend in the number of mercury devices placed on the market, 20 years scope is regarded appropriate. As the average lifetime of mercury containing devices is around 10 years in most applications, the restriction would have its full effect 10 years after adoption, i.e. in 2024, when all the existing mercury containing devices would be replaced. Thus, year 2024 was selected as a representative year to illustrate annualised impacts.

Table 9 gives details of the amount of mercury that is estimated not to be placed on the market in the EU as a result of the proposed restriction. Both the representative year (2024) and the total effect of the 20 years (i.e. 2015-2034) are presented.

Table 9: Estimated amount of mercury not placed on the market as a result of the proposed restriction in 2015-2034 as well as in 2024

Device	2024 per annum kg	2015-2034 cumulative kg
Sphygmomanometers*	1 932	39 217
Thermometers (including hygrometers)*	345	7030
Barometers**	350	7 000
Manometers (including tensiometers)**	200	4 000
Strain gauges**	14	280
Pycnometers	not available	not available
Metering devices	not available	not available
Total	2 841	57 527

Source: Derived from Annexes 1-9

Notes: * Number of the mercury containing devices projected to decline by 5% per annum as described in the device specific annexes 3a and 5a

** Assuming no change in the trend

The compliance costs of the proposed restrictions are estimated to be €4.4 million in 2024, or cumulatively €42.7 million for 2015-2034 (Table 10). The compliance costs for barometers, manometers, metering devices, pycnometers and strain gauges are not quantified. Nevertheless, in the case of barometers and manometers the qualitative evidence strongly suggests that the alternatives to mercury devices cost the same as mercury devices. In other words, the additional cost is about €0 in this case. For metering devices, pycnometers and strain gauges no information was available on the

costs of alternatives. However, compliance costs related to these devices are considered to be insignificant compared with sphygmomanometers and thermometers.

Table 10: Estimated compliance costs of the proposed restriction in 2015-2034 as well as in 2024

Device	2024 per annum € million	2015-2034 cumulative € million
Sphygmomanometers	3,2	29,0
Thermometers	1,2	13,7
Barometers	~0	~0
Manometers (including tensiometers)	~0	~0
Metering devices	not quantified	not quantified
Pycnometers	not quantified	not quantified
Strain gauges	not quantified	not quantified
Total	4,4	42,7

Source: Annexes 1-9

As the environmental and human health impacts are not quantified, no further comparison between the benefits and costs of the proposal is possible. However, it was possible to quantify the reduction in the amount of mercury placed on the market in the EU as a result of the proposed restrictions. Based on these estimates the cost-effectiveness of the proposed restrictions is estimated. These are given in Table 11. Overall the cost-effectiveness of the proposed restriction is estimated to be €1,400/kg Hg but naturally there are variations between the different measuring devices.

Table 11: Estimated cost effectiveness of the proposed restrictions

Device	Cost-effectiveness (€/kg)
Sphygmomanometers*	1 313
Thermometers (including hygrometers) *	3 703
Barometers	~0
Manometers (including tensiometers)	~0
Strain gauges**	not available
Pycnometers**	not available
Metering devices**	not available
Total*	1 354

Source: Annexes 1-9

Note: * Weighted average (kg of mercury used as the weight)

** Based on qualitative assessment of costs, it seems that the costs are low and thus, cost effectiveness close to €0/kg Hg

Assessment of practicality

All the device specific restriction proposals concern the placing on the market of the mercury included in or used with the measuring devices. No use or other conditions are proposed, even though for some devices they are assessed to some extent. In general, no problems related to the implementability and manageability of the proposed restriction were identified.

The enforcement of the placing on the market of the mercury measuring devices can be assessed mainly by inspecting producers, and by verifying if importers and distributors still supply mercury measuring devices.

However, enforceability of the proposed derogations in the restriction for thermometers might be more problematic (see Annex 5a).

Assessment of monitorability

The monitorability of the restriction options for different measuring devices is not assessed in the device specific Annexes. The monitoring of the restriction for all the devices will be done through enforcement and no additional monitoring is envisaged. The current monitoring of environmental concentrations of mercury or methylmercury does not give information on the effectiveness of the existing restriction for mercury measuring devices and it is not feasible to target the monitoring to provide such information. This is because of the share of mercury measuring devices is only about 4% of the total amount of the mercury used in the EU. The share of measuring devices of the emissions caused by the intentional use in the EU is not known. Furthermore, there are mercury releases from other sources than intentional use in articles and processes (e.g. power plants).

Other community-wide measures than restriction

Other community-wide measures are not assessed in detail in the device specific annexes. This approach is taken as the review clause in the existing restriction asks for extension of the current restriction where technically and economically feasible alternatives are available.

Mercury is already covered by several pieces of Community legislation. On the basis of assessment described in Section B.5, the current legislation and in particular waste legislation is not sufficient to address the concerns related to measuring devices containing mercury. Based on available information, as described for instance in Box 1 of Annex 7 (Porosimeters) and in Appendix 3, with regard to measuring devices using mercury hazardous waste requirements appear to be complied with to a substantially higher extent. In addition, there are no indications that the newly established occupational exposure limits for mercury would be insufficient to protect the workers. Restriction options 2 and 3 in Annex 7 (Porosimeters) discuss the needs and possibilities to strengthen the compliance with the existing obligations under waste and occupational health legislation by introducing conditions in Annex XVII of REACH. However, such conditions are not proposed due to reasons given in Annex 7.

The proposed restrictions and summary of the device specific justifications

Measuring devices containing mercury

- Barometers

Proposal: Restriction on the placing on the market of mercury barometers.

Justification: Technically feasible alternatives are available and electronic alternatives already dominate the market. The alternatives are available at approximately the same price as mercury barometers. Consequently restricting the placing on the market of mercury barometers would not introduce additional costs (cost-effectiveness is around €0 per kg Hg not placed on the market).

- Manometers (including tensiometers)

Proposal: Restriction on the placing on the market of mercury manometers and tensiometers.

Justification: Technically feasible alternatives are available and in use. The alternatives are available at approximately the same price as mercury manometers. Consequently restricting the placing on the market of mercury barometers would not introduce additional costs (cost-effectiveness is around €0 per kg Hg not placed on the market).

- Sphygmomanometers

Proposal: Restriction on the placing on the market of mercury sphygmomanometers with limited derogations for (i) long-term, epidemiological studies and (ii) using mercury sphygmomanometers as reference standards in clinical validation studies of mercury-free sphygmomanometers.

Justification: Technically feasible alternatives are available with very limited exemptions based on the opinion of SCENIHR. Based on the assessment of compliance costs (in Annex 3b), the alternatives are also regarded as economically feasible. The cost of avoiding mercury (around €1300/kg Hg) is considered to be proportional.

- Strain gauges (used with plethysmographs)

Proposal: Restriction on the placing on the market of plethysmographs designed to be used with mercury strain gauges.

Justification: Technically feasible alternatives for mercury strain gauges used with plethysmographs are available. The alternatives seem to be also economically feasible as long as existing plethysmographs relying on

mercury strain gauges are allowed to be used until end of their service-life.

- Thermometers (including hygrometers)

Proposal: Restriction on the placing on the market of mercury thermometers and other non-electrical thermometric applications containing mercury with derogations for i) thermometers to perform specific analytical tests according to standards that require the use of a mercury thermometer (time-limited); ii) mercury triple point cells that are used for the calibration of platinum resistance thermometers; and iii) mercury-in-glass thermometers used in industrial applications to measure temperatures above 200°C.

Justification: Technically feasible alternatives are available for all applications, with the exception of: thermometers used for testing according to analysis standards that prescribe mercury thermometers, because some time is needed to amend those standards; and mercury triple point cells because mercury is needed as a reference point in the 1990 International Temperature Scale. Economically feasible alternatives are available for all applications, with the exception of industrial mercury-in-glass thermometers measuring temperatures above 200°C, where economic feasibility could not be established, as cost of avoiding mercury is estimated to be about €330,000 /kg Hg.

Measuring devices using mercury

- Mercury electrodes (used in voltammetry)

Proposal: No restriction.

Justification: Technically feasible alternatives are not available in all applications. The technical limitations are related, for instance, to mobility and sensitivity of the alternative devices and to the parameters measured. In addition, two main alternatives seem not to be economically feasible due to higher price and recurrent costs and requirements on the laboratory infrastructure.

- Metering devices for determination of softening point

Proposal: Restriction on the placing on the market of metering devices for determination of softening point.

Justification: Technically feasible alternatives are available and they seem to dominate the market. No information has been found indicating that the alternatives would be economically infeasible.

- Porosimeters

Proposal: No restriction.

Justification: Technical feasibility of the alternatives could not be established under the framework of this report. The alternatives may not be feasible for the users as they do not measure exactly the same parameters. The comparability of the measurement results is difficult to assess. In addition the applicability of the alternatives is limited in terms of pore sizes covered and the type of sample (e.g. applicable only to hydrophobic samples). Assessment of technical feasibility is complicated by the fact that porosimeters are used in several application areas which all have their own technical features. As the technical feasibility could not be established, the economical feasibility was not assessed in details. In addition, waste management of mercury and mercury contaminated samples and other materials is part of the normal operation of the laboratories performing measurements with these devices. The reported practices in laboratories appear to support the view that the waste handling of mercury used in the measurements would be conducted in accordance to the requirements of the hazardous waste legislation (see Annex 7 and Appendix 3).

- Pycnometers

Proposal: Restriction on the placing on the market of mercury pycnometers.

Justification: Technically feasible alternatives are available and they seem to dominate the market. No information has been found indicating that the alternatives would be economically infeasible.

Justification for derogations and conditions common for all devices

Justification to propose a transitional period of 18 months

The actors need some time to adapt after a regulation has entered into force. The reasons are technical, economic, practical and regulatory.

Examples of technical adaptation are: when measuring devices change, industry, laboratories and their customers may need to adapt the processes where the measurement takes place. In some cases the products using measuring devices need to be changed, too.

Examples of reasons for adaptation due to economic reasons are: it would seem economically disproportionate if manufacturers, importers, wholesale and retail sellers could suddenly not place on the market their existing stocks of devices. These considerations are particularly important due to the fact that many operators in measuring device market are small and medium sized companies.

Examples for practical reasons for a transitional period are: responsible authorities may need to make arrangements to be able to enforce the new restrictions. It takes some time for them to inform each other as well as the suppliers and customers in all markets about the change in legislation. This is also a specific issue for importers who need to inform non-EU suppliers about the change in EU regulation.

Theoretically, the length of the transitional period could be different for different devices. However, for reasons of clarity to enforcers and to the actors who have to comply with the restrictions, there is a merit of having one single transitional period, unless there are good grounds to do otherwise.

For some devices like barometers, manometers, pycnometers and metering devices where the alternatives already dominate the market, a shorter transitional period could be justified. However, as only relatively small amounts of mercury, if any, is currently placed on the EU market in these devices, an earlier date would not reduce the mercury placed on the market considerably. Therefore, risk reduction capacity would not be significantly higher (due to low tonnages) and it is regarded to be more valuable to have a more coherent entry with the same transitional period for all the devices.

For the above reasons a transitional period of 18 months is considered reasonable for the market operators and administration to adapt to the requirements of the proposed restriction. A shorter period could imply implementation problems and there seems to be no need for a longer one, apart from the issue relating to the use of mercury thermometers prescribed by analysis standards. In this latter case a transitional period of 5 years is suggested.

Derogation for historical devices

In addition to device specific derogations, a general derogation for placing on the market of old devices (more than 50 years old) is proposed. This derogation is similar to the one in the existing restriction on consumer devices (Entry 18a).

The derogation is proposed to allow the selling and buying of old, historically valuable mercury containing devices which can be regarded as antiques or cultural goods. This derogation is relevant in particular to allow (technical) museums to purchase and exchange old measuring devices. The negative impact of this derogation on the risk reduction capacity is insignificant. As the continued use of the existing devices is proposed to be allowed, the derogation would simply allow a very limited number of old devices to be placed on the market, if needed. Furthermore, the emptied (of mercury) measuring devices can be placed on the market. Nevertheless, less than 50 years old mercury pycnometers and metering devices would not be allowed to be placed on the market, even though there is no intention to use them anymore.

The same date as in the equivalent derogation in the existing restriction (more than 50 years old on 3 October 2007, paragraph 3 a) in entry 18a of Annex XVII of REACH) could be used. Setting the same date for all devices keeps the entry simpler and clearer, and thus easier to comply with and more enforceable.

Justification for not proposing a review clause

During the preparation of this report it has been considered whether a review clause would be helpful for mercury devices for which a restriction had not been proposed. Such review clause could be focussed on the availability of technically and economically feasible alternatives for mercury devices and it could promote the development of the alternative devices, substances and methods. However, it was recognised that it is difficult to estimate the impact of such a review clause.

A Member State or ECHA can propose a re-examination of an existing restriction in accordance with Article 69(5) of REACH when this is deemed necessary.

In conclusion, for reasons of legislative coherence and clarity, a review clause was not proposed in this restriction report.

F. Socio-economic assessment

F.1 Human health and environmental impacts

For the reasons explained in Part B, the risk reduction capacity of the proposed restriction has been described by using as a proxy the amount of mercury placed on the market in the EU included in or to be used with the measuring devices. These amounts have been described in the device specific annexes. It is important to note that the specific human health or environmental impacts of introducing a restriction could not be quantified. Furthermore it was not considered proportionate to even aim at such quantification given the scope of this restriction report. As human health and environmental impacts could not be quantified, it is also not possible to monetise these impacts.

The proposed restriction is estimated to reduce the amount of mercury placed on the EU market (in devices or to be used in measurements) by 57 tonnes between 2015 and 2034. Table E1 in Part E gives details. It is evident that not placing 57 tonnes of mercury on the market has a positive impact on the environment and human health. Some of these effects have been discussed in the literature review in Appendix 2.

F.2 Economic impacts

Apart from the assessment the economic feasibility of alternatives and for some devices assessing the compliance costs, no additional economic impacts from introducing the proposed restrictions have been assessed. Detailed compliance cost assessments for sphygmomanometers and thermometers can be found in Annexes 3b and 5b.

The administrative costs related to the proposed restrictions have been qualitatively reflected in device specific annexes, where this has been possible and regarded proportional. In general administrative costs both to authorities and market operators concerned are assumed to be low.

The compliance costs of the proposed restrictions are estimated to be €4.4 million in 2024, or cumulatively €42.7 million for 2015-2034. Table E2 in Part E gives details. Furthermore Table E3 gives the average cost-effectiveness of replacing mercury devices with mercury-free ones. Overall the proposed restrictions would cost about €1,354 per kg Hg on the average. Note that this average has been calculated using kilograms as weights. A simple, unweighted average would have given misleading information about the economic impact.

Based on a literature review, Appendix 2 presents the compliance costs, human health benefits and restoration costs of reduced mercury emissions. Based on this review benchmarks have been derived for the purpose of this Annex XV report to assess to what extent restrictions should be applied on mercury devices.

F.3 Social impacts

Restricting the placing on the market of mercury measuring devices affects the employment of those who are currently producing them. Table 12 presents the number of identified producers of each measuring device in and outside the EU, number of employees in production of mercury devices in the EU and the share of production in the EU to internal markets. Unfortunately, the number of employees producing mercury measuring devices is not known for all devices, as such information is not easy to collect.

Table 12: Number of producers of mercury measuring devices in EU in 2007

Measuring device	Number of identified producers in the EU	Number of identified producers outside the EU	Number of employees in production of mercury devices in the EU	Share of production in the EU to internal markets
Barometers ^{*)}	1 (possibly a couple)	Unknown	2-20	not available
Devices using mercury electrodes	1	1 (Switzerland)	not available	not available
Manometers (incl. tensiometers)	2 ^{**)}	Unknown	not available	not available
Mercury porosimeters	0	4 (USA)	0	not applicable
Mercury pycnometers	0	1 (USA)	0	not applicable
Metering devices ^{*)}	1	Unknown	not available	not available
Sphygmomanometers ^{*)}	4	Unknown	30-50	15%
Strain gauges (used with plethysmographs)	1	1 (USA)	not available	not applicable
Thermometers (incl. hygrometers) ^{*)}	11	Unknown	1000-1500	50%

Source: Lassen et al. (2008), Lassen et al. (2010), see Appendix 3

Notes: ^{*)} Manufacturers are known to produce also mercury free devices

^{**)} The production of mercury tensiometers may be discontinued in the EU (Lassen et al., 2008)

All identified producers of mercury barometers, metering devices (for determination of softening point), sphygmomanometers and thermometers in EU produce also the mercury-free alternatives. Mercury porosimeters and pycnometers are not produced in the EU. For manometers and barometers, the markets of mercury containing devices are very small compared to mercury-free alternatives.

Given that exports would not be restricted²⁰ and given that most of the producers are producing also the mercury-free alternatives, European companies will be allowed to both i) continue producing mercury containing measuring devices for exports and ii) produce the alternative mercury-free devices to the EU markets. Thus, the social impacts would be minimal.

In conclusion, the proposed restriction is estimated to have either no or very small social impacts, in particular on the employees in companies as well as on the aggregate employment of companies producing measuring devices. For the users of the restricted mercury containing measuring devices, no negative social impacts have been identified.

F.4 Wider economic impacts

Specific care has been taken to ensure that the proposed restriction on mercury containing measuring devices is compatible with the international trade rules under the World Trade Organisation. This has been done by adhering to the following principles.

Restricting the placing on the market of mercury measuring devices means that the non-EU producers will no longer be able to export them into the EU. However, these producers can export the alternatives to mercury containing devices into the EU. Thus, the competitiveness of the EU measuring device producers is not affected to the detriment of their competitors outside the EU. In sum, devices containing mercury produced in as well as imported to the EU are regulated exactly in the same manner.

F.5 Distributional impacts

Mercury containing measuring devices are used in laboratories, small and large industry installations, hospitals as well as private practitioners. Thus, regulating the placing on the market of new devices will affect both small or micro (also self-employed) enterprises²¹ as well as big companies. Nevertheless, as mercury-free devices cost normally around the same as the mercury device and as the use of existing devices until the end of their service-life is allowed, the impacts on users (including SME's) is small. Therefore any distributional impact would also be small.

Most of the companies producing mercury containing measuring devices are small or medium sized, i.e. are categorised as SME companies (Lassen et al., 2008). As the restriction treats all of these in the same manner all across the EU and as no economies of scale exist in the production of measuring devices, no specific SME related impacts have been identified.

It is not known to what extent the mercury containing measuring devices are used more in the new Member States compared to the EU15. In some Member States (see Section B.5) there have been national measures to move away from the mercury

²⁰ Restrictions on export under Regulation (EC) No 1102/2008, see page 6.

²¹ In "micro" enterprises, there are less than 10 staff, in "small" enterprises there are less than 50 staff.

measuring devices. Thus, these Member States have already partly replaced the mercury devices so it is possible that this restriction proposal would induce relatively speaking slightly higher implementation costs to new Member States. It should also be considered that some devices may be used more in relative terms in the EU15 compared to new Member States. This is due to for instance economic structure. Thus the distributional impacts in terms of costs across different Member States are estimated to be minor.

F.6 Main assumptions used and decisions made during analysis

Throughout the analysis a 4% discount rate has been used as this is in line with ECHA (2008) and the Commission (2008a). The time period of the analysis is 20 years (between 2015-2034) as this represents a period during which most of the direct impacts of the restriction will occur. Results are also presented as annualised using the year 2024 as a representative year, when most of the proposed restrictions would be in full effect.

The causal chain from production or use of mercury devices to health impacts has been explained in Part B. Given that the health and environmental impacts of the proposed restriction have not been estimated (see Section B.2), the methodology used in SEA has been that of cost-effectiveness. As a proxy for effectiveness of risk reduction, the amount of mercury included in or used with the measuring devices sold annually in EU has been used.

G. Stakeholder consultation

In December 2009, ECHA contracted Cowi consulting company, together with ENTEC and IOM to carry out a focussed stakeholder consultation (Lassen et al. 2010, see Appendix 3). The consultation took place between January and May 2010. The objective was mainly to collect input data to assess the proportionality of the restriction options and for socioeconomic analysis – in particular on costs of alternatives as well as technical and economic feasibility of replacement.

In this consultation questionnaires tailored to each equipment type were sent to identified producers. In some cases more detailed information was requested through follow-up questions. Based on (Lassen et al., 2008) it was deemed that the contacted producers represent the majority of producers in the EU. Still, in segments where import from countries outside the EU takes place, it was not always possible to consult the non-EU producers. It was considered unnecessary to consult the producers of barometers due to earlier work giving already an adequate information basis.

In addition to work by Lassen et al (2010), during January-April 2010, ECHA consulted those Member States that were identified to have national bans for mercury measuring devices. The data are reported in Section B.5.

Other Member States were not approached when preparing this report. Nevertheless, Commission has consulted Member States in summer 2008. The review by Commission (see Appendix 5), describes the consultation of Member states and stakeholders as follows:

“In summer 2008, DG-Enterprise & Industry has launched a consultation with Member States and other interested stakeholders. More specifically, questionnaires were prepared and circulated to the Members of the Commission Experts Working Group on Limitation of Chemicals (LWG) and to the Experts Working Group on Medical Devices (MDEG) asking them to provide input concerning:

- the availability of alternatives to mercury-containing sphygmomanometers in the Member States and whether these are adequately validated and calibrated;
- essential uses of mercury-containing sphygmomanometers that are required in Member States (e.g. treatment of special medical conditions);
- other mercury-containing measuring devices used for research and in industrial uses and the availability of alternatives for such devices.

In addition, the Commission sent the questionnaires to interested NGOs, industry trade associations, and scientific organisations requesting them to submit any information (reports of relevant studies/clinical trials etc.) which would be helpful for the purposes of the review.”

In addition to the stakeholder consultation carried out in the framework of preparing this restriction report and to the review of Commission (see Appendix 5), a lot of information on mercury containing measuring devices had been collected by the Commission and stakeholders in recent years. During the preparation of these reports stakeholders have also been consulted. The following reports have been used as a main source when preparing this Annex XV restriction dossier:

- Lassen et al. (2008), published by DG ENV: Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society
- Concorde (2009) published by EEB: Turning up the pressure: Phasing out mercury sphygmomanometers for professional use
- SCENIHR (2009) opinion on Mercury Sphygmomanometers in Healthcare and the Feasibility of Alternatives.

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Device specific Annexes

Annex 1: Barometers

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1. Technical description of mercury barometers

Mercury barometers are instruments used to measure atmospheric pressure by measuring the changes in the height of the mercury column. A mercury barometer is typically a glass tube filled with mercury. One end of the tube is sealed while the other end of the tube is submerged in a container filled with mercury. Large barometers for professional use (e.g. laboratory use) may contain up to 1.1 kg of mercury according to the Lassen et al. (2008). Typically the more precise equipment has wider columns and consequently more mercury.

As the placing on the market mercury barometers for the general public has been restricted in the EU from 3 October 2009 (Entry 18a in Annex XV of the REACH Regulation), the remaining uses are industrial and professional applications including weather stations, meteorological departments, airports and airfields, wind tunnels, oil refineries, engine manufacturing, sporting sites, offshore installations (e.g. windmill parks) and on ships. According to one supplier small local airfields may still use their old mercury-containing equipment, as the automatic reading of the meter is not essential (Lassen, C. and Maag, J., 2006).

2. Description of release and exposure

Based on the approach described in Part B of the main document, the estimations on i) the total amount of mercury accumulated in devices in the EU and ii) the amount of mercury placed on the market annually in the EU are used to describe the potential release and exposure during the waste phase of the devices (see Table A1-1). Furthermore, to get a more comprehensive picture, the annual amounts iii) used in the production of devices, iv) imported into the EU and v) exported from the EU are given to illustrate the potential for direct exposure of workers during the production and service-life of the devices. However, it is stressed that this report does not further assess the potential concerns related to workers as explained in Part B. If quantitative estimates are not available, a qualitative description is given.

Table A1-1: Amounts of mercury accumulated, used in production, placed on the market and imported and exported in barometers.

Mercury	Estimated amounts
Pool accumulated in barometers (in industrial and professional use)	~ 3 t Hg Assuming 10 years lifetime for a barometer (Lassen et al., 2008) and no trend in number of devices placed on the market, results in 3 tonnes of Hg accumulated in barometers in industrial and professional applications.
Placed on the market in barometers in the EU	0.1-0.5 t Hg/y (Lassen et al., 2008)
Used in production of barometers in the EU	No data available to quantify. At least one (possibly few) producers of Hg barometers in the EU (Lassen et al., 2008).
Imported into the EU in barometers	No data available.
Exported from the EU in barometers	The producers of barometers also export devices. Up to 40 kg of Hg is exported from the UK annually in barometers. (Lassen et al., 2008)

Box 1: General qualitative description of potential release and exposureProduction phase

According to Lassen et al. (2008) there is at least one (possibly few) producer of mercury barometers in the EU. Nevertheless, there is no data available to quantify the amount of mercury used in the production. The producers also export mercury barometers outside the EU, for example up to 40 kg mercury per year is exported from the UK in barometers. It is estimated that in the EU around 2-20 persons are full time employed in the production of mercury barometers for both the EU and non EU markets. The only identified producer of mercury barometers is a SME size enterprise. (Lassen et al., 2008)

There is no data available on emissions and exposure during the production phase, but it is assumed that some emissions may occur during the production of these devices due to the volatile properties of mercury.

Service-life

There is no reliable information on the number of mercury barometers in industrial and professional use and thus on the related accumulated amount of mercury in the barometers. However, according to Lassen et al. (2008) the professional barometer market in the EU is estimated to use 0.1-0.5 tonnes of mercury per year. Assuming an average service-life of 10 years for barometers, and having no trend in the number of devices placed on the market, results in accumulated stock of around 3 tonnes. Nevertheless, according to Lassen et al. (2008) the market is estimated to be decreasing.

In the UK, the professional barometer market is estimated to use less than 10 kg mercury per year (Collin 2008 as cited in Lassen et al., 2008). The users are scientific, medical and special test laboratories, airfields as well as some educational institutes. Some scientific mercury barometers are used for calibration of other barometers such as aneroid and electronic types.

According to WMO (2008) the main risks to workers occur in laboratories where mercury barometers are frequently emptied or filled. Emissions might occur in meteorological stations if mercury is not cleaned up immediately after spillages or when the device is broken. Some companies in the EU are specialised in restoration of mercury barometers and some information on maintenance can be found on their websites:

http://www.bafra.org.uk/html_pages/articles_mercurialbarometer.html

<http://www.quicksilver-barometers.co.uk/>

<http://www.czajkowski-furniture.co.uk/barometer-restoration-and-conservation.htm>

Waste phase

The accumulated amount of mercury in the industrial and professional barometers is estimated to be around 3 tonnes. Nevertheless, the amount of mercury to be disposed of as waste each year corresponds to the amount of mercury placed in the market in barometers 10 years earlier (assuming 10 years service-life). As the mercury barometer market is estimated to be declining (Lassen et al., 2008), the amount of mercury disposed of in barometers (in industrial and professional use) is assumed to be higher than annual amount of mercury placed on the market in the same year.

There is no specific information on how mercury barometers and the mercury content are collected and handled. However, it is assumed that professional users of mercury barometers (e.g. weather stations) are better complying with hazardous waste requirements than the average user of any mercury measuring device. This is supported by the WMO (2008), which gives detailed instructions on how to clean up mercury spillages. In addition advice is given that collected mercury can be either disposed or recovered with a reference to contact local authorities and/or suppliers. Based on this, it is assumed that the collection rate might be somewhat higher for mercury in barometers than the roughly estimated average collection rate of 20 % as hazardous waste for mercury containing measuring devices as stated in Lassen et al. (2008).

3. Available information on alternatives (Part C)

3.1 Identification of potential alternatives

Several barometers have been identified by Lassen et al. (2008) as alternatives for mercury containing barometers. These include electronic barometers, electronic

resistance or capacitance barometers, aneroid mechanical barometers and mercury free liquid barometers.

Barometers having an electronic read-out (with equivalent accuracy and stability) have many advantages compared to mercury barometers. These can be operated also remotely while mercury containing barometers need to be observed by people at the place of measurement. The ratio of purely automatic weather stations to observer-staffed weather stations increases steadily. (WMO, 2008)

Lassen et al. (2008) state that: ‘No specific applications for which mercury barometers cannot be replaced have been identified.’ The reasons for using the mercury barometers seem to be that users are used to this barometer and that it is easy to recognise when the equipment is not functioning correctly.

3.2 Human health and environment risks related to alternatives

Electronic barometers might contain small amounts of lead and possibly some other hazardous substances (including in batteries and solar cells), and thus may cause problems during the waste phase. Nevertheless, one producer of electronic barometers state that some of the devices have low power consumption (Vaisala, 2010). In general, the human health and environmental risks are insignificant in comparison with the potential emission and exposure associated with the amount of mercury in barometers.

According to user’s guide of the mercury free liquid barometers the barometers contain chemicals (red-pigmented manometer oil and gas) which are skin and eye irritant and are “hazardous to marine life” (Stormglassbarometer, 2010). No further information on the substances is available.

Overall the human health and environmental risks related to mercury seem to be more significant than the risks related to the alternative devices.

3.3 Technical feasibility of alternatives

Based on the information described below, technically feasible alternatives to mercury barometers exist.

3.3.1 Electronic barometers

Electronic barometers are already widely used by professionals in the EU. They use of transducers which transform the sensor response into a pressure-related electrical quantity in the form of either analogue or digital signals. Many electronic barometers have automatic data logging. Such devices have currently the highest market share in the EU. Electronic barometers are marketed for different kind of professional applications like weather stations, aviation, laboratories and industrial pressure measurements. The electronic barometers are regarded as precise as the mercury

barometers. (Lassen et al., 2008). The electronic barometers are used also for calibration of other barometers (personal communication with Lassen, 2010)

The following kind of electronic barometers are used:

- i) A cylindrical resonator barometer (or vibrating cylinder air-pressure transducer) is designed to measure absolute air pressure using the vibrating element principle. It provides a frequency output from which pressure is computed and it can be read by a computer. For example, in Denmark, this type of barometer is normally used for calibration of other barometers.
- ii) An aneroid displacement transducer contains a sensor with electrical properties (resistance or capacitance) that changes as the atmospheric pressure changes. In Denmark these barometers are today used e.g. by weather stations, ships, airports.
- iii) A modern version of the pressure transducer using piezoelectric transducer (digital piezoresistive barometer) determines two resonance frequencies of the piezoelectric element. By calculating a linear function of these frequencies and with an appropriate set of variables obtained after calibration, a pressure is calculated by a microprocessor which is independent of the temperature of the sensor.

According to a producer of mercury barometer for the professional market, electronic barometers can replace mercury containing barometers for all applications (Lassen et al., 2008). According to the WMO (2008) mercury barometers are, in general, regarded as having good long-term stability and accuracy, but are now losing favour to equally accurate electronic barometers, which are easier to read.

The WMO (2008) guide specifies that electronic barometers should be calibrated about once a year. According to the guide this calibration is done more frequently than for mercury barometers.

3.3.2 Aneroid mechanical barometer

The mechanical aneroid barometer consists of an evacuated metal diaphragm linked mechanically to an indicating needle. These barometers have been used for 200 years and are considered just as accurate as the traditional mercury barometer. According to WMO (2008) the greatest advantages of conventional aneroid barometers over mercury barometers are their compactness and portability, which make them especially practical at sea or in the field.

3.3.3 Mercury-free liquid barometer

According to a producer in the EU, a mercury-free liquid barometer is a U-shaped glass tube filled with a red silicone fluid and gas. The principle to measure air pressure is based on the compressibility of gasses instead of the weight of liquid mercury. There is one producer of this type of barometer, and it is marketed for use in

schools and hospitals. Adjacent to the barometer tube is a thermometer filled with blue coloured methyl-alcohol.

3.3.4 Bourbon-tube barometers

Bourbon tube barometers consist of a sensor element that changes its shape under the influence of pressure changes and a transducer that transforms the changes into a form directly usable by the observer. Precise and stable digital instruments with quartz Bourbon tubes are used as working standard reference barometers in calibration laboratories (WMO, 2008).

3.4 Economic feasibility

According to Lassen et al. (2008) the price of the mercury barometers varies from €100 to 1000 and non-electronic alternatives are available at the same price range. However, the prices are difficult to compare as some of them are affected by the decorative purpose of the given barometers. Even for professional users the barometers are sometimes regarded as a piece of furniture (personal communication with Lassen, 2010).

Electronic precision barometers based on vibrating element sensors are available at higher prices. However, these have many additional features (e.g. measuring more parameters than only air pressure) that explain the cost difference. Therefore, it is difficult to compare directly the price of an electronic precision barometer with the price of a mercury containing device. (Lassen et al., 2008)

Mercury-free liquid barometers are between 30 and 50 % cheaper than the comparable mercury containing barometers (Lassen et al., 2008). In spite of the cheaper price of mercury-free barometers, some users might be in favour of using the mercury containing barometer because of the tradition. E.g. it is easier to see if the mercury barometer functions correctly (Lassen et al., 2008).

Lassen et al. (2008) roughly estimated that changing to alternatives would not increase the costs to the users. This is supported by Gallican et al. (2003) who concluded that the aneroid and electronic barometers are cost-competitive and acceptable alternatives to the mercury barometers. Based on the information described above, alternatives are regarded as economically feasible.

4. Justification why the proposed restriction is the most appropriate Community-wide measure (Part E)

4.1 Identification and description of potential risk management options

4.1.1 Risks to be addressed – the baseline

The amount of mercury placed on the market in barometers for industrial and professional use is estimated to be 0.1-0.5 t per year in the EU. It is estimated that the amount of mercury barometers used by professionals is decreasing (WMO, 2008).

Lassen et al. (2008) estimated that roughly 20 % of the mercury in measuring devices, including sphygmomanometers, barometers, etc. is collected as hazardous waste. However, the collection rate might be somewhat higher for barometers as described in section B.4.x (waste phase). Hence, it is estimated that some of the mercury end up in uncontrolled waste streams in the EU, although due to uncertainties this is not quantifiable.

4.1.2 Options for restrictions

The following options for restriction were identified:

- 1) restriction on the placing on the market of new mercury containing barometers,
- 2) restriction on the placing on the market of new mercury containing barometers and the use of existing mercury containing barometers, and
- 3) restriction on the placing on the market of new mercury containing barometers with a derogation for calibration.

Only the option 1 has been taken for further assessment for the following reasons.

The banning of the use of existing mercury barometers is not assessed further based on the following reasons; It is estimated that the number of mercury barometers used by professionals has already been decreasing. In addition it is assumed that the collection rate for these specialised uses is higher than what has been assumed for instance for sphygmomanometers. Considering the relatively low risk reduction capacity and the costs related to replacing the barometer before the end of the service life, the use ban is not considered to be proportional. In addition the enforcement of the use ban would require resources and might be in practice difficult to carry out in effective way.

Denmark has in its national ban a derogation for calibration purposes and the Danish Meteorological Institute has as a national reference a mercury containing barometer. However, it has not been used in recent years and it seems that it has not been

maintained either (Personal communication with Lassen, 2010). In the Netherlands, Sweden and Norway no derogation for the use of mercury barometers for calibration exists in their national bans. Therefore it can be concluded that there seems to be no need to introduce an exemption for calibration in this restriction proposal. The average life time of barometers is 10 years (Lassen et al., 2008) which gives flexibility to use existing mercury barometers for calibration purposes during this period.

4.2 Assessment of risk management options

4.2.1 Restriction of the placing on the market barometers

4.2.1.1 Effectiveness

Risk reduction capacity

The risk reduction achieved by introducing the restriction will be an annual reduction of metallic mercury entering the EU society of approximately 0.1-0.5 tonnes per year. As mercury barometers are produced in the EU for export as well, some emissions during the production phase may remain. According to Lassen et al. (2008) there are only one or few producers of mercury barometers in the EU. Emissions related to the use and waste phase of devices already on the market will not be affected by the proposed restriction.

It is assumed that compared to mercury devices the alternatives do not pose significant environmental or human health risks.

Proportionality

Technical feasibility

As stated in Section 3.3 technically feasible alternatives are available (Lassen et al. (2008) and WMO (2008)). Electronic barometers dominate already the market for professional use in the EU.

Economic feasibility

Based on the information given in Section 3.4, it is concluded that the costs to the users would not increase if mercury barometers are replaced by alternatives. In some cases the costs are not comparable as for example electronic barometers have features like automatic data logging, the possibility to measure many parameters at the same time etc. that are different compared with the mercury barometer and might for these reasons result in higher prices. It depends on the case whether these additional features are of relevance (and of economic value).

In the EU at least one (possibly few) producer of mercury barometers exist. During the stakeholder consultation of the existing restriction of the placing on the market

mercury barometers for sale to the general public, two producers²² of mercury barometers were opposed to the proposal. Their claim was that if a restriction is introduced it would lead to a negative impact on their future business. However, the current EU markets are only for professional. This is minor compared what the markets used to be before the placing on the market of mercury barometers to households was restricted²³. Thus, the impact to the producers to further restrict the markets of mercury barometers is estimated to be small.

According to WMO (2008) the calibration of electronic barometers will need to be done more frequently than for mercury barometers, thus potentially increasing the cost to National Meteorological Services, particularly those with extensive barometer networks. However, as the trend has been to move away from mercury barometers these costs of calibration are not considered to cause major impacts among users, in particular since certain new features have been gained with this change.

Based on the information above, it is estimated that restricting the placing on the market of mercury barometers would not introduce compliance costs (i.e. the cost-effectiveness ~€0 per kg Hg not placed on the market).

Given that the additional costs of using mercury free barometers are ~€0 it is evident that the proportionality of these costs to the risks related to mercury is “well established”. Appendix 2 gives further details.

4.2.1.2 Practicality

Implementability and manageability

Technically feasible alternatives are available and it is estimated that the costs to the users would not increase significantly. As it is not proposed to restrict the current use, the mercury barometers may be used until the end of their service life.

Enforceability

The compliance with the restriction on the placing on the market of mercury barometers can be verified by following the fairly limited number of producers (one to few), importers and distributors of these devices.

²² Five producers were identified, but only one produce mercury barometers for industrial and professional use

²³ Total mercury consumption in barometers in 2007 was estimated to be 2-5 tonnes Hg/year of which 0.1-0.5 tonnes was for professional use (Lassen et al., 2008). From 3 October 2009, the placing on the market of mercury barometers has been prohibited in the EU.

4.3 The proposed restriction and summary of the justifications

Proposal:

Restriction on the placing on the market of mercury containing barometers after 18 months of entry into force of the amendment of Annex XVII.²⁴

Summary of justification:

The main purpose of the proposed restrictions is to reduce the mercury pool in the society, thus avoiding negative impacts on human health and environment. Technically and economically feasible alternatives to mercury containing barometers are available and electronic barometers already dominate the market in the EU.

²⁴ The scope of the current entry related to barometers in the Annex XVII will become wider.

Annex 2: Manometers and tensiometers

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1. Technical description of manometers and tensiometers

Manometers are instruments for measuring pressure. The mercury containing manometers measure the difference in gas pressure between the measured environment and a reference.

Manometers usually consist of a U-shaped glass or plastic tube containing a liquid (usually water, alcohol or mercury). The surface of the liquid in one end of the tube moves proportionally with changes in pressure on the liquid in the other end. When pressure is applied, the liquid level in one arm rises, while the level in the other drops. A set of calibrated markings beside one of the arms permits a pressure reading to be taken, usually in inches or millimetres.

The column (U-tube) may be either vertical or inclined from the vertical to elongate the scale and further amplify the liquid movement. The inclined-tube manometer is used for smaller pressure measurements or where greater accuracy is required. One limb of the inclined tube manometer forms into a reservoir and the other is inclined at a known angle. Their accuracy relies less on the reader's skills, are more sensitive but unless the inclined limb is relatively long they cannot be used over a wide range of pressures. Inclined tube manometers cannot be read remotely and it is usually used with gases.

Manometers have a variety of laboratory, industrial and specific applications such as visual monitoring of air and gas pressure for compressors, vacuum equipment and special tank applications such as medical gas cylinders, fire extinguishers, etc. In addition, mercury manometers are used for calibration purposes.

Tensiometers are designed to measure the surface tension of liquids, to determine the soil moisture tension and for measuring the tension in a wire, fibre or beam (answers.com, 2010). The mercury containing tensiometers are devices used for measuring the suction or negative pressure of soil water (soil water potential). The reason why tensiometers are covered with manometers in this report is that the only part of tensiometer potentially containing mercury is the manometer.

A mercury tensiometer comprises of capillary tubing linking to the mercury manometer. The capillary tubes have at the other ends, inserted in the soil, porous cups, normally constructed from ceramic.

Tensiometers are mainly used for research applications, in the scientific study of soils and plants, or in agriculture for planning the irrigation scheduling (Lassen et al., 2008, Smajstrla & Harrison, 2002).

2. Description of release and exposure

Based on the approach described in the Part B of the main document, the estimations on i) the total amount of mercury accumulated in devices in the EU and ii) the amount of mercury placed on the market annually in the EU are used to describe the potential release and exposure during the waste phase of the devices (Table A2-1). Furthermore, to get a more comprehensive picture, the annual amounts iii) used in the production of devices, iv) imported into the EU and v) exported from the EU are given to illustrate the potential for direct exposure of workers during the production and service-life of the devices. However, it is stressed that this report does not further assess the potential concerns related to workers as explained in Part B. If quantitative estimates are not available, a qualitative description is given.

Table A2-1: Amounts of mercury accumulated, used in production, placed on the market and imported and exported in manometers (including tensiometers).

Mercury	Estimated amounts
Pool accumulated in manometers	~ 4 t Hg Assuming 20 years lifetime for a manometer and no trend in number of devices placed on the market, results in 4 tonnes of Hg accumulated in manometers.
Placed on the market in manometers in the EU	0.04-0.4 t Hg/y (Lassen et al., 2008)
Used in production of manometers in the EU	No data available to quantify. At least one producer of Hg manometers and one of Hg tensiometers ²⁵ in the EU (Lassen et al., 2008).
Imported into the EU in manometers	No data available.
Exported from the EU in manometers	No data available.

Box 1: General qualitative description of potential release and exposure

Production phase

Only one producer of mercury manometers and one producer of mercury tensiometers have been identified in the EU and the production of tensiometers was discontinued in 2008. (Lassen et al., 2008)

As the manometers and tensiometers are supplied without mercury due to weight and transport costs (the customers fill them in with mercury before use), there are no mercury emissions during the production phase.

²⁵ According to Lassen et al. (2008), the production of tensiometers may be discontinued.

Use phase

There is no reliable information on the number of mercury manometers in use and thus on the related accumulated amount of mercury in the manometers. However, around 10-15 tensiometers are estimated to be sold per year in the EU (Lassen et al., 2008). According to Lassen et al. (2008) the professional manometer and tensiometers market in the EU is estimated to use 0.04-0.4 tonnes of mercury per year. Assuming an average service-life of 20 years for manometers and tensiometers, and having no trend in the number of devices placed on the market, results in accumulated stock of around 4 tonnes.

In Denmark, before the Danish ban, the mercury use was estimated at 4-8 kg per year (Lassen et al., 2010).

The mercury content of a U-tube manometer may vary but it is estimated that normally a manometer contains 70-140g mercury. Nevertheless, special manometers may contain up to 10 kg of mercury e.g. mercury manometer used as reference instrument in Denmark. It contains a 6 m mercury column with up to 5-10 kg of mercury. It is read with a laser and data are processed electronically.

The mercury manometers and tensiometers are shipped without mercury and filled with mercury by the user. Thus the risks related to use phase may be more relevant for manometers and tensiometers than other devices filled during the production. In addition, some mercury may be released in case of breakage e.g. over pressuring the manometer can result in the mercury being blown out of the tube and contaminating the surroundings. Nevertheless, risks related to waste phase are regarded to be most relevant for manometers.

Waste phase

The appropriate collection of mercury manometers and the handling of these devices in accordance with hazardous waste legislation are crucial for the potential releases of mercury to the environment. According Lassen et al. (2008) around 20 % of mercury in measuring devices is collected as hazardous waste. This indicates that emissions during the waste phase are likely to occur.

3. Available information on alternatives (Part C)

3.1 Identification of potential alternative techniques

Different types of alternatives have been identified for mercury manometers: Liquid filled in tube manometers, elastic pressure sensors and electronic manometers (or digital manometers). The mercury manometers contained by the tensiometers are commonly replaced by elastic pressure sensors or electronic manometers. In addition, the moisture soil measurement can be carried out by quantitative methods like

gravimetric soil sampling, neutron scatter, or dielectric constant methods (Morris, 2006).

Liquid filled in tube manometers are built on the same principle as the mercury ones, but they use other liquids, like water (most common used after the mercury) or alcohols.

Elastic pressure sensors contain elements that flex, stretch, or temporarily deforms when a pressure is applied. They initially convert pressure into a displacement which is then read on a scale. The following two types of elastic pressure sensors have been identified:

The Bourdon tube manometers consist of a tube of elliptical or oval cross section. A common design is the C-shaped tube sealed at one end and connected to a pointer. When increased pressure is applied to the open end, it deflects outwards proportionate with the pressure. This motion is transferred through a link to gear train connected to an indicating needle. Bourdon gauges are normally connected to gas cylinders to give an indication of the quantity of gas in the cylinders.

The pressure gauges with diaphragms consist of an elastic pressure element (a threaded connection called socket), a sector and pinion gear mechanism (called the movement) and the protective case, dial, and a viewing lens assembly. The pressure element is connected to the movement mechanism, which rotates a pointer throughout a graduated dial.

Electronic manometers make use of transducers which transform the sensor response into a pressure-related electrical quantity in the form of either analogue or digital signals. They measure the pressure by use of pressure transducers, e.g. piezoelectric or capacitance pressure transducers which are connected via an analogue to digital converter to a display or data logger.

3.2 Human health and environment risks related to alternatives

The risks associated with mercury-free manometers are considered to be small. The electronic manometers and tensiometers might contain small amounts of lead and possibly some other hazardous substances (included in batteries and solar cells), and thus may cause problems during the waste phase. **In general**, the human health and environmental risks are insignificant in comparison with the potential emission and exposure associated with the amount of mercury in manometers and tensiometers.

When the soil moisture is measured by other quantitative methods than by mercury tensiometers, like gravimetric soil sampling, neutron scatter, or dielectric constant methods, the associated risks vary as the techniques are based on totally different principles. The apparatus needed by these methods could contain other hazardous substances or they can be given by the high electrical power used or due to radioactive sources contained.

Overall the human health and environmental risks related to mercury seem to be more significant than the risks related to the alternative devices.

3.3 Technical feasibility of alternatives

According to a European producer of mercury manometers, there is no application for which mercury manometers cannot be replaced by other devices (Giussani 2008 as cited in Lassen et al., 2008).

According to report from 2004 (Kemi, 2004), a special type of pressure measurement is required in the polyethylene manufacturing industry where a precision measurement is made at high temperature. The polyethylene product is evaluated by this pressure measurement, which is an important quality-assurance parameter. Alternatives have been tested but none of them have given the required result. Nevertheless, Swedish Chemicals Agency (Kemi) reports that there have not been any applications for exemptions to their national restriction for mercury barometers from 2005 up to now. As far as they are aware of, there have been no applications for exemption before 2005 either. Based on this information, technically feasible alternatives are available in this application.

Liquid filled in tube manometers

Any fluid can be used in manometers instead of mercury, but the mercury has the advantages of high density and low vapour pressure. For low pressure differences well above the vapour pressure of water, water is commonly used (and "inches of water" is a common pressure unit).

Bourdon tube manometers

Bourdon tube manometers are more robust than mercury manometers and more suitable for measuring higher pressures. They are today sold for applications, where U-tube manometers with mercury were previously used (Lassen and Maag, 2006).

Pressure gauges with diaphragm elements

Pressure gauges with diaphragm are considered just as accurate as the traditional mercury manometer. For low-pressure applications metallic diaphragms and bellows are used (hydraulicspneumatics.com, 2010). Diaphragm elements are often used in gauges to indicate absolute pressure. A variety of options and accessories are available to enhance life and operation of gauges.

Electronic manometers (or digital manometers)

Electronic manometers are already widely used by professionals and there is increasing market for them. They have many advantages compared to mercury manometer as they require less servicing and maintenance and far less expertise and can thus be used by less experienced users. Compared with electronic manometers, the mercury manometers are more difficult to handle. Electronic manometers are also

more precise than a mercury manometer if properly calibrated. They can be used for automatic and remote control.

For the heating and sanitation sectors, a type of small hand-held electronic manometers is available from many suppliers. They may serve similar purposes as the mercury manometers and are more user-friendly.

Other alternative methods for (tensiometers) the soil moisture measurement

The gravimetric method is a direct technique for determining the water content of soils. It involves weighing soil samples, drying them to a constant value of mass at 105°C, and using the difference in weight to calculate the amount of water in soil. While too time consuming, labor-intensive, requiring sample equipment, weighing scale and an oven to be used for day-to day management decisions, this highly accurate and low-cost method is often used to calibrate other tools and indirect methods, such as neutron probe or di-electric constant methods. The spatial variability of soils and their water content implies a large number of samples.

For the soil moisture measurements of high value crops, large farms and scientific research purposes there are other techniques available: *neutron scatter*, *di-electric constant methods*, *time-domain reflectometry (TDR)*, *frequency domain reflectometry (FDR)*, and *infrared thermometry*. They are generally more expensive, providing more features and not comparable to the more narrowed use of tensiometers.

3.4 Economic feasibility

According to Lassen and Maag (2006), the price of a U-tube mercury manometer is around 108 €. All the other prices quoted below are based on internet search conducted in February 2010 by ECHA and are meant to be indicative only.

Alternatives can replace the mercury manometer in all applications and, even more, they are usually cheaper than the corresponding mercury manometer. Liquid filled in tube manometers are built on the same principle as the mercury ones and their prices are on the range of €16 to 20. The market prices of bourdon tube manometers are also typically lower than the price of the mercury one and they are more robust and more suitable for measuring higher pressures (Lassen and Maag 2006). Prices for them range from €54 to 122. Prices for pressure gauges range from €30 to 76, depending on the used material. Finally, the electronic manometers have many advantages over the mercury ones, and there is increasing market for them. However, the price of electronic manometers is about 3-4 times higher for similar pressure range. As the electronic manometers have the advantage of automatic measurements they cannot be directly compared to mercury manometers (Lassen and Maag 2006). The internet search suggested a price range from €110 to 350 for electronic manometers.

Since there is no application for which mercury manometers cannot be replaced by other devices and because alternatives are usually available at approximately the same price as that of a mercury manometer (see e.g. Lassen et al., 2008) there is no need for further compliance cost analysis to show that these devices are economically feasible options.

Two technically feasible devices, electronic tensiometers and bourden tube tensiometers, are already replacing the mercury tensiometers in all applications. According to Lassen et al. (2008) the prices of alternatives are below or equal to the prices of mercury tensiometers in the case of electronic devices and slightly higher for the tensiometers containing mechanical bourdon manometers. There is no evidence suggesting that there would be differences in recurrent costs between mercury and mercury-free tensiometers.

4. Justification why the proposed restriction is the most appropriate Community-wide measure (Part E)

4.1. Identification and description of potential risk management options

4.1.1 Risk to be addressed – the baseline

As presented in Part B, manometers are sold without mercury and filled in by the users. The maximum emission potential is estimated to be 0.04-0.4 tonnes per year in the EU including tensiometers (Lassen et al., 2008). No response was received from the producers of manometers and tensiometers during the stakeholders consultation to assess the trend in the number (or the current number) of mercury manometers supplied annually to the EU markets.

4.1.2 Options for restrictions

Since there is no application for which mercury manometers and tensiometers cannot be replaced by mercury-free alternatives already available, the only assessed restriction option is the restriction on the placing on the market of new mercury manometers and tensiometers for professional use. An exemption for mercury manometers that were more than 50 years old on 3 October 2007 is proposed. This exemption is to allow the placing on the market of historically valuable devices and is part of the existing restriction of barometers.

4.2 Assessment of risk management option: Restriction of the placing on the market of mercury manometers and tensiometers

4.2.1 Effectiveness

Risk reduction capacity

The maximum risk reduction achieved by introducing the restriction will be an annual reduction of metallic mercury entering the EU society of approximately 0.04-0.4

tonnes per year. The emissions resulting from the use and waste phase of the mercury manometers already in use will not be affected.

Proportionality

Technical feasibility

Based on the information from Lassen et al. (2008) technically feasible alternatives are available and in use.

Economic feasibility

The alternatives are usually cheaper than mercury manometers. Electronic manometers are an exception being 3-4 times more expensive but also offering automatic measurement. Given that technically equivalent alternatives are cheaper, it is estimated that restricting the placing on the market of mercury manometers and tensiometers would not introduce additional costs. In other words the compliance costs of the restriction would be ~€0 (i.e. cost-effectiveness ~€0 per kg Hg not placed on the market).

Given that the additional costs of using mercury free manometers and tensiometers are ~€0 it is evident that the proportionality of these costs to the risks related to mercury is “well established”. Appendix 2 gives further details.

4.2.2 Practicality

Implementability and manageability

The technical feasible alternatives are already in use and it is not expected to have changes in the costs affecting the users. As it is not proposed to restrict the current use, the mercury manometers may be used until the end of the service life.

Enforceability

The compliance with restriction on placing on the market of mercury manometers can be verified by following the fairly limited number of producers, importers and distributors of these equipments.

4.3 The proposed restriction(s) and summary of the justifications

Proposal:

Restriction on the placing on the market of mercury manometers and tensiometers after 18 months of entry into force of the amendment of Annex XVII.

Summary of justification:

The main purpose of the proposed restrictions is to reduce the mercury pool in the society, thus avoiding negative impacts on human health and environment. Technically and economically feasible alternatives to mercury containing manometers (including tensiometers) are available and in use. The alternatives are available at approximately the same price as mercury manometers.

Annex 3a: Sphygmomanometers

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1. Technical description of sphygmomanometers

Mercury sphygmomanometers are devices used to measure blood pressure. They include a mercury manometer, an upper arm cuff, and a hand inflation bulb with a pressure control valve and require the use of a stethoscope. The method relies on the auscultatory technique, in which a clinician determines systolic and diastolic blood pressures (SBP and DBP) by listening (auscultating) for sounds that characterise different stages of blood flow during cuff deflation (Korotkoff sounds).

2. Description of release and exposure

Based on the approach described in the Part B of the main document, the estimations on i) the total amount of mercury accumulated in devices in the EU and ii) the amount of mercury placed on the market annually in the EU are used to describe the potential release and exposure during the waste phase of the devices. (Table A3a-1). Furthermore, to get a more comprehensive picture, the annual amounts iii) used in the production of devices, iv) imported into the EU and v) exported from the EU are given to illustrate the potential for direct exposure of workers during the production and service-life of the devices. However, it is stressed that this report does not further assess the potential concerns related to workers as explained in Part B.

Table A3a-1: Amounts of mercury accumulated, used in production, placed on the market and imported and exported in sphygmomanometers.

Mercury	Estimated amounts
Pool accumulated in sphygmomanometers	~ 26-51 t Hg
Placed on the market in sphygmomanometers in the EU	~ 3-5 t Hg/y
Used in production of sphygmomanometers in the EU	~ 6-9 t Hg/y (Based on EEB, 2009).
Imported into the EU in sphygmomanometers	~ 2-4 t Hg/y (Based on EEB, 2009)
Exported from the EU in sphygmomanometers	~ 5-8 t Hg/y (EEB, 2009), i.e. 85 % of production (Lassen et al., 2008)

Box 1: General qualitative description of potential release and exposure

Production phase

In addition to releases from the use and waste phase of sphygmomanometers, as described below, some emissions to the environment and exposure of workers occur in the production phase of mercury sphygmomanometers. It is estimated that around 6-9 tonnes of mercury is used annually in the production of sphygmomanometers in the EU. Around 5-8 tonnes of that is exported from the EU in sphygmomanometers.

(EEB, 2009) According to Lassen et al. (2008) the production of mercury sphygmomanometers employ 30-50 persons in the EU.

Considering that the waste phase is seen as the main problem, and considering that having quantitative information on emissions would not impact the conclusions on the feasibility of alternatives, no further efforts were made to obtain such information.

Service-life

The current pool of mercury in sphygmomanometers in society is roughly estimated to be between 26 and 51 tonnes²⁶.

Mercury-containing measuring devices are used by private practitioners as well as in hospitals. The amount of mercury in each single place of use is small (around 85 g per device) and the use is geographically wide spread.

In the event of breakage or leaks occurring during the use of sphygmomanometers, workers and patients may be exposed (Lassen et al. (2008) and EEB (2009)). Cleaning up of spills is not likely to happen in an appropriate way, and proper ventilation of the room might be forgotten. In addition breakage and leakage can result in releases to the environment.

Waste phase of sphygmomanometers

The amount of mercury in sphygmomanometers placed on the market in the EU in 2010 is estimated to be between 2.6 and 5.1 tonnes. This amount is in the range estimated by Lassen et al. (2008) of 3-6 tonnes per year. This indicates also the amount of mercury disposed with sphygmomanometers annually. However, due to the assumed declining trend in the number of mercury sphygmomanometers placed on the market per year after 2010, also the amount of mercury disposed with these devices is declining (Lassen et al., 2010). Lassen et al. (2008) estimated the collection rate as hazardous waste for all the mercury containing measuring devices of 20%.

In particular the waste phase (separate collection of mercury sphygmomanometers and the handling of these devices in accordance with hazardous waste legislation) is crucial for the potential releases of mercury to the environment. The appropriate collection of sphygmomanometers at the end of their service life as hazardous waste has been reported to be poor in hospitals. A survey by the European Environmental Bureau (EEB) in 8 countries (Czech Republic, France, Germany, Greece, Hungary, Italy, Spain and United Kingdom) revealed that only half of the 37 interviewees (senior administrators, administrators, doctors, nursing directors, nurses, biomedical and technical specialists and other staff) were aware that mercury waste has to be collected separately to other waste streams. Some interviewees said that infectious

²⁶ Lassen et al. (2008) estimated that around 30 000 to 60 000 mercury sphygmomanometers are placed on the market annually in the EU 27. Assuming that there was no trend in number of devices sold annually between 2000 and 2010, and assuming a lifetime of 10 years for mercury sphygmomanometers gives an estimate of 300 000 to 600 000 mercury sphygmomanometers accumulated in the society in 2010. Assuming that one mercury sphygmomanometer contains in average 85 g of mercury gives an estimate of 26 to 51 tonnes of mercury accumulated in the society in sphygmomanometers.

hospital waste and hazardous waste streams were collected in the same bins. Even 30% of the interviewees stated that cleaning staff would discard mercury waste with the normal waste (Concorde East/West 2009). This relatively strong picture might need to be moderated bearing in mind the small sample size (n=37). Nevertheless the survey gives an indication that the awareness on how to dispose off mercury is poor, and that collection rates for mercury-containing measuring devices are low.

The sphygmomanometer waste ends-up partly in hospital waste for incineration, partly in municipal waste, and partly in hazardous waste. There is no information on how well the private practitioners take care of the separate collection and correct disposal of the mercury devices. However, it is not likely that the situation would be better than in hospitals. Overall this matches the general collection estimates for mercury-containing measuring devices in the report from Lassen et al. (2008) (estimated collection rate as hazardous waste of 20%).

3. Available information on alternatives (Part C)

The opinion of SCENIHR (2009) is the main basis for the information in this section and it provides more detailed information on mercury sphygmomanometers and mercury-free alternatives.

3.1 Identification of potential alternative techniques

There are several types of mercury-free alternatives on the market for blood pressure measurement to address the full range of functions required by the health care sector. These alternatives are based on either auscultatory or oscillometric techniques. There are also devices on the market utilising both techniques. Different types of sphygmomanometers in use can be categorised for instance in terms of inflation method, manometer type, need for using a stethoscope, blood pressure measurement frequency, placement of the pressure cuff, need for electrical current, etc.

The following categorisation into alternative devices is used in Sections 3.3 and 3.4 when assessing the technical and economic feasibility:

- Sphygmomanometers based on auscultatory technique
 - Non-automated aneroid sphygmomanometers (e.g. shock-resistant aneroid)
 - Non-automated electronic sphygmomanometers
 - Automated auscultatory sphygmomanometers

- Sphygmomanometers based on oscillometric techniques
 - Semiautomatic oscillometric sphygmomanometers
 - Automated oscillometric sphygmomanometers

3.2 Human health and environment risks related to alternatives

The human health and environmental risks associated with the use and disposal of the aneroid devices are considered to be small. Electronic sphygmomanometers might contain small amounts of lead and possibly some other hazardous substances (including in batteries), and thus may cause problems during the waste phase. In general, the human health and environmental risks are insignificant in comparison with the potential emission and exposure associated with the amount of mercury in thermometers. The accuracy and reliability of the blood pressure measurements with alternative devices is assessed and documented in Section 3.3 (technical feasibility of alternatives) below.

3.3 Technical feasibility of alternatives

3.3.1 Sphygmomanometers based on auscultatory technique

The auscultation method is based on the observation of the recurrence of the blood flow in the occluded artery (by using a cuff) of the upper arm by listening to the sounds when the occlusion is completely removed (by dilation of the cuff) and normal blood flow is restored. All the mercury containing sphygmomanometers are based on the auscultatory method.

Compared to the mercury sphygmomanometers, the validated manual mercury-free sphygmomanometers allow, in some cases, obtaining a faster reading. In addition, the use of them obviously avoids all hazards and costs generated by the mercury. All manual mercury-free devices are prone to the problems related to the auscultatory technique, like observer bias and terminal digit preference, a phenomenon whereby an observer rounds off a measurement to a digit of his or her choosing. In this respect there is no difference to mercury-containing devices. (Concorde East/West, 2009)

Non-automated aneroid sphygmomanometers (e.g. shock-resistant aneroid)

The aneroid sphygmomanometers for manual reading work in a similar way as the mercury sphygmomanometers, but they contain an aneroid gauge that replaces the mercury manometer. Their accuracy and reliability vary with the design and quality of device. The aneroid sphygmomanometers have been in use for about 100 years and when used properly, and a proper maintenance protocol is followed, give accurate results.

The aneroid devices may be susceptible to calibration drift without this being apparent to the user. In general, aneroid sphygmomanometers should be calibrated according to the manufacturer's recommendation, or at least annually (IAG, 2005). According to Concorde (2009), the recommended calibration frequency by the British Hypertension Society (BHS) for aneroid shock-resistant sphygmomanometers is once a year, compared to the mercury devices typically needing calibration once every two years. Better designs to deal with this problem have recently appeared, after producers

introduced a new concept with a resulting more shock resistant sphygmomanometer and a 5-year calibration warranty.

For the clinical use, several aneroid sphygmomanometers are validated by the British Hypertension Society (BHS 2008).

Non-automated electronic sphygmomanometers

The manual electronic sphygmomanometers work in a similar way to the mercury sphygmomanometers, but combine an electronic manometer (electrical transducer instead of mercury) with a digital display (numerical, circular/linear/bar graph) for manual reading. Validated manual electronic sphygmomanometers are available and provide the same accuracy as mercury devices. According to Concorde (2009), the BHS recommends electronic auscultatory sphygmomanometers to be calibrated once in three years.

Automated auscultatory sphygmomanometers

The automated auscultatory devices were designed in the 1970's to replace the observer and stethoscope with a microphone and some analogue electronics. These devices automatically display each detected Korotkov sound. Automated auscultatory sphygmomanometers are still used to replace oscillometric devices for patients with an irregular heart beat. The reliability of automated auscultatory devices depends on the correct placement of the microphone.

3.3.2 Sphygmomanometers based on oscillometric techniques

Oscillometric sphygmomanometers measure changes in artery pulsation during cuff inflation/deflation and then use software containing algorithms to calculate the systolic and diastolic values. As oscillometric devices operate on the bases of a different principle, they have not been considered as one-to-one alternatives for mercury sphygmomanometers.

Oscillometric devices have many advantages, and there is an increasing market for them. They require less servicing and maintenance than mercury sphygmomanometers, although they need to undergo regular checks. They also require far less expertise and can be used by patients themselves, thus removing the white-coat effect and offer more reproducible blood measurements. Oscillometric devices can also be used by patients with infirmities such as arthritis and deafness. They have also been reported to be more predictive of cardiovascular events.

Despite the above mentioned advantages of oscillometric devices, the auscultatory blood pressure measurements are necessary for some specific clinical conditions including arrhythmia, pre-eclampsia and certain vascular diseases. Thus, calibrated manual devices should be available in all clinical areas in case they are needed to check any non-auscultatory blood pressure measurements on individual patients.

Semi-automatic oscillometric sphygmomanometers

Semi-automatic devices based on the oscillometric technique include an electronic monitor with a pressure sensor, a digital display, an upper arm cuff and a hand-operated inflation bulb. The semi-automatic electronic devices are today standard for home/self assessment and also widely used by general medical practitioners.

According to SCENIHR (2009) opinion, some validated semi-automated sphygmomanometers based on oscillometry are available and partly replacing the mercury sphygmomanometers, even though they are not regarded as technically equivalent alternatives. They can be used by hospitals and general practitioners in most clinical conditions, but they are not suitable for measuring blood pressure of patients with pre-eclampsia, arrhythmias such as fibrillation, and for reasons that are not always apparent, probably influenced by arterial wall properties and pulse pressure (SCENIHR, 2009).

Automated oscillometric sphygmomanometers

Automated blood pressure devices for hospital use are more advanced equipment, which often combines the measurements of blood pressure with monitoring of temperature, heart rate and blood oxygen level. An accurate automated sphygmomanometer capable of providing printouts of systolic and diastolic blood pressure, together with heart rate and the time and date of measurement, should eliminate errors of interpretation, abolish observer bias and terminal digit preference. The devices for both 24-hour measurements and blood pressure measurements at home are more reproducible and predict cardiovascular events more precisely than blood pressure measurements in the clinic. The price of this equipment is typically on the order of 10 times the price of a mercury sphygmomanometer, but these advanced devices cannot be directly compared to mercury sphygmomanometers, as they have many more features.

3.3.3 Opinion of SCENIHR

SCENIHR (2009) recognised in its opinion that technically feasible alternatives exist, and that the mercury sphygmomanometers are gradually disappearing from clinical use.

Mercury-free blood pressure measuring devices (when clinically validated) are generally reliable substitutes for mercury-containing sphygmomanometers in clinical practice. SCENIHR (2009) identified only two minor applications, where mercury containing measuring devices would still be needed.

- (1) “For on-going, long-term, epidemiological studies currently using mercury sphygmomanometers it is advisable not to change the method of measurement. Therefore it will be necessary to keep mercury sphygmomanometers available in order to compare them with the alternatives in these studies.” (SCENIHR 2009)

(2) “It is recommended that mercury sphygmomanometers remain available as a reference standard for clinical validation of existing and future mercury-free blood-pressure measurement devices. Therefore, the mercury sphygmomanometer should remain available as a reference standard until an alternative device is developed and recognised as such.” (SCENIHR 2009)

3.4 Economic feasibility

Different models of sphygmomanometers even within each category (e.g. shock-resistant aneroid) vary in terms of quality and properties and there is correspondingly a large price range. In addition the way sphygmomanometers are used (and misused) varies greatly among different users (e.g. the level of maintenance and frequency of calibration ranges from none at all to precisely following the producer’s recommendations). Thus, it is difficult to estimate how well the assumptions made when assessing the economic feasibility (including compliance costs in Annex 3b) of “representative” devices reflects the reality.

Two technically feasible devices based on auscultatory method, i.e. shock-resistant aneroid and (non-automated) electronic sphygmomanometers, are assessed against their economic feasibility. They can replace the mercury sphygmomanometer in all clinical conditions. The main results concerning economic feasibility are given in table A3a-2. It should be noted that the annualised costs of devices are highly sensitive to assumptions regarding the average lifetime and calibration frequencies. A detailed analysis including input data is available in Annex 3b.

Table A3a-2: Average prices of representative sphygmomanometers (ex factory, without VAT)

	Sphygmomanometer			
	Auscultatory			Oscillometric
	Mercury containing	Shock-resistant aneroid	Electronic	Semi-automatic
Investment cost (price of the device)	€40	€40	€110	€40
Average lifetime	10 years	5 years	10 years	not available
Annualised recurrent cost (including e.g. calibration and waste treatment costs)	€9	€16	€9	not available
Annualised cost per device (including investment and recurrent costs)	€14	€25	€22	not available

Source: Lassen et al. (2010), for oscillometric device Lassen et al. (2008)

Semi-automatic oscillometric devices are also reported to replace mercury sphygmomanometers. According to Lassen et al. (2008) they are available at approximately the same price as that of a mercury or shock-resistant aneroid

sphygmomanometer. While these devices seem to be economically feasible they have not been analysed further neither in Annex 3b nor in section E. This is justified as the results of the analysis would not differ much from compliance cost calculations of shock resistant aneroid sphygmomanometers, which are analysed in detail.

The annualised cost of alternatives is estimated to be around €10 higher than the annualised cost of mercury sphygmomanometer. However, as the labour cost of using sphygmomanometer is much higher than the price of the equipment the overall impact on health care costs is insignificant²⁷. Thus the alternatives are considered to be economically feasible for the users.

4. Justification why the proposed restriction is the most appropriate Community-wide measure (Part E)

4.1 Identification and description of potential risk management options

4.1.1 Risk to be addressed – the baseline

As described in the Chapter 2, the amount of mercury in sphygmomanometers placed on the market in the EU is estimated to be around 4 tonnes in the EU in 2010. Based on information from producers of sphygmomanometers (Lassen et al., 2010) it is estimated that without additional legislative action the European market of mercury sphygmomanometers will decline by about 5% annually, i.e. from 45,000 in 2010 to about 28,000 in 2020.

The pool of mercury in sphygmomanometers in use in the EU is estimated to be around 40 tonnes in 2010 as described in the Chapter 2. The above mentioned declining trend in the placing on the market the mercury sphygmomanometers has an effect on the pool in the future.

Lassen et al. (2008) estimated that only 20% of the mercury in measuring devices, including sphygmomanometers, is collected as hazardous waste. It is difficult to estimate the future trend of collection and the share of proper waste management. However, there is no indication that the collection rate would improve without new targeted action in the future.

²⁷ Assuming that EU average cost of a 20 minute visit to a health care provider is (with overhead) €50 one can estimate that the cost of a blood pressure measurement (of 2 minutes) is about €5 in labour cost while the additional equipment cost is about €0.025 per measurement (€10 euros per annum divided by an assumed average blood pressure measurements of 400 per year). Comparing with the labour cost of measuring blood pressure, the additional cost is about 0,5%.

4.1.2 Options for restrictions

Based on the tentative screening of possible restriction options, two options to reduce the risk from mercury containing sphygmomanometers in the EU have been assessed more in detail. They are 1) Restriction on the placing on the market and 2) Restriction on the use of mercury sphygmomanometers. The option 2 should be regarded as a possible additional element to option 1 and its impacts are not assessed independently. Both options include derogations for specific applications of mercury sphygmomanometers based on the opinion of SCENIHR (2009). In addition, both options have a derogation to allow the placing on the market of historically valuable sphygmomanometers.

1) Restriction on the placing on the market with limited derogations:

Restriction of placing on the market mercury containing sphygmomanometers after 18 months of entry into force with derogations for

- a. on-going (at the time of entry into force) long-term epidemiological studies
- b. validation of new mercury-free devices

2) Restriction of use of mercury containing sphygmomanometers in addition to option 1:

Restriction of use of mercury containing sphygmomanometers after 6.5 (i.e. 5 years after ban on placing on the market) years of entry into force with derogations for

- a. on-going (in the time of entry into force) long term epidemiological studies
- b. validation of new mercury-free devices

In addition to these two restriction options which are further assessed in this report, the following additional aspects were considered, but for reasons explained below not retained for further assessment:

- Conditions to prevent non-compliance were considered in conjunction with restriction options 1 and 2. Since the use of mercury containing sphygmomanometers for validation purposes and for long-term epidemiological studies would not be restricted, mercury-containing devices would still be available on the market, and might be bought and used (illegally) for restricted uses. To prevent this kind of non-compliance, suppliers of mercury sphygmomanometers could be required to keep a list of their customers and their uses. Such a list could be used by enforcement authorities when checking the compliance with the restriction. Another possibility to prevent non-compliance, would be to require suppliers to inform the end-user about the allowed uses. These conditions were not considered further. The reason was that the administrative burden was considered rather high and not to be proportionate to the relatively small risk of some

professional end-users buying mercury containing sphygmomanometers for a restricted use.

- Introducing special conditions for efficient separate collection and proper waste handling of mercury containing sphygmomanometers was considered. This could have been for instance a take-back duty of mercury sphygmomanometers for the suppliers. However, administrative efforts to implement such a system for mercury sphygmomanometers were deemed to be disproportionately high. Furthermore, waste management requirements already exist. The possibility of addressing the concern of mercury in measuring devices with further measures under waste legislation is discussed in section B.5 of the main document.

4.2 Assessment of risk management options (sphygmomanometers)

4.2.1 Option 1: Restricting the placing on the market of mercury sphygmomanometers

4.2.1.1 Effectiveness

Risk reduction capacity

The risk reduction achieved by introducing the restriction is described as an annual reduction of metallic mercury used in the EU. That is 3.8 tonnes in 2010 and declining 5 % annually. E.g. in 2015 risk reduction capacity is 3.0 tonnes and in 2024 1.9 tonnes of avoided mercury.

The number of new devices required for long-term epidemiological studies and for validation of new mercury-free alternatives is expected to be very low, probably much less than 100 sphygmomanometers per year. Consequently, these derogations would result in very low volumes of ‘new’ mercury.

The risk associated with the alternative aneroid and electronic devices is considered to be insignificant in comparison with the potential emission and exposure associated with the amount of mercury in mercury-containing sphygmomanometers (see section C.1.2).

The exposure types that will be avoided are described under section B.4. Emissions associated with the production of mercury containing sphygmomanometers will remain unaffected to the extent they will continue to be produced in the EU for export and for exempted uses. Emissions related to the use and waste phase of devices already on the market will not be affected.

Proportionality

The proposed restriction is targeted to reduce the mercury pool in the society by gradually substituting mercury-containing sphygmomanometers with technically and economically feasible mercury-free alternatives. The proposed derogations for long-term epidemiological studies and for validation of new mercury-free alternatives have been designed to ensure that the proposed restriction is proportionate.

Technical feasibility

The technical feasibility of alternatives is discussed more in detail in Chapter C.1.3.1. The SCENIHR (2009) opinion established that technically feasible alternatives are already available on the market and have a considerable market share. Two technically feasible alternatives have been identified. The alternatives are based on the auscultatory technique: i) shock resistant aneroid sphygmomanometer and ii) electronic sphygmomanometer. In addition, some oscillometric semi-automatic or automatic devices can replace mercury devices in most of the applications.

SCENIHR (2009) identified two applications where the use of mercury-containing sphygmomanometers would still be necessary because they considered that in these applications technically feasible alternatives do not exist. Based on the evidence given by SCENIHR, it is proposed that derogations apply for the following two applications:

- (1) use of mercury containing sphygmomanometers as a reference standard for clinical validation studies of existing and future non-mercury-containing sphygmomanometers ; and
- (2) use of mercury containing sphygmomanometers for on-going, long-term, epidemiological studies currently using mercury sphygmomanometers.

Economic feasibility (including the costs)

In section C.1.3.1 the economic feasibility of alternatives was described. In this section the compliance and administrative costs are summarised. More detailed information on compliance costs including the values used in calculations can be found in Annex 3b. Two alternatives using auscultatory technique are assessed against their economic feasibility. These are i) shock-resistant aneroid and ii) electronic sphygmomanometer with manual reading.

A third alternative – based on oscillometric technique – has also been analysed to some extent in Chapter C, as it is according to SCENIHR (2009) replacing mercury-containing sphygmomanometer by some users. In this compliance costs analysis the oscillometric devices are not separately addressed. The reason is that even if some proportion of mercury containing devices were replaced by sphygmomanometers based on oscillometric method the related costs would be quite similar to the costs of shock-resistant aneroid devices.

The overall costs for an end-user of a sphygmomanometer consist of the investment (price of the device) and recurrent costs. Recurrent costs related to sphygmomanometers are caused for instance by calibrating, waste handling, batteries, spill response and training. As the available estimates for spill response and training have more uncertainty than other parameters, they are not considered in the “central” case. The central case can be regarded as the best estimate. Nevertheless, the effect of spill response is taken into account in the sensitivity analysis. Compliance cost calculations for sphygmomanometers are highly sensitive to the cost and frequency of calibration.

The table A3a-3 presents the main outcomes of the compliance cost analysis. Taking into account the uncertainties, the additional annualised cost per device is estimated to be between €25 and -€23, negative value representing cost savings. This means that substituting the mercury sphygmomanometer with mercury-free alternative would either decrease or increase the annualised cost of the user. In the central case estimate the additional annualised cost would be around €11 per device.

Table A3a-3: Summary of compliance costs of avoiding mercury in sphygmomanometers and cost effectiveness

	Sensitivity analysis		
	Central case	Scenario 1 "high costs"	Scenario 2 "low costs"
Annualised cost of mercury sphygmomanometer per device	€14	€9	€35
Annualised cost of alternative²⁸ per device	€25	€34	€12
Additional annualised cost of alternative¹ per device	€11	€25	-€23
Compliance costs (present value 2015-2034 in the EU)	€29 million	€120 million	-€44 million
Compliance costs (in 2024 in the EU)	€3.2 million	€12 million	-€4.2 million
Cost per kg of mercury avoided	€1300	€3000	-€2400

Source: Annex 3b

Based on the above results on additional costs per device, it is estimated that the annual cost for reducing 1 kg of mercury in the production of sphygmomanometers is around €1300 per kg of mercury avoided. For sensitivity, two other estimates have been calculated. In the “high cost” scenario the cost per kg of mercury avoided would be €3000. However, the “low cost” scenario actually results €2400 savings for each kg of mercury avoided. This saving is due to lower recurrent costs for operating electronic sphygmomanometers than for mercury containing devices.

To better understand the compliance costs in relation to other actions and policies, one can compare the cost effectiveness of the proposed restriction (€1313/kg Hg) with the policy options reviewed in Appendix 2. In Appendix 2 it was concluded for the purpose of this restriction report that a benchmark of €10,000 /kg Hg is regarded as indicating that proportionality of costs to the risks related to mercury is “well established”. The proposed restriction for sphygmomanometers is well below this benchmark. Appendix 2 gives further details.

²⁸ A representative device which takes into account the replacement ratio between aneroid and electric sphygmomanometers, i.e. in base case 80 % replaces the hg sphygmomanometer with aneroid and 20 % with electronic device, in Scenario 1 0/100% and in Scenario 2 95/5%.

Administrative costs

The restriction of placing on the market of sphygmomanometers has not been analysed with regard to administrative costs. The reasons are explained in sections E.2.1.2 (practicality) and E.2.1.3 (monitorability). In summary, the administrative costs are assumed to be so low that no specific analysis was carried out.

4.2.1.2 Practicality

Implementability and manageability

According to the SCENIHR (2009) opinion and as discussed in Section C technically feasible alternatives for mercury containing sphygmomanometers are already readily available in the EU. In Section 3.4 above and Annex 3b it is demonstrated that these alternatives are also economically feasible. As the production of mercury containing sphygmomanometers may continue for export, and the import of the devices is also allowed for derogated uses, the availability of mercury sphygmomanometers for derogated uses is covered. In summary, the necessary technology and economically feasible alternatives are already available on the market and the transitional period of 18 months would allow the retailers to handle the existing stock within the timeframe set in the restriction.

The proposed restriction and derogations are simple and therefore easy to understand for the actors. As the number of devices needed for derogated uses is marginal, the mercury containing sphygmomanometers should not to be advertised in the EU markets anymore. This will contribute to a better awareness on the restriction among the users of sphygmomanometers.

Enforceability

The compliance with the restriction on placing on the market of mercury containing sphygmomanometers can be verified by following the fairly limited number of producers, importers and distributors of these equipments.

As a result of the restriction, the number of mercury containing sphygmomanometers will decrease dramatically over time. The restriction on the placing on the market of mercury containing devices may also raise, at least temporarily, the awareness of the users of the devices on the need for special care during the use and disposal of the devices. Therefore, the restriction may help in the implementation and enforcement of waste legislation.

4.2.1.4 Overall assessment of restriction option 1

The amount of mercury introduced to the European market is estimated to reduce by 3.0-1.2 tonnes per annum between 2015 and 2034. The range is due to the declining trend in the number of mercury sphygmomanometers sold annually. The continued use of existing devices until the end of their service-life, taking into account the uncertainties related to their proper disposal, will continue to cause some emissions and exposure. The technical feasibility of alternatives is demonstrated by SCENIHR

(2009) and the specific derogations for long term epidemiological studies and validation purposes were suggested. The cost of reducing the use of mercury in sphygmomanometers is estimated to be between -€2400 (i.e. saving) and €3000 with a central estimate of €1300 per kg of mercury. The cost is considered to be proportional taking into account the risk reduction capacity and the costs of taking similar other actions to reduce the potential emissions of mercury.

4.2.2 Option 2: Restricting the use of sphygmomanometers

Restricting the use of existing sphygmomanometers is an additional element to restricting the placing on the market of the new devices. A transitional period of five years for a use ban after entry into force of restriction on placing on the market (Option 1) is proposed, i.e. the ban on the use would become effective 6.5 years after entry into force. This will allow the use of newly purchased equipment for a reasonable time and would give sufficient time to users to replace their devices. When assessing the effectiveness and practicality of this additional element, all results reported above for restriction on the placing on the market would apply as well.

4.2.2.1 Effectiveness

Risk reduction capacity

A use ban is a chance for implementing more effective national collection campaigns, and a possibility to bring the message of proper collection of the mercury containing devices across. In this way a higher proportion of the devices in use could be collected in compliance with waste legislation. Thus, mercury emissions will be reduced from the waste phase. The impacts are difficult to assess and depend on the efforts taken by Member States to raise awareness on the use ban and to promote proper waste collection. In addition restricting the use of mercury containing sphygmomanometers could reduce the emission and exposure during the use and maintenance of the devices already on the market.

In addition, if the use of the devices is not restricted the awareness of proper waste handling of mercury sphygmomanometers among the few users still left after 10 or 20 years, will probably get worse. This may lead to more emissions to environment from the waste phase.

It can be estimated that the use ban after 6.5 years of the entry into force would affect approximately 200,000 mercury sphygmomanometers²⁹, i.e. 17 tonnes of mercury. The affected sphygmomanometers would be collected on average 2.5 years before the end of the service-life. Hence, the risk reduction capacity is dependent on the proposed transitional period.

²⁹ It can be assumed that banning the use after 5 years of the ban on placing on the market would have an effect on 200 000 mercury sphygmomanometers, as devices bought during five last years before the ban on placing on the market (between 2011-2015) would need to be replaced before end of their service-life.

Proportionality

Technical feasibility

Technical feasibility and availability of mercury-free sphygmomanometers is the same as for restriction option 1.

Achieving the risk reductions requires that Member States raise awareness on the use restriction and on proper disposal of sphygmomanometers. This can be achieved by different means, for instance by using the routine information channels and campaigns on proper collection and handling of hazardous waste. More targeted information campaigns could include the use of associations of medical professionals (websites, special magazines, events etc) or sending information letters to hospitals and private practitioners.

It might be sufficient to use and promote the use of existing hazardous waste collection points and treatment facilities. There can of course be national or local voluntary action to appoint temporary additional collection points. The suppliers of sphygmomanometers could also agree to voluntarily take back mercury-containing devices when new devices are bought.

Economic feasibility (including the costs)

Compliance costs

If the use of mercury containing sphygmomanometers were banned 5 years after the restriction for placing on the market becomes effective, it would truncate the service-life of around 200,000 existing devices. This will cause two kinds of additional costs for users. Before the use ban would become effective, it increases the annualised cost by reducing the life-time of the device (i.e. introducing a loss of residual value of the capital). After that it increases the annualised costs of the users as alternative devices are assessed to be more expensive in the central case. The additional present value compliance cost (for 2011-2024) is estimated to be around €8 million, i.e. approximately 26 % of the compliance costs of banning the placing on the market (present value for 2015-2034). To simplify the analysis, these calculations are based on the assumption that all the mercury sphygmomanometers are replaced by aneroid devices. The compliance costs are highly depended on the proposed transitional period, just like the risk reduction capacity. For details, see Annex 3b.

Administrative costs

As the existing waste collection system can be used to collect sphygmomanometers no significant costs arising from the collection are foreseen. In fact the collection of existing devices can introduce cost savings related to enforcement of waste legislation and to keeping up the awareness and systems for collection of mercury sphygmomanometers.

Costs related to possible information campaign depends on the efforts taken by Member States. As an example, the cost of contacting all the doctors in the EU by

sending letters is roughly estimated to be between €300,000-600,000³⁰. The high awareness on the use restriction does not automatically translate to a high compliance. More intensive enforcement with additional inspections can be a way to promote the compliance, but can also introduce significant costs.

Total costs

The compliance costs of replacing 200 000 mercury sphygmomanometer before the end of their service-life are estimated to be around €8,000,000 (present value 2011-2024) and possible administrative costs between €300,000-600,000. Furthermore it is estimated that the cost of bringing forward the collection would be around €500 per kg of mercury. This cost is related to existing mercury sphygmomanometers and to bringing forward the disposal. It cannot be compared with cost-effectiveness as calculated in Restriction option 1.

4.2.2.2 Practicality

Implementability and manageability

Technically feasible alternatives available and the slightly increased costs for users due to earlier replacement of devices do not significantly affect the users.

As the mercury sphygmomanometers are widely used by general practitioners, achieving high awareness on requirements demands information campaigns. Without these campaigns the desired compliance and reduction in risk is not likely to be achieved. Due to high number of users, the efforts needed from Member States to raise the awareness to an adequate level can become significant. Member States may also use professional organisations to reach the practitioners. In addition, manufacturers and sellers of sphygmomanometers will promote the awareness on the legal requirements quite effectively, as they gain from the early replacement of mercury devices.

Enforceability

Mercury containing sphygmomanometers are widely used by general practitioners. Additional efforts needed to ensure high compliance can be significant, even if awareness is regarded to be at adequate level. In practice the enforcement of users may be very difficult due to dispersive use of sphygmomanometers.

4.2.2.4 Overall assessment of restriction option 2

Restricting the use of existing mercury containing sphygmomanometer is not suggested due to practical difficulties mainly in enforceability. After adequate

³⁰ According to Eurostat, there is approximately 1.5 million doctors in the EU. Hospitals can be contacted with one letter, and it is assumed that 60-80% of doctors would be reached through hospitals. In addition, the staff time to prepare the letters is estimated to be 4-8 hours per Member State, i.e. 108-216 hours. Assuming an hourly expense of €30, the preparation of the letters would cost between €3240-6480 in total. Sending a letter can be estimated to cost €1 per letter.

awareness among users is achieved, the authorities would need to ensure high compliance. This could be done through enforcement. The risk reduction capacity is difficult to assess, but if a real improvement in waste handling is achieved, it could reduce the emissions from the waste phase significantly. The cost of bringing forward the collection of some mercury sphygmomanometers is estimated to be around €500 per kg of mercury.

4.3 The proposed restriction(s) and summary of the justifications

Proposal:

The placing on the market of mercury containing sphygmomanometers after 18 months of entry into force of the amendment of Annex XVII with derogations to devices that are used (i) in long-term, epidemiological studies which are on-going on entry into force; (ii) as reference standards in clinical validation studies of mercury-free sphygmomanometers.

Summary of justification:

The main purpose of the proposed restrictions is to reduce the mercury pool in the society, thus avoiding negative impacts on human health and environment. Technically feasible alternatives to mercury containing sphygmomanometers are available with very limited exemptions as justified in the opinion of SCENIHR. Based on the assessment of compliance costs (in Annex 3b), the alternatives are also regarded as economically feasible. The cost-effectiveness (around €1300/kg) to avoid mercury is regarded as proportional.

Annex 3b: Compliance cost calculations for Sphygmomanometers

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1. Introduction

This report presents the compliance costs calculations of substituting mercury-containing sphygmomanometers with mercury-free alternatives after their service-life (restriction option 1 in the Annex XV restriction report). In addition, the additional cost impacts arising from the possible replacement of the existing stock of mercury containing sphygmomanometers (restriction option 2) is covered with limited efforts in Chapter 5. Two alternative devices (shock-resistant aneroid and electronic) are covered in the analysis due to their technical properties, which are quite similar to mercury-containing sphygmomanometer (e.g. manual reading as for mercury-containing sphygmomanometer). The technical feasibility of these alternatives has been assessed and verified by the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR 2009) and is not further discussed in this paper. Compliance costs are also calculated for this scenario, where both alternatives will gain a specific proportion of the markets.

2. Defining the temporal scope and choosing a representative year

The temporal scope of the analysis is established from the time when restriction is assumed to become effective in 2015 to 2034³¹. Taking into account the uncertainties related to available data and the assumed declining trend in the number of mercury sphygmomanometers 20 years scope is regarded sufficient. As the average lifetime of a mercury containing sphygmomanometer is estimated to be 10 years, the restriction would have its full effect in 2024, when all the existing mercury containing devices would be replaced.

The costs are reported in two ways:

1. In the cumulative approach the present values of costs are calculated for 2015-2034.
2. In the representative year approach the annualised costs, using the year 2024 as a representative year, are calculated.

³¹ This temporal scope is chosen for illustrative purposes. In reality the time when the restriction becomes effective (2015 in this analysis) depends on the speed of the decision making process and the transitional periods after entry into force.

3. Input data

The main sources of data used in the analysis are Lassen et al. (2008)³², Concorde (2009)³³ and Lassen et al. (2010)³⁴. The Table 1 below presents the input data used in the analysis. The prices of devices (investment costs) are factory gate prices excluding VAT, but for other costs (recurrent costs) it is not known if the VAT is included or not.

In addition to data used for central case, the Table A3b-1 presents the values for parameters used in sensitivity analysis (scenarios 1 and 2). The sensitivity analysis with results is presented in Chapter 7.

4. Changes in the characteristics of the good

The value related to changes in characteristics of the good is not assessed in this analysis due to lack of data on end-users needs and perceptions. The technical feasibility of alternatives has been assessed and verified by Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). The fact that end-users have not replaced the mercury sphygmomanometers with possibly more economical alternatives (resulting in cost savings calculated in Scenario 2), may indicate that certain characteristics of mercury devices are more valuable than perceived in this analysis. This might also be due to asymmetric (incorrect) information among practitioners on quality of alternative devices.

³² Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society published by DG Environment. Available at http://ec.europa.eu/environment/chemicals/mercury/pdf/study_report2008.pdf

³³ Turning up the Pressure: Phasing out Mercury Sphygmomanometers for Professional Use published by European Environmental Bureau. Available at http://www.eeb.org/publication/2009/SphygReport_EEB_Final-A5_11Jun2009.pdf

³⁴ Appendix 3 of the restriction report

Table A3b-1: Input data used in the analysis

Parameter	Device	Central case	Scenario 1: High costs	Scenario 2: Low costs
Discount rate		4%	4%	4%
Mercury devices sold per year 2010		45000	45000	45000
Annual decrease in number of devices sold		5%	0%	10%
Mercury per device (kg)		0.085	0.085	0.085
Average lifetime (years)	Mercury	10	10	9
	Shock-resistant aneroid	5	4	6
	Electronic	10	6	15
Investment cost (price of device)	Mercury	€ 40	€ 40	€ 40
	Shock-resistant aneroid	€ 40	€ 40	€ 40
	Electronic	€ 110	€ 110	€ 90³⁵
Calibration costs (per calibration)	Mercury	€ 15	€ 30	€ 30
	Shock-resistant aneroid	€ 20	€ 30	€ 30
	Electronic	€ 20	€ 40	€ 40
Calibration frequency (once in x years)	Mercury	2	5	2
	Shock-resistant aneroid	1	1	5
	Electronic	3	3	4
Batteries (per year)	Mercury	€ 0	€ 0	€ 0
	Shock-resistant aneroid	€ 0	€ 0	€ 0
	Electronic	€ 3	€ 4	€ 2
Waste treatment (per device) ³⁶	Mercury	€ 30	€ 10	€ 40
	Shock-resistant aneroid	€ 1	€ 2	€ 1
	Electronic	€ 2	€ 4	€ 1
Spill response (per year)	Mercury	€ 0	€ 0	€ 12
	Shock-resistant aneroid	€ 0	€ 0	€ 0
	Electronic	€ 0	€ 0	€ 0
Replacement ratio ³⁷		75/25	100/0	95/5

³⁵ To cover the possible trend of the price of the electronic sphygmomanometer, it is simply assumed in Scenario 2 that the price would be 90 € throughout the analysis (2015-2034). This has approximately the same effect on compliance costs as 2 % annual decrease in the price.

³⁶ It is not known if the estimate considers that not all the users dispose of the mercury sphygmomanometers in accordance of the hazardous waste legislation.

³⁷ The ratio of replacement of the mercury containing sphygmomanometers by aneroid or electronic alternatives.

5. Cost calculations

The calculations have been carried out in Excel sheets using NPV (for present value) and PMT (for annualised cost) worksheet functions. All values used in this analysis refer to year 2010 price level, i.e. the prices are “real” as the effect of inflation has not been included in the analysis. Throughout the analysis a 4% discount rate is used and the expenditures are assumed to occur in the beginning of each year, i.e. 1 of January.

Calculating investment costs

In the central case it is assumed that prices of mercury-containing and alternative devices do not change between 2015 and 2034. In reality, there could be change in the prices in favour of electronic sphygmomanometers due to relatively new technology used in the device. This assumption is included in the Scenario 2 presented in Chapter 7. Table A3b-2 presents the calculation of investment costs of mercury-containing sphygmomanometer and two alternative devices.

Table A3b-2: Annualised investment costs per device (in 2010 price level)

Year	Investment costs (€) per device		
	Baseline: Mercury sphygmomanometer	Alternative 1: Shock resistant aneroid sphygmomanometer	Alternative 2: Electronic sphygmomanometer
1	40	40	110
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0		0
7	0		0
8	0		0
9	0		0
10	0		0
Annualised	5	9	14
Additional annualised		4	9

The prices of the mercury and shock-resistant aneroid devices are estimated to be €40, and electric device €110. Due to shorter lifetime of the Alternative 1 compared to mercury-containing device, the additional annualised investment cost is estimated to be €4 per device. For Alternative 2 additional annualised investment cost is estimated to be €9 per device.

Calculating recurrent costs

The recurrent costs of sphygmomanometers consist mainly of calibrating costs. In addition there are costs related to batteries for electronic device, waste handling, spill response and training but some of these costs are not considered in the central case analysis for the reason explained below. The devices are bought calibrated, i.e. the first calibration takes place at the earliest one year after the investment. The table A3b-3 presents the calculations of recurrent costs for different devices.

Table A3b-3: Annualised recurrent costs per device (in 2010 price level)

Year	Recurrent costs (€) per device		
	Baseline: Mercury sphygmomanometer	Alternative 1: Shock resistant aneroid sphygmomanometer	Alternative 2: Electronic sphygmomanometer
1	0	0	0
2	0	20	3
3	15	20	3
4	0	20	23
5	15	20	3
6	0	1	3
7	15	0	23
8	0	0	3
9	15	0	3
10	0	0	23
11	30	0	2
Annualised	9	16	9
Additional annualised		8	0

The values of different parameters of recurrent costs are listed in table A3b-1 in Chapter 3. The additional annualised recurrent cost per device is estimated to be €8 for alternative 1 and €0 for alternative 2 compared to the baseline.

According to Concorde (2009) the annualised spill response cost per device is estimated to be €12 for the mercury containing sphygmomanometer and zero for alternatives (as there is no fear of mercury spill). The cost includes estimates on cost of spill kit, person-hours, spill area closure and cost of downtime, waste disposal etc. In addition it is assumed that there is a spill from 3 % of the mercury containing sphygmomanometers annually. The annualised training costs per device are estimated to be €5 for mercury containing, €2 for aneroid and €3 for electronic device. These parameters (spill response and training) are not considered in the base case analysis due to limited information on the assumptions behind the estimates. It is also difficult to assess if these actions take a place in the reality. Nevertheless, the spill response estimate is included in the Scenario 2 in sensitivity analysis. Taking into account these estimates changes the total recurrent costs in favour for alternatives.

Total costs and compliance costs

The following calculations (central case) are made assuming 5% annual decrease in the number of mercury-containing sphygmomanometers sold per year in the next 20 years, i.e. approximately 30 000 devices in 2020 compared to 45 000 in 2010. This reduction in using mercury-containing devices is at least partly due to increase in awareness of harmful properties of mercury. Table A3b-4 presents the calculations of total costs of mercury-containing sphygmomanometer and the two alternative devices.

Table A3b-4: Annualised total costs per device (in 2010 price level)

Year	Total costs (€) per device		
	Baseline: Mercury sphygmomanome ter	Alternative 1: Shock resistant aneroid sphygmomanome ter	Alternative 2: Electronic sphygmomanome ter
1	40	40	110
2	0	20	3
3	15	20	3
4	0	20	23
5	15	20	3
6	0	1	3
7	15	0	23
8	0	0	3
9	15	0	3
10	0	0	23
11	30	0	2
Annualised	14	25	22
Additional annualised		12	9

The additional annualised cost per device is estimated to be €12 for alternative 1 and €9 for alternative 2 compared to the mercury-containing device. These results can be derived from Tables 1 and 2 as sums of additional investment and recurrent costs.

In reality some of the users would replace the mercury sphygmomanometer with shock-resistant aneroid, some with electronic devices and some with alternatives not covered in this analysis due to their technical properties. According to SCENIHR (2009), in addition to sphygmomanometers covered in this analysis, also validated oscillometric devices are currently replacing mercury containing sphygmomanometers. Nevertheless, as the price of oscillometric device is approximately the same as aneroid shock-resistant sphygmomanometer, and there are no reasons to assume significant difference in recurrent costs, there is no need to assess them separately. Based on information from industry (Lassen et al., 2010) we assume in the central case that 75% of the mercury devices would be replaced with the shock-resistant aneroid sphygmomanometer and 25% with electronic one.

Table A3b-5 presents the compliance costs from replacing the mercury sphygmomanometer with shock-resistant or electronic alternative or with combination (75/25) of those as described above.

Table A3b-5: Annualised and present value compliance costs for alternatives 1, 2 and the combination of alternatives (in 2010 price level)

	Compliance costs (€)		
	Alternative 1: Shock resistant aneroid sphygmomanometer	Alternative 2: Electronic sphygmomanometer	Alternatives 1+2
2015	421102	310914	393555
2016	822152	607023	768370
2017	1204104	889032	1125336
2018	1567869	1157612	1465304
2019	1914311	1413402	1789083
2020	2244255	1657011	2097444
2021	2558488	1889021	2391121
2022	2857758	2109982	2670814
2023	3142777	2320421	2937188
2024	3414223	2520839	3190877
2025	3251641	2400799	3038930
2026	3096801	2286475	2894219
2027	2949334	2177596	2756399
2028	2808890	2073901	2625142
2029	2675133	1975143	2500136
2030	2547746	1881089	2381081
2031	2426424	1791513	2267697
2032	2310880	1706203	2159711
2033	2200839	1624955	2056868
2034	2096037	1547577	1958922
Replacement ratio	75%	25%	
Compliance cost (present value 2015-2034)	31,348,553	23,145,723	29,297,845
Annualised compliance cost (2024)	3,414,223	2,520,839	3,190,877

The present value compliance costs for 2015-2034 are estimated to be between €23 million and €31 million and annualised compliance costs (2024) between €2.5 million and €3.4 million depending on the replacement ratio.

Costs related to banning the use of mercury containing sphygmomanometers

The compliance costs of banning the use of existing mercury containing sphygmomanometers are sensitive on the length of the possible transitional period between entry into force of the restriction and time when it becomes effective. The following compliance costs in Table A3b-6 are calculated based on assumption that no new mercury containing devices would be purchased after 2015, as there would be a ban on placing on the market, and that the use ban would become effective in 2020. For simplicity, it is assumed that all the mercury sphygmomanometers would be

replaced by the aneroid alternative. As the annualised cost per device for the mercury sphygmomanometers with only 5 years lifetime is lower than for alternatives (with central case assumptions), it is assumed that the use ban would not effect the demand of mercury devices before 2015.

Table A3b-6: Compliance costs of banning the use of mercury containing sphygmomanometers after 5 five year transitional period (in 2010 price level)

Year	Type of effect	Compliance cost (€)
2011		57,373
2012	Higher annualised cost per sphygmomanometer due to reduced lifetime of mercury sphygmomanometer (lost of residual value of capital)	114,027
2013		244,279
2014		381,662
2015		627,956
2016		627,956
2017		627,956
2018		627,956
2019		627,956
2020	Additional costs due to higher annualised costs of aneroid sphygmomanometer compared to mercury device	2,326,856
2021		1,815,004
2022		1,327,525
2023		863,260
2024		421,102
Compliance cost (present value 2011-2024)		7,732,792
Cost effectiveness (€ per kg)		467

The use ban results in two kinds of effects for the users. Before 2020, when the use ban would be effective, it increases the annualised cost by reducing the life-time of the device i.e. introducing a loss of residual value of the capital. As the lifetime of a mercury containing sphygmomanometer is assumed to be 10 years, the use ban would cut down the service-life of devices bought between 2011 and 2015. After 2020 the use ban introduces an increase in the annualised costs of the users, as alternative devices are calculated to be more expensive (central case). This cost impact is similar to cost impacts in restriction option 1 in the restriction report (ban on placing on the market). As the last mercury devices are assumed to be purchased in the beginning on 2015, the last compliance costs take place in 2024, i.e. after the 10 years lifetime.

Introducing the use ban (in 2020) in addition to a ban for placing on the market (in 2015) for mercury sphygmomanometers would introduce an additional compliance cost of around €8 million which means approximately 26 % increase in compliance costs. Assuming 8 years transitional period instead of 5 would introduce compliance costs of around €1.5 million, but at the same time affect only to 6 tonnes of mercury instead of 17.

6. Cost effectiveness

Table A3b-7 presents the costs of reducing the consumption of mercury by one kg when banning the placing on the market of mercury sphygmomanometers. The calculation is based on the annualised compliance costs and on assumption that one mercury sphygmomanometer contains 85 g of mercury. The cost effectiveness is calculated using the following formula:

$$C - E = \Delta C_i \times y \times \frac{1}{m}, \quad (1)$$

where

$C - E$ = cost effectiveness (€/kg),

ΔC_i = additional annualised cost per device (€/year),

i = the device (Alternative 1 or Alternative 2)

y = lifetime of mercury-containing sphygmomanometer (years) and

m = mercury content per device (kg).

Table A3b-7: Cost effectiveness of replacing the mercury sphygmomanometers (in 2010 price level)

	Central case	Scenario 1: High costs	Scenario 2: Low costs
Cost of reducing 1 kg of mercury consumption (€/kg)	1,313	3,014	-2,379

In the central case the cost of reducing 1 kg consumption of mercury in production of sphygmomanometer is estimated to be €1300. With parameters used for sensitivity analysis the cost is estimated to be between €3000 and – €2400 (cost savings) per kg.

One of the assumptions, the number of mercury-containing devices sold per year, does not have effect on cost-efficiency of action as both benefits (reduction in mercury consumption) and costs (compliance costs) will be affected by the same ratio. This is partly due to limited scope of our analysis (taking only into account the costs faced by end-users) which is not including e.g. regulatory costs. Nevertheless, the effect of annual number of mercury devices sold on cost-efficiency is assumed to be insignificant.

7. Assumptions and sensitivity analysis

One main assumption used in the analysis is the number of mercury-containing sphygmomanometers sold per year, which is assumed to decrease approximately 5 % annually 2015 and 2034 (45 000 devices sold in 2010) without regulation in central case. The other main assumption is that prices of devices are assumed to be stable between 2015 and 2034.

The assumptions, as well as the input data presented in Chapter 3, include more or less uncertainty especially as a quite long time horizon is adopted and the uncertainty tends to increase over a time.

To address the issue of uncertainty two scenarios are considered: a “high costs” with assumptions increasing the compliance costs (Scenario 1) and “low costs” in favour of banning mercury-containing devices (Scenario 2). Table A3b-8 gives the present value (2015-2034) and annualised (2024) compliance costs for the two scenarios. The values used in sensitivity analysis can be found in the Table A3b-1 in Chapter 3. The values in bold differ from the central case calculations and are chosen for sensitivity analysis as they are estimated to include significant uncertainty or possible trends before 2034.

Table A3b-8: Results of sensitivity analysis presented as annualised and present value compliance costs for the combination of alternatives (in 2010 price level)

	Central case	Scenario 1: High costs	Scenario 2: Low costs
Compliance cost (present value 2015-2034) (€)	72,295,288	116,054,281	-43,600,611
Annualised compliance cost (2024) (€)	6,903,029	11,529,562	-4,234,129

The annualised and present value compliance costs of Scenarios 1 and 2 can be regarded as lower and upper limit estimates with reasonable values for key parameters. Thus, the present value compliance costs are estimated to be between €116 million cost and €44 million savings.

8. Summary

The compliance costs of banning the placing on the market of mercury sphygmomanometers with mercury-free alternatives are estimated to be around €70 million (present value 2015-2034) or around €7 million (annualised in 2024). However, due to uncertainties in the data, high and low cost scenarios are analysed and they suggest present value compliance costs between €116 million and €43 million savings. This results in cost-effectiveness estimate between €3000 and – €2400 (cost savings) per kg of mercury avoided.

In addition, compliance costs for banning the use of mercury sphygmomanometers currently in use in 2020 (present value 2011-2024) is estimated to be around €8 million.

Annex 4: Strain gauges (used with plethysmographs)

Content

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1. Technical description of strain gauges

Strain gauges are used for blood pressure measurements in body parts using a technique called strain gauge plethysmography³⁸ (measuring how limbs change in size at different pressures). They consist of a fine rubber tube filled with mercury which is placed around the body part in which the blood pressure or blood flow is measured. The method is used for instance for diagnosing certain kinds of arteriosclerosis. According to the Northeast Waste Management Officials' Association a standard mercury strain gauge contains approximately 1.25 grams of elemental mercury (NEWMOA 2010).

2. Description of release and exposure

Based on the approach described in Part B of the main document, the estimations on i) the total amount of mercury accumulated in devices in the EU and ii) the amount of mercury placed on the market annually in the EU are used to describe the potential release and exposure during the waste phase of the devices (see Table A4-1). Furthermore, to get a more comprehensive picture, the annual amounts iii) used in the production of devices, iv) imported into the EU and v) exported from the EU are given to illustrate the potential for direct exposure of workers during the production and service-life of the devices. However, it is stressed that this report does not further assess the potential concerns related to workers as explained in Part B. If quantitative estimates are not available, a qualitative description is given.

Table A4-1: Amounts of mercury accumulated, used in production, placed on the market, imported and exported in strain gauges.

Mercury	Estimated amounts
Pool accumulated in strain gauges	~14 kg Hg
Placed on the market in strain gauges in the EU	~14 kg Hg/y
Used in production of strain gauges in the EU	0.015 kg in Sweden (Kemi, 2007)
Imported into the EU in strain gauges	<14 kg Hg/y
Exported from the EU in strain gauges	0 kg (One identified producer in Sweden producing less than 150 mercury strain gauges annually for Swedish markets)

³⁸ Mercury strain gauges are always used with a separate device, namely plethysmograph. No measurements with strain gauges are possible without the device.

Box 1: General qualitative description of potential release and exposureProduction, use and waste phase of mercury strain gauges

Kemi (2005) estimates that in Sweden no more than 200 mercury strain gauges are needed annually. When extrapolated to the whole EU27 (based on the population of Sweden which is approximately 1.8% of the population of EU27), it would suggest that only around 14 kg of mercury is used in mercury strain gauges sold annually in the EU27 (in around 10,000 strain gauges). This is also more or less the stock of mercury in strain gauges in the EU as the average service-life of a gauge is estimated to be 1 year (Kemi 2005). In Sweden the placing on the market of mercury strain gauges has been prohibited for many years, with only limited exemptions (Kemi, 2007). Therefore, the estimate of 14 kg for the whole EU may be a significant underestimate. Nevertheless, there is no data available from the other Member States.

Some emissions to the environment and exposure of workers may occur in the production phase of mercury strain gauges. However, there is only one identified producer in the EU using only around 20 g of mercury annually.

The average lifetime of a mercury strain gauge is around 1 year (Kemi 2005). The relatively short service-life might be caused by the aging of the silicon tube (Kemi 2007). In addition the aging of the strain gauge causes the copper to dissolve in the mercury and thus the pressure in the gauge will go down and it cannot be used anymore (NEWMOA 2010).

As the rubber tubes are quite strong, the strain gauges are not susceptible to break and emissions occurring during the service-life are estimated to be low. As the strain gauges are mainly used by hospitals, the level of proper waste handling may be similar to the situation with sphygmomanometers at hospitals. As described in Annex 3a (Sphygmomanometers), there are reported problems related to waste handling of sphygmomanometers used in hospitals.

3. Available information on alternatives (Part C)³⁹

Several kinds of mercury-free alternatives exist for mercury strain gauges including:

- Strain gauges with indium-gallium
- Photo cell
- Laser-Doppler techniques
- Ultrasound

³⁹ There are indications that indium-gallium strain gauges can replace mercury in all applications and can be used with existing plethysmographs. This information could not be verified before the submission of this report, but should be further investigated later on during the processing of this Annex XV report. This may influence the assessment of the restriction options. Risks related to indium-gallium are not assessed in this report, but some information on gallium can be found in Annex 5a (Thermometers).

- Ultrasound-Doppler
- Filtrass

The strain gauges with indium-gallium are marketed for the same purposes as mercury strain gauges. The photo-cell technique registers changes in tissue colour at different pressures. The laser-Doppler technique measures the velocity of red blood cells to determine the blood flow in different pressures. Filtrass is a type of plethysmographic method, but it does not use strain gauges. Different alternatives can be used for different measurements (Kemi 2007).

According to Kemi (2005) these alternatives are replacing mercury containing strain-gauge equipment that is used for measuring blood pressure in fingers, toes and other specific areas. The reasons why mercury containing strain gauges are still used are both technical and economical. The mercury-free products are fully competitive in terms of quality. Mercury tube itself is not so expensive. However, the tube functions with complex electronic equipment that cost more than €20,000. As the service-life for the electronic equipment is 10-15 years, the hospitals hesitate to invest in new equipment unless the old one breaks down. The service-life of the mercury tube itself is around 1 year. (Kemi 2005)

There is no information available if specific mercury-free strain gauges could function or could be designed to function with existing plethysmographs. This question was addressed in the stakeholder consultation, but no response from the producer was received.

Secondly, according to Kemi (2005) the mercury strain gauges are still needed in research of absolute blood flow in arms and legs due to the huge amount of reference material available. It is also reported that mercury equipment is still in use for the diagnosis and monitoring of critical limb ischemia and monitoring certain kinds of arteriosclerosis. Kemi (2005) estimated that within 4 to 5 years (i.e. by 2010) mercury-free plethysmographic equipment will be validated for all areas where mercury strain gauges are used.

As described in Section B.5 the current Swedish ban from 2007 has time limited exemptions (that can be prolonged) for strain gauges that reads:

“The applicant may manufacture and sell up to 150 mercury containing strain gauges each year and these must be used in already existing equipment

- to measure blood flow in a muscle within clinical routine activities up to 2010-12-31*
- for other uses within clinical routine activities up to 2009-12-31*
- for research and development up to 2012-12-31 given that the project started prior to 2007-12-31. If the research concerns blood flow in a muscle the project may start not later than 2010-12-31.*
- to validate mercury free alternatives up to 2010-12-31.*

The applicant has the duty to keep records on the uses.”

This exemption indicates that some flexibility may be needed in the restriction to allow the continuation of use in some specific application requiring use of mercury strain gauges at least for some time.

4. Justification why the proposed restriction is the most appropriate Community-wide measure (PART E)

4.1 Identification and description of potential risk management options

4.1.1 Risk to be addressed – the baseline

As discussed in Part B, the accumulated stock of mercury in measuring devices is used as an indicator of maximum emission potential for most of the devices. For strain gauges this is roughly estimated to be 14 kg (in around 10.000 gauges). This is also the amount of mercury included in the strain gauges sold annually in the EU, as the lifetime is estimated to be 1 year. There are no data available to assess the trend of using mercury strain gauges but given the overall tendency to reduce mercury, it would seem appropriate to assume that the trend is declining.

4.1.2 Options for restrictions

Only one option to reduce the risks related to use of mercury in strain gauges is assessed further in the report:

1. Ban on placing on the market new plethysmographs designed to be used with mercury strain gauges 18 months after the entry into force

This option allows continuing the use of existing plethysmographs using mercury strain gauges, but new plethysmographs would need to rely on alternatives. The same effect would be achieved by restricting the use of mercury strain gauges in plethysmographs that are placed on the market after 18 months of the entry into force.

In addition the following options were identified but after tentative consideration discarded.

2. Ban on placing on the market of mercury strain gauges after 18 months of the entry into force.

Even though the risks related to mercury in strain gauges would be totally eliminated, it would introduce high costs as plethysmographs are expensive and currently relying on mercury strain gauges and they would need to be replaced before the end of their service-life.

3. Ban on placing on the market of mercury strain gauges after a 10-15 years transitional period.

Risks related to mercury in strain gauges would be eliminated after 10-15 years. In principle this option would not introduce significant costs as all the plethysmographs should be replaced already (lifetime of 10-15 years assumed). In addition, possible problems with the reference material in research as mentioned in Chapter 3, should have been resolved in 10 years. This option is quite similar to the proposed restriction, but discarded from the further analysis as it does not directly require plethysmographs designed to be used with mercury-free strain gauges to be placed on the market already after 18 months.

4.2 Assessment of risk management options

Restricting the use of mercury strain gauges in plethysmographs placed on the market after 18 months of the entry into force

The risk reduction capacity of the proposed restriction is around 14 kg per year. The capacity decreases over time as more plethysmographs would be replaced by equipments relying on mercury-free alternatives even without a new restriction. The proposed restriction should not introduce costs to users as the use of existing plethysmographs relying on mercury strain gauges is not endangered and there is no information available suggesting additional costs related to the use of plethysmographs relying on mercury-free gauges.

Based on the experiences from Sweden additional time for users might be needed in some specific applications of mercury strain gauges. This is addressed in this restriction option by allowing the use of mercury strain gauges with existing plethysmographs. In addition the restriction option is targeted only to new devices and old devices could still be placed on the market. This could allow for instance the continuation of research projects in case of a breakage of a plethysmograph during these projects.

With this restriction, it will be possible to reduce a small amount of mercury (14 kg per year) from the market. It would not be worth the effort to regulate strain gauges alone as the administrative costs related to setting up a restriction would be relatively high. Given that a restriction needs to be set on many other devices, there is no significant additional administrative cost related to restricting the mercury strain gauges.

4.3 The proposed restriction(s) and summary of the justification

As described above, mercury strain gauges are used in plethysmographs. To allow using the existing plethysmographs, the restriction is not targeted to placing on the market of mercury strain gauges, but to placing on the market of plethysmographs.

Proposal:

Restriction on the placing on the market of pletysmographs designed to be used with mercury strain gauges after 18 months of entry into force of the amendment of Annex XVII.

Summary of justification:

The main purpose of the proposed restrictions is to reduce the mercury pool in the society, thus avoiding negative impacts on human health and environment. Technically and economically feasible alternatives to mercury strain gauges are available as long as existing plethysmographs (relying on mercury strain gauges) can be used until the end of their service-life. This is the case as it is proposed to restrict the placing on the market instead of the use of plethysmographs (or placing on the market of mercury strain gauges).

Annex 5a: Thermometers⁴⁰

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⁴⁰ Including psychrometers (hygrometers) and other applications of mercury as a thermometric liquid.

1. Technical description of mercury thermometers

Mercury thermometers can be used for manual reading of all temperature measurements in the interval from the freezing point of mercury, -39°C , up to about 800°C , with an accuracy up to 0.01°C for high-precision laboratory thermometers (Lassen et al., 2008). Mercury-thallium thermometers can be used down to -58°C . Amongst the advantages of mercury as a thermometric liquid are cited that it does not age, does not cause wetting of the glass surface⁴¹, and has a good expansion linearity over a wide temperature range (Ludwig Schneider, 2010).

Five types of mercury thermometers are identified and assessed in this restriction report:

- Mercury-in-glass thermometers
- Six's thermometer (maximum minimum thermometer)
- Maximum thermometers
- Mercury dial thermometers
- Mercury psychrometer (hygrometer)

In addition, mercury heat indicators, mercury triple point cells and possible other non-electrical thermometric applications are assessed. Hydrometers are sometimes specifically mentioned to have a mercury thermometer inside. They are not assessed separately since they are only one of the many applications of thermometers.

Mercury tilt switches in thermostats and mercury thermoregulators (also designated contact thermometer or accustat) are not in the scope of this restriction report, since they are dependent on electric currents in order to work properly, and therefore fall under the definition of 'electrical and electronic equipment' in the RoHS Directive (see section B.2 and Appendix 4).

Psychrometers (hygrometers) are based on thermometers and, therefore, they are covered in this mercury thermometer section of the restriction report.

Mercury-in-glass thermometers

Mercury-in-glass thermometers consist of mercury encased in a thin glass tube that rises and falls (expands and contracts) with temperature.

The amount of mercury in thermometers can vary significantly according to the application and design. Lassen et al. (2008) reported the mercury content of thermometers used for laboratories and in industry settings to range from 1 to 20 g, with an average content of 3-4 g. This is consistent with a producer, who reported a typical content of 3.5g/piece (Lassen et al., 2010).

⁴¹ Non-wetting of glass is a colloquial term pointing to the very low adhesive properties of mercury to glass compared to the strong cohesive forces in liquid mercury, causing very low capillary action and a convex meniscus of mercury in a glass tube (water in a glass tube for example has a concave meniscus and high capillary action).

Thermometers used in laboratories contain typically around 14g of mercury (Lassen and Maag, 2006). In Lassen et al. (2010), producers reported a typical mercury content of 3, 4 and 11g per laboratory thermometer.

In laboratories precision is often of importance. Precision laboratory thermometers typically have reading scales varying from 1 to 0.1°C. High-precision laboratory thermometers are used for determining ice point and boiling point, for calorimetry, and for other purposes, and have reading scales down to 0.01°C. In industrial settings a resolution of 0.1°C is generally not necessary (Lassen et al., 2010). This is confirmed by information in a catalogue of engine thermometers from two producers. Both usually have a reading scale less precise than 1°C, and only a few models have a 0.5°C scale (Ludwig Schneider, 2010 and Palmer Wahl, 2010).

Six's thermometers (maximum minimum thermometer)

Six's thermometer is a mercury-in-glass thermometer with a U-shaped tube that can be used to indicate minimum and maximum temperature during a given period of time. It is a less expensive, but generally less accurate, way to measure minimum and maximum temperature, compared to the standard combination of a separate mercury containing maximum thermometer and a spirit filled minimum thermometer (Finklin and Fischer, 1990). Alcohol is used as thermometric liquid, while the mercury serves merely as an indicator. This type of thermometer is still used to measure the extremes of temperature at a certain location, where great precision is not essential (Finklin and Fischer, 1990), for instance for professional gardening.

Maximum thermometers

Maximum thermometers are used for reading maximum temperatures in meteorology (daily temperatures), and industrial processes (Lassen et al., 2010), such as sterilisation (Amarell, 2010). A capillary constriction prevents the mercury column to flow back after cooling. The column has to be shaken back after every measurement. Maximum thermometers are provided by several producers, with a resolution down to 0.1°C (Lassen et al., 2010).

Mercury dial thermometers

Mercury dial thermometers consist of a mercury filled metal bulb connected to a dial (a bourdon coil and a needle for reading the temperature). They are applied mostly in the process industry and for marine applications. This group of thermometers has only a very limited remaining market.

For remote measurement, to e.g. control of large engines or combustion processes, thermometers consisting of a sensor and a mercury filled capillary connecting the sensor to the dial are used. Lassen et al. (2008) reported that these capillaries might be up to 40 m, and according to a consulted product catalogue even up to 76m long (Palmer Wahl 2010).

The mercury content of mercury dial thermometers ranges from about 5 to 200 g (Lassen et al., 2008).

Mercury psychrometer (hygrometer)

A mercury psychrometer is a type of hygrometer used in the measurement of relative humidity and consists of two mercury thermometers, one with a dry bulb and one with a wet bulb. Evaporation from the wet bulb lowers the temperature. The temperature difference between the wet and the dry bulb provides the basis for calculating the relative humidity. Unless mentioned otherwise, mercury psychrometers are considered to be comprised in the word “thermometer” for the sake of simplicity.

Other non-electrical thermometric applications

Producer AGA Rangemaster Limited informed ECHA that it uses ‘mercury heat indicators’ in its AGA cookers. The heat indicator provides a guide to the user that the cooker has sufficient heat stored by means of an indicator band. The device does not give an actual temperature reading. The visual indication of the stored heat allows adjustment of a separate thermostat that regulates the desired amount of stored heat. Once set, the ovens then operate at fixed temperatures. The heat indicators carry approximately 1.8g of mercury and the EU annual market is around 2500 cookers containing such a device. This results in approximately 4.5kg of mercury used for these high temperature applications, which is negligible in comparison with the use of mercury for thermometers. The producer believes the device is not used in other similar equipment or products. Nevertheless other non-electrical thermometric applications of mercury might exist. (AGA Rangemaster, pers. comm., 2010)

Equipment for the calibration of platinum resistance thermometers using the *triple point of mercury* is prescribed in the 1990 International Temperature Scale (ITS-90). ITS-90 uses numerous defined points, all of which are based on various thermodynamic equilibrium states of fourteen pure chemical elements and one compound (water) (Wikipedia, 2010e). One of those elements is mercury (mercury triple point cell). Three types of mercury triple point cells described by Strouse and Lippiatt (2001) contain 2,6 to 3,4 kg of mercury. However there are thought to be only a very limited amount in certain dedicated calibration laboratories. According to Lassen et al. (2008), the use of mercury for these applications is estimated to be negligible. As far as is known, at least the Nederlands Meetinstituut (Nmi - Dutch Measuring Institute) would have such a device (see also Peruzzi et al., 2007). Mercury triple point cells would amongst others be produced by the National Physical Laboratory in the UK (Lassen et al., 2010).

2. Description of release and exposure

In addition to the general restriction to place mercury measuring devices on the market for sale to the general public (including thermometers), specifically, the placing on the market of mercury-in-glass thermometers as a fever thermometer is restricted for all uses (i.e. including professional use) by Entry 18a of Annex XVII as of 3 April 2009. To date, mercury-in-glass thermometers can still be placed on the market for the industrial and professional uses including as ambient temperature thermometers, laboratory thermometers and as thermometers for combustion and

industrial processes. Thus the description of release concentrates on these types of thermometers.

Based on the approach described in the section B of the main document, the estimations on i) total amount of mercury accumulated in devices in EU and ii) the amount of mercury placed on the market annually in the EU are used to describe the potential release and exposure during the waste phase of the devices. (Table A5a-1). Furthermore, to get a more comprehensive picture, the annual amounts iii) used in the production of devices, iv) imported into EU and v) exported from EU are given to illustrate the potential for direct exposure of workers during the production and service-life of the devices. However, it is stressed that this report does not further assess the potential concerns related to workers as explained in Part B. If quantitative estimates are not available, a qualitative description is given.

Table A5a-1: Amounts of mercury accumulated, used in production, placed on the market, imported and exported in thermometers in the EU in 2010

Mercury	Estimated amounts
Pool accumulated in thermometers	90 tonnes *
Placed on the market in thermometers	0.7-1.6 tonnes per year **
Used in the production of thermometers	1.0-1.5 tonnes per year **
Imported in thermometers	0.2-0.8 *
Exported in thermometers	0.5-0.8 *

Sources: * calculated from Lassen et al. (2008), see Box 1. **Lassen et al. (2008).

Box 1: General qualitative description of potential release and exposure

Production phase

It is estimated that the EU use of mercury for thermometer production is somewhere in the order of 1.0-1.5 t/y, of which around 50% is destined for the EU market (Lassen et al., 2008). The volume also includes mercury included in thermometers that are present in hydrometers. About 1000-1500 employees are involved in the EU production of mercury thermometers (Lassen et al., 2008).

In addition to releases from the waste phase of thermometers, some emission to the environment and exposure of workers may occur in the production phase of thermometers.

Service life

Mercury thermometers have a vast application area. Such areas include chemical and other process industries; laboratories in industry; research and education; machines and engines; climate and refrigeration equipment; storehouses; museums; food sector (conservation and preparation); meteorology. Mercury is present in thermometers in small amounts and the use of thermometers can be characterised as being geographically very dispersed.

Roughly around half of the mercury used in thermometers for the EU market is for laboratory use, the other half for industrial and marine applications (Lassen et al., 2008). Lassen et al. (2008) estimated that around 0.6-1.2t/y is used in mercury-in-glass thermometers for the EU market, 0.1-0.3 t/y in mercury dial thermometers, and 0.01-0.1 t/y in psychrometers, which gives a total use of mercury in thermometers for

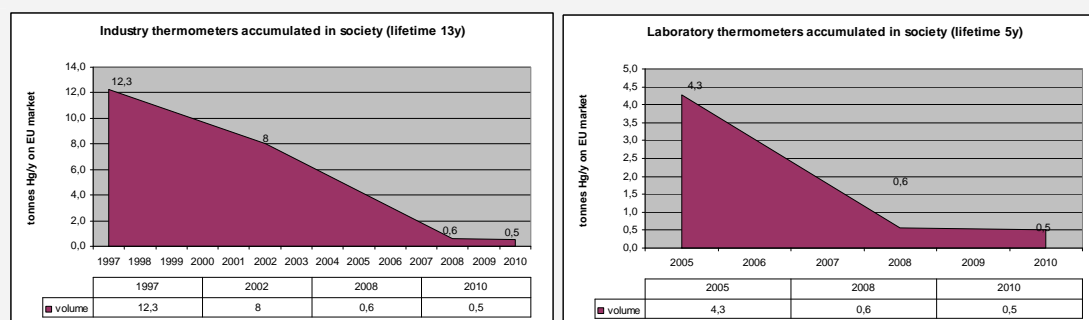
the EU market of around 0.7-1.6t/y. The remaining (professional) uses of mercury room thermometers and other meteorological applications might not be included in this estimate, but are thought to be relatively small. It has not been possible to obtain information on the volumes for these applications during the preparations and consultations carried out for this report.

The following gives a general qualitative description of potential release and exposure from the pool of thermometers that were brought on the market in the past and are currently still in use.

Based on estimates reported by Lassen et al. (2008), the volume of mercury that is included in non-fever thermometers⁴² for the EU market in 1995 was estimated to be 28t/y (out of 55 t/y in measuring devices).

In 2002, the figure for all measuring devices was estimated to be 33 t/y, or around 17t/y for non-fever thermometers, if the same proportions are applied to this figure as for the 1995 estimate. From 2008 on the mean estimate of 0.7-1.6t/y is used for non-fever thermometers based on the estimations made by Lassen et al. (2008). Based on these figures, and assuming linearity between the data points, the accumulated volume of mercury included in industry thermometers is estimated to be 78 tonnes (lifetime of 13y⁴³), in laboratory thermometers roughly 8 tonnes (lifetime of 5y), totalling to around **90 tonnes** in 2010. This is considerably more than the estimated volume of 40-100 tonnes for all measuring devices by Lassen et al. (2008), where a lifetime of thermometers of 5 years was used for all thermometers. If a lifetime of 5 years is used for industry thermometers in the above calculations, the estimated pool of mercury circulating in society would be 34 tonnes in 2010.

In addition to emissions from the waste phase (see below), mercury in glass thermometers for laboratory and industrial use easily break which results in emissions to the environment as well as direct human exposure (Lassen and Maag, 2006).



Waste stage

As described in section B.4 of the main document, the waste phase is crucial for the potential releases of mercury to the environment (whether the mercury thermometers

⁴² Lassen et al. use the term 'medical thermometers' in stead of 'fever thermometers'. It is assumed that they are interchangeable in this context, since the authors write for example that 'mercury use in medical thermometers is now banned in the EU'.

⁴³ See assumptions for lifetimes in Annex 5b (Compliance cost calculations for thermometers).

are collected separately from other waste streams and whether the separately collected devices are handled in accordance with hazardous waste legislation). Partly the thermometer waste ends-up with unsorted municipal waste, another part is collected as hazardous waste. Lassen et al. (2008) estimated that only 20% of mercury containing measuring devices would be collected as hazardous waste. There does not seem to be evidence showing that this estimate would not be valid for thermometers, but it has to be noted that the figure is entailed with high uncertainty.

3. Available information on alternatives (Part C)

3.1 Identification of potential alternative substances and techniques

Alternatives are available for all applications of mercury-containing thermometers (Lassen and Maag, 2006). The following alternatives are described in this section:

- Mercury-free liquid-in-glass thermometers
- Gas or liquid dial thermometers
- Bi-metal dial thermometers
- Electronic thermometers
- Infrared thermometers

• *Mercury-free liquid-in-glass thermometers*

The mercury-free liquid-in-glass thermometer is the most common replacement of the mercury thermometer at temperatures up to 250°C (Lassen et al., 2008). These thermometers are similar to mercury-in-glass thermometers, but use a different thermometric liquid.

The liquids typically used in mercury-free liquid-in-glass thermometers are organic liquids such as alcohol, pentane, pentanol, toluene, kerosene, creosote, petroleum, i-amyl benzoate, and citrus-extract-based solvents are reported to be used (Lassen et al., 2008) (Ludwig Schneider, 2010). To make the liquid more visible usually a red or blue dye is added.

Apart from organic liquids, also gallium or gallium alloys are used. Gallium has a very high liquid range, and compared to mercury has a low vapour pressure at high temperatures. Gallium alloy thermometers can be used in temperature ranges from 0 to 1200°C (Ludwig Schneider, 2010). Unlike mercury, liquid gallium metal is wetting. Wetting action of gallium-alloys can be overcome by covering the glass with a layer of gallium(III) oxide (Wikipedia, 2010a). Gallium is also used in Galinstan, an alloy of gallium, indium and tin, that is used in medical thermometers (Geratherm, 2010). One company markets a maximum-thermometer for laboratory appliances with gallium filling for measurements up to 750°C (Amarell, 2010).

Liquid-in-glass lab thermometers with a resolution up to 0.1°C and psychrometers with alcohol filling with a reading scale of 0.2°C exist in the market (Ludwig Schneider, 2010). A liquid-in-glass lab thermometer with organic filling,

PerformaTherm™, has a resolution of 0.1°C and satisfies ASTM⁴⁴ standards (Lassen et al. 2008, and Lassen et al. 2010). Industry thermometers with “red/blue/green special liquid” fillings up to 360°C and a scale of 2°C exist on in the EU market (Amarell, 2005).

Liquid-in-glass thermometers are not only an alternative to mercury thermometers. They also complement mercury thermometers outside their measurement range (-58°C to +800°C). For low temperature, for example ethanol can be used, which has a melting point of -114 °C (EC JRC, 2000a). For high temperature measurements, gallium fillings can be used. In addition, minimum thermometers are normally liquid-in-glass thermometers with organic filling (WMO, 2008). A producer markets meteorological precision minimum thermometers with alcohol filling, having a scale of 0.2 or 0.5 °C depending on the needs (Ludwig Schneider, 2010).

- *Gas or liquid dial thermometers*

Gas or liquid dial thermometers are similar to the mercury dial thermometers, but are filled with gas or liquid instead of mercury. Examples of such liquids are xylol (xylene) or silicon oil, as used in a model “Expansion Thermometer Model 70, with stainless steel case and capillary (WIKA, 2010).

A producer offers capillary lengths up to 5m for liquid filled remote systems, with liquid fillings both in “remote” and “rigid” (i.e. not remote) systems that can be used up to 500°F (260°C) (Palmer Wahl, 2010). The models in this catalogue have the same resolution whether they are actuated with mercury or with another liquid. According to Lassen and Maag (2006), such thermometers are available for measurements up to +600°C, which is confirmed by a product catalogue of WIKA, that offers “Gas Actuated Thermometers” within the ranges of -60°C to +600°C, scale spacing from 1 to 10 °C according to the model, and capillary lengths according to user specifications.

Gas or liquid dial thermometers are direct replacements of mercury dial thermometers for temperature measurements from the lowest range up to +600°C. The resolution seems not to be affected (see above), but is anyhow not an important characteristic for the industrial applications where dial thermometers are used (Lassen et al., 2010).

- *Bi-metal dial thermometers*

A bi-metal dial thermometer uses a bimetallic strip wrapped into the form of a coil. One end of the coil is fixed to the housing of the device and the other drives an indicating needle. The bimetallic strip converts a temperature change into mechanical displacement. The strip consists of two layers of different metals which expand at different rates as they are heated. The different expansions force the flat strip to bend if heated. (Wikipedia, 2010c)

⁴⁴ ASTM International (American Society for Testing and Materials) is one of the largest voluntary standards development organizations.

Bi-metal thermometers are available for measuring temperatures in the range from about -70°C to 600°C (Lassen et al., 2008). Bi-metal thermometers have reading scales varying according to the model from 1 to 5 °C according to consulted product catalogues (WIKA, 2010) (Ludwig Schneider, 2010).

The dial thermometers have typically replaced mercury-in-glass thermometers for the temperature range above 250°C, e.g. for measuring the temperature of exhaust gases of diesel engines (Lassen et al., 2008), and are considered as replacements of mercury dial thermometers (Lassen et al., 2010). It is assumed that the authors refer to gas or liquid dial thermometers, as well as bi-metal dial thermometers.

- *Electronic thermometers*

Electronic thermometers are also designated ‘digital thermometers’. The working of this group of alternatives is based on the thermoelectric effect, which is the conversion of temperature differences to electric voltage. The three main types – thermocouples; platinum resistance thermometers and thermistors – are described below. Electronic thermometers can be connected to a data logger via an analogue-to-digital converter.

Electronic thermometers are generally more accurate than mercury-containing thermometers, if properly calibrated (Lassen et al., 2008). Ripple and Strouse (2005) mention as advantages of electronic thermometers (PRTs, thermistors and thermocouples) possibly smaller uncertainties, the ease of automation, the independence of the reading from the visual judgement of the user, and the absence of mercury. As disadvantages the need for a power source and somewhat higher initial costs are mentioned. Also higher calibration frequency, and thus higher recurrent costs could be mentioned as a disadvantage (see section 3.4 and Annex 5b). In addition mercury-in-glass and liquid-in-glass thermometers used below 150°C can be calibrated using the ice-point only, whereas PRTs and thermistors usually require a minimum of three calibration points.

Electrical thermometers with a digital display and/or automatic data logging make up an increasing part of the thermometer market. They are used throughout industry for automatic temperature measurements, and use in laboratories is reported to represent an increasing part of the market in Denmark⁴⁵ (Lassen et al., 2008).

According to the World Meteorological Organisation electrical thermometers are in widespread use in meteorology. Their main virtue there is said to lie in remote indication, recording, storage, or transmission of temperature data. For soil temperature measurement, mercury thermometers are even regarded as unsuitable in comparison with electrical thermometers. (WMO, 2008)

Electronic thermometers approved by international insurance companies are marketed for refrigerated containers (Lassen and Maag, 2006).

⁴⁵ Note that laboratory use is exempted from the Danish restriction of mercury thermometers, see section B.5

1) Thermocouples

A thermocouple is made of two dissimilar metals joined so that a potential difference generated between the points of contact is a measure of the temperature. Thermocouples have a wide range from -270°C to 1800°C (MicroDAQ, 2010) and fast response time (under a second in some cases according to Burns Engineering, 2010).

Certain combinations of alloys have different sensitivities, and resulted in industry standard types such as K, S, R, E, J, and N thermocouples. Type K (chromel–alumel) is the most common general purpose thermocouple. Selection of the thermocouple type is driven by cost, availability, convenience, melting point, chemical properties, stability, and output (Wikipedia, 2010b).

2) Platinum resistance thermometers

An platinum resistance thermometer is a resistance temperature detector (RTD) that uses platinum for its element. Their function is based on the principle that electrical resistance of the metal changes in a predictable way depending on the rise or fall in temperature. The temperature range is -260 to 850°C (MicroDAQ, 2010).

The Pt100 sensor has a resistance of 100 ohms at 0°C and is by far the most common type of RTD sensor. The Pt500 sensor has a resistance of 500 ohms at 0°C and the Pt1000 has 1000 ohms resistance at 0°C (Omega, 2010). These thermometers are very accurate, and are used by laboratories accredited for calibration (Lassen et al., 2008). They are for example widely used for monitoring the temperature of foodstuffs during transport (Lassen et al., 2008). A very high precision system has a resolution of 0.001°C and a temperature range of -200 to $+400^{\circ}$. This device is marketed for process monitoring and production control in the chemical, pharmaceutical and food industries, as well as for research and development (Ludwig Schneider, 2010). On the internet the device is indicated to cost €980 (without VAT) (Labnewsletter.com, 2010). The temperature sensor is available separately, and is provided with a DKD calibration certificate⁴⁶.

ASTM E1137 (Standard Specification for Industrial Platinum Resistance Thermometers) is a standard establishing physical, performance, and testing requirements, as well as resistance-temperature relationship and tolerances for metal-sheathed industrial platinum resistance thermometers (PRT) suitable for direct immersion temperature measurement (ASTM, 2010)

3) Thermistors

Thermistors also rely on the known variation of electrical resistance with temperature of a specially constructed resistor to convert temperature into a measurable electrical property, but unlike the above described platinum

⁴⁶ The DKD Calibration Certificate documents officially the traceability of measuring results to national and international standards as required by the standards DIN EN ISO 9001 and ISO/IEC 17 025 for the monitoring of measuring instruments

resistance thermometers (PRTs) the material used in a thermistor is generally a ceramic or polymer, instead of metals (Wikipedia, 2010d). Thermistors have stabilities approaching a few thousandths of a degree Celsius per year, and are highly sensitive (approximately 4% change in resistance per degree Celsius). The typical temperature range is -80 to 150°C (MicroDAQ, 2010). However, the usable temperature range is limited to not more than 100°C for a single thermistor, and the maximum temperature of use is 110°C (Ripple and Strouse, 2005).

- *Infrared thermometers*

Apart from the previously described electronic thermometers, infrared thermometers can be used to measure temperature in applications where conventional sensors cannot be employed. Infrared thermometers appear to have replaced mercury pyrometers (Lassen et al., 2008). An infrared thermometer is a non-contact temperature measurement device. The most basic design consists of a lens to focus the infrared (IR) energy on to a detector (thermocouple), which converts the energy to an electrical signal that can be displayed in units of temperature (Omega, 2010).

3.2 Human health and environment risks related to alternatives

In this section the human health and environment risks related to alternatives are described.

- *Mercury-free liquid-in-glass thermometers*

Risks as a result of organic liquids used in liquid-in-glass thermometers are in general considered to be low. As described in section B.4, the main problem with the use of mercury in thermometers is related to the waste phase and the persistency of mercury as an element. Substances such as ethanol and pentane are readily biodegradable, and are not considered to pose any environmental risks in the waste phase (EU RAR n-pentane, 2003) (EC JRC, 2000a). Also pentanol quickly degrades (EC JRC, 2000b). Substances such as kerosene, creosote and petroleum, might degrade slower when landfilled or released to the environment. The proportion of organic filled thermometers that goes to incineration does not cause risks. There might be some direct human exposures arising from the production phase or use (event of breaking), but these would not result in higher risks compared to similar exposures with mercury, and are in comparison with the problem of mercury in the waste phase insignificant.

Properties of gallium are reported not to have been fully investigated, but gallium is reported to cause skin, eye and respiratory tract irritation, and may cause bone marrow abnormalities with damage to blood forming tissues (ACI Alloys, 2010). Administration of gallium to humans has caused metallic taste, skin rashes, and bone marrow depression. Ingestion (which is an irrelevant exposure route) may cause gastrointestinal irritation with nausea, vomiting and diarrhea. Since gallium has a very

low vapour pressure, exposure through inhalation is not considered relevant for thermometer users, and minimal during the production phase. Considering the properties described above, some cases of skin irritation might occur. Overall there are no indications that there would be considerable risks associated with gallium filled thermometers.

- *Gas or liquid dial thermometers*

Similarly to liquid-in-glass thermometers, xylol (xylene), silicon oil, and other substances used in gas or liquid dial thermometers are not considered to pose any considerable risks in comparison with mercury actuated systems.

- *Electronic thermometers*

Electronic thermometers (including infrared thermometers) might contain small amounts of lead and possibly some other hazardous substances (including in batteries and solar cells), and thus may cause problems during the waste phase⁴⁷. In general, the human health and environmental risks are insignificant in comparison with the potential emission and exposure associated with the amount of mercury in thermometers.

- *Bi-metal dial thermometers*

There are no indications of risks to human health or the environment related to the use of bi-metal dial thermometers.

3.3 Technical feasibility of alternatives

An overview of the technical feasible alternatives to mercury thermometers is given in Table A5a-2. Alternatives exist for all applications of mercury-containing thermometers (Lassen and Maag, 2006). It is generally accepted that alternatives exist to all uses of mercury dial thermometers and mercury-in-glass thermometers at measuring resolution of 1°C and below 200°C (Lassen et al., 2008). Indeed, none of the producers consulted in the course of preparing this restriction report have indicated that mercury thermometers for measuring temperatures below 200°C at a resolution > 0.5 °C would be an essential use (Lassen et al., 2010).

Liquid-in-glass thermometers are in general fully suitable -and are the most common-replacement for all uses that do not require an accuracy better than 0.1°C, as long as the temperature measurements are below the 250°C range (Lassen et al., 2008) (Lassen et al., 2010). The maximum temperature of 105°C, response time, and separation of the liquid, have been mentioned as obstacles for the wide-spread use of the liquid-in-glass thermometer PerformaTherm™ (Lassen et al., 2008) (Lassen et al., 2010). Consulted companies have not given technical reasons why gallium thermometers would not be technically feasible alternatives (Lassen et al., 2010).

⁴⁷ In the future, these devices normally will fall in the scope of RoHS. But even once they do, they are likely to contain some hazardous substances, such as lead exempted for certain solders, and substances not restricted by RoHS. See also Appendix 4 on the status of electronic measuring equipment in relation to the scope of RoHS.

Mercury dial thermometers used in the industry and marine applications can be replaced by gas or liquid dial thermometers or by bi-metal coil thermometers for all purposes. The producer Brannan (UK) claimed that mercury dial thermometers do not need to use mercury as an actuating medium, since alternatives exist (Lassen et al., 2008).

For laboratory thermometers that require measurements at 0.1°C or better, the alternatives are electronic thermometers (Lassen et al., 2008). For laboratory measurements that need high temperature measurements gallium or electronic thermometers can be used.

Room temperature thermometers, including Six's thermometers, can be replaced directly by liquid-in-glass alternatives (Lassen et al., 2008). This would also apply for the thermometers that are inside hydrometers. For meteorological applications that would require higher precision than 0.1°C, the situation is similar to laboratory thermometers.

Maximum thermometers were mentioned by one producer in the consultation ECHA carried out for preparing this restriction report (Lassen et al., 2010). However there is no known reason to treat them differently from other mercury thermometers that require high precision (Lassen et al., 2010), and are therefore not treated separately in the report.

According to a producer, electronic alternatives to psychrometers (hygrometers) could in *'some cases not be used because of the structure of their temperature and chemical resistant sensor housing'* (Lassen et al., 2010). According to Lassen et al. (2010), this seems not to be justified: psychrometers have been banned for many years in Denmark, and consulted calibrating laboratories were not able to identify any applications where it has been difficult to replace mercury psychrometers. Klif confirmed that placing on the market of psychrometers is prohibited in Norway. It seems that psychrometers have successfully been replaced in Denmark, Sweden and Norway without any reported problems (see section B.5).

In industrial settings a resolution of 0.1°C is generally not necessary (Lassen et al., 2010). For temperature measurements above 200°C at a resolution of 1°C, dial thermometers with coiled bimetal or a liquid or air filled metal cylinder with a dial for manual reading are available (Lassen et al., 2008).

According to the Commission's review (Appendix 5), a company would have defended the use of mercury in a limited number of highly specialised professional uses, such as retort⁴⁸ thermometers in the canning industry (Appendix 5). However, several producers offer electronic alternatives for retort thermometers, such as "Palmer Wahl DST600" (Palmer Wahl, 2010), and "Digital Temperature Gauge for Retort Applications" (Anderson, 2010). In addition bi-metal thermometers can be used in the canning industry (Omega, 2010).

⁴⁸ Retort: A retort is a machine similar to a domestic pressure cooker, where batches of cans are heat processed under pressure. The retort has temperature and pressure gauges and should also have temperature / time recording charts. (<http://www.cip.ukcentre.com/keywords.htm#R>)

Mercury heat indicators and other non-electrical thermometric applications

Producer AGA Rangemaster Limited informed ECHA that it has alternative solutions in place for its mercury heat indicator in their *electric* ovens. The producer says there are no known alternatives for the heat indicator for ovens that operate *without electricity*, and function on gas or oil. It is also said that the area where the heat indicator is located would be ‘far too hot for an electronic solution’. In addition, supply of replacement parts for existing devices are mentioned as an obstacle. The producer indicated that to date suppliers have been unable to provide a high temperature infill which lasts more than 4 months, although they would have samples on trial. Producer AGA Rangemaster Limited estimates a need of 12 months for substitution of the mercury heat indicator with alternatives in new devices. (AGA Rangemaster, pers. comm., 2010)

On the basis of this information it is understood that there will be feasible technical alternatives available before the potential entry into force of a restriction.

There are no known technical feasible alternatives to mercury triple point cells for calibration of platinum resistance thermometers. As described in section 1 it is one of the elements *defining* the 1990 International Temperature Scale (ITS-90). The Dutch mercury restriction has a derogation for “*equipment for the calibration of platinum resistance thermometers using the triple point of mercury*” for these reasons.

Based on the available information it is concluded that there are technically feasible alternatives available for the minor use of mercury in mercury heat indicators, and possible other non-electrical thermometric applications. It would not be technically feasible to restrict the use of equipment for the calibration of platinum resistance thermometers using the triple point of mercury.

Table A5a-2 Overview of the technical feasible alternatives to mercury thermometers

Application area & product type	Alternatives	Applicability	remarks
Mercury-in-glass thermometers (T range -58°C to +800°C and accuracy up to 0.01°C for high precision thermometers)			
For laboratory use, including industry labs for material testing (precision and high precision thermometers). Reading scale Hg thermometer up to 0,01°C	Liquid-in glass thermometers	T range <250°C, accuracy 1°C, and up to 0,1°C	Typically replace mercury-in-glass thermometers for T-range < 200°C, where accuracy >0,1°C is not required
	Gallium thermometers	T-range 0-1200°C, accuracy 5°C or 2°C (possibly more accurate as well)	Seems to be a niche market for economical and it appears also technical reasons. Seems to be used as a very wide range thermometer
	Electronic thermometers	More accurate than Hg in glass, very large T range (-200 to 1800°C), resolution 0.1°C (or better)	Advantages are data recording and remote reading. Might replace many mercury thermometers.
	High precision electronic thermometers	Resolution up to 0.001°C, T range -200 to +400°C	Higher resolution than high precision Hg-in-glass thermometers. Might replace many mercury thermometers.
For industrial use. Reading scale Hg thermometer usually 1-5°C, sometimes 0,5°C	Liquid-in glass thermometers	T range <250°C, accuracy 1°C	Typically replace for T-range < 200°C
	Dial thermometers	T range -70°C to +600°C, accuracy 1°C	Replacement for T-range > 200°C, also used as a mechanical back-up for electronic thermometers
	Electronic thermometers	More accurate than Hg in glass, very large T range (-200 to 1800°C), resolution 0.1°C or better	Accuracy higher than 1°C is normally not an issue for industry thermometers. Reasons to choose electronic thermometers might be: data logger, possibilities for remote reading, real-time monitoring & feedback mechanisms, alarm systems,...
Meteorological measurements and room temperature measurement. Reading scale of Hg meteorological thermometers usually not smaller than 0,2°C.	Liquid-in glass thermometers	Accuracy 1°C, and up to 0,2°C	All room temperature thermometers and Six's thermometers, and most if not all other meteorological applications such as psychrometry, can be directly replaced by LiG thermometers.
	Electronic thermometers	Resolution 0.1°C (or better)	Data recording and remote reading. Widespread use in meteorology. For soil temperature much better than mercury thermometers.
Mercury dial thermometers (5-200g Hg/piece)			
	Dial thermometers	T range -70°C to +600°C, accuracy 1°C	Replacement for T-range > 200°C, also used as a mechanical back-up for electronic thermometers
	Electronic thermometers	More accurate than Hg in glass, very large T range (-200 to 1800°C), resolution 0.1°C or better	Data logger, possibilities for remote reading, real-time monitoring & feedback mechanisms, alarm systems,...
Mercury heat indicators (approximately 1.8g Hg/piece)			
	other liquids or other systems		Producer AGA Rangemaster Limited estimates a need of 12 months for substitution of the mercury heat indicator with alternatives in new devices
Mercury triple point cells used for calibration of platinum resistance thermometers			
	none		Application is prescribed in the 1990 International Temperature Scale (ITS-90)

Standards prescribing the use of a mercury thermometer

Analysis standards often list equipment and techniques to be used, and step-by-step instructions how to use the equipment. Such analysis standards might specifically refer to the use of mercury thermometers, and might therefore constitute a practical obstacle for using alternatives to the mercury thermometers in laboratories.

These references to mercury thermometers in *analysis standards (test methods)* can be made in the form of references to a certain specific *technical standard (technical specification)* of a mercury thermometer. Technical standards are defining technical specifications including accuracy and dimensions. They play an important role for production and choice of industrial as well laboratory thermometers. An example of such a technical standard is ASTM E1 - 07 Standard Specification for ASTM Liquid-in-Glass Thermometers⁴⁹.

According to Ripple and Strouse (2005), many hundreds of ASTM test methods would rely on mercury-in-glass (ASTM E1) or liquid-in-glass thermometers (ASTM E1 for low accuracy and E 2251 for high accuracy⁵⁰).

In addition, according to information from one producer, 60 to 80 %, and in some sectors nearly a 100% of thermometers used in laboratories would be used for measurements where procedures prescribe standard thermometers (Lassen et al., 2010). The latter does not imply that these standard thermometers are mercury thermometers.

Although traditionally many standards have prescribed mercury thermometers in analysis, many standards now allow for the use of alternatives (Lassen et al., 2010)⁵¹. Standards for testing in the petrochemical sector in general allow for electronic devices to be used, and automatic equipment is available for most tests (Lassen et al., 2010). An example of this is flash-point determination where standards often have been cited to prescribe mercury thermometers. In fact, currently the standards fully allow for the use of electronic alternatives (at least all ISO and ASTM standards), and in fact it seems that at least in Germany the use of automatic apparatus for flash point determination is common practise (Lassen et al., 2010).

Three cases of analysis standards that still would prescribe the use of mercury thermometers were identified in the course of the information gathering and consultations by Lassen et al. (2010):

- method A1 “Melting/freezing temperature”, in the Test Method Regulation, Regulation (EC) No 1031/2008, would specify technical standards for thermometers that require mercury;

⁴⁹ ASTM International is a major standardisation organisation.

⁵⁰ ASTM E1 is a technical standard for mercury thermometers, and low-precision liquids. ASTM standard E2251 - Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids, has a list of thermometers with alternative liquids that can replace some of the mercury thermometers specified in ASTM standard E1, Specification for ASTM Liquid-in-Glass Thermometers.

⁵¹ Relevant standards for materials testing are developed by ISO, CEN, ASTM, DIN and IP/BS (Lassen et al., 2010). The focus here is on ASTM because most of the available information describes ASTM standards (Lassen et al., 2010 and ASTM International (2010)). ISO and CEN appear to develop standards together, at least in the area of flash point determination (Lassen et al., 2010).

- a national standard, DIN 51755, which is mentioned in community legislation, such as Regulation (EC) No 1031/2008 ; and
- a drop point apparatus with a mercury thermometer is described in the European Pharmacopoeia 5.0 from 2005.

According to ASTM, there would still be many standards referring to the use of a thermometer according to ASTM standard E1 or call out the usage of a mercury thermometer (ASTM, pers. comm., 2 June 2010). However this does not necessarily mean that the standard doesn't allow for alternatives to be used. As examples of standards that call out for the usage of a mercury thermometer, ASTM mentioned D97, D566, D938, D972 and D2595 (ASTM, pers. comm., 14 June 2010).

ASTM standards have to be reviewed every 5 years, but can be updated at any time. Since the start of the mercury initiative of ASTM in 2006, ASTM International is working to identify industrial standards and test methods that require the use of mercury thermometers in order to determine whether the use of alternatives is feasible (ASTM 2010). This action is supported by the US EPA initiative to phase-out mercury thermometers used in industrial and laboratory settings (US EPA 2010).

Where removal of the reference or requirement from an ASTM standard was relatively straightforward, changes have been completed (ASTM, pers. comm., 2 June 2010). Reasons for cases where this has not yet happened can be because of a lack of industry support for the change; lack of testing for a suitable replacement; and needs for new interlaboratory studies (costs and time associated with it and lab participation) (ASTM, pers. comm., 2 June 2010).

As ASTM points out, although electronic alternatives might be preferable because of their higher accuracy, there might be issues of bias between temperature readings from electronic thermometers in comparison with mercury thermometers: *“Most electronic thermometers considered as alternatives are minimally or not at all affected by emergent stem temperature. Therefore, in this type of test method, as in many ASTM test methods, the use of an alternative temperature measurement device may provide more accurate temperature measurements but may not reproduce the previously accepted values of the test method.”*(ASTM, 2009). Because of these reasons, there is a need for research comparing data obtained with an alternate device of well-defined geometry and construction and the specified mercury-in-glass thermometers with samples of the same test material. The ASTM subcommittee E20.05 will determine effects on charts, data, and precision & bias statements (ASTM, 2009).

Information that ECHA has received from Denmark, the Netherlands and Norway in early 2010 shows that current national restrictions on mercury thermometers foresee exemptions for mercury thermometers where analysis standards prescribe a mercury thermometer (see section B.5). This information is to a certain extent supportive to the evidence that standards would constitute a technical obstacle.

Sweden seems to be an exception. With regard to CEN and ISO standards, Sweden has not implemented standards that prescribe the use of mercury measuring devices since 1998 (KemI, 2004). According to information received from the Swedish Chemicals Agency (KemI), the only remaining exemption on mercury thermometers

is issued for flash point determination according to Directive 67/548/EEC, which was granted in 2007 and will expire on the 30th of June 2011.

Conclusions on technical feasibility of alternatives

For all known applications, there are technically feasible alternatives that can replace all mercury thermometers and other non-electrical thermometric devices using mercury, with the exception of

- **thermometers used for testing according to analysis standards (test methods) that prescribe mercury thermometers, and**
- **mercury triple point cells that are used for the calibration of platinum resistance thermometers.**

3.4 Economic feasibility

The analysis of economic feasibility builds on the technical feasibility of alternatives, and on the compliance cost calculations for thermometers that are presented in Annex 5b.

Both mercury thermometers and their alternatives have very variable properties -even within each market segment. The best endeavour is made to compare mercury containing devices with alternatives that have similar technical properties for each of the main market segments. Factors that seem to influence the price of mercury thermometers and their alternatives are accuracy, temperature range and level, compliance with standards, calibration certification, and suitability to measure temperature in adverse environmental conditions. For electronic alternatives also additional features and optional interfaces can be added to this complexity of elements influencing the price of a particular thermometer. The combinations of all factors results in a substantial price diversity of thermometers. Therefore, the analysis of economic feasibility (including compliance costs calculations in Annex 5b) is based on what is considered by producers to be a “typical mercury containing thermometer” and a “typical alternative thermometer” taking into account all available information, in particular from Lassen et al. (2008) and Lassen et al. (2010).

The price of liquid-in-glass thermometers is roughly the same as for mercury thermometers. For this reason, and because of the many common technical properties, liquid-in-glass thermometers are the most common replacement for mercury thermometers up to 200°C and with resolution not better than 0.1°C (Lassen et al., 2008 and Lassen et al., 2010). They can directly replace mercury room temperature thermometers (Lassen et al., 2008). Gallium thermometers are reported to have a low market share, which seems to be related to their (higher) price (Lassen et al., 2010). They are not further considered in the assessment.

Prices of the electronic alternatives are higher than mercury thermometers. However, the electronic devices have additional features such as automated temperature

recording, alarm systems, real-time process monitoring and feedback systems⁵². Thus, the prices cannot be compared directly. In fact, the advantage of electronic reading for example is one of the drivers for replacing mercury thermometers with electronic devices. Due to the additional features customers are willing to pay a higher price for the electronic devices (Lassen et al., 2010). No information is available to quantify the value of these additional features and to deduct it from the investment costs of the electronic alternatives. Therefore, the costs associated with the transitioning from a mercury thermometer to an electronic alternative are likely to be overestimated.

The users of analysis standards that prescribe mercury thermometers might have to pay an additional cost for a standard update originating from a restriction (a restriction would require standards to be amended in order to allow for the use of non-mercury alternatives, see also section 3.3). It seems that the cases where an update would be a direct result from a restriction would be limited. It is not considered possible to estimate the compliance costs related to the purchase of standards, but it is thought that the additional cost for the lab thermometer market segment would not be substantial⁵³.

A problem that has been mentioned is the need for modification of existing equipment, also called retrofitting (Lassen et al., 2010)⁵⁴. On the basis of the available information, it was concluded that usually the effect on the investment costs would be neglectable. See Annex 5b for a more detailed discussion.

The economic feasibility of the following main market segments are discussed in this section: laboratory thermometers, industrial thermometers, and thermometers for meteorological measurements.

⁵² Amongst additional features are higher precision and automation offered by electronic thermometers. These advantages can result in additional savings in industrial applications, e.g. lower operational costs due to the use of less energy to, for example, heat large industrial volumes to a certain temperature. Automatic reading and data storage are likely to reduce the need for labour due to less time spent to collect temperature readings manually and additional savings associated with reducing human reading errors. Automated temperature feedback mechanisms might result in higher efficiency of reactions, or to a better quality of the end-product. Temperature alarm systems (and to a certain extent automated temperature feedback mechanisms) might substantially reduce the risks of damage. All these benefits may have substantial value, however, whether these additional functions are of importance depends on the application (see also Annex 5b).

⁵³ It is unknown how many standards would actually prescribe mercury thermometers to be used, and therefore it is not known how many standards would have to be changed as result of a restriction. Considering the difficulty in identifying standards that would *prescribe* mercury thermometers during the information gathering and consultations carried out in the course of preparing this dossier, it is thought that the amount would be limited. When a new version of a standard is published, customers need to purchase the entire standard again, but note that one analysis standard is likely to cover several thermometers in one lab (ASTM standards vary in price from \$34 to \$120 USD each (ASTM, 2010, pers. comm.)). However, in so far a standard is updated during the normal update process it is thought there would be no additional cost that can be attributed to a restriction. In the case of ASTM standards that are already in the process of being modified under the mercury initiative, it would be difficult to argue if, and to what extent, an update would result from a restriction in the EU.

⁵⁴ This is considered to be an economical issue rather than a technical feasibility issue since it seems that these modifications can always be carried out (at a certain cost).

Laboratory thermometers

Mercury-free liquid-in-glass lab thermometers are one of the most common replacements for mercury-in-glass thermometers used to measure temperature below 200°C in applications where high precision is not needed. Their price is roughly the same as for mercury thermometers or about 10% lower (Lassen et al., 2010). In the main scenario used for laboratory thermometers in this segment, investment costs are assumed to be the same. However, the operating costs for the liquid-in-glass thermometers would be lower due to their assumed lower waste treatment costs in comparison to their mercury-containing counterparts. Table A5a-3 shows that the lower operating costs would result in savings of €2.6 per year for each liquid-in-glass thermometer compared to a mercury-in-glass lab thermometer in this market segment. Therefore, liquid-in-glass thermometers are an **economically feasible alternative** to the mercury-containing devices when measuring temperature **below 200°C** in applications where **high precision is not needed**.

Table A5a-3 also shows the costs for mercury-in-glass thermometers used in laboratories where an **accuracy of 0.1°C or better** is needed **or** for temperature measurements **above 200°C**. The purchase price of an electronic system is higher than their mercury counterparts. However, as it is assumed that four mercury thermometers can be replaced by one electronic alternative, the analysis concludes that laboratories would pay €1.8 (i.e., 1.5%) more per year for each alternative device. Calibration frequency of mercury thermometers is considered to be equal (once a year), and the life-times are considered to be similar. In sum, electronic thermometers are an **economically feasible alternative** to the mercury-containing devices in this market segment.

Table A5a-3: Costs of mercury containing thermometers and their alternatives in laboratory applications⁵⁵

Device Costs (€)	Lab (res >0.1°C and T<200°C)		Lab (res 0<.1°C or T>200°C)	
	Mercury- in-glass	Liquid- in-glass	Mercury- in-glass	Electroni c
Investment cost	40.0	40.0	80.0	112.5*
Lifetime of device (years)	5	5	5	5 (10)**
Annualised investment cost	9.0	9.0	18.0	20.0
Recurrent costs	104.9	102.3	104.9	104.7
Annualised total cost	113.9	111.3	122.8	124.7
Additional annualised total cost	0.0	-2.6	0.0	1.8

Source: Tables 1-4 and 7-10 in Annex 5b

Notes: * The investment cost for electronic thermometers is much lower than the purchase price of a full measurement set because of the assumption that four mercury-in-glass thermometers can be replaced by one electronic alternative.

**5 years for the probe and 10 years for the data reader.

⁵⁵ The costs in the analysis represent factory gate prices excluding VAT for investment costs, but for other costs (recurrent costs) it is not known if the VAT is included or not. All values used in this analysis refer to year 2010 price levels.

Industrial thermometers

In the market segment of industrial thermometers measuring temperatures **below 200°C**⁵⁶, mercury-free liquid-in-glass industrial thermometers cost somewhat less than mercury-containing devices. Table A5a-4 shows that the transition to liquid-in-glass thermometers will result in annual savings to users (assuming that the waste treatment costs of the alternatives are lower than the mercury-containing devices). Thus, in this market segment there **are economically feasible alternatives**.

Mercury-in-glass thermometers used in industry to measure temperature **above 200°C**, can be replaced by electronic or mercury-free dial thermometers. The additional annualised costs for users of the alternative are about €98 per device (Table A5a-4). This indicates that the alternatives are more expensive, and thus the economic feasibility in this market segment **can be questioned**.⁵⁷

The calibration costs and calibration frequency of the alternative devices have a major impact on the costs. These factors are uncertain and it is thought that there are differences between the recommended calibration frequency and the real frequency in practice. The analysis in Annex 5b assumes that alternatives have a four times higher calibrated frequency. If calibration costs are ignored, the additional annualised costs would be lower, i.e. largely representing the difference in annualised investment costs: €23.3 and €40.2 per device per annum for respectively the electronic and mercury-free dial thermometers⁵⁸. If it is assumed in this market segment that the only difference between mercury-containing thermometers and their alternatives were investment costs, the economic feasibility would still be an issue but less so.

⁵⁶ Precision is not an issue for industrial thermometers, see section 3.3.

⁵⁷ There are a number of reasons why the transition to alternatives in the high resolution/T>200°C lab segment is more cost-effective than the industry segment over 200°C. The main factors include: the lower long-term investment cost of the alternative due to the assumption that four mercury lab thermometers can be replaced by one electronic alternative; the calibration neutrality of the cost calculations for lab thermometers as the calibration frequency and cost of both mercury and alternative thermometers is assumed to be the same, and the shorter lifetime (5 years in lab instead of 13 years in industry) that is equal for both mercury and alternative lab thermometers (see Annex 5b).

⁵⁸ The mercury-free dial thermometers are more expensive due to their short life-time

Table A5a-4: Costs of mercury-in-glass thermometers and their alternatives in industrial applications⁵⁹

Device Costs (€)	Industry (T<200°C)		Industry (T>200°C)		
	Mercury-in-glass	Liquid-in-glass	Mercury-in-glass	Mercury-free Dial	Electronic
Investment cost	23.0	23.0	45.0	125.0	134.2
Lifetime of device (years)	13	13	13	3	5
Annualised investment cost	2.3	2.3	4.5	45.0	26.0
Recurrent costs	28.6	27.8	28.6	85.6	104.7
Annualised total cost	30.9	30.0	33.1	130.6	130.7
Additional annualised total cost		-0.8		97.5	97.6

Source: Tables 13-16 and 19-22 in Annex 5b

Mercury dial thermometers used in industry can be replaced by electronic or mercury-free dial thermometers. In the absence of information, the costs of mercury dial thermometers and their alternatives are assumed to be the same as the mercury-in-glass industrial thermometers for measuring temperatures above 200 °C (Table A5a-5), and thus the economic feasibility in this market segment can be questioned. Nevertheless, mercury dial thermometers are confirmed by producers to hold only a very limited residual market because alternatives have taken over (Lassen et al., 2008), and no consulted producers have mentioned that alternatives to dial thermometers would not be economically feasible (Lassen et al., 2010). The economic importance of mercury dial thermometers is thought to be marginal⁶⁰.

For these reasons it is thought that in reality there are economically feasible alternatives to mercury dial thermometers.

⁵⁹ The costs in the analysis represent factory gate prices excluding VAT for investment costs, but for other costs (recurrent costs) it is not known if the VAT is included or not. All values used in this analysis refer to year 2010 price levels.

⁶⁰ In addition, because the market of these thermometers was known to be marginal, little effort has been given to better estimate costs and life-times of these devices. Therefore the data from mercury-in-glass thermometers was used. It has to be emphasised that the cost estimate is as a conservative result in several ways. The assessment used a conservative estimate of a lifetime of 13 years for mercury dial thermometers vs. three years for gas or liquid actuated dial alternatives, and a yearly calibration of the alternatives vs. once every 4 years for the mercury dial thermometer. It seems however that the technology of the mercury dial thermometers gas or liquid actuated dial alternatives is not very different, and in reality the lifetimes and calibration frequencies might be equal or similar (analogue to the situation of mercury-in-glass and liquid-in-glass alternatives). Assuming that the mercury dial thermometers have the same lifetime and calibration frequency as their gas-actuated alternative systems, the additional annualised total cost would be €24.30 (for mercury-free dial) and €24.40 (electronic) instead of 97.5€/ device.

Table A5a-5: Costs of mercury dial thermometers and their alternatives in industrial applications

Device Costs (€)	Mercury Dial Mercury-free		
	Mercury Dial	Dial	Electronic
Investment cost	45.0	125.0	134.2
Lifetime of device	13 years	3 years	5 years
Annualised investment cost	4.5	45.0	26.0
Recurrent costs	28.6	85.6	104.7
Annualised total cost	33.1	130.6	130.7
Additional annualised total cost		97.5	97.6

Source: Tables 13-16 and 19-22 in Annex 5b

Thermometers for measuring ambient temperature and other meteorological measurements (including Six's thermometers and psychrometers)

The transition from mercury-containing to mercury-free ambient thermometers, psychrometers (hygrometers), and most other thermometers for meteorological applications, is expected to result in additional annualised savings, similar to mercury-in-glass lab and industrial thermometers for measuring temperature below 200°C and with a resolution not better than 0.1°C. This is likely to take place due to the following reasons:

- the price of the liquid-in-glass alternatives in ambient temperature is similar to the mercury-containing thermometers (no resolution <0.1°C needed);
- Six's thermometers with organic liquids are available at similar or lower prices than the mercury filled counterparts (Lassen et al., 2010);
- electronic or spirit-filled psychrometers are available for most applications at approximately the same price as mercury psychrometers (Lassen et al., 2010);
- it costs less to dispose of a mercury-free device at the end of its useful life;
- the calibration frequency and costs of the mercury and liquid-in-glass devices are similar; and
- the lifetime of the mercury and liquid-in-glass devices is similar.

Therefore, it can be concluded that alternatives to mercury thermometers for measuring ambient temperature and other meteorological measurements (including Six's thermometers and psychrometers) are economically feasible.

Conclusions on economic feasibility of alternatives

The economic feasibility of the alternatives to mercury thermometers is well established for all laboratory and meteorological measurements, as well as for temperature measurements in industry below 200°C. Replacement of the industrial mercury dial thermometers is likely to be economically feasible. However, for temperature measurements in industry above 200°C, the economic feasibility of alternatives has not been established.

4. Justification why the proposed restriction is the most appropriate Community-wide measure (PART E)

4.1 Identification and description of potential risk management options

4.1.1 Risk to be addressed – the baseline

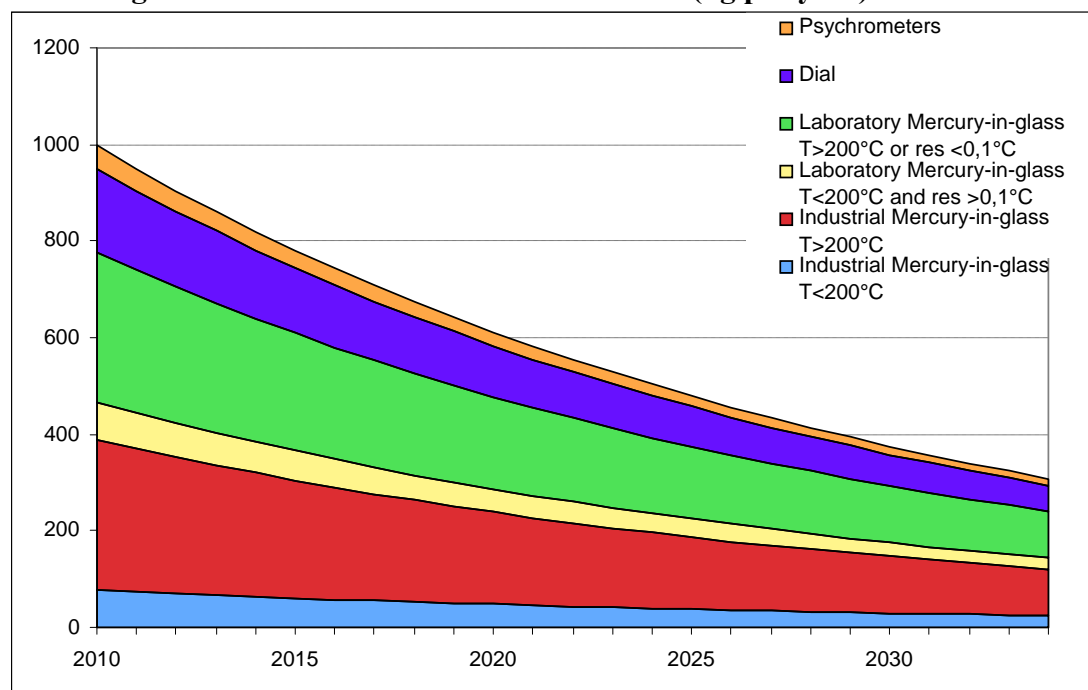
In 2007, between 0.7-1.6 tonnes of mercury was placed on the market in the EU in new thermometers (Lassen et al., 2008). Based on the declining trend in the thermometer market, as described in Box 1 in section 2 of this annex, it is assumed that without additional legislative action the European market of mercury thermometers will decline by about 5% annually. Thus, in 2010 this would result in a volume brought on the market of 0.6-1.5 tonnes. For the purposes of the analysis of the baseline of thermometers, it is assumed that the mid-point, i.e. 1 tonne, will be placed on the market in 2010 and that this amount will decline by 5% annually. Table A5a-6 and Figure 5a-1 give the baseline for thermometers. In addition, the accumulated amount in the years 2015-2034 is presented in Table A5a-6 for use in section 4.2.

Table A5a-6: Amount of mercury placed on the market each year in mercury containing thermometers for 2010-2034 - Baseline assumptions (kg per year)

<i>Year</i>	Thermometer type						<i>Total</i>
	<i>Industrial</i>			<i>Laboratory</i>		<i>Psycho- meters</i>	
	<i>Mercury-in-glass</i>		<i>Dial</i>	<i>Mercury-in-glass</i>			
	<i>T<200° C</i>	<i>T>200° C</i>		<i>T<200°C and res >0,1°C</i>	<i>T>200°C or res <0,1°C</i>		
2010	78	311		173	78	311	48
2011	74	296	165	74	296	45	950
2012	71	282	157	71	282	43	905
2013	67	269	149	67	269	41	862
2014	64	256	142	64	256	39	820
2015	61	244	135	61	244	37	781
2016	58	232	129	58	232	35	744
2017	55	221	123	55	221	33	708
2018	53	210	117	53	210	32	675
2019	50	200	111	50	200	30	642
2020	48	191	106	48	191	28	612
2021	45	182	101	45	182	27	583
2022	43	173	96	43	173	26	555
2023	41	165	92	41	165	24	528
2024	39	157	87	39	157	23	503
2025	37	150	83	37	150	22	479
2026	36	142	79	36	142	21	456
2027	34	136	75	34	136	20	434
2028	32	129	72	32	129	19	414
2029	31	123	68	31	123	18	394
2030	29	117	65	29	117	17	375
2031	28	112	62	28	112	16	357
2032	27	106	59	27	106	15	340
2033	25	101	56	25	101	15	324
2034	24	96	54	24	96	14	309
Σ 2015- 2034	800	3,190	1,770	800	3,190	470	10,210

Source: Estimate based on figures from Lassen et al. (2008).

Note: No estimates were available for other meteorological applications than psychrometers, but the volumes are thought to be very small.

Figure 5a-1: Amount of mercury placed on the market each year in mercury containing thermometers for 2010-2034 - Baseline (kg per year)

Source: Table A5a-6

As described in the Chapter 2 of this annex, the pool of mercury in lab and industry thermometers currently used in society is estimated to be roughly 90 tonnes in 2010.

As described in section B.4 of the main report collection efficiencies of mercury in measuring devices, including mercury thermometers, in accordance with requirements set out in the hazardous waste legislation are estimated to be low. It is difficult to estimate the future trend of collection and share of proper waste management, however, there is no indication that the collection rate would improve without new targeted action and considerable efforts by the Member States in the future. Even with improved collection compared to the current situation, it seems unlikely that high enough collection rates would be achieved⁶¹.

4.1.2 Options for restrictions

A tentative identification of possible restriction options was carried out based on the conclusions from the technical and economic feasibility in sections 3.3 and 3.4 of this Annex. The main results are presented in Table A5a-7. Based on those conclusions, two main issues need to be assessed further. These relate to analysis standards that refer to mercury thermometers for certain laboratory applications (including laboratories in industry), and to temperature measurements above 200°C in industry. Since these issues impact a separate market segment, it is considered more practical to assess the restriction options of industry and laboratories separately⁶². For the sake of

⁶¹ Collection efficiencies above 50% should in general not be expected (Lassen et al., 2008; Lassen et al., 2008).

⁶² The described options are considered to be independent from one another. In real life, a restriction in one of the market segments might have an influence on other market segments. As an example, a

that approach, the meteorological applications were included in the laboratory assessment.

Table A5a-7: Information to help determine options to reduce mercury placed on the market in thermometers

	Technical feasible?	Economically feasible?	Volume Hg in thermometers in 2015-2034 (kg)	Cost-effectiveness to reduce mercury (€/kg)
Laboratory thermometers				
Lab res>0.1°C and T<200°C	Yes, but standards	Yes	800	-3,700
Lab res<0.1°C or T>200°C	Yes, but standards	Yes	3,190	2,600
Industrial thermometers				
Industry T<200°C	Yes	Yes	800	-3,100
Industry T>200°C	Yes	No	3,190	362,200
Dial thermometers	Yes	Most likely	1,770	12,400
Meteorological thermometers				
Psychrometers	Yes	Yes	470	*
Others	Yes	Yes	**	*

Source: Sections 3.3 and 3.4, and Table 5a-6 of this Annex, and Annex 5b.

Notes: Negative value means saving

*Cost calculations for psychrometers and other meteorological thermometers are not available but due to the reasons described in section 3.4 and Annex 5b, their cost-effectiveness is expected to be high (even resulting in negative values), similar to mercury-in-glass lab and industrial thermometers for measuring temperature below 200°C and with a resolution not better than 0.1°C.

**No data is available about the size of this market segment.

Based on the tentative identification of possible restriction options, 5 options to reduce the risk from mercury contained in thermometers in the EU have been assessed in greater detail ('options for analysis'). It was concluded to repeat two limited derogations, namely:

- 1) a derogation for mercury triple point cells that are used for the calibration of platinum resistance thermometers in the options for the laboratory market segment (on the basis of technical feasibility, see section 3.3); and

reduced overall market after restriction of a segment can influence prices in another segment, and there may be some issues in relation to enforceability or implementability. However, such effects are thought to be minor.

- 2) a derogation to allow the placing on the market of thermometers of historic value (in all options).

The impact of these two derogations on risk reduction capacity and economic feasibility of the restriction options is considered negligible. See Part E of the main document for the derogation on thermometers with historic value. The mercury placed on the market in mercury triple point cells that are used for the calibration of platinum resistance thermometers is estimated to be negligible (Lassen et al., 2008).

Options for analysis

- Laboratory (& meteorology)

Option 1a: Restriction on the placing on the market of all mercury laboratory thermometers and thermometers for meteorological applications from 2015⁶³ onwards with the two recurring derogations.

Option 1b: A restriction as in option 1a, and in addition a *time-limited* derogation of 5 years⁶⁴ for mercury laboratory thermometers exclusively intended to perform tests according to standards that require the use of mercury thermometers.

- Industry

Option 2a: Restriction on the placing on the market of all industrial mercury thermometers from 2015 onwards with the recurring derogation on thermometers of historic value.

Option 2b: A restriction as in option 2a, and in addition a derogation for mercury-in-glass thermometers used in industrial applications for temperature measurements above 200°C as demonstrated by the reading scale.

Option 2c: A restriction as in option 2b, and in addition a derogation for dial thermometers.

Options not retained for further assessment

In addition to the restriction options described above and that were assessed in detail, the following additional aspects have been considered, but for reasons explained not retained for further assessment:

- A derogation for mercury-in-glass thermometers in laboratories > 200°C or with a resolution <0.1°C.

⁶³ Assuming that a restriction would apply 18 months after the entry into force, it is estimated for the purpose of this assessment that the restriction comes into effect in the year 2015.

⁶⁴ Based on the available information (see section 3.3) it seems that not many standards would prescribe mercury thermometers to be used anymore, and at least ASTM is already in the process of phasing out mercury thermometers from its standards from 2006. Since ASTM standards would have to be reviewed every 5 years, it seems reasonable to assume that all remaining ASTM and other standards still prescribing mercury can be amended by approximately 2018.

Similarly to the derogation in restriction Option 2b for the market segment of mercury-in-glass thermometers in industry for measurements above 200°C, a derogation on the restriction for lab thermometers for all applications that need a resolution better than 0.1°C or used for measurements >200°C could be envisaged. However, unlike for the industry segment, the estimated additional annualised cost per thermometer is only marginally higher⁶⁵ and the measure is cost-effective (€2600€/kg of mercury not placed on the market, see Annex 5b). A derogation was not deemed warranted and this option was not analysed further.

- Restriction on the placing on the market of mercury thermometers with a derogation for all industry mercury-in-glass thermometers

This restriction would be similar to Option 2b with the difference that in addition thermometers measuring temperature below 200°C would be derogated. This would imply that during 2015-34 some 4 tonnes of mercury would still be placed on the market in thermometers for measuring temperature below 200°C. Derogating all industrial mercury-in-glass thermometers might be legally somewhat clearer and easier to enforce, but since the transition to alternatives would be cost neutral or even imply savings, enforceability and legal clarity were not deemed to be sufficient reasons for such a derogation (Table A5a-7).

- A system might be installed by which users or suppliers could apply for an exemption on the general restriction (as in the Swedish and Norwegian restriction, see section B.5 in the main report).

Administrative efforts to implement such a system were deemed to be disproportionately high, and the risk reduction capacity is unlikely to improve substantially in comparison with derogations in the options. Also the enforceability of such a system might be slightly reduced. For these reasons, this option was not considered further.

- A restriction on the professional use of mercury fever thermometers.

It was considered whether a use ban of existing fever thermometers in the medical sector, might be combined with a possible use ban of sphygmomanometers. The total volume of the mercury included in fever thermometers still in society is estimated to be 12 tonnes in 2010,

⁶⁵ There are a number of reasons why the transition to alternatives in the high resolution/T>200°C lab segment is more cost-effective than the industry segment over 200°C. The main factors include: the lower long-term investment cost of the alternative due to the assumption that four mercury lab thermometers can be replaced by one electronic alternative; the calibration neutrality of the cost calculations for lab thermometers as the calibration frequency and cost of both mercury and alternative thermometers is assumed to be the same, and the shorter lifetime (5 years in lab instead of 13 years in industry) that is equal for both mercury and alternative lab thermometers (see Annex 5b).

but is steeply declining to an estimated volume of 0 already in 2014 (the restriction of placing on the market fever thermometers entered into force in April 2009). At the time the use restriction would come into effect, due to the short estimated useful lifetime of fever thermometers, there could only be some amount of fever thermometers recuperated that are 'lingering on' in store rooms in hospitals and with general practitioners. Because of the low volumes, and because a use ban on sphygmomanometers was not considered to be proportionate (see Annex 3a), this option was not analysed further.

- A derogation for long-term studies for laboratory mercury thermometers.
There might be a bias between temperature readings from alternatives to mercury thermometers. Lowe (2009) suggests that readings of mercury thermometers, Galinstan thermometers and electronic thermometers do not differ significantly. This study was limited to fever thermometers, however.
Conversely, according to ASTM (2009) there is a need for research comparing data obtained with alternate devices and the mercury-in-glass thermometers. All ASTM test methods (see section 3.3) are required to have a Precision and Bias statement, and based on information received from ASTM (2010) it seems that such issues would have to be resolved before a standard can be published in its updated form (i.e. allowing the use of alternatives). Because of this, the issue is directly linked to a possible derogation for analysis standards. A separate derogation for laboratory thermometers is therefore not considered further.

4.2 Assessment of risk management options

4.2.1 Option 1a: Restriction on all laboratory thermometers

Restriction to place mercury on the market in non-electrical equipment used to measure or indicate temperature in laboratories and for meteorological applications, after 18 months of entry into force with derogations for:

- mercury triple point cells that are used for the calibration of platinum resistance thermometers; and
- placing on the market thermometers that are more than 50 years old

4.2.1.1 Effectiveness

Risk reduction capacity

The risk reduction capacity that can be achieved by introducing restriction Option 1a is described as an annual reduction of mercury placed on the market in the EU (see section B.2 of the main report). Assuming an annual declining trend of 5%, restriction Option 1a would avoid placing on the market a volume of around 220 kg of mercury

in 2024⁶⁶, or a cumulatively amount of about 4.5 tonnes of mercury would not be placed on the market in the period 2015-34 (Table A5a-6). Note that the amounts for other meteorological applications other than psychrometers are not estimated and thus, not included in this number.

The risk associated with placing on the market of alternatives to mercury thermometers is not considered to be significant in comparison to the risk associated with mercury thermometers (see Section 3.2).

Emissions associated with the production of mercury thermometers will remain where production continues for export. Emissions related to the service-life and waste phase of mercury thermometers already in use will not be affected by restriction Option 1a.

Proportionality

Technical feasibility

In section 3.3 it was concluded that – apart from the issue relating to standards and the two recurring derogations – there are no known technical obstacles to replace all mercury thermometers for all applications.

Until standard organisations have updated their analysis standards referring to mercury thermometers in order to support the use of alternatives, it will in practice not be possible to replace mercury thermometers in certain laboratory applications.

As a conclusion it is not considered technically feasible to restrict placing on the market of mercury thermometers with the limited derogations as proposed in Option 1a.

Economic feasibility (including the costs)

Section 3.4 of this Annex described the economic feasibility of alternatives. This section summarises the compliance and administrative costs associated with the proposed restriction Option 1b from the compliance cost analysis in Annex 5b. Table A5a-8 presents the main outcomes.

As a result of the implementation of Restriction Option 1a, the replacement of 220 kg⁶⁷ of mercury in 2024⁶⁸ (or cumulatively 4.5 tonnes for the period 2015-34). This is estimated to cost €0.3 million in 2024 (or €3.6 million cumulatively in 2015-34).⁶⁹

⁶⁶ The year 2024 is a chosen as a representative year for compliance cost calculations, see section E of the main document for the justification.

⁶⁷ The mid-point of the estimated mercury use in the EU in 2010: 780-1,040 kg.

⁶⁸ The year 2024 is a chosen as a representative year for compliance cost calculations, see section E of the main document for the justification.

⁶⁹ No cost estimates are available for psychrometers.

Table A5a-8: Restriction Option 1a: Amount of mercury not placed on the market in thermometers, compliance costs and cost effectiveness for laboratory thermometers

	Amount of mercury not placed on the market in thermometers		Additional annualised costs for alternative (€ /device /annum)	Total compliance cost		Cost effectiveness (€/kg)
	in 2024 (kg)	cumulative 2015-34 (kg)		in 2024 (€ million)	cumulative 2015-34 (€ million)	
Lab res>0.1°C and T<200°C	39	797	-2.6	-0.2	-2.0	-
Lab res<0.1°C or T>200°C	157	3,188	1.8	0.5	5.6	2630.8
Psychrometers	23	470	*	*	*	*
Total	220	4,455		0.3	3.6	-

Notes:

Negative values represent cost savings.

*Cost calculations for psychrometers are not available but due to the reasons described in section 3.4 and Annex 5b, their additional annualised and total compliance costs are expected to be low and even negative, similar to mercury-in-glass lab and industrial thermometers for measuring temperature below 200°C and with a resolution not better than 0.1°C. Similarly, the cost effectiveness of psychrometers is expected to be high (even resulting in negative values).

Source: Annex 5b

Although the socio-economic benefits of reducing mercury use have not been estimated, the cost-effectiveness of the alternatives (Table A5a-8) in comparison to other measuring devices and other implemented policies (Appendix 2) suggests that Option 1a is economically feasible.

Administrative costs resulting from the restriction of placing on the market of mercury laboratory thermometers is considered to be small, or might even result in savings (see sections 4.2.1.2 Practicality).

4.2.1.2 Practicality

Implementability and manageability

As the cost difference of electronic alternatives is small, and as laboratories are already using such equipment for the advantages they have, no major problems are foreseen in terms of implementability or manageability of this market segment, with the exception of thermometers for measurements according to analysis standards prescribing mercury thermometers.

No problems concerning implementability have been reported by Denmark, The Netherlands, Norway and Sweden with regard to implementation of their national restrictions (see also section B.5 of the main report). However, Denmark, the Netherlands and Norway have an exemption for thermometers used for analysis standards or laboratory use in general.

Because of the simplicity of a restriction with only two limited derogations, the legal clarity of restriction Option 1a would be high for all actors, including enforcers.

The administrative burden for laboratory operators of restriction Option 1a would be negligible. In fact there may be savings since many of the thermometers would be replaced by electronic thermometers that have significant advantages concerning keeping temperature records, and inserting data in computer models etc.

As mentioned before, for mercury laboratory thermometers that are used for measurements according to analysis standards, the restriction Option 1a is not considered to be technically feasible, and thus not implementable.

Enforceability

The compliance with restriction Option 1a can be assessed by inspecting producers (at least 11 in the EU according to Lassen et al., 2008), and by verifying if importers and distributors still supply mercury thermometers. Amongst importers can be users (labs or meteorological institutes) that buy thermometers from outside the EU. This last group would be more difficult to inspect. The clarity of the legal obligations would be high.

It would often be sufficient to visually inspect the thermometers to ensure that they do not use mercury as a thermometric liquid. In some circumstances gallium fillings might initially be confused with mercury, because gallium has a similar silvery liquid metal appearance. However, the capillary would have a concave instead of convex meniscus observed with mercury in a glass capillary.

4.2.1.3 Overall assessment of restriction Option 1a

The advantage of the restriction option is the legal clarity and the highest achievable risk reduction capacity for the laboratory segment. Restriction Option 1a would avoid placing on the market a volume of around 220 kg mercury (including in psychrometers) in 2024 (or cumulatively 4.5 tonnes between 2015 and 2034). This is estimated to cost €0.3 million in 2024 (or €3.6 million cumulatively for the period 2015-34).⁷⁰ The restriction would be cost-effective.

However, this option has as a major shortcoming originating from the fact that it does not address the issue of analysis standards. This issue is addressed in option 1b.

⁷⁰ No cost estimates are available for psychrometers.

4.2.2 Option 1b Restriction on laboratory thermometers with a time-limited derogation for use according to analysis standards.

Restriction to place mercury on the market in non-electrical equipment used to measure or indicate temperature in laboratories and for meteorological applications, after 18 months of entry into force with derogations for:

- mercury triple point cells that are used for the calibration of platinum resistance thermometers;
- placing on the market thermometers that are more than 50 years old; and
- *a time-limited derogation of 5 years for mercury laboratory thermometers exclusively intended to perform tests according to standards that require the use of mercury thermometers.*

4.2.2.1 Effectiveness

Risk reduction capacity

The avoided volume of mercury placed on the market in the EU would be slightly lower than in Option 1a during the 5 year period the derogation on analysis standards would apply (it has not been possible to estimate the derogated volume).

In the years after the derogated period, the risk reduction capacity would be similar to Option 1a (from approximately the year 2018 onwards).

Proportionality

Technical feasibility

The only problem concerning technical feasibility that was identified and discussed in Option 1a, would be lifted with the derogation for laboratory thermometers exclusively intended to perform specific analytical tests according to established standards. Based on the available information (see section 3.3) it seems that not many standards would prescribe mercury thermometers to be used anymore, and at least ASTM is already in the process of phasing out mercury thermometers from its standards from 2006. Since ASTM standards would have to be reviewed every 5 years, it seems reasonable to assume that all remaining ASTM and other standards still prescribing mercury can be amended by approximately 2018.

Economic feasibility (including costs)

The compliance cost of implementation of the Restriction Option 1b is estimated to be similar to Option 1a, but with the following differences:

- The total compliance cost would be somewhat lower as the total number of thermometers that have to be replaced would be lower (5 year derogation);
- The cost-effectiveness of Option 1b would be the same (as the cost effectiveness is not affected by the number of thermometers on the market).

Overall, Option 1b is in all aspects similar to Option 1a in terms of economic feasibility.

4.2.2.2 Practicality

Implementability and manageability

Option 1a had a problem relating to technical feasibility due to the fact that it did not take into account the need to perform specific analytical tests according to established standards with mercury containing thermometers in laboratories. Option 1b remedies this problem with the time-limited derogation for laboratory thermometers exclusively intended to perform specific analytical tests according to established standards.

However, legal clarity would be reduced in comparison with Option 1a as a result of the derogation.

Enforceability

A temporarily decreased enforceability would be the main difference with Option 1a. In the 5 years the derogation would be applicable, enforcement would have to take place on the level of users (laboratories) in order to confirm that laboratory thermometers placed on the market are indeed used for measurements according to analysis standards. Enforcing the derogation might require a high level of technical knowledge from enforcement authorities, and additional resources would be required for enforcers to familiarise themselves with the analysis standards that are prescribing mercury thermometers. The need for resources would significantly increase (in terms of personnel, time, travelling costs, administrative costs, etc.) and would therefore represent an obstacle for the enforceability of a derogation as proposed in this Option.

4.2.2.3 Overall assessment of restriction Option 1b

The risk reduction capacity would be slightly lower in Option 1b than in Option 1a. However, implementability and technical feasibility would be optimised in comparison with Option 1a. However, effective enforcement of the time-limited derogation might be problematic.

4.2.3 Option 2a Restriction on all industrial mercury thermometers

Restriction to place mercury on the market in non-electrical equipment used to measure or indicate temperature in industrial applications, after 18 months of entry into force with derogations for:

- placing on the market thermometers that are more than 50 years old.

4.2.3.1 Effectiveness

Risk reduction capacity

The risk reduction capacity that can be achieved by introducing restriction Option 2a is described as an annual reduction of metallic mercury used in the EU (see section B.2 of the main report). Assuming an annual declining trend of 5%, restriction Option 2a would avoid placing on the market a volume of around 280 kg of mercury in 2024, or a cumulative amount of about 5.8 tonnes of mercury would not be placed on the market in the period 2015-34 (Table A5a-6).

The risk associated with placing on the market alternatives to mercury thermometers is not considered to be significant in comparison with the risk associated with mercury thermometers (see section 3.2).

Emissions associated with the production of mercury thermometers will remain where production continues for export. Emissions related to the service-life and waste phase of mercury thermometers already in use in the industry will not be affected by restriction Option 2a.

Proportionality

Technical feasibility

The technical feasibility of Option 2a has been demonstrated in section 3.3 of this Annex. The current national restrictions on mercury thermometers in Denmark, The Netherlands, Norway, and Sweden have no exemptions on industrial thermometers. This would support the assessment that from a technical point of view there is no obstacle to replace mercury thermometers with alternatives for all industrial applications.

Economic feasibility (including the costs)

Table A5a-9 presents the main outcomes of the compliance cost analysis. As a result of the implementation of Restriction Option 2a the replacement of 280 kg of mercury in 2024 (or cumulatively 5.8 tonnes between 2015 and 2034). This is estimated to cost €56 million in 2024 (or €600 million cumulatively for the period 2015-34).

Table A5a-9: Restriction Option 2a: Amount of mercury not placed on the market in thermometers, compliance costs and cost effectiveness for industrial thermometers

Thermometer Market Segment	Amount of mercury not placed on the market in thermometers		Additional annualised costs for alternative (€ / device / annum)	Total compliance cost		Cost effectiveness (€/kg)
	in 2024	cumulative 2015-34		in 2024	cumulative 2015-34	
	(kg)	(kg)		(€ million)	(€ million)	
Industry T<200°C	39	797	-0.84	-0.12	-1.28	-3,127
Industry T>200°C	157	3,188	97.5	55.1	591.6	362,165
Dial thermometers	87	1,771	97.5	1.1	11.3	12,367
Total	284	5,757		56.0	601.6	-

Note: Negative values represent cost savings.

Source: Annex 5b

Although the socio-economic benefits of reducing mercury use have not been estimated, the cost-effectiveness of the alternatives (Table A5a-9) in comparison to the situation for sphygmomanometers (see Annex 3b) and other implemented policies (Appendix 2) suggests that Option 2a is not economically feasible. In particular, the

economic feasibility of industrial thermometers measuring temperatures above 200°C can be questioned. This is the result of: the higher purchase price, shorter service life, and higher calibration frequently of the alternatives in comparison to the mercury containing thermometers. Annex 5b gives further details.

4.2.3.2 Practicality

Implementability and manageability

For most industrial applications electronic alternatives are replacing mercury thermometers due to the advantage of automation (Lassen et al., 2008). Mercury dial thermometers are confirmed by producers to hold only a very limited residual market because alternatives have taken over (Lassen et al., 2008). In fact, when the estimated volumes of mercury included in thermometers that are placed on the EU-market is considered, it is evident that there is in general a steep decline in thermometers used in all segments of the market.

No problems concerning implementability have been reported by Denmark, The Netherlands, Norway and Sweden with regard to implementation of their national restrictions (see also section B.5). None of the national restrictions foresees any derogations for industry thermometers. From this experience it appears that a restriction for all thermometers in industry would be implementable as well as technically feasible in those countries. This does not imply that a restriction on all industrial mercury thermometers would be economically feasible in the whole EU. As mentioned before, it is concluded that the economic feasibility to restrict the market segment for industry mercury-in-glass thermometers for temperature measurements above 200°C can be questioned.

Because of the simplicity of a restriction with only two derogations, the legal clarity of restriction Option 2a would be high for all actors, including enforcers.

The administrative burden for industry of restriction Option 2a would be negligible. In fact, there may be administrative cost savings since many of the thermometers would be replaced by electronic thermometers that have significant advantages concerning keeping temperature records, and inserting data in computer models etc., and thus, can avoid significant amounts of manual work, and reduce human errors (see sensitivity analysis in Annex 5b for industrial thermometers in the >200°C market segment).

Enforceability

The compliance with restriction Option 1a can be assessed by inspecting the fairly limited number of producers (at least 11 in the EU according to Lassen et al., 2008), and by verifying if importers and distributors still supply mercury thermometers. The clarity of the legal obligations would be high.

It would often be sufficient to visually inspect the thermometers to ensure that they do not use mercury as a thermometric liquid. In some circumstances gallium fillings might initially be confused with mercury, because gallium has a similar silvery liquid

metal appearance. However, the capillary would have a concave instead of convex meniscus observed with mercury in a glass capillary.

With regards to dial thermometers, it might be required to open (damage) devices under protected conditions (to avoid occupational exposure), since it might not be clear from merely a visual inspection whether dial thermometers contain mercury or not (there is no glass capillary). However, considering that the limited residual market for dial thermometers, this should not be seen as a significant hurdle to enforceability.

4.2.3.3 Overall assessment of restriction Option 2a

The advantage of the restriction option is the legal clarity and the highest achievable risk reduction capacity for the industrial market segment. Restriction Option 2a would avoid placing on the market a volume of around 280 kg of mercury in 2024 (or cumulatively 5.8 tonnes in 2015-34). However, this option has as a major shortcoming, since it is assessed that the option is not economically feasible because of the prohibitively high compliance cost related to industrial mercury-in-glass thermometers for maximum temperature measurements above 200°C.

4.2.4 Option 2b Restriction on industrial mercury thermometers with a derogation for mercury-in-glass thermometers for temperature measurements above 200°C.

Restriction to place mercury on the market in non-electrical equipment used to measure or indicate temperature in industrial applications, after 18 months of entry into force with derogations for:

- placing on the market thermometers that are more than 50 years old; and
- *industrial mercury-in-glass thermometers that have a reading scale indicating a maximum temperature that is higher than 200°C.*

4.2.4.1 Effectiveness

Risk reduction capacity

The risk reduction capacity that can be achieved by introducing restriction Option 2b is much lower than in Option 2a. The restriction would avoid placing on the market a cumulative volume of around 2.6 tonnes of mercury between 2015 to 2034 (Table A5a-10), which is close to 60% lower than Option 2a which has a risk reduction of approximately 5.8 tonnes over the same period.

Proportionality

Technical feasibility

The technical feasibility of Option 2b has been demonstrated.

Economic feasibility (including the costs)

As a result of the implementation of Restriction Option 2b, 130 kg of mercury will be replaced in 2024 (or cumulatively 2.6 tonnes for the period 2015-34). This is estimated to cost €0.9 million in 2024 (or €10 million cumulatively in 2015-34). See also Table A5a-10.

Table A5a-10: Restriction Option 2b: Amount of mercury not placed on the market in thermometers, compliance costs and cost effectiveness for industrial thermometers. Derogation for industrial thermometers for temperature measurements above 200°C.

Thermometer Market Segment	Amount of mercury not placed on the market in thermometers		Additional annualised costs for alternative	Total compliance cost		Cost-effectiveness
	in 2024	cumulative 2015-34		in 2024	cumulative 2015-34	
	(kg)	(kg)	(€ / device / annum)	(€ million)	(€ million)	(€/kg)
Industry T<200°C	39	797	-0.84	-0.12	-1.28	-3,127
Dial thermometers	87	1,771	97.5	1.1	11.3	12,367
Total	127	2,568		0.9	10.0	-

Note: Negative values represent cost savings.

Source: Annex 5b

The cost-effectiveness is much higher than in Option 2a due to the derogation on industrial thermometers measuring temperatures above 200°C, and in addition, for reasons described in section 3.4 of this annex, the cost estimates for dial thermometers might be too conservative.

In sum, the cost-effectiveness of the alternatives (Table A5a-10) in comparison to other measuring devices and other implemented policies (Appendix 2) suggests that Option 2b is economically feasible.

4.2.4.2 Practicality

Implementability and manageability

The economic feasibility problem that was identified and discussed in Option 2a would be addressed with the derogation for industrial mercury-in-glass thermometers for maximum temperature measurements above 200°C.

However, legal clarity of Option 2b would be slightly reduced in comparison with Option 2a as a result of the derogation.

Enforceability

Enforcing the derogation would be similar to Option 2a, although enforcers would have to check the maximum temperature level that an industrial mercury-in-glass thermometer can indicate on its reading scale. If the maximum is below 200°C a breach can be concluded. This can easily be verified by visual inspection.

4.2.4.3 Overall assessment of restriction Option 2b

Restriction Option 2b would avoid placing on the market a cumulative volume of approximately 2.6 tonnes of mercury in thermometers between 2015 and 2034. The risk reduction capacity is close to 60% lower compared to Option 2a. In return, Option 2b is economically feasible due to the derogation for industrial mercury-in-glass thermometers measuring temperature above 200°C, which was the reason for the high compliance costs of Option 2a.

4.2.5 Option 2c Restriction on industrial mercury thermometers with a derogation for mercury-in-glass thermometers for temperature measurements above 200°C and a derogation for mercury dial thermometers.

Restriction to place mercury on the market in non-electrical equipment used to measure or indicate temperature in industrial applications, after 18 months of entry into force with derogations for:

- placing on the market thermometers that are more than 50 years old;
- *industrial mercury-in-glass thermometers that have a reading scale indicating a maximum temperature that is higher than 200°C; and*
- *mercury dial thermometers.*

4.2.5.1 Effectiveness

Risk reduction capacity

The risk reduction capacity that can be achieved by introducing restriction Option 2c is much lower than in Option 2a and Option 2b. A cumulative amount of mercury of about 0.8 tonnes would not be placed on the market between 2015 to 2034 (Table A5a-11), instead of 5.8 tonnes in Option 2a or 2.6 tonnes in Option 2b.

Proportionality

Technical feasibility

The technical feasibility of Option 2c has been demonstrated.

Economic feasibility (including the costs)

The implementation of Restriction Option 2c will result in the replacement of 39 kg of mercury in 2024 (or cumulatively 0.8 tonnes between 2015 and 2034) (Table A5a-11). The implementation of this restriction option can result in cost savings of approximately €120,000 in 2024 (or €1.3 million cumulatively for the period 2015-34), due to the assumed lower waste treatment costs of the alternative liquid-in-glass

thermometers than their mercury counterparts. Clearly Option 2c is economically feasible.

Table A5a-11: Restriction Option 2c: Amount of mercury not placed on the market in thermometers, compliance costs and cost effectiveness for industrial thermometers. Derogation for dial as well as industry thermometers that have maximum temperature measurements above 200°C.

Thermometer Market Segment	Amount of mercury not placed on the market in thermometers		Additional annualised costs for alternative	Total compliance cost		Cost-effectiveness
	in 2024	cumulative 2015-34		in 2024	cumulative 2015-34	
	(kg)	(kg)	(€ / device / annum)	(€ million)	(€ million)	(€/kg)
Industry T<200°C	39	797	-0.84	-0.12	-1.28	-3,127

Source: Annex 5b

Note: Negative values represent cost savings.

4.2.5.2 Practicality

Implementability and manageability

The implementability and manageability of restriction Option 2c would be similar to Option 2b, however, legal clarity of Option 2c would be slightly reduced in comparison with Option 2b as a result of the introduction of an additional derogation.

Enforceability

A derogation on dial thermometers will be just slightly easier to enforce with regard to Option 2b. Enforcers would not need to check if dial thermometers would contain mercury or not.

4.2.5.3 Overall assessment of restriction Option 2c

The restriction would avoid placing on the market a cumulative amount of mercury of about 0.8 tonnes from 2015 to 2034 – much lower than in Option 2a and Option 2b. Option 2c would be cost neutral or even result in savings, but the risk reduction capacity is considered insufficient to address the risk. In sum, Option 2c seems not to be a proportionate response to the concern related to mercury.

4.3 Comparison of the risk management options

Table A5a-12 summarises the risk reduction capacities and costs associated with the implementation of different restriction options.

Table A5a-12: Summary of risk reduction capacities and costs associated with the implementation of different restriction options

Options	Amount of mercury not placed on the market in thermometers		Total compliance cost		Cost Effectiveness (weighted average) (€ million)
	in 2024	cumulative 2015-34	in 2024	cumulative 2015-34	
	(kg)	(kg)	(€ million)	(€ million)	
Option 1a	220	4,455	0.3	3.6	1,366
Option 1b	<220	<4,455	<0.3	<3.6	<1,366
Option 2a	284	5,757	56.0	601.6	203,956
Option 2b	127	2,568	0.9	10.0	7,558
Option 2c	39	797	-0.1	-1.3	-3,127

Source: Annex 5b

* The risk reduction capacity and the costs related to Option 1b are estimated to be slightly lower than Option 1a.

Table A5a-13 gives a qualitative overview of the risk management options. The table can be seen as summary of the main elements of the assessment, and allows for a rough comparison of the options on the basis of technical feasibility, risk reduction capacity, economic feasibility, and practicality. Based on the assessment, a combination Options 1b and 2b is considered the most appropriate risk management measure. Combining of options 1b and 2b is thought to be additive, and not to have important side-effects. For example, it is not thought to be realistic that laboratories would buy industry thermometers since industry thermometers have a low precision and do not satisfy the required standards for laboratories.

Table A5a-13 Overview of the risk management options

Options	derogation	Technically feasible?	Risk reduction capacity	Economic feasibility	Remarks practicality
Lab					
Option 1a	none	yes, but standards	++++	+++	/
Option 1b	standards	yes	+++	++++	Enforceability ?
Industry					
Option 2a	none	yes	++++	-	/
Option 2b	MiG* >200°C	yes	++	+++	/
Option 2c	MiG >200°C +dial	yes	+	++++	/

*MiG = mercury-in-glass thermometers

Note: The indication “/” means that no major additional concerns relating to practicality have been identified

4.4 The proposed restriction(s) and summary of the justifications

The restriction that is proposed for thermometers is a combination Options 1b and 2b:

Restriction to place mercury on the market in non-electrical equipment used to measure or indicate temperature after 18 months of entry into force with derogations for:

- mercury triple point cells that are used for the calibration of platinum resistance thermometers;
- placing on the market thermometers that are more than 50 years old; and
- a time-limited derogation of 5 years for mercury laboratory thermometers exclusively intended to perform tests according to standards that require the use of mercury thermometers.
- industrial mercury-in-glass thermometers that have a reading scale indicating a maximum temperature that is higher than 200°C.

Justification

Based on the assessment of risk management options and on the comparison of restriction options in section 4.3, a combination of Options 1b and 2b is the most appropriate risk management measure.

The main purpose of the proposed restrictions is to reduce the mercury pool in the society, thus avoiding negative impacts on human health and the environment. The proposed restriction would avoid placing on the market of around 350 kg of mercury in 2024. Cumulatively, the proposed restriction would avoid placing on the market an amount of mercury of about 7 tonnes in the period 2015-34. The cost of this reduction effort would be €1.2 million per annum or €13.7 million for the period 2015-34.

Certain analysis standards (test methods) currently require the use of mercury thermometers and are thus preventing the use of alternatives. A time-limited derogation of 5 years for mercury laboratory thermometers exclusively intended to perform tests according to such standards is therefore considered justified.

To better understand the compliance costs in relation to other actions and policies, one can compare the cost effectiveness of the proposed restriction with the policy options reviewed in Appendix 2. As indicated in Table 5a-7 the cost-effectiveness of restricting different thermometer market segments varies considerably. In Appendix 2 it was concluded for the purpose of this restriction report that a benchmark of €10,000 /kg Hg is regarded as indicating that proportionality of costs to the risks related to mercury is “well established”. Industrial thermometers measuring temperature under 200 °C as well as all laboratory thermometers belong to this category. In the case of dial thermometers, the cost effectiveness was €12,000/kg Hg, i.e. slightly higher than the benchmark. However, because they are known to hold only a very limited residual market,⁷¹ the economic importance of mercury dial thermometers is thought to be

⁷¹ It is estimated that the mercury dial thermometers represent less than 1% of the estimated total industrial and lab thermometers in 2010.

marginal (see section 3.4⁷²). Thus, the proposed restriction for dial thermometers is deemed proportionate.

In the case of industry thermometers measuring temperature above 200 °C the cost-effectiveness is low (€362,200/kg Hg). It was discussed that if electronic devices would save labour costs by e.g. 5 hours per year, the economic feasibility could be established (see Annex 5b). However, such evidence is not available. Thus, it is concluded that economic feasibility is "not established". Appendix 2 gives further details.

Since it is assessed that the economic feasibility of a restriction on industrial mercury-in-glass thermometers for maximum temperature measurements above 200°C would be questionable, a derogation for these thermometers is deemed to be justified.

The proposed restriction is considered proportionate, implementable, manageable and enforceable.

⁷² In addition the cost is likely overestimated

Annex 5b: Compliance cost calculations for thermometers

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1. Introduction

This annex presents the compliance costs calculations of substituting mercury-containing thermometers with mercury-free alternatives in support of the development of restriction options for thermometers in the Annex XV restriction report (Annex 5a). From section 1 “Technical description of mercury thermometers” in Annex 5a it is apparent that the applications and types of mercury thermometers on the market are very diverse. Similarly to section 3.3 of annex 5a on the technical feasibility of alternatives, the thermometer market was split in three main groups for the purposes of calculating the costs of compliance with the proposed restriction:

- Mercury-in-glass laboratory thermometers
 - Thermometers measuring temperature typically from -58°C to up to 200°C and where an accuracy of 0.1°C or better is not needed, i.e. generic thermometers;
 - Thermometers measuring temperature above 200°C or where an accuracy of 0.1°C or better is needed. This includes certain meteorological measurements; and
 - Mercury thermometers measuring ambient temperature and for most other meteorological measurements (including Six’s thermometers and psychrometers).⁷³
- Mercury-in-glass industrial thermometers
 - Thermometers measuring temperature typically from -58°C to up to 200°C, i.e. generic thermometers; and
 - Thermometers measuring temperature above 200°C (e.g., with application in the processing industry, marine applications, engines, etc.).
- Mercury dial thermometers

2. Defining the temporal scope and choosing a representative year

The temporal scope of the analysis is from the time when the restriction is assumed to become effective in 2015 to 2034.⁷⁴ Taking into account the uncertainties related to available data and the assumed declining trend in the number of mercury thermometers, 20 years scope is regarded sufficient. This temporal scope was also selected for consistency purposes to present comparable results to the analysis of sphygmomanometers.

The costs are reported in two ways:

1. In the cumulative approach, the present values of costs are calculated for 2015-2034.
2. In the representative year approach, the annualised costs, using the year 2024 as a representative year, are calculated.

⁷³ No specific cost information on this market segment has been gathered, since it is considered to be a residual market. For the sake of simplicity they are combined with the laboratory market segment (see Section 5.1.3)

⁷⁴ This temporal scope is chosen for illustrative purposes. In reality the time when the restriction becomes effective (2015 in this analysis) depends on the speed of the decision-making process and the transitional periods after entry into force.

3. Data sources and approach

The main sources of data used in the analysis are Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society published by DG Environment (Lassen et al. 2008)⁷⁵ and Appendix 3 of the restriction report (Lassen et al., 2010).

The calculations have been carried out in Excel using NPV (for net present value) and PMT (for annualised cost) worksheet functions.

4. Main assumptions

Mercury volume in thermometers for the EU-market

The mercury volume in mercury-in-glass thermometers for the EU-market is estimated at 0.6-1.2 tonnes for 2007. Based on information from producers, it is estimated that approximately half of the mercury is used in thermometers for laboratory use and the other half is used for industrial and marine applications (Lassen et al. 2008). For the purposes of this analysis, it is assumed that the number of mercury-containing thermometers sold per year in the next 20 years will decline annually by 5%. This reduction in using mercury-containing devices is partly due to increased awareness of the harmful properties of mercury and partly because of the advantages of some alternatives, particularly related to automation.

Therefore, it is estimated that in 2010 the use of mercury for placing on the EU market industrial and lab mercury-in-glass thermometers is approximately 390kg each.⁷⁶ As it is unclear what portion of that is for thermometers measuring temperature above 200°C, for the purpose of this analysis it is assumed that they represent 80% of the volume in the total lab and industry segment of the EU thermometer market. This number is supported by information from a German producer that estimated the market to be 100 kg of mercury per year for the industry thermometer segment (>200°C), and 100 kg for lab >200°C segment in Germany alone. If this is compared to the estimated EU volume of 300 – 600 kg mercury per year⁷⁷, the percentage has to be relatively high. The impact of this assumption is assessed in the sensitivity analysis.

The use of mercury for placing on the EU market mercury dial thermometers is estimated to be 0.1-0.3 tonnes for 2007 in the EU (Lassen et al., 2008). Based on the assumption of 5% annual decline, for the purpose of this analysis it is estimated that the volume in the European Union is approximately 150kg in 2010.

Psychrometers represent a small market segment of the mercury market. The mercury volume in psychrometers placed on the EU-market is estimated at 0.01-0.1 tonne in 2007 (Lassen et al., 2008). No data is available for thermometers used for other meteorological applications, but the residual market is thought to be limited (see Section 5.1.3).

Mercury content

⁷⁵ Available at http://ec.europa.eu/environment/chemicals/mercury/pdf/study_report2008.pdf

⁷⁶ Based on the 50% mid-point of the 2007 consumption level in the EU of 0.6-1.2 tonnes.

⁷⁷ Total of 0.6-1.2 tonnes per year, where the industry and lab market represent about half each.

The mercury content of thermometers used for laboratories and in industry range from 1 to 20 g per thermometer, with an average content of 3-4 g (Lassen et al. 2008). The analysis assumes that all mercury-in-glass thermometers contain on average 3.5g of mercury. This average was also supported by producers describing “typical” thermometers (Lassen et al., 2010). The sensitivity analysis assesses the influence of the mercury content on compliance costs taking into account that some high precision, broad temperature range thermometers can have higher mercury content.

The mercury content of dial thermometers tends to be very variable, ranging from about 5 to 200 g (Lassen et al., 2008). The “rigid” type has relatively low mercury content, whereas the “remote” type can have a much higher content, since they can have a mercury filled capillary up to 40 m or more. The mid-point of 102.5g mercury per device is assumed for this analysis.

Lifetime

Mercury-in-glass industrial thermometers

The average technical lifetime of mercury thermometers can exceed 25 years. As no data are available for the breakage rate and other influencing factors such as changing of production lines, etc., a shorter useful life estimate of 13 years is adopted, as per the response of a major producer of mercury thermometers that a realistic average lifetime of these thermometers in practice is between 10 and 15 years (Lassen et al., 2010).

Mercury dial thermometers

It is likely that the actual lifetime of the “rigid” type will be very different from the “remote” type, since it can be expected that the capillaries are especially vulnerable to breakage, wearing, and loss of accuracy. It is possible that the actual lifetime of dial thermometers is comparable to the alternative liquid- or gas-actuated systems. However, as there is no specific information for the lifetime of mercury dial thermometers, as a conservative assumption, the same average lifetime as other industrial thermometers is used for the analysis.

Mercury-free dial thermometers

The lifetime of bi-metal and liquid- or gas-actuated dial thermometers varies depending on the type of the dial thermometer and the conditions in which it is used. The average lifetime for the dial thermometer is indicated by the mercury thermometer manufacturer to be 1-2 years whereas the manufacturer of alternatives indicates 1-5 years for mechanical systems depending on the environment. A Danish manufacturer of mechanical thermometers estimates the typical lifetime of bimetallic thermometers at 2-5 years and of gas-filled thermometers at 5-10 years (Lassen et al., 2010). A three-year lifetime for all mechanical systems is assumed for the purpose of this analysis.

Electronic thermometers

The lifetime of the electronic probes (sensors) is generally shorter than for the rest of the system (the data reader or indicator), as the probes are often placed in more harsh environments (vibration, temperature, humidity, corrosive gases, etc.) and are in general more delicate than the rest of the system. The lifetime of thermocouple probes can vary between one and five years and 1-10 years for the resistance

thermometers. In very harsh environments with higher temperatures (e.g. waste incinerators) the lifetime of the probes is less than half a year. Based on the available data a typical lifetime for the electronic sensors is considered three to six years (Lassen et al., 2010). A five-year lifetime for all electronic probes is assumed for the purpose of this analysis. As there is no detailed information for the lifetime of the data reader, a 10 year lifetime is assumed for the purpose of this analysis.

Mercury-in-glass lab thermometers

The analysis assumes a lifetime of five years for this market segment, which is based on an estimate of the University of Minnesota, Floyd *et al.* (Lassen et al. 2008, Lassen et al., 2010). It is assumed that a high rate of breakage would be indeed more typical for the lab thermometers, since the thermometers are frequently handled manually, are often not fixed in a device, can have a long stem length of 30-70cm, and, compared to industry thermometers, are usually not protected by sturdy encasings. All these factors will result in a shorter lifetime than the lifetime of industrial thermometers.

Replacement ratio of mercury thermometers with alternatives

The analysis assumes that one mercury-containing device can be replaced by one mercury-free mechanical alternative. However, when it comes to electronic alternatives, in certain circumstances, one electronic system can replace a number of mercury thermometers. Therefore, different replacement ratios are assumed for mercury in glass thermometers in labs and industry for measuring temperature above 200°C. The assumptions made are explained in greater detail in the respective sections for laboratory and industry thermometers.

Device prices

The price of mercury thermometers and their alternatives is assumed to be a function of factors such as accuracy, temperature range and level, compliance with standards, calibration certification, and suitability to measure temperature in adverse environmental conditions. Prices of the electronic alternatives are also driven by additional features such as automated temperature recording, alarm systems, real-time process monitoring and feedback systems, etc. The various combinations of these factors (based on customer requirements) results in a substantial price diversity of thermometers available on the market. Therefore, the analysis is based on prices of what is considered by producers to be a “typical thermometer” and a “typical alternative” taking into account information in the Lassen et al. (2008) and Lassen et al. (2010).

Due to the uncertainty associated with the device prices and as the alternative market is thought to have reached maturity in certain segments, it is assumed that the prices of mercury-containing and alternative devices do not change between 2015 and 2034. In reality, there could be a change in prices in favour of the alternatives as the technology further matures.

The costs in the analysis represent factory gate prices excluding VAT for investment costs. Recurrent costs also likely exclude VAT. All values used in this analysis refer to year 2010 price levels, i.e. the prices are “real” as the effect of inflation has not been included in the analysis.

Alternatives considered

The analysis takes into account technically feasible alternatives identified in Section 3.3 of Annex 5a. Investment and recurrent costs of the mercury containing devices are specifically compared to alternatives identified as “typical” in Lassen et al. (2010). When several alternatives are shown to be technically feasible, the analysis assumes that customers will replace the mercury-containing thermometers with the cheaper alternatives.

Gallium thermometers are technically feasible alternatives to the mercury thermometers, in particular as a very wide range thermometer and for measuring temperature outside the range of mercury thermometers (above 750°C). These thermometers are difficult to manufacture as each thermometer has to be individually filled resulting in high prices for these thermometers (Lassen et al., 2010). Gallium thermometers are excluded from the cost calculations due to their limited application in practice because of their high costs and because their use is rather complementary to mercury thermometers (outside the temperature range of mercury thermometers).

Comparability of alternatives

As far as possible, alternative devices with technical properties similar to mercury-containing thermometers are considered in the analysis. Electronic alternatives have additional features that mercury thermometers do not possess. These include: automated temperature recording, alarm systems, real-time process monitoring and feedback systems, etc. These additional benefits may lead to energy savings, labour cost savings, minimisation of human reading errors, higher efficiency of reactions, a better quality of the end-product, reduced risks of damage, etc. These additional benefits present a challenge in the direct comparison of the alternatives to the mercury-containing thermometers (and impact the price of the alternatives). In fact, the advantage of electronic reading for example is one of the drivers for replacing mercury thermometers with electronic devices, which for many customers offsets the extra costs of the thermometers (Lassen et al., 2010). No information was available to estimate the value of these additional features and to deduct it from the investment costs of the electronic alternatives.

Calibration frequency

Calibration frequency is particularly difficult to estimate due to the diverse requirements for calibration and industry practices. For the purposes of this analysis it is assumed that all devices are bought calibrated.

Mercury-containing industrial thermometers

Mercury thermometer producers reported that industrial mercury-in-glass thermometers do not need frequent recalibration because its glass capillary keeps its accuracy for 30 years and more. The actual calibration frequencies, however, are dependent on the procedures set up by the users in their quality management system. Thermometers are thought to be checked regularly when used to measure temperature in industrial processes where temperature is of high importance (e.g., in the dairy industry). Lassen et al. (2010) estimates that calibration once every three to five years would be typical (based on information from producers and a Danish reference lab). For the purpose of this analysis it is assumed that all industrial mercury thermometers

(including dial) will be calibrated once every four years for all industrial (including dial) segments.

Mercury-free industrial thermometers

According to the information in Lassen et al., 2010, the calibration frequency of the alternative mechanical (dial) system is 6-12 months, while the frequency for the electronic systems is 6-24 months. According to a Danish producer it is typically necessary to recalibrate the probe after installation where the probe is “aged” by changing the temperature about 10 times. After the aging, the probe is often stable for some 5 years and does not drift more than 0.1°C. Many customers calibrate the thermometers every year because it is required by their quality management system. The analysis assumes that both dial and electronic alternatives are calibrated once a year for all thermometer segments.

Liquid-in-glass industrial thermometers

As no specific information was gathered for liquid-in-glass thermometers, and because of their similarities, it is assumed that they have the same calibration frequency as mercury-in-glass thermometers.

Mercury-in-glass and mercury-free lab thermometers

Similar to industrial mercury thermometers, it is difficult to determine the frequency of a typical mercury lab thermometer. One manufacturer indicated that the mercury thermometers do not need calibration while another – a 15 year validity of calibration. According to a Danish manufacturer, certified test laboratory mercury thermometers are usually calibrated every 3-5 years (Lassen et al., 2010). However, it was noted that in many laboratories the frequency of calibration is one to two calibrations per year independent on thermometer type (Lassen et al., 2010). For the purpose of this analysis, it is assumed that all laboratory thermometers will be calibrated annually.

Calibration costs

The cost of a calibration depends among others on the number of calibration points used. Lassen et al, (2010) indicates a price of €100-€150 for the calibration of an electronic thermometer. For this study the cost of calibration, done by a certified laboratory in Denmark, is reported to be about €200-€300, where the calibration of high precision thermometers tends to be more expensive. A price of €200 has been reported by a major German producer of electronic thermometers. With a traceable certificate the cost of calibration from the producer is about €350 (Lassen et al., 2010). As all the estimates for calibration costs in Lassen et al. (2010) are for Western European users, this analysis assumes the mid-point of the lowest estimates (€125) for all thermometers, to take into account the lower labour costs in Eastern Europe. These calibration costs are assumed for all thermometers included in the compliance cost calculations.

The cost of calibration is higher than the cost of new electronic equipment, but used electronic equipment is more stable than new equipment (Lassen et al., 2010).

Other recurrent costs

In addition to calibration costs, the analysis also takes into account other recurrent costs such as costs for power or batteries for the electronic device and waste handling. It is assumed that the device is purchased with batteries.

Waste treatment expenditures are assumed to occur the year after the end of the useful life of the device. As no specific data was gathered for these recurrent costs for thermometers, the analysis is based on assumptions presented in the cost calculations for sphygmomanometers. It is not known whether this estimate for sphygmomanometers considers that not all users dispose of the mercury devices in accordance with hazardous waste legislation. The values presented for sphygmomanometers were reduced by half to reflect the lower mercury content and the smaller size of thermometers.

In the event of breakage of a mercury containing thermometer, there are costs associated with the cleaning of the spill. As no information was gathered regarding these costs they are not considered in the analysis.

One particular problem mentioned is the need for modified/additional installations in existing facilities if spare mercury thermometers are not available (“retrofitting”) (Lassen et al., 2010). Mercury-free replacement thermometers (spare parts) fitting into the existing installations are sometimes claimed not to be readily available. A Danish producer of thermometers informed that the price of the adjusted alternatives is only slightly higher than the standard thermometer (Lassen et al., 2010). This is supported by product catalogues and on-line information assessed by ECHA. The alternatives encountered all use the same industry standards (such as DIN) for dimensions, fittings, etc. that are used for mercury thermometers. Usually producers mention that besides the standard versions, also custom dimensions, connection heads, transmitters, etc. can be supplied upon request.

As a specific case of retrofitting, finding solutions to accommodate certain older autoclaves with electronic alternatives has been reported as problematic. For these reasons, mercury-containing maximum thermometers to be placed inside older autoclaves are exempted from the restriction in Norway.⁷⁸ However, a report by the Swedish Chemicals Agency (KemI) indicates that mercury thermometers are being replaced with for example thermocouples in this equipment, and that this has advantages with respect to automated data collection and recording (Lassen et al., 2010).

It is concluded that on average there is no problem with retro-fitting, since in general the alternatives use the same industry dimensions, and that for the cases where

⁷⁸ The Norwegian Climate and Pollution Agency (Klif) mentioned two possibilities for retrofitting of older autoclaves (where the thermometers are placed inside the autoclave) that both seem to be problematic. One is to place an electronic thermometer with data logger inside the autoclave, but the loggers are said not to withstand high temperatures. Another alternative is to place a thermocouple inside with connections to a meter outside. Some laboratories would have tried to lay thin conducting wires through the gasket, but it would have been difficult to avoid leakage caused by the high pressure. (Klif, 2010, pers. comm.)

customisation is needed, in most cases this has little effect on the investment costs. Therefore, for the purpose of the cost calculations, the installation/modification costs are considered immaterial and therefore, ignored in the analysis.

Discount factor

Throughout the analysis a 4% discount rate is used and the expenditures are assumed to occur in the beginning of each year, i.e. 1 of January.

5. Cost calculations

5.1. Mercury-in-glass lab thermometers

5.1.1. Mercury-in-glass lab thermometers (<200°C and resolution not better than 0.1°C)

5.1.1.1. Introduction

A number of mercury-in-glass thermometers are used to measure temperature below 200-250°C in applications where high precision and broader temperature range is not needed. Mercury-free liquid-in-glass thermometers are one of the most common replacements of these thermometers. Most mercury-free liquid-in-glass thermometers are not suitable for accurate measurements at 0.1°C resolution, but are fully suitable for less accurate measurements (Lassen et al., 2010). Their price is roughly the same as for mercury thermometers or about 10% lower (Lassen et al., 2010). It is assumed that the prices of these devices is approximately half the price of the mercury-in-glass lab thermometer for measuring temperature above 200°C, as it is assumed that high-precision, broad temperature range thermometers command higher prices.

Other thermometers that can replace mercury devices in this market segment include electronic thermometers and gallium-indium thermometers. These thermometers command higher prices (up to 10-times the price of mercury-thermometers) due to their additional features such as data logger (for electronic thermometers) or broader temperature range (gallium thermometers). Therefore, for the purposes of estimating the cost effectiveness of substituting the mercury-in-glass thermometers measuring temperature below 200°C, only liquid-in-glass thermometers are considered.

Assuming 3.5g of mercury content for thermometers in this market segment, it is estimated that there are approximately 22,200 thermometers in the EU in 2010.

Table A5b-1 presents the input data used in the analysis.

Table A5b-1: Input data – Mercury-in-glass lab thermometers (<200°C)

Parameter	Device	Central case
Discount rate		4%
Mercury devices sold per year 2010		22,200
Annual decrease in number of devices sold		5%
Mercury per device (kg)		0.0035
Average lifetime (years)	Mercury	5
	Liquid-in-glass	5
Investment cost (price of device)	Mercury	€ 40
	Liquid-in-glass	€ 40
Calibration costs (per calibration)	Mercury	€ 125
	Liquid-in-glass	€ 125
Calibration frequency (once in <i>x</i> years)	Mercury	1
	Liquid-in-glass	1
Batteries (per year)	Mercury	€ 0
	Liquid-in-glass	€ 0
Waste treatment (per device)	Mercury	€ 16
	Liquid-in-glass	€ 2

5.1.1.2. Cost calculations

Investment costs

Table A5b-2 presents the investment costs of the mercury- and liquid-in-glass thermometers for measuring temperature below 200°C.

Table A5b-2: Annualised investment costs per device (in 2010 price level) – Mercury-in-glass lab thermometers (<200°C)

Year	Total Investment costs (€) per device	
	Baseline: Mercury-in-glass Lab Thermometer	Alternative: Liquid-in-glass Thermometer
Investment costs	40	40
Present value (for lifetime)	40	40
Average lifetime (years)	5	5
Annualised	9	9
Additional annualised		0

As the price of the alternative is the same as the mercury-in-glass thermometer, the transition to the alternative results in no additional annualised investment costs per device.

Recurrent costs

Table A5b-3 presents the recurrent costs of the mercury- and liquid-in-glass thermometers for measuring temperature below 200°C.

Table A5b-3: Annualised recurrent costs per device (in 2010 price level) – Mercury-in-glass lab thermometers (<200°C)

Year	Recurrent costs (€) per device	
	Baseline: Mercury-in-glass Lab Thermometer	Alternative 1: Liquid-in-glass Thermometer
1	0	0
2	125	125
3	125	125
4	125	125
5	125	125
6	16	2
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
Present value (for lifetime)	467	455
Annualised	105	102.3
Additional annualised		-2.6

The lower waste treatment costs result in an annualised savings of recurrent costs of €2.60 per device when the mercury lab thermometer is replaced with a liquid-in-glass thermometer.

Total costs and compliance costs

Table A5b-4 presents the calculations of total costs of mercury thermometers and liquid-in-glass thermometers.

Table A5b-4: Annualised total costs per device (in 2010 price level) – Mercury-in-glass lab thermometers (<200°C)

Year	Total costs (€) per device	
	Baseline: Mercury-in-glass Lab Thermometer	Alternative: Liquid-in-glass Thermometer
Present value (for lifetime)	507	495
Average lifetime (years)	5	5
Annualised	114	111
Additional annualised		-2.6

Due to lower waste treatment costs of the liquid-in-glass thermometers, it is estimated that the transition to the alternative will result in additional annualised savings per device of €2.60. The results in the table above can be obtained by addition of the investment and recurring costs presented in Tables A5b-2 and A5b-3.

Table A5b-5 presents the compliance costs from replacing the mercury-in-glass lab thermometer with a liquid-in-glass thermometer.

Table A5b-5: Annualised and present value compliance costs (in 2010 price level) – Mercury-in-glass lab thermometers (<200°C)

	Compliance costs (€) Alternative 1: Liquid-in-glass Thermometer
2015	-44960
2016	-87780
2017	-128560
2018	-167399
2019	-204388
2020	-194655
2021	-185386
2022	-176558
2023	-168150
2024	-160143
2025	-152517
2026	-145255
2027	-138338
2028	-131750
2029	-125476
2030	-119501
2031	-113811
2032	-108391
2033	-103230
2034	-98314
Compliance cost (present value 2015-2034)	-1,963,574
Annualised compliance cost (2024)	-160,143

Assuming that approximately 22,200 mercury thermometers are placed on the market annually (with a 5% declining rate over the study period), the compliance costs savings of replacing the mercury-filled with liquid-in-glass thermometers over the study period is close to €2 million (NPV) or €160 thousand as of 2024 on the representative year basis.

This tendency to replace the mercury containing thermometers with liquid-in-glass alternatives is already observed in the market. The reasons for continued use of the mercury containing thermometers can be explained with perceived higher level of quality of the mercury thermometers (which is a trusted, time tested method of measuring temperature) or customers' failure to take into account the long-term (recurrent) costs associated with the mercury thermometers.

5.1.1.3. Cost effectiveness

As the alternative has lower recurring costs, reducing the marketed volume of mercury by 1kg when replacing mercury lab thermometers with liquid-in-glass thermometers results in cost savings of approximately €3,700. The calculation is based on the present value compliance costs and on the assumption that one mercury thermometers contains 3.5g of mercury.

Table A5b-6 presents a summary of the compliance cost calculations associated with the transition from mercury-in-glass thermometers to liquid-in-glass thermometers.

Table A5b-6: Annualised and present value compliance costs (in 2010 price level) – Mercury-in-glass lab thermometers (<200°C)

Main assumptions for device			
Number of devices per year (2010)		22,200	
Trend		-5%	per year
Amount of mercury per device		0.0035	kgs
Lifetime of device		5	years
Costs (€)		Baseline: Mercury-in-glass Lab Thermometer	Alternative 1: Liquid-in-glass Thermometer
Investment cost	annualised	9	9
Recurrent cost	annualised	105	102
Total cost	annualised	114	111
Additional total cost	annualised		-2.6
Cost effectiveness	annualised		-739
Cost effectiveness	per lifetime of device		-3,693
Compliance cost	2024		-160,143
Compliance cost	total		-1,963,574

5.1.1.4. Sensitivity analysis

If waste treatment costs are ignored in the cost calculations, the transition to the liquid-in-glass alternative will be cost neutral, i.e., total compliance costs and the cost effectiveness will be 0€/kg Hg.

If we assume that the price of the liquid-in-glass alternatives is approximately 10% lower than the mercury containing device (Lassen et al., 2010), the transition to the alternative will result in higher cost savings: €5,000 per 1kg of mercury (cost effectiveness) or a total compliance cost for 22,200 mercury devices of €2.7 million (NPV) or €216 thousand (as of 2024).

Depending on the size of this market segment, the total compliance costs can range from €0 (assuming that all lab thermometers are used to measure temperature above 200°C) to €3.9 million savings on NPV basis or €320 thousand as of 2024 on representative year basis when it is assumed that this market segment represents 40% of all lab mercury-in-glass thermometers (44,400 devices as of 2010). The cost-effectiveness under this scenario will remain the same.

5.1.2. Mercury-in-glass lab thermometers (resolution better than 0.1°C or >200°C)

5.1.2.1. Introduction

This section addresses thermometers used in laboratory applications where an accuracy of 0.1°C or better is needed or to measure temperature above 200-250°C. Other technical requirements may include: a broad temperature range, high maximum temperature, and certification requirements for quality management (related to standards and calibration).

Assuming mercury content of 3.5g per thermometer, it is estimated that in the European Union, in 2010 there are approximately 88,900 mercury-in-glass thermometers in this market segment (assuming the segment represents 80% of total mercury-in-glass lab thermometers). The impact of this assumption on the compliance cost calculations is tested in the sensitivity analysis.

There are a number of technically feasible alternatives that have replaced mercury-in-glass lab thermometers with accuracy <0.1°C or for the temperature range above 200°C. These mainly include electronic thermometers such as thermocouples and platinum resistance thermometers (PRTs), as described in Section C: Technical feasibility.

Thermocouples and PRTs are three to five times more expensive and require additional data readers, which cost three to four times the cost of the mercury thermometers (Lassen et al., 2010). However, their higher prices are partially attributable to additional features such as data logger, possibilities for remote reading, alarm systems, etc. Due to lack of detailed information no attempt has been made to quantify the value of these additional features. For the purposes of this analysis, it is assumed that the price of the electronic system is €450.

An electronic thermometer typically has a much broader temperature range than mercury thermometers. It can be assumed that several mercury thermometers can be replaced by one electronic thermometer (probe with a data reader). One supplier of thermometers for measuring viscosity informs that a digital meter for these specific applications may replace four mercury thermometers as it in practice covers four relevant measuring points (Lassen pers. comm. 2010). One electronic thermometer could replace a whole set of narrow range (high) precision mercury thermometers, or even several of those sets. Such sets typically consist of six to 11 thermometers. However, other factors come into play and the actual replacement rate will be highly dependent on the needs of a lab.

In addition, several probes may be connected to one indicator (data reader), but on the other hand measurements might have to be done simultaneously on different locations in the lab. It was not considered possible to estimate the respective influence of these parameters.

Therefore, the analysis assumes a moderate replacement ratio of 4:1 for both the probe and the data reader. The impact of this assumption on cost effectiveness and compliance cost calculations is tested in the sensitivity analysis.

Table A5b-7 below presents the input data used in the analysis.

Table A5b-7: Input data used in the analysis – Mercury-in-glass lab thermometers (>200°C)

Parameter	Device	Central case
Discount rate		4%
Mercury devices sold per year 2010		88,900
Annual decrease in number of devices sold		5%
Mercury per device (kg)		0.0035
Average lifetime (years)	Mercury	5
	Electronic	5
Investment cost (price of device)	Mercury	€ 80
	Electronic	€ 240
Calibration costs (per calibration)	Mercury	€ 125
	Electronic	€ 125
Calibration frequency (once in x years)	Mercury	1
	Electronic	1
Batteries (per year)	Mercury	€ 0
	Electronic	€ 3
Waste treatment (per device)	Mercury	€ 16
	Electronic	€ 2
Investment cost (price of data reader)	Mercury	€ 0
	Electronic	€ 210
Average lifetime per data reader (years)	Mercury	0
	Electronic	10
Replacement (Hg : electronic)		4:1

5.1.2.2. Cost calculations

Investment costs

Table A5b-8 presents the calculation of investment costs of mercury-in-glass lab thermometers and electronic thermometers. As noted above a replacement ratio of 4:1 is applied to the probe and the data reader.

Table A5b-8: Annualised investment costs per device (in 2010 price level) – Mercury-in-glass lab thermometers (>200°C)

Year	Total Investment costs (€) per device	
	Baseline: Mercury-in-glass Thermometer	Alternative: Electronic (probe & data reader)
Investment costs	80	113
Present value (for lifetime)	80	113
Average lifetime (years)	5	5
Annualised	18	20
Additional annualised		2

Due to shorter lifetime and higher price compared to mercury-containing devices, the additional annualised investment cost is estimated to be €2 for the alternative.

Recurrent costs

Table A5b-9 presents the calculations of recurrent costs for mercury-in-glass lab thermometers and electronic thermometers. The assumed lower waste disposal costs of the electronic thermometer result in small savings per device of an estimated €0.10 annually.

Table A5b-9: Annualised recurrent costs per device (in 2010 price level) – Mercury-in-glass lab thermometers (>200°C)

Year	Recurrent costs (€) per device	
	Baseline: Mercury-in-glass Thermometer	Alternative: Electronic
1	0	0
2	125	128
3	125	128
4	125	128
5	125	128
6	16	2
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
Present value (for lifetime)	467	466
Annualised	105	105
Additional annualised		-0.1

Total costs and compliance costs

Table A5b-10 presents the calculations of total costs of mercury-containing thermometers and the alternative device. The results in the table above can be obtained by the addition of the investment and recurring costs presented in Tables A5b-8 and A5b-9.

Table A5b-10: Annualised total costs per device (in 2010 price level) – Mercury-in-glass lab thermometers (>200°C)

Year	Total costs (€) per device	
	Baseline: Mercury-in-glass Thermometer	Alternative: Electronic
Present value (for lifetime)	547	579
Average lifetime (years)	5	5
Annualised	123	125
Additional annualised		1.8

When taking into account the replacement ratio of the probe and the data reader, the shorter lifespan and the higher investment costs of the alternative result in annualised cost of €2 per device.

Table A5b-11 presents the compliance costs from replacing the mercury-in-glass lab thermometer with an electronic thermometer. The calculations are made assuming 5% annual decrease in the number of mercury-containing thermometers sold per year in the next 20 years, i.e. approximately 44,900 devices in 2024.

Table A5b-11: Annualised and present value compliance costs (in 2010 price level) – Mercury-in-glass lab thermometers (>200°C)

	Compliance costs (€) Alternative: Electronic
2015	128,276
2016	250,443
2017	366,792
2018	477,602
2019	583,134
2020	555,366
2021	528,920
2022	503,733
2023	479,746
2024	456,901
2025	435,144
2026	414,423
2027	394,688
2028	375,894
2029	357,994
2030	340,946
2031	324,711
2032	309,249
2033	294,522
2034	280,498
Compliance cost (present value 2015-2034)	5,602,231
Annualised compliance cost (2024)	456,901

The present value compliance costs for 2015-2034 are estimated at close to €5.6 million and the annualised compliance costs (2024) at approximately €457 thousand.

5.1.2.3. Cost effectiveness

As the alternatives have higher investment costs, reducing the marketed volume of mercury by 1kg when replacing mercury lab thermometers with electronic thermometers results in compliance costs of approximately €2,630. The calculation is based on the present value compliance costs and on the assumption that one mercury thermometer contains 3.5g of mercury. It is important to note that due to the additional features of the electronic thermometers (such as automatic data-logging, alarm, etc.), the mercury and electronic alternatives are not completely comparable, and that the compliance cost might be slightly overestimated because this factor is not quantified.

Table A5b-12 presents a summary of the main results of the compliance cost calculations associated with the transition from mercury-in-glass lab thermometers (>200°C) to an electronic alternative.

Table A5b-12: Cost effectiveness of replacing the mercury thermometers (in 2010 price level) – Mercury-in-glass lab thermometers (>200°C)

Main assumptions for device			
Devices per year (2010)		88,900	number
Trend		-5%	per year
Amount of mercury per device		0.0035	kgs
Lifetime of device (probe)		5	years
Costs (€)		Baseline: Mercury-in-glass Thermometer	Alternative: Electronic (probe)
Investment cost	Annualised	18	20
Recurrent cost	Annualised	105	105
Total cost	Annualised	123	125
Additional total cost	Annualised		1.8
Cost effectiveness	Annualised		526
Cost effectiveness	per lifetime of device		2,631
Compliance cost	2024		456,901
Compliance cost	total		5,602,231

It is important to note that the analysis above does not take into account the need to use mercury devices to meet requirements set in certain standards.

5.1.2.4. Sensitivity analysis

The mercury content of high precision lab thermometers can range between 1 and 20g (Lassen et al. 2008). Assuming a higher average mercury content for lab thermometers in this market segment – 11g (Lassen et al., 2010), the costs of reducing the volume of mercury placed on the EU market will be three times lower or €840 per

kg (see also section 2 of this annex). The total compliance costs under this scenario will remain the same as in the central case.

When relaxing the central case assumptions for the replacement ratio, i.e., assuming a one-to-one relationship between the mercury thermometer and the probe and data reader of the electronic thermometer, the costs of reducing the marketed volume of mercury can reach €88,130 per kg. The total compliance costs are €187.7 million (NPV) and €15.3 million (2024 on annualised basis). The plausibility of this scenario is difficult to assess due to lack of information of the replacement rate of mercury thermometers with electronic alternatives.

Depending on the size of this market segment (based on central case assumptions), the total compliance costs can range (on NPV basis) from €4.2 million (assuming that this market segment represents 60% of all mercury-in-glass lab thermometers or 66,600 devices as of 2010) to €7 million, assuming that this market segment represents 100% of all lab mercury-in-glass thermometers (111,100 devices as of 2010). Under this scenario, as of 2024, on representative year basis, the total compliance costs will range from €342 thousand to €571 thousand. The cost effectiveness under these scenarios will remain the same, as this measure is not impacted by the number of devices on the market.

5.1.3. Mercury thermometers used in meteorological applications

As stated in section 3.4 of Annex 5a, mercury-in-glass thermometers for ambient air temperature measurements (including for min/max measurements) are almost fully substituted by liquid-in-glass thermometers or, where additional accuracy and features (e.g., remote reader) are desired, by electronic thermometers.⁷⁹ Similarly, electronic and liquid-filled alternatives to psychrometers with mercury thermometers dominate the market. Psychrometers represent a small market segment of the mercury market: the mercury volume in psychrometers placed on the EU-market is estimated at 0.01-0.1 tonnes in 2007 (Lassen et al., 2008). A proportion of psychrometers may require higher accuracy. These are considered to be included in the assessment for mercury-in-glass lab thermometers with resolution better than 0.1°C or for temperatures >200°C.

Because the residual market is thought to be very limited, detailed information for this market segment was not gathered; and therefore, no compliance cost calculations could be prepared. However, the transition from the mercury-containing ambient thermometers for meteorological applications is expected to result in additional annualised savings because:

- the price of the liquid-in-glass alternatives for ambient temperature measurement is similar to the mercury-containing thermometers (when no resolution <0.1°C needed);
- Six's thermometers with organic liquids are available at similar or lower prices than the mercury filled counterparts (Lassen et al., 2010);

⁷⁹ This is also true for hydrometers that have a mercury thermometer inside.

- electronic or spirit-filled psychrometers are available for most applications at approximately the same price as mercury psychrometers (Lassen et al., 2010);
- it costs less to dispose of a mercury-free device at the end of its useful life;
- the calibration frequency and costs of the mercury and liquid-in-glass devices are similar; and
- the lifetime of the mercury and liquid-in-glass devices is similar.

For the purpose of exploring restriction options, the meteorological applications are included in the laboratory assessment.

5.2. Mercury-in-glass industrial thermometers

5.2.1. Mercury-in-glass industrial thermometers (<200°C)

5.2.1.1. Introduction

This section discusses thermometers measuring temperature typically from -58°C to up to 200°C, i.e., generic thermometers which do not require certification and high precision. For the purpose of this analysis it is assumed that the price of the mercury-in-glass industrial thermometers (<200°C) is about half of the industrial thermometers (>200°C) to reflect the lower temperature range (and lower level of protection needed in the form of high quality encasings, which is included in the price of the industrial thermometers for above 200°C). Assuming 3.5g of mercury content for thermometers in this market segment, it is estimated that there are approximately 22,200 thermometers in the EU in 2010 (20% of the total number of mercury-in-glass industry thermometers).

The liquid-in-glass thermometers can directly replace mercury thermometers to measure temperature in industrial processes where high temperature and accuracy are not a requirement. Their price is roughly the same as for mercury thermometers or about 10% lower (Lassen et al., 2010). Mercury-free liquid-in-glass thermometers are not suitable for accurate measurements at better than 0.1°C resolution, but in industrial processes it is generally not necessary to measure the temperature at this high resolution (Lassen et al., 2010).

Other thermometers that can replace mercury devices in this market segment include electronic thermometers and gallium-containing thermometers. These thermometers command higher prices (up to 10-times the price of mercury thermometers) due to their additional features such as data logger (for electronic thermometers) or broader temperature range (gallium thermometers). Therefore, for the purposes of evaluating the cost effectiveness of substituting the mercury-in-glass industrial thermometers measuring temperature below 200°C, only the cheapest alternative, being the liquid-in-glass thermometers are considered. If more expensive electronic thermometers are used as replacement, it is assumed that this would be because of their advantages of automatic reading and other features not directly applicable to mercury-containing devices.

The Table A5b-13 presents the input data used in the analysis.

Table 5b-13: Input data – Mercury-in-glass industrial thermometers (<200°C)

Parameter	Device	Central case
Discount rate		4%
Mercury devices sold per year 2010		22,200
Annual decrease in number of devices sold		5%
Mercury per device (kg)		0.0035
Average lifetime (years)	Mercury	13
	Liquid-in-glass	13
Investment cost (price of device)	Mercury	€ 23
	Liquid-in-glass	€ 23
Calibration costs (per calibration)	Mercury	€ 125
	Liquid-in-glass	€ 125
Calibration frequency (once in <i>x</i> years)	Mercury	4
	Liquid-in-glass	4
Batteries (per year)	Mercury	€ 0
	Liquid-in-glass	€ 0
Waste treatment (per device)	Mercury	€ 16
	Liquid-in-glass	€ 2

Investment costs

Table A5b-14 presents the investment costs of the mercury-in-glass industrial thermometer (<200°C) and the lowest cost alternative: liquid-in-glass thermometers.

Table A5b-14: Annualised investment costs per device (in 2010 price level) – Mercury-in-glass industrial thermometers (<200°C)

Year	Total Investment costs (€) per device	
	Baseline: Mercury-in-glass Industrial Thermometer	Alternative: Liquid-in-glass Thermometer
Investment costs	23	23
Present value (for lifetime)	23	23
Average lifetime (years)	15	15
Annualised	2	2
Additional annualised		0

As the price of the alternative is the same as the mercury-in-glass thermometer, the transition to the alternative results in no additional annualised investment costs per device.

Recurrent costs

Table A5b-15 presents the recurrent costs of the mercury-in-glass industrial thermometer (<200°C) and the lowest cost alternative: liquid-in-glass thermometers. The lower waste disposal costs of the alternative result in small savings per device of an estimated €0.80 annually.

Table A5b-15: Annualised recurrent costs per device (in 2010 price level) – Mercury-in-glass industrial thermometers (<200°C)

Year	Recurrent costs (€) per device	
	Baseline: Mercury-in-glass Industrial Thermometer	Alternative 1: Liquid-in-glass Thermometer
1	0	0
2	0	0
3	0	0
4	0	0
5	125	125
6	0	0
7	0	0
8	0	0
9	125	125
10	0	0
11	0	0
12	0	0
13	125	125
14	16	2
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
Present value (for lifetime)	286	277
Annualised	29	27.8
Additional annualised		-0.8

Total costs and compliance costs

Table A5b-16 presents the calculations of total costs of mercury-containing thermometers and the alternative device for this industry segment (<200°C). The results in the table can be obtained by the addition of the investment and recurring costs presented in Tables A5b-14 and A5b-15.

Table A5b-16: Annualised total costs per device (in 2010 price level) – Mercury-in-glass industrial thermometers (<200°C)

Year	Total costs (€) per device	
	Baseline: Mercury-in-glass Industrial Thermometer	Alternative 1: Liquid-in-glass Thermometer
Present value (for lifetime)	308	300
Average lifetime (years)	15	15
Annualised	30.9	30.0
Additional annualised		-0.8

The additional annualised savings per device is estimated to be €0.80 compared to the mercury-containing device.

Table A5b-17 presents the compliance costs from replacing the mercury-in-glass industrial thermometer with a liquid-in-glass thermometer. The results are based on the assumption that this market segment represents 20% of the industrial mercury-in-glass thermometers, i.e. 11,200 in 2024, assuming 5% annual decline of mercury thermometers on the market.

Table A5b-17: Annualised and present value compliance costs (in 2010 price level) – Mercury-in-glass industrial thermometers (<200°C)

	Compliance costs (€)
	Alternative: Liquid-in-glass Thermometer
2015	-14646
2016	-28595
2017	-41879
2018	-54531
2019	-66581
2020	-78057
2021	-88986
2022	-99395
2023	-109308
2024	-118749
2025	-127740
2026	-136304
2027	-144459
2028	-137580
2029	-131029
2030	-124789
2031	-118847
2032	-113188
2033	-107798
2034	-102664
Compliance cost (present value 2015-2034)	-1,275,721
Annualised compliance cost (2024)	-118,749

The compliance cost savings of replacing the mercury-filled with the mercury-free alternative over the study period is close to €1.3 million (NPV) or €119 thousand as of 2024 on the representative year basis.

A tendency to replace the mercury containing thermometers with liquid-in-glass alternatives is already observed on the market (Lassen et al., 2008). The reasons for continued use of the mercury containing thermometers can be explained with perceived higher level of quality of the mercury thermometers (trusted, time tested method of measuring temperature) or customers' failure to take into account the long-term (recurrent) costs associated with the use of mercury thermometers.

5.2.1.2. Cost effectiveness

As the alternative has lower recurring costs, reducing the volume of mercury placed on the EU market by 1kg when replacing mercury industrial thermometers with liquid-in-glass thermometers results in cost savings of approximately €3,130. The calculation is based on the present value compliance costs and on the assumption that one mercury thermometer contains 3.5g of mercury.

Table A5b-18 presents a summary of the compliance cost calculations associated with the transition from mercury-in-glass thermometers (<200°C) to liquid-in-glass thermometers.

Table A5b-18: Cost effectiveness of replacing the mercury thermometers (in 2010 price level) – Mercury-in-glass industrial thermometers (<200°C)

Main assumptions for device			
Devices per year (2010)		22,200	number
Trend		-5%	per year
Amount of mercury per device		0.0035	kgs
Lifetime of device		13	years
Costs (€)		Baseline: Mercury-in-glass Industrial Thermometer	Alternative 1: Liquid-in-glass Thermometer
Investment cost	annualised	2	2
Recurrent cost	annualised	29	28
Total cost	annualised	31	30
Additional total cost	annualised		-0.8
Cost effectiveness	annualised		-241
Cost effectiveness	per lifetime of device		-3,127
Compliance cost	2024		-118,749
Compliance cost	total		-1,275,721

It is important to note that the analysis above does not take into account the need to use mercury devices to meet requirements set in certain standards.

5.2.1.3. Sensitivity analysis

If waste treatment costs are ignored in the cost calculations, the transition from a mercury-in-glass industrial thermometer to the liquid-in-glass alternative for measuring temperature up to 200°C is cost neutral, i.e., total compliance costs and the cost effectiveness will be zero.

If we assume that the price of the liquid-in-glass alternatives is approximately 10% lower than the mercury containing device (Lassen et al., 2010), the transition to the alternative will result in higher cost savings: €3,960 per 1kg of mercury (cost effectiveness) or a total compliance savings of €1.6 million (NPV) or €150.5 thousand (as of 2024).

Depending on the size of this market segment, the total compliance savings range (on NPV basis) from €0 (assuming that all industrial thermometers are used to measure temperature above 200°C) to €2.6 million or €237.5 thousand as of 2024 on a representative year basis when it is assumed that this market segment represents 40% of all industrial mercury-in-glass thermometers (44,400 devices as of 2010).

5.2.2. Mercury-in-glass industrial thermometers (>200°C)

5.2.2.1. Introduction

A number of mercury-in-glass thermometers are used to measure temperature in industrial processes. The technical requirements include high temperature measurements (up to 800°C), endurance to aggressive environments, and certification requirements for quality management (related to standards and calibration).

The mercury content of the industrial thermometers ranges from about 1 to 20 g with an average content of 3-4 g (Lassen et al. 2008). Assuming mercury content of 3.5g per thermometer, it is estimated that in the European Union, in 2010 there are approximately 88,900 mercury-in-glass thermometers in this market segment (assuming the segment represents 80% of total mercury-in-glass industrial thermometers). The impact of this assumption on the compliance cost calculations is tested in the sensitivity analysis.

The price of a typical mercury thermometer for industry in this segment is reported to be €30 - 60 (Lassen et al., 2010) inclusive of the casing for the thermometer. The mid-point is selected for the purpose of this analysis.

There are a number of technically feasible alternatives that have replaced mercury-in-glass thermometers for the temperature range above 200°C. The analysis focuses on two technically feasible alternatives: mechanical (liquid- or gas-filled or bi-metal dial) thermometers and electronic thermometers (thermocouples).

Producers of mercury thermometers have indicated that the prices of the mechanical (dial) thermometers are typically 3-5 times the price of the mercury thermometer. Other data shows that the price of the dial thermometers replacing the assumed typical industrial thermometer (>200°C) ranges between €100 and €150 (Lassen et al., 2010).⁸⁰ The mid-point is selected as the price of a typical dial replacement for the purpose of this analysis.

Thermocouples are three to five times more expensive and require additional data readers, which costs three to four times the price of the mercury thermometers (Lassen et al. 2008). The analysis assumes an average price for electronic alternatives of €175. Their higher prices are partially attributable to additional features such as data logging, possibilities for remote reading, real-time monitoring and feedback mechanisms, alarm systems, etc. No data have been available by which it can be

⁸⁰ This is consistent with the estimate that prices of the electronic alternatives are three to five times higher than the mercury containing device.

estimated how the price of the data acquisition systems can be allocated to the individual thermometers (Lassen et al., 2010). To obtain such data extensive market surveys need to be conducted. Therefore, taking into account that several probes and other inputs such as pressure gauges can be connected to one data reader, a replacement ratio of 2:1 is used in the central case for the data reader. This replacement ratio is not applied to the probes as in most if not all circumstances they are installed in equipment.

In addition, it is generally known that the life of the probe is shorter than for the rest of the system, as the probes are often placed in more harsh environments (vibration, temperature, humidity, corrosive gases, etc.) (Lassen et al., 2010). As no specific information is available, for the purpose of the analysis, it is assumed that the lifetime of the data reader is twice as long as that of the probes.

Table A5b-19 below presents the input data used in the compliance costs calculations associated with the transition from mercury industrial thermometers to mercury-free dial thermometers and thermocouples.

Table 5b.19: Input data used in the analysis – Mercury-in-glass industrial thermometers (>200°C)

Parameter	Device	Central case
Discount rate		4%
Mercury devices sold per year 2010		88,900
Annual decrease in number of devices sold		5%
Mercury per device (kg)		0.0035
Average lifetime (years)	Mercury	13
	Dial	3
	Electronic	5
Investment cost (price of device)	Mercury	€ 45
	Dial	€ 125
	Electronic	€ 93
Investment cost (price of data reader)	Mercury	€ 0
	Dial	€ 0
	Electronic	€ 82
Calibration costs (per calibration)	Mercury	€ 125
	Dial	€ 125
	Electronic	€ 125
Calibration frequency (once in x years)	Mercury	4
	Dial	1
	Electronic	1
Batteries (per year)	Mercury	€ 0
	Dial	€ 0
	Electronic	€ 3
Waste treatment (per device)	Mercury	€ 16
	Dial	€ 2
	Electronic	€ 2
Average lifetime per data reader (years)	Mercury	0
	Dial	0
	Electronic	10
Replacement (Hg : electronic data reader)		2:1

5.2.2.2. Cost calculations

Investment costs

Table A5b-20 presents the calculation of investment costs of mercury-in-glass industrial thermometers (>200°C) and two alternative devices.

Table A5b-20 Annualised investment costs per device (in 2010 price level) – Mercury-in-glass industrial thermometers (>200°C)

Year	Total Investment costs (€) per device		
	Baseline: Mercury-in-glass Thermometer	Alternative 1: Mercury-free Dial Thermometer	Alternative 2: Electronic (probe & data reader)
Investment costs	45	125	134
Average lifetime (years)	13	3	5
Annualised	5	45	26
Additional annualised		40.5	21.5

Due to the shorter lifetime and higher price compared to the mercury-containing device, the additional annualised investment cost for the alternatives are estimated to be €41 for Alternative 1 and €21 for Alternative 2.

Recurrent costs

Table A5b-21 presents the calculations of recurrent costs for different devices. The values of different parameters of recurrent costs are listed in Table A5b-19. The more frequent calibrations and shorter lifespan of the alternatives result in higher recurrent costs in comparison to the mercury thermometer: additional annualised costs per device of €57 for Alternative 1 and €76 for Alternative 2.

Table A5b-21: Annualised recurrent costs per device (in 2010 price level) – Mercury-in-glass industrial thermometers (>200°C)

Year	Recurrent costs (€) per device		
	Baseline: Mercury-in-glass Thermometer	Alternative 1: Mercury-free Dial Thermometer	Alternative 2: Electronic
1	0	0	0
2	0	125	128
3	0	125	128
4	0	2	128
5	125	0	128
6	0	0	2
7	0	0	0
8	0	0	0
9	125	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	125	0	0
14	16	0	0
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0
21	0	0	0
Present value (for lifetime)	286	238	466
Annualised	29	86	105
Additional annualised		57	76

Total costs and compliance costs

Table 5b.22 presents the calculations of total costs of mercury-containing thermometers and the two alternative devices. The results in the table above can be obtained by the addition of the investment and recurring costs presented in Tables A5b-20 and A5b-21.

The more frequent calibrations, shorter lifespan and higher investment costs of the alternatives result in additional annualised costs per device in comparison to the mercury-containing device: respectively €97.50 for Alternative 1 and €97.60 for Alternative 2.

Table A5b-22 Annualised total costs per device (in 2010 price level) – Mercury-in-glass industrial thermometers (>200°C)

Year	Total costs (€) per device		
	Baseline: Mercury-in-glass Thermometer	Alternative 1: Mercury-free Dial Thermometer	Alternative 2: Electronic
Present value (for lifetime)	331	363	600
Average lifetime (years)	13	3	5
Annualised	33.1	130.6	130.7
Additional annualised		97.5	97.6

Table A5b-23 presents the compliance costs from replacing the mercury dial thermometer with the mercury-free dial or electronic alternative as described above.

Table 5b-23: Annualised and present value compliance costs (in 2010 price level) – Mercury-in-glass industrial thermometers (>200°C)

	Compliance costs (€)	
	Alternative 1: Mercury-free Dial Thermometer	Alternative 2: Electronic
2015	6791832	6798510
2016	13260244	13273281
2017	19420637	19439730
2018	25287677	25312539
2019	30875334	30905690
2020	36196913	36232500
2021	41265083	41305653
2022	46091911	46137227
2023	50688891	50738726
2024	55066966	55121106
2025	59236562	59294801
2026	63207606	63269749
2027	66989552	67055414
2028	63799574	63862299
2029	60761499	60821237
2030	57868094	57924988
2031	55112471	55166655
2032	52488067	52539671
2033	49988635	50037782
2034	47608224	47655031
Compliance cost (present value 2015- 2034)	591,585,833	592,167,456
Annualised compliance cost (2024)	55,066,966	55,121,106

Assuming that 88,900 new mercury containing industrial thermometers are placed on the market in 2010 (with 5% annual rate of decline), the present value of the compliance costs for the period 2015-2034 are estimated to range between €591.6 million and €592.2 million and on annualised compliance costs (2024) basis between close to €55.07 million and €55.12 million depending on whether the mercury thermometer is replaced exclusively with Alternative 1 or Alternative 2.

Further on, the analysis assumes that 100% of the mercury-containing thermometers will be replaced with the slightly cheaper alternative - the mercury-free dial thermometer, even though in reality some of the users would replace the mercury thermometer with mercury-free dial thermometer, some with electronic devices and some with alternatives not covered in this analysis. In fact, it is thought that users will in most circumstances prefer the electronic alternative because of the low price difference between the two alternatives in combination with the additional features the electronic alternative offers (such as automation).

5.2.2.3. Cost effectiveness

As the alternatives have higher investment costs, reducing the volume of mercury placed on the EU market by 1kg when replacing mercury industrial thermometers (>200°C) with mercury-free dial thermometers results in compliance costs of close to €362,200. The calculation is based on the present value compliance costs and on the assumption that one mercury thermometer contains 3.5g of mercury and 100% of the mercury-containing thermometers will be replaced with the slightly cheaper alternative: the mercury-free dial thermometer.

Table A5b-24 presents a summary of the main results of the compliance cost calculations associated with the transition from mercury-in-glass industrial thermometers (>200°C) to a mercury-free dial thermometers.

It is important to note that the analysis above does not take into account additional benefits from the use of more accurate (electronic) alternatives. The use of these alternatives can be associated with additional cost savings in industrial applications, e.g., lower operating costs due to the use of less energy to, for example, heat large industrial volumes to a certain temperature. Another example is labour cost savings due to automation of data reading. Due to the difficulty of their estimation on industry-wide basis, these benefits are not taken into account in the costs calculations. However, the benefits of these additional features could explain the penetration of the alternatives in the market (see also the sensitivity analysis).⁸¹

⁸¹ Lassen et al. (2008) estimated that the alternatives dominate the mercury-in-glass industrial market but that the latter also have a significant market share. The report also notes that there are certain applications where mercury is difficult to substitute.

Table A5b-24 Cost effectiveness of replacing the mercury thermometers (in 2010 price level) – Mercury-in-glass industrial thermometers (>200°C)

Main assumptions for device				
Devices per year (2010)		88,900		number
Trend			-5%	per year
Amount of mercury per device			0.0035	kgs
Lifetime of device			13	years
Costs (€)		Baseline: Mercury-in- glass Thermometer	Alternative 1: Mercury-free Dial Thermometer	Alternative 2: Electronic (probe)
Investment cost	annualised	5	45	26
Recurrent cost	annualised	29	86	105
Total cost	annualised	33	131	131
Additional total cost	annualised		97.5	97.6
Cost effectiveness	annualised		27,859	27,886
Cost effectiveness	per lifetime of device		362,165	362,522
Compliance cost	2024		55,066,966	55,121,106
Compliance cost	total		591,585,833	592,167,456

5.2.2.4. Sensitivity analysis

Calculating a “break-even” point for the use of industrial thermometers

In the calculations behind table 5b-24 it has been assumed that electronic measuring devices would not imply any changes in labour or other operating costs (apart from calibration costs and waste treatment costs). However, electronic devices may induce savings in labour input. To analyse this, a “break-even” point has been calculated as sensitivity analysis. This has been estimated as follows:

- the cost of replacing one mercury industrial thermometer is approximately €97.6 per year (see Table 5b-24);
- assuming that electronic measuring would reduce the need to monitor the thermometer (as the thermometer could e.g. alert automatically or store the data and thus, would need less frequent monitoring);
- assuming an average salary (with company overhead) of €20/hour.

The “break-even” point of using an electronic thermometer would be if the employer would save 5 hours of work per year (although, it should be noted that beside possible labour cost savings, there might be several other advantages of electronic thermometers that could impact company costs). For any company that saved this amount of work, replacing mercury containing devices with electronic alternatives would reduce its overall costs. This sensitivity analysis demonstrates that it is not only the cost of the alternative device (as calculated in Table 5b-24) and the mercury

content of the thermometer that matters. From a company point of view it is the overall cost of measurement that is important.

It is not known how relevant and important the labour (or other operating cost) savings of electronic thermometers would be in industrial applications. For instance, monitoring might take place during other operations and thus, there might be no saving of labour costs due to electronic measurement. Due to these difficulties, these savings have not been taken into account in the compliance cost calculations. However, it seems prudent to conclude that the additional compliance cost of €97.6 per year estimated in Table 5b-24 is an upper limit of the compliance costs. Therefore, the cost of €362,165 /kg Hg is also an upper limit.

Relaxing the assumption of replacement ratio

Relaxing the replacement ratio assumption (of 2:1) for the data reader of the thermocouple does not change the cost effectiveness and total compliance costs for the transition from mercury-in-glass industrial thermometers (>200°C) to alternatives, as the analysis assumes that the mercury devices are replaced with the slightly cheaper alternative: mercury-free dial thermometers to which the replacement ratio does not apply.

Relaxing the assumption for market size

Depending on the size of this market segment, the total compliance costs can range from €443.2 million (assuming that this market segment represents 60% of all industrial thermometers or 21,200 devices as of 2010) to €739.3 million on NPV basis when it is assumed that this market segment represents 100% of all industrial mercury-in-glass thermometers (111,100 devices as of 2010). Under this scenario, as of 2024, on representative year basis, the total compliance costs will range from €41.3 thousand to €68.8 million. The cost effectiveness under these scenarios will remain the same as it is not impacted by the number of devices on the market.

Relaxing the assumption for calibration

During the data gathering stage of preparation of the Annex XV restriction report, it was noted that some users do not follow the recommended frequency of calibrations. Assuming that there are no calibration costs for the mercury-in-glass and the cheaper alternative (dial thermometer), the cost effectiveness is lower by 2.5 times or €149,000 per kg mercury.

5.3. Mercury dial thermometers

5.3.1. Introduction

The mercury content of dial thermometers depends largely on whether the dial thermometer is of the “rigid” or “remote” type (whether it has a capillary or not). It can range from about 5g to 200g (Lassen et al. 2008). Between 0.1 and 0.3 tonnes/year of mercury was used in mercury dial thermometers for the European market in 2007. For the purpose of this analysis, the mid-point in these ranges are taken, i.e., 102.5g of mercury per thermometer or 150kg of mercury used in mercury dial thermometers for the EU-market in 2010 (assuming 5% annual decline in volume).

A number of bi-metal and liquid- and gas-actuated dial thermometers are available as alternatives to mercury dial thermometers (Lassen et al. 2008). Other technically feasible alternatives include electronic thermometers such as thermocouples and RTDs (resistance temperature device). From the available information, there is no indication that liquid-in-glass thermometers would be alternatives to the dial thermometers for measurement below 200°C⁸². Taking into account that several probes and other inputs such as pressure gauges can be connected to one data reader, a replacement ratio of 2:1 is used in the central case for the data reader, similar to the industrial mercury-in-glass thermometers (>200°C). This replacement ratio is not applied to the probes as in most if not all circumstances they are installed in equipment. In addition, it is assumed that the lifetime of the data readers of the electronic devices is twice as long as that of the probes.

The Table A5b-25 below presents the input data used in the compliance costs calculations associated with the transition from mercury dial thermometers to mercury-free dial thermometers and thermocouples. As no specific pricing information is available for mercury dial thermometers, it is assumed that these thermometers and their alternatives will have similar costs as the mercury-in-glass industrial thermometers (>200°C).

⁸²Lassen et al. 2008 report (Table 2-23) suggests that liquid-in-glass thermometers are not used as replacements for mercury dial thermometers. However, it cannot be entirely excluded that in some applications liquid-in-glass thermometers might be replacements for dial thermometers for temperature measurements <200°C. Given the small market size of this segment and the almost full replacement of the mercury dial thermometers (Lassen et al., 2008), the analysis assumes that if a substitution with liquid-in-glass was possible it was already adopted by users. Therefore, for the purpose of this analysis, we examine the transition from mercury dial thermometers to mercury-free dial thermometers and thermocouples.

Table 5b-25: Input data used in the analysis – Mercury dial thermometers

Parameter	Device	Central case
Discount rate		4%
Mercury devices sold per year 2010		1,700
Annual decrease in number of devices sold		5%
Mercury per device (kg)		0.1025
Average lifetime (years)	Mercury	13
	Dial	3
	Thermocouple	5
Investment cost (price of device)	Mercury	€ 45
	Dial	€ 125
	Thermocouple (probe)	€ 93
Investment cost (price of data reader)	Mercury	€ 0
	Dial	€ 0
	Thermocouple	€ 82
Calibration costs (per calibration)	Mercury	€ 125
	Dial	€ 125
	Thermocouple	€ 125
Calibration frequency (once in x years)	Mercury	4
	Dial	1
	Thermocouple	1
Batteries (per year)	Mercury	€ 0
	Dial	€ 0
	Thermocouple	€ 3
Waste treatment (per device)	Mercury	€ 16
	Dial	€ 2
	Thermocouple	€ 2
Average lifetime per data reader (years)	Mercury	0
	Dial	0
	Thermocouple	16
Replacement (Hg : electronic)		2:1

5.3.2. Cost calculations

Investment costs

Table A5b-26 presents the calculation of investment costs of mercury-containing dial thermometers and two alternative devices.

Due to their assumed shorter lifetime (respectively three and five years) and higher price compared to mercury-containing devices, the additional annualised investment cost is estimated to be €40.5 for Alternative 1 and €21.5 for Alternative 2.

Table A5b-26: Annualised investment costs per device (in 2010 price level) – Mercury dial thermometers

Year	Total Investment costs (€) per device		
	Baseline: Mercury Dial Thermometer	Alternative 1: Mercury-free Dial Thermometer	Alternative 2: Thermocouple (probe & data reader)
Investment Cost	45	125	134
Average lifetime (years)	13	3	5
Annualised	5	45	26
Additional annualised		40.5	21.5

Recurrent costs

Table A5b-27 presents the calculations of recurrent costs for the three devices.

Table A5b-27 Annualised recurrent costs per device (in 2010 price level) – Mercury dial thermometers

Year	Recurrent costs (€) per device		
	Baseline: Mercury Dial Thermometer	Alternative 1: Mercury-free Dial Thermometer	Alternative 2: Thermocouple
1	0	0	0
2	0	125	128
3	0	125	128
4	0	2	128
5	125	0	128
6	0	0	2
7	0	0	0
8	0	0	0
9	125	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	125	0	0
14	16	0	0
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0
21	0	0	0
Present value (for lifetime)	286	238	466
Annualised	29	86	105
Additional annualised		57	76

The values of different parameters of recurrent costs are listed in Table A5b-25. The more frequent calibration and shorter lifespan of the alternatives result in higher additional recurrent costs in comparison to the mercury dial thermometer: an estimated €57 for Alternative 1 and €76 for Alternative 2.

Total costs and compliance costs

Table A5b-28 presents the calculations of total costs of the mercury dial thermometers and the two alternative devices.

Table A5b-28 Annualised total costs per device (in 2010 price level) – Mercury dial thermometers

Year	Total costs (€) per device		
	Baseline: Mercury Dial Thermometer	Alternative 1: Mercury-free Dial Thermometer	Alternative 2: Thermocouple
Present value (for lifetime)	331	363	600
Average lifetime (years)	13	3	5
Annualised	33	131	131
Additional annualised		97.5	97.6

The assumed more frequent calibration, shorter lifespan and higher investment costs of the alternatives result in additional annualised costs per device in comparison to the mercury-containing device: respectively €97.5 for Alternative 1 and €97.6 for Alternative 2. These results can be derived from Tables A5b-26 and A5b-27 as sums of additional investment and recurrent costs.

Table A5b-29 presents the compliance costs from replacing the mercury dial thermometer with alternatives as described above.

The present value compliance costs for 2015-2034 are estimated to be between €11.31 million and €11.32 million depending on whether all mercury dial thermometers are replaced only by Alternative 1 or Alternative 2. In reality some of the users would replace the mercury dial thermometer with a mercury-free dial thermometer, some with electronic devices and some with alternatives not covered in this analysis.

Further on this analysis assumes that 100% of mercury dial users will replace the devices with the cheaper alternative – the mercury-free dial whose recurrent cost are slightly lower than those of thermocouple.

Table A5b-29 Annualised and present value compliance costs (2010 price level) – Mercury dial thermometers

	Compliance costs (€)	
	Alternative 1: Mercury-free Dial Thermometer	Alternative 2: Thermocouple
2015	129878	130005
2016	253570	253820
2017	371373	371738
2018	483566	484042
2019	590417	590997
2020	692179	692860
2021	789096	789872
2022	881398	882264
2023	969304	970257
2024	1053024	1054059
2025	1132758	1133871
2026	1208694	1209883
2027	1281015	1282275
2028	1220014	1221214
2029	1161918	1163061
2030	1106589	1107677
2031	1053894	1054930
2032	1003709	1004696
2033	955913	956853
2034	910393	911289
Compliance cost (present value 2015-2034)	11,312,665	11,323,787
Annualised compliance cost (2024)	1,053,024	1,054,059

5.3.3. Cost effectiveness

As the alternative has higher annualised costs, reducing the use of mercury by 1kg when replacing mercury dial thermometers with thermocouples results in compliance costs of approximately €12,370. The calculation is based on the present value compliance costs and on the assumption that one mercury dial thermometer contains 102.5 g of mercury.

Table A5b-30 presents a summary of the main results of the compliance cost calculations associated with the transition from mercury dial to mercury-free dial thermometers.

Table A5b-30 Cost effectiveness of replacing the mercury thermometers (in 2010 price level) – Mercury dial thermometers

Main assumptions for device				
Devices per year (2010)		1,700		number
Trend			-5%	per year
Amount of mercury per device			0.1025	grams
Lifetime of device			13	years
Costs (€)		Baseline: Mercury Dial Thermometer	Alternative 1: Mercury-free Dial Thermometer	Alternative 2: Thermoco uple (probe)
Investment cost	annualised	5	45	26
Recurrent cost	annualised	29	86	105
Total cost	annualised	33	131	131
Additional total cost	annualised		98	98
Cost effectiveness	annualised		951	952
Cost effectiveness	per lifetime of device		12,367	12,379
Compliance cost	2024		1,053,024	1,054,059
Compliance cost	total		11,312,665	11,323,787

5.3.4. Sensitivity analysis

In the absence of information, the assessment used a conservative estimate of a lifetime of 13 years for mercury dial thermometers vs. three years for gas or liquid-actuated dial alternatives, and a yearly calibration of the alternatives vs. once every 4 years for the mercury dial thermometer. It appears, however, that the technology is not very different, and the lifetimes and calibration frequencies might be equal or similar of the mercury and gas- or liquid-actuated thermometers. Assuming that the mercury dial thermometers have the same lifetime and calibration frequency as their gas-actuated alternative systems, the cost effectiveness is lower by 94% or €710. The total compliance costs are also much lower as under this scenario mercury dial thermometers have higher annualised total costs per device (€106) and due to the early retirement of the mercury thermometers. They are €0.9 million (NPV) or €66 thousand on a representative year basis (2024).

The assumption of an annual decrease of 5% of the thermometer market might be conservative, as according to the manufacturers of mercury dial thermometers, there is a very limited remaining market (see section 3.4). Assuming a faster replacement of mercury dial thermometers of 10% annually, the total compliance costs are more than five times lower than the central case scenario: €2.2 million (NPV) or €144 thousand on a representative year basis (2024).

Relaxing the replacement ratio assumption (of 2:1), i.e., no replacement ratio, for the data reader of the thermocouple, will result in an increase of the annualised investment cost of the alternative. Under this assumption, the mercury-free dial will remain the cheaper alternative; therefore, the total compliance costs will remain as presented in Table 5b-29.

During the data gathering stage of preparation of the Annex XV restriction report, it was noted that some users do not follow the recommended frequency of calibrations. Assuming that there are no calibration costs for the thermocouple and the cheaper alternative (mercury-free dial), the cost effectiveness of decreasing the volume of mercury placed on the EU-market by 1kg is 60% lower or €5,100. Total compliance costs under this scenario are €1.5 million (NPV) or €109 thousand on a representative year basis (2024).

6. Summary

Table A5b-31 presents a summary of the main results of the compliance cost calculations associated with the transition from mercury-containing thermometers to feasible alternatives.

Table A5b-31 Cost effectiveness and total compliance costs related to the transition from mercury-containing thermometers to feasible alternatives (in 2010 price level)⁸³

Thermometer Market Segment	Mercury volume in 2010 (kg)	Estimated cost Effectiveness (€/kg)	Total Compliance Cost for 2024 (€)
Industry (T<200°C)	80	-3,100	-118,700
Industry (T>200°C)	310	362,200	55,067,000
Industry - total	390		54,948,300
Lab (>0.1°C res T<200°C)	80	-3,700	-160,100
Lab (<0.1°C res or T>200°C)	310	2,600	456,900
Lab - total	390		296,800
Dial	170	12,400	263,900
Total	950		55,509,000

Table A5b-31 shows that the transition from mercury industrial thermometers, in particular of thermometers designed to measure temperature above 200°C, to feasible alternatives, will be associated with substantial costs for users. Lab and dial thermometers will have lower compliance costs with the proposed restriction of the placing on the market of mercury-containing devices. Although there are a number of similarities in the assumptions for industry and lab segments for thermometers

⁸³ Excludes psychrometers and ambient thermometers.

measuring temperature above 200°C, the compliance cost for lab thermometers is lower. The main factors influencing this outcome include: the lower long-term investment cost of the alternative due to the assumption that four mercury lab thermometers can be replaced by one electronic alternative; the calibration neutrality of the cost calculations for lab thermometers as the calibration frequency and cost of both mercury and alternative thermometers is assumed to be the same; and the shorter (5 years instead of 13 years in industry) and equal lifetime of both mercury and alternative lab thermometers. The main reasons for the high cost effectiveness for industrial thermometers ($T > 200^{\circ}\text{C}$) is the higher investment costs and the more frequent calibration of alternative devices.

The transition to the alternatives from thermometers designed to measure temperature up to 200°C (including ambient thermometers and psychrometers) will likely result in long-term savings for users.

Annex 6: Mercury electrodes used in voltammetry

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1. Technical description of mercury electrodes⁸⁴

Voltammetry

Voltammetry is an analytical technique, measuring the current flowing through an electrode dipped in a solution containing the sample, under an applied potential (Amel, 2001).

The voltammetric techniques allow to distinguish between the different oxidation status of metals, the differentiation between the free and bound metal ions, (Amel, 2001, Lassen et al., 2010) the analysis of the environmentally relevant anions like cyanides, sulphides, nitrites and nitrates and the specification of the biological availability of heavy metals (UNESCO, 2002, Lassen et al., 2010).

Measuring devices based on voltammetry

The *polarograph* comprises of a potentiometer for adjusting the potential, a galvanometer for measuring the current and a polarographic cell (made of glass or teflon) containing three electrodes, a reference one with a constant potential, an auxiliary electrode (a platinum wire inserted on a teflon rod) and the working electrode, a capillary connected to a mercury reservoir. A tube for bubbling nitrogen is inserted into the polarographic cell. (Lassen et al., 2008)



Example of a Modern polarograph from Metrohm

During the polarographic measurements the voltage is increased linearly with time (a voltage ramp) and the current variations are recorded automatically. The working electrode can be for instance mercury electrode. If the electrode is formed by a drop of mercury hanging from a tip or capillary, the technique is called *polarography* (Amel, 2001).

Besides polarography, mercury electrodes are used in the *stripping voltammetry*, and they usually consist of either a drop or a film of mercury. This technique follows two

⁸⁴ Mercury reference electrodes are not covered by this title, and are not assessed because they are dependant on electric current and contain mercury as an integral part of the device (See also appendix 4).

main steps: a preconcentration of the analyte onto the electrode and the successive stripping of the accumulated compound in an inverse direction, onto the electrode towards the solution (it is also named inverse voltammetry). It allows to considerably enhance the sensitivity during the preconcentration stage and to reduce the quantity of the mercury used as electrode. (Amel, 2001)

The devices based on voltammetry are relatively simple, fast, and the theoretical background is precise. All together with the high reproducibility of the curves (current-voltage or current-potential) makes the method one of the most sensitive and versatile one (Electrochemistry Encyclopedia, 2010).

Mercury electrodes

The mercury electrodes used in voltammetry (e.g. with above mentioned devices), serve as sensor electrodes. According to a producer of polarographs, mercury is considered the best metal for cathodic scanning because of its large overpotential and for the possibility to be renewed before each analysis (Amel, 2001).

The mercury electrode is a drop of mercury hanging at the orifice of a fine-bore glass capillary. The capillary is connected to a mercury reservoir so that mercury flows through it at the rate of a few milligrams per second. The outflowing mercury forms a drop at the orifice, which grows until it falls off. The lifetime for each drop is 2 to 5 seconds. Each drop represents a new electrode with the surface practically unaffected by processes taking place on the previous drop. The dropping electrode is immersed in the investigated solution from the cell. (Electrochemistry Encyclopedia, 2010)



The Metrohm 3 electrode system. (the real physical diameter of the mercury drop is typically between 0.3 mm and 0.4 mm; the size is adjustable in certain narrow limits).

The modern versions of mercury electrodes used in polarography are:

- *The dropping mercury electrode (DME)*; a flow of mercury passes through an insulating capillary producing a droplet which grows from the end of the capillary in reproducible way. Each droplet grows until it reaches a diameter of about a millimeter and releases. As the electrode is used mercury collects in the bottom of the cell (Amel 2001).
- *The hanging mercury drop electrode (HMDE)* is a variation on the dropping (DME). It consists of a partial mercury drop of controlled geometry and surface area at the end of a capillary in contrast to the dropping mercury electrode (DME) which steadily releases drops of mercury during an experiment; the whole potential sweep takes place at this single drop.
- *The static mercury electrode (SMDE)* combines the properties of the dropping mercury electrode (DME) and the hanging mercury electrode (HMDE). It

comprises of a capillary (0.15 to 0.2 mm ID) connected to the mercury container. A valve, operated by a PC, adjusts the dimension of the drop, while a platinum wire ensures the electrical connection with the electrical circuit. The drop surface is constant during the measurement (Amel 2001).

The modern instruments allow the use of any of these electrodes, depending on the application they are used for (Schröder & Kahlert, 2002).

The mercury electrodes used in voltammetry usually have very small surfaces in order to assume quickly and accurately the potential imposed by the electrical circuit. (Amel, 2001)

Application areas

As voltammetry is a non-destructive technique it allows the sample to be analyzed for several times and with different analytes. It also allows the determination of metals at different oxidation numbers (e.g. Cr(III), Cr(IV), Fe(II), Fe(III), As(III), As(V)) and has a high sensitivity for Pb, Cd and Se. (Amel, 2001)

Nickel (Amel 2001), Cd, Pb, Cu, Cr and Fe (Metrohm, 2009) can be analysed (and the speciation is also possible) in sea water only using voltammetry and by this the ability of the water sample to form heavy metal complexes can be characterized (the complexing agents like natural organic compounds of anthropogenic origin, humic acids can mobilize heavy metals) (Metrohm, 2009).

The voltammetric method for metal trace analyses are recommended for small and medium sized laboratories with a low number of samples and a large variety of elements or other compounds to be determined and it has to be used in large laboratories for sensitivity or matrix problems or when a validation of the method is required (Amel, 2001).

The applications for mercury electrodes used in voltammetry are for instance:

- Mechanistic studies (especially of organic compounds) which are important for basic research, structure-activity relationship investigation, study of supramolecular interactions etc.
- Trace metal determination and speciation (information on the oxidation state of the metal, free metal and metal ion in different individual complexes)
- Trace determination of organic substances in the field of pharmaceutical analysis, food analysis, forensic analysis, toxicology and environmental analysis
- Voltammetric immuno assays (UNESCO, 2002, Metrohm, 2009)

2. Description of release and exposure

As described in the approach to assess the risks related to measuring devices using mercury as described in Section B.4 of the main document, there is no single parameter to sufficiently describe the potential release and exposure from either the use or the waste phase. However, according to Lassen et al. (2008) around 0.1-0.5 tonnes of mercury is used per year in polarography.

During the service-life of the polarograph, the mercury has to be continuously added to the device (Lassen et al., 2008), indicating that the use phase may cause both occupational exposure and releases to the environment. The amount of mercury used in measurements is used to describe the potential release and exposure from both the use and the waste phase.

Box 1: General qualitative description of potential release and exposure

Production phase

The mercury is not included in the polarographs during the production of the devices, thus the production phase of polarographs is not relevant for potential release and exposure.

Use phase

Mercury has to be continuously added to the polarographs (Lassen et al., 2008). According to Lassen et al. (2008) around 0.1-0.5 tonnes of mercury is used per year in polarography. This is in the same order of magnitude as the estimation of world-wide use of 0.35 tonnes per year by a producer of devices containing mercury electrodes and used in voltammetry (Metrohm, 2009).

The amount of mercury used is significantly reduced in the modern instruments and one filling requires 6 ml of mercury (81g). This can be used to create 200,000 drops necessary for 0.5 to 1 year of use (Metrohm, 2009). According to one manufacturer, the modern instruments are fully sealed (Amel, 2001).

According to a user of a polarograph, the mercury drops are collected during the analysis in the polarography cell. After the analysis the whole liquid including the mercury amalgam is collected in a special vessel for mercury waste and covered by a water layer. When the accumulated waste reaches a reasonable quantity, the mercury can be either distilled in-house, or sent to external specialized companies. Only pure mercury can be used in polarography (Diacu, 2010).

There is no data available to quantify or assess further the emissions from the use phase. Due to relatively low tonnages (e.g. compared to mercury used in porosimeters) and the way the mercury is used in the measurements, the exposure of workers and releases to the environment from the use phase are assumed to be limited and in any case covered by the occupational limit value (coming into force in

December 2010).

Waste phase

As the mercury is used in the analysis the waste stage of the device is not relevant, but the waste handling of mercury is, according to a polarograph user (Diacu, 2010), the mercury used in polarography is either distilled in-house, or sent to specialised companies after measurements. There is no data available to assess further the waste stage and the situation may vary between users and possibly also between Member States.

3. Available information on alternatives (Part C)

3.1 Identification of potential alternative techniques

There are several methods and combinations of methods which can replace polarography or mercury electrodes used in voltammetry only in certain applications. They can be divided in the following categories.

Spectroscopic techniques (usually coupled with another separation technique):

- Atomic absorption/emission spectroscopy (AAS/AES) is an instrumental technique for detecting concentrations of atoms to parts per million by measuring the amount of light absorbed/emitted by atoms or ions vaporized in a flame or an electrical furnace.
- Inductively coupled plasma (ICP), an analytical technique used for the detection of trace metals with A(O)ES atomic (optical) emission spectroscopy (ICP-A(O)ES). A(O)ES is a type of emission spectroscopy that uses the inductively coupled plasma to produce excited atoms and ions emitting characteristic electromagnetic radiation <http://www.answers.com/topic/electromagnetic-radiation> of a particular element. Its intensity is used to determine the concentration of the element.
- Mass Spectrometry (MS) is an analytical technique by which substances are identified by sorting the mass of gaseous ions using electric and magnetic fields. The molecules ionized in the target sample, are accelerated in the mass spectrometer. The speed of the molecules attain during acceleration is proportional to their mass (their mass-charge ratio), which thus can be calculated (answers.com, 2010).

Other non-electrochemical techniques (than spectroscopic techniques)

- High performance liquid chromatography (or high pressure liquid chromatography (HPLC) usually coupled with mass spectrometry (MS) (HPLC-MS) is a form of column chromatography to separate, identify, and quantify compounds based on their polarities and interactions with the column's stationary phase.
- Neutron Activation Analysis (NAA) is a sensitive multi-element analytical technique used for both qualitative and quantitative analysis of major, minor, trace and rare elements, via the element characteristic emission of particles, or

gamma-rays. The activation nuclear process is used for very accurately determining certain concentrations of elements in a vast amount of materials.

- X-ray emission; measure these X-rays having characteristic energy of elements. E.g. following X-ray emission methods exist:
 - X-ray fluorescence (XRF) is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by bombarding with high-energy X-rays or gamma rays.
 - Particle-Induced X-ray Emission or Proton Induced X-ray Emission (PIXE) analyses atomic interactions occurring in the X-ray part of the electromagnetic spectrum specific to elements.
 - microPIXE; Recent extensions of PIXE using tightly focused beams (down to 1 μm) gives the additional capability of microscopic analysis. This technique can be used to determine the distribution of trace elements in a wide range of samples (answers.com, 2010).

Electrochemical techniques using electrodes (others than mercury electrodes):

Other electrochemical techniques exist that work on the same voltammetry principle but use different types of electrodes.

- voltammetric solid sensors (gold, carbon silver or bismuth electrodes),
- rotating disk electrodes,
- disposable electrodes (Metrohm, 2009).

Using alternative electrodes in polarography

Galinstan, a registered trademark of the German company Geratherm Medical AG, is an eutectic alloy of gallium, indium, and tin, liquid at room temperature, and is considered to be a promising alternative to the commonly used mercury electrodes in polarography (Surmann, P. and Zeyat, H., 2005). It can be employed as a liquid electrode instead of mercury in the voltammetric analysis of different metal ions, such as lead and cadmium, in supporting electrolytes.

3.2 Human health and environment risks related to alternatives

The risks associated with the alternative devices/methods vary, as the methods/techniques are very different. Taking into account the low amount of mercury used in mercury electrodes, the technical features to prevent releases and the uncertainty related to the possibly hazardous substances needed with the alternative methods, it has not been possible to conclude that the risks related to the alternatives would be significantly lower than related to the use of the mercury electrodes.

3.3 Technical feasibility of alternatives

As some of the alternatives apply totally different methods and principles than the mercury electrodes used in voltammetry, their technical feasibility is difficult to be

assessed. Nevertheless, below are presented some problems and limitations related to alternative methods.

Spectroscopic techniques

The ion matrices analyzed by spectroscopic techniques require custom-designed analysis, usually an additional pre-separation phase (by co-precipitation, extraction, hydride generation, separation on cation exchange resin, adsorption) and often pre-concentration are required to provide acceptable levels of detection when using AAS or HPLC. The flame emission instruments (used in AES) lack the sensitivity offered by the mercury devices (Thompson, 1991).

The spectroscopic techniques allow only the total metal content determination, and they do not distinguish between different oxidation stages of metal ions, or between free and bound metals (Lassen et al., 2010).

Other non electrochemical methods

All the non-electrochemical methods (excluding spectroscopic techniques) described above are well accepted. Nevertheless, most of them allow only the total element detection and need high investments (for purchasing, running and maintenance), have limited mobility and require special laboratory infrastructure. There are some problems with some sample matrices (sea water, pure chemicals), as they can generate more interferences and by this, they are less sensitive.

When using Neutron Activation Analysis (NAA) the irradiated sample remains radioactive for many years. As the number of suitable activation nuclear reactors is declining, the technique may become more expensive.

Other electrochemical techniques using other types of electrodes (than mercury electrodes)

Other electrochemical techniques have high sensitivity and may replace some mercury applications but have limited analytical performance due to dynamic range and versatility (less elements can be determined). In addition they generate more interferences and by this, they are less sensitive. The lifetime of sensors is limited and they need more electrode maintenance (Metrohm, 2009).

Using alternative electrodes

Galinstan tends to wet and adhere to many materials, including glass, which limits its use compared to mercury (HERC, 2010). The inner glass tubes must be coated with gallium oxide to prevent the alloy from wetting the glass surface. In addition, its aggressiveness could be a major obstacle for its use: it corrodes many other metals by dissolving them (Cadwallader, 2003). With the existing information it is difficult to assess the technical feasibility of galinstan in polarography.

3.4 Economic feasibility

The modern voltammetry instruments using mercury electrodes have a low price, low running costs and compact dimensions (they do not require special build laboratory space) (Lassen et al., 2010, Metrohm, 2009).

Two most relevant and widely used alternative techniques could in principle be assessed against their economic feasibility, namely, atomic absorption spectroscopy (AAS) and Inductive coupled plasma (ICP) spectrometers with OES (Optical emission detection) or with MS (Mass spectrometric detection). However, even these alternatives can replace the mercury electrodes only in certain subsets of applications not necessarily in all uses (Metrohm, 2010).

Secondly, there is not enough data available for either of the alternatives for the full economic comparison. However, below we sketch a comparison given the existing data.

The one-time investment cost of one polarograph is €20,000 compared to over €40,000 for AAS and €40,000-100,000 for ICP (Lassen et al., 2010). The comparison of the numbers is hindered as the average lifetime of the two alternatives is not available. Furthermore, the difference in the investment costs is underlined as the two aforementioned alternatives i) generally require laboratory infrastructure, ii) are less mobile and iii) have smaller number of suitable applications.

Recurrent costs for polarography is suggested to be about €2000-2500 annually translating to about €1 per analysis given generally 100-5000 analysis per year. A full comparison of the recurrent costs can neither be done as the data for recurrent costs and annual number of analysis is missing for alternatives. However, first one of the alternatives, AAS, is reported to require costly accessories (lamps, graphite furnaces), and users of the ICP alternatives are reported to need to spend € 20 000 – 30 000 per year only for argon gas needed in the process. (Lassen et al., 2010)

Given the scarcity of the data it can only be said, that the relatively higher investment costs, more narrow uses and special needs for laboratory infrastructure in case of the two alternatives would require that the lifetime and/or the productivity of the alternatives would need to be considerably higher in order for those to be able to compensate the limitations.

4. Justification why the proposed restriction is the most appropriate Community-wide measure (PART E)

4.1 Identification and description of potential risk management options

4.1.1 Risk to be addressed – the baseline

As discussed in Part B, the current pool of mercury in measuring devices is used as an indicator of maximum emission potential for most of the devices in this report. For the mercury drop electrodes there is not such a pool as the mercury is used in the measurements, and it does not accumulate in the products. For mercury drop electrodes the maximum potential for emissions is the amount of mercury used annually by the users. As described in Chapter B.4. it is estimated to be 0.1-0.5 tonnes yearly. According to the only identified European producer, the world-wide use of mercury is estimated to be 350 kg per year (Metrohm, 2009).

According to a producer of the devices (Metrohm, 2009) the risks related to both use and waste phase are very much reduced in the most modern devices as a result of the minimization of the mercury used (around 80 grams for one filling, necessary for 0.5 to 1 year of use). As a result of the replacing existing devices by modern equipments, the trend of mercury used in voltammetry is likely to be declining. Nevertheless, there is no information available to assess the trend in the number of mercury drop electrodes used in voltammetry, placed on the market annually.

4.1.2 Options for restrictions

As a result of the low quantities of mercury used in voltammetry and strong evidence suggesting that feasible alternatives do not exist, only one restriction option is assessed:

Restriction on the placing on the market of mercury to be used as mercury electrodes in voltammetry.

4.2 Assessment of risk management options

Restriction of the placing on the market of mercury to be used as mercury electrodes in voltammetry

The maximum risk reduction capacity of this option is estimated to be between 0.1 and 0.5 tonnes annually. As described in Section C the alternatives for polarographs have limitations related to both technical and economic feasibility. Thus no restriction

on the placing on the market of mercury used as electrodes in voltammetry is proposed.

Due to obvious limitations on technical and economic feasibility of alternatives, no further efforts have been taken to assess the restriction option.

4.3 The proposed restriction(s) and summary of the justifications

Proposal:

No restriction proposed.

Summary of justification:

Technically feasible alternatives for mercury electrodes used in voltammetry are not available in all applications. In addition two main alternatives seem not to be economically feasible.

Annex 7: Porosimeters

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1. Technical description of porosimeters

Porosimeters are instruments that are capable of measuring pore volume and their distribution, based on the principle of either liquid intrusion or extrusion into or from pores. They are used e.g. in automotive, biotechnology, pharmaceuticals, ceramic and textile industry. According to a producer of porosimeters around 60% of porosimeters are used for research and 40% for quality control purposes (Commission, 2009b). Contrary to devices containing mercury as an integral part, mercury is used when measuring with mercury porosimeters and the equipment must be refilled regularly.

The application of mercury porosimeters is based on the gradual increase in pressure to enable mercury to enter the pores in a sample, as there is a relationship between the applied pressure and the pore diameter. Mercury porosimeters can be used for wide range of pore sizes i.e. routinely from 0.003 μm to ca. 1000 μm . In addition to pore volume and distribution, mercury porosimeters can provide information about the surface area, particle size distribution, tortuosity, permeability, fractal dimension, compressibility, pore shape, network effects and the skeletal and bulk density. (IUPAC task group, 2010)

2. Description of release and exposure

As described in the approach to assess the risks related to measuring devices using mercury as described in Section B.4 of the main document, there is no single parameter to sufficiently describe the potential release and exposure from either the use or the waste phase. Waste management of mercury and mercury contaminated samples and other materials is one part of the normal operation of the laboratories performing measurements with these devices. The reported practices in laboratories appear to support the view that the waste handling of mercury used in the measurements would be conducted in accordance with the requirements of the hazardous waste legislation (Lassen et al., 2010, see Appendix 3). Thus, the annual amount of mercury disposed of as a waste does not reflect the emissions that could occur from the uncontrolled waste streams. Nevertheless it describes the magnitude of mercury involved in the waste phase. Similarly, the amount of mercury used annually in the measurements gives an idea of the magnitude of the mercury involved in the use phase of porosimeters.

Based on the calculations and information presented in Box 1,

- The amount of mercury bought annually by the users of porosimeters is estimated to be around 5-14 tonnes per year in the EU. However, the amount of mercury used in the measurements is estimated to be 12-58 tonnes per year, as some of the mercury is used several times by the users as described in Box 1.
- The amount of mercury disposed of annually as hazardous waste is estimated to be around 1.2-3.4 tonnes.

- The mercury that is not disposed of as hazardous waste by the users is sent to specialised companies for purification or regeneration.

There is no data available to quantify the amounts of mercury released during the normal use of porosimeter or the amounts of mercury ending up to non-controlled waste streams. Nevertheless, based on the information gathered during the preparation of this report, these amounts are likely to be relatively small (Lassen et al. (2010) in Appendix 3).

In addition to general qualitative description of potential release and exposure presented in Box 1, Appendix 3 (Lassen et al. 2010) contains a detailed description of the actual measuring activity and a screening of potential release sources for porosimeters.

Box 1: General qualitative description of potential release and exposure

Amounts of mercury bought and used by the users of porosimeters

According to a survey carried out by the Commission (see Appendix 5), a user of porosimeter buys on average 7.2 kg of new mercury per year. Assuming that 700-2000 porosimeters are in use in the EU (Commission, 2009; Lassen et al., 2008), a total amount of 5-14 tonnes of new mercury is bought annually by these users⁸⁵. This estimate does not consider the fact that some users have a lot of mercury in storage, e.g. 400 kg reported by one user (see Appendix 5), and they do not need to buy new mercury annually.

As visualised in Figure A7-1 below, oil is needed in the measurements. Around 35 % of the users of porosimeters are able to separate the mercury from the oil themselves (see Appendix 5)⁸⁶ after the measurement and some laboratories send the mercury and oil to specialised companies for separation. Laboratories can use a batch of mercury 5-10 times or even more often (Lassen et al., 2010). Based on these assumptions it can be estimated that 12-58 tonnes of mercury is used annually for the measurements⁸⁷.

The cycle of mercury when using porosimeters

There are several steps in the “cycle of mercury” when using porosimeters as described in the figure A7-1. After measurement some of the mercury can be used again after separation from oil.

⁸⁵ 7.2 kg (Hg bought annually by user) x 700-2000 (Number of users in EU) = 5-14 t/y

⁸⁶ This result is not reported in the Commission’s review report (COM, 2009), but is based on the individual responses for the survey which have been made available for ECHA.

⁸⁷ 5-14 t (Hg bought annually) x 0.35 (35% of laboratories conducting in-house separation of Hg from oil) x 5-10 (Hg reused 5 to 10 times) + 5-14 (Hg bought annually) x 0.65 (65% of laboratories not using Hg several times) = 12-58 t/y

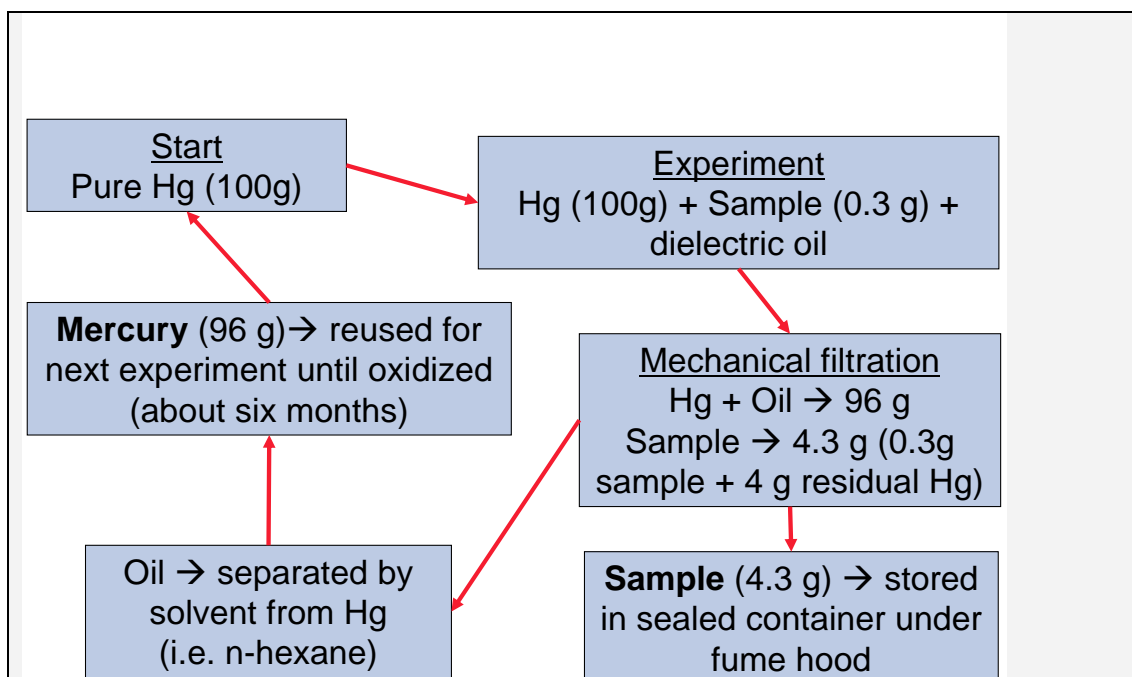


Figure A7-1: The cycle of mercury in measurement with mercury porosimeter
Source: Thermofisher, as cited in Lassen et al., 2010 (see Appendix 3)

Around 4% of mercury used in a measurement will stay in the sample and 96% of mercury is mixed with the oil and needs to be separated. The separated (in-house or externally) mercury can be used in a new measurement until it is oxidised. There is no data available on the rates of oxidation of mercury during or between the measurements, but it is dependant on the material of the measured samples. The oxidised mercury may be sent to specialised companies to be regenerated, i.e. reduced back to the metallic form. (Lassen et al. 2010, see Appendix 3)

Production phase

The mercury is not included in the porosimeters during the production of the devices, thus the production phase is not relevant for potential release and exposure of mercury.

Use phase

Some of the mercury is likely to evaporate during the use of porosimeters and causes occupational exposure or ends up in the environment. There is no data available to estimate the possible release from the use, but the relevance can not be excluded due to relatively high volumes of mercury used. The release is highly dependant on the risk management measures and safety procedures used in the laboratories, and may vary significantly between laboratories and Member States.

The following release routes of mercury from the use and waste phase are identified by Lassen et al. (2010):

⁸⁸ 1.7 kg (Hg disposed as waste by one user) x 700-2000 (number of porosimeters in EU) = 1.2-3.4 t

⁸⁹ 0.04 (4% of Hg stays in the sample) x 13-58 t (Hg used for measurements) = 0.5-2.3 t

1. Releases from the porosimeter through the exhaust of the porosimeter. From mercury spilled by filling of container, droplets on penetrometer, cleaning of valves, cleaning of high pressure tank, etc.
2. Releases from the fume hood through the exhaust of the fume hood. From mercury spilled or directly evaporated by emptying and cleaning the penetrometer and mercury spilled or directly evaporated by regenerating the mercury. Mercury releases from small droplets on gloves, cleaning pads, etc.
3. Release from the fume hood through the drain of the sink (if the fume hood has a sink). From mercury spilled by emptying and cleaning the penetrometer, mercury spilled by regenerating the mercury, from small droplets on gloves, cleaning pads, etc. the mercury may inter into a sink in the fume hood.
4. Releases from the laboratory's general ventilation system. From mercury spills outside the fume hood or porosimeter.
5. Long term releases from mercury contaminated waste. All mercury contaminated waste (>0.1 % w/w) has to be disposed of as hazardous waste, in accordance with EU waste regulation.
6. Releases from recycling of mercury by recycling companies.
7. Mercury in solvent disposed of as solvent waste. Mercury is not dissolved in the solvents and the waste solvent seems not to be considered mercury containing.

No data has been available for quantification of any of these releases, but according to Lassen et al. (2010) the main source of mercury releases from the use phase of porosimeters is assumed to be from the fume hood, where several operations with mercury are conducted.

A detailed description of the measuring process of porosimeter and description of potential releases can be found in the Appendix 3.

Waste phase

Most of the mercury used in analysis is regenerated to be used again. This regeneration is not recycling as described in the revised waste framework directive (2008/98/EC), as the mercury is not intended to be discarded by the user. In addition, some of the mercury waste disposed of as a hazardous waste will be recycled. It is highly unlikely that the mercury mixed with the oil or the oxidised mercury would end up to non-controlled waste streams, but it can not be excluded either.

The main mercury waste fraction is the contaminated sample. In addition, some mercury ends up in the waste stream from the protecting gloves filters etc. Based on the individual responses to Commission's survey (see Appendix 5) and interviews with users of porosimeters (Lassen et al., 2010) it seems that the users dispose of the mercury in accordance with the requirements of the hazardous waste legislation. Thus the proportion of mercury ending up in non-controlled waste streams seems to be small.

Based on the reported amounts of mercury disposed as waste by users (see Appendix 5), it can be estimated that around 1.2-3.4 tonnes of mercury would be disposed of as

waste per year⁸⁸. According to Lassen et al. (2008) most of the mercury losses are expected to be caused by the mercury-saturated samples. Assuming that 4% of mercury stays in the sample after a measurement (Thermofisher as cited in Lassen et al. 2010) results in having around 0.5-2.3 tonnes of mercury in the samples annually⁸⁹. The amount depends on the material of the sample, and a rate as high as 20% has been reported (Lassen et al., 2010)

There is no data to further assess the amounts of mercury ending up in hazardous or non-controlled waste streams from the waste fractions or to assess the recycling rate for the mercury disposed of as waste.

3. Available information on alternatives (Part C)

3.1 Identification of potential alternative techniques

There are several alternatives for mercury porosimeters with different kind of limitations on the feasibility. The following alternative techniques and methods have been identified a report by IUPAC task group (2010).

- Intrusion of other non-wetting liquids
Alternative liquid metals e.g. gallium, indium and their alloys can be used instead of mercury in devices relying on the same method as mercury porosimeters.
- Methods based on capillary condensation equilibria obtained through drainage and/or evaporation

Liquid porosimetry (i.e. extrusion porosimetry) can utilize any wetting fluid e.g. pure water and hexane. Instead of positive pressure to intrude the liquid into sample, liquid porosimetry applies negative pressure to drain the wetting liquid from the pores. The sample is exposed, in a test chamber, to varying and precisely controlled air pressure. With the variation of pressure, different size pore groups drain the liquid and their pore volume is equal with the one of the liquid.

Gas adsorption porosimeter is based on the adding (or removing) a quantity of gas (nitrogen, argon or krypton, CO₂) to samples, at cryogenic temperatures, where weak molecular attractive forces cause the gas molecules to adsorb on material in order to obtain adsorption-desorption isotherms. The volume of the gas adsorbed by the sample can be determined from the ideal gas law and also the surface area and pore size distribution of the sample can be derived (ZAG Ljubljana, Micromeritics Analytical Services, Green Chemistry Centre of excellence). According to Mitchell et al. (2008) gas adsorption is the most commonly used method for determining pore size distributions in addition to mercury porosimetry.

Contact (or standard) porosimetry is based on the gravimetric measurements of the liquid in the sample and by simultaneously investigating from adsorption and capillary isotherms the pores at the thermodynamic equilibrium conditions. The automated version, automated standard porosimeter (ASP), includes a computer, an electronic balance, an automatic manipulator, a device with electromagnetic valves for a controlled drying of the porous samples by a flow of dry inert gas. It is used e.g. for the investigation of porous materials used in electrochemical devices (electrodes, membranes).

The bulk condensation method consists in the oversaturation of the sample in order to fill all the pores and then the analysis of the desorption branch from the adsorption isotherms.

Water desorption calorimetry consists in the saturation of the porous medium with a liquid which is then slowly desorbed in quasi-equilibrium conditions. The equilibrium relative pressure is deduced from a differential transducer between the sample cell and the reference cell that is filled with pure liquid. The desorbed liquid is determined by using the heat flow.

- **Permeation of a liquid (permeameters)**
Porous samples can be characterized by permeation of a gas or a liquid through the sample material followed by a prediction, or at least correlation of the pressure drop to the flow rate by using various equations for the laminar flow regime. (IUPAC task group, 2010)
- **Freezing-melting porosimetry**
When a liquid fills a porous sample its freezing and melting points are depressed. These changes are connected with the width of the pore. Together with the volume of molten liquid in a given temperature it is possible to get information on pore-size distribution. The method is completed by *Differential Scanning Calorimetry (i.e. Thermoporometry)* when the measured temperature depression is determined and directly related to the pore width or *Nuclear Magnetic Resonance (NMR) cryoporometry*, when the depression of the melting point of a crystalline solid is determined by analyzing the proton NMR signal as function of temperature.
- **Imaging techniques**
Imaging techniques including e.g. *Magnetic Resonance Imaging, X-ray Tomography, Electron Microscopy, Light microscopy/Laser methods, Pulsed-field Gradient* and *Hybrid Imaging* allow pore size mapping.
- **Statistical reconstruction of porous materials**
Statistical modelling can be used to characterise a disordered porous medium with several pore shapes presented. Structural correlations aim to correlate the structural state of different points with functions such as bulk, surface autocorrelation or pore-surface correlations functions and use of statistical geometrical analysis, mathematical morphology.

3.2 Human health and environment risks related to alternatives

Some alternatives use other liquids than mercury to measure the porosity of the sample. They vary from water to liquid metals like Indium, Gallium and their alloys (IUPAC task group 2010). The environmental and health risks related alternative substances and methods are not assessed further in this report⁹⁰, but there are no indications that risks would be at the same level as related to mercury. For most of the alternatives the risks would be significantly lower.

3.3 Technical and economic feasibility of alternatives

Only one producer of mercury porosimeters (out of four contacted) responded to the questionnaire in the stakeholder consultation. The producer with wide selection of alternative devices did not respond (based in the USA). Thus, the following information is based more or less on the limited literature search and one response during the stakeholder consultation. Identified alternatives have different limitations related to e.g. applicable pore sizes, applicable size and material of samples, measured parameters and duration of measurement. The mercury porosimeter has limitations in applicability as well e.g. limited pore size range (0.003-1000 μm) and requirements on the durability of the sample as high pressure is applied. Below some identified limitations and advantages of different alternative devices

- Intrusion of other non-wetting liquids
According to a brochure of a producer of porosimeters, a specific porosimeter is able to use both mercury and other liquids (only water mentioned) (Porous Materials, 2010). Based to the brochure the only limitation seems to be that the fluid needs to be non-wetting to the tested material. There is no data available on the potential fluids (in addition to water) to be used or their wetting properties in different sample materials (and thus in different application areas).

Intrusion of water is applicable only on hydrophobic samples and the preliminary surface treatment to make the sample hydrophobic (if needed) is a time consuming task. According to a producer of porosimeters, the hydrophobic materials cover less than 5% of applications and the water intrusion porosimeter is only applicable to samples with pore sizes between 0.001-20 μm . (Lassen et al., 2010)

According to a producer of water intrusion porosimeters, potential application areas include automotive, chemical, pharmaceuticals, battery separator, fuel cells, powder metallurgy, ceramic, paper and filtration industries (Porous Materials, 2010).

⁹⁰ Some information on gallium can be found in Annex 5b (Thermometers).

- Methods based on the capillary condensation equilibria obtained through drainage and/or evaporation

Liquid porosimetry (i.e. extrusion porosimetry)

Liquid porosimetry can be used for deformable materials (IUPAC task group, 2010). According to Lassen et al. (2010) a producer of porosimeter has indicated that the method involves a very expensive gravimetric technique and is applicable to pore sizes between 1-1000 μm , even though an application range of 0.06-1000 μm is indicated by another producer. According to a producer of liquid extrusion porosimeters, potential application areas include automotive (particle filters for diesel fuels), filtration, nonwovens, biotechnology & healthcare, geotextiles, pharmaceuticals, ceramic, household & personal hygiene and textiles industries (Porous Materials, 2010).

Adsorption (nitrogen) porosimeter is applicable only for pore sizes below 0.05-0.1 μm . (IUPAC task group, 2010).

Contact (or standard) porosimetry is applicable for pore size between 0.01-100 μm . (IUPAC task group, 2010)

The bulk condensation method is not applicable for pore size above 0.4 μm

Water desorption calorimetry still has some problems related to kinetics and is not applicable for pore sizes above 10 μm .

The methods based on the capillary condensation equilibria are applied at least to some extent for the same pore sizes as mercury porosimetry and are thus possible alternatives to replace the mercury porosimetry in the future. (IUPAC task group, 2010)

- Permeation of a liquid (permeameters)
The results can be linked to pore size in the 0.1 to 1000 μm range, or other characteristic of the material. A major problem is with samples composed of different pore sizes, as the flow rate through the larger pores will be more than proportionally larger than flow through smaller pores. In addition no standard equipment is readily available with broad applicability. (IUPAC task group, 2010)
- *Freezing-melting porosimetry* is applicable for wet and fragile samples which do not withstand drying or outgassing. It has also advantages of being a clean method (usually using water), relatively fast measurement (around 3 hours), requirement of small sample (10 mg) and reasonably comparable results with other methods. (IUPAC task group, 2010)
Nevertheless, the sample must withstand the liquid and avoid any unwanted transformation (IUPAC task group, 2010). In addition, nuclear magnetic resonance cryoporometry has the disadvantage over mercury intrusion of having an upper measurable size limit below 1 μm (Vargas-Florencia et al., 2006).

IUPAC task group (2010) concludes that there are no technically feasible well-established alternatives to mercury porosimeters in pore sizes between 0.05µm and 400µm. Nevertheless, it has not been possible to rule out during the preparation of this report that a combination of several devices and methods would allow measuring more or less similar parameters as by mercury porosimeters. It is possible that the technical infeasibility is more related to the comparability of the results measured by mercury porosimeters and alternatives than physical limitations like pore sizes. This problem could be solved at least partly by allowing adequate time for the users to run measurements concurrently. According to Lassen et al. (2010) a producer of porosimeters has indicated that some 3 years would be needed for validation and re-calibration of quality control procedures and 4 years for development of new certified reference materials for the results validation. There are no data available on the relevance of the comparability of results for research purposes.

Three national bans in Denmark, Netherlands and Norway have derogations for use in porosimeters. In addition in Sweden companies have a possibility to apply for national authorisation for purchase of porosimeters and between 1996 and 2010 this possibility has been used twice. This indicates that the technical feasibility of alternatives has not been easily established in those Member States which already have wide national restrictions related to mercury in other measuring devices.

The full screening and assessment of all the alternative devices and methods, and their technical feasibility in each application area, has not been conducted when preparing this report due to highly technical nature of the work and high workload. This is backed up by the fact that we have not identified a single application or group of applications covering a significant share of measurements. Thus a further assessment was not considered proportional in the framework of preparing this report considering the anticipated results. In addition, after identifying technically feasible alternatives (or combination of alternatives) for some application areas, the economic feasibility would still need to be assessed as well.

According to Lassen et al. (2010) a mercury porosimeter cost around €20,000-€40,000. At least some alternative devices are cheaper than the mercury porosimeters (Lassen et al., 2008). Nevertheless, several alternative devices may be needed to cover all the measured parameters and all the sample materials that can be measured by a mercury porosimeter. The information received from a producer of porosimeters suggests that the costs of using flow porometer would be in the same magnitude as using mercury porosimeter (Lassen et al., 2010). As the technical feasibility of alternatives has not been verified in any application area, the economic feasibility is not assessed in the report either.

4. Justification why the proposed restriction is the most appropriate Community-wide measure (Part E)

4.1 Identification and description of potential risk management options

4.1.1 Risk to be addressed – the baseline

As discussed in Part B, the annual amount of mercury used in measuring devices is used as an indicator of the potential release and exposure in this report. For mercury porosimeters, one way to describe the annual use is the amount of mercury purchased by the users which is estimated to be 5-14 tonnes per year. However, the possibility to reuse the mercury several times means that around 12-58 tonnes of mercury is fed in to porosimeters annually to conduct the measurements. This amount describes the relevance of mercury porosimeters as source of exposure and emissions during the use phase. In addition, it is estimated that around 1.2-3.4 tonnes of mercury is disposed of as waste.

The risk related to both use and waste phase might be slightly reduced over time as devices and instructions, e.g. ISO standard, will be developed further. Nevertheless, these effects would not apply to all the users and old devices. There is no data available to estimate the trend in number of measurements done with mercury porosimeters.

4.1.2 Options for restrictions

The following tentative options to reduce the risks related to use of mercury in porosimeters were identified when preparing this restriction report. Options 1a, 1b and 1c are aimed to reduce the amount of mercury used in porosimeters and thus affect both the use and waste phase. Option 2 is only considering the waste phase, whereas options 3a and 3b concentrates on the use phase. Option 4 is a way to collect information to further assess the technical feasibility of the alternatives, as it was not possible to fully assess it when preparing this report. The variety of options reflects the fact that the mercury used in porosimeters could cause risks at both the use and the waste phase.

After tentative consideration only options 1a and 4 are considered more in detail in Chapter E.2 for the reasons presented below.

Reducing the amount of mercury used in porosimeters

1a) Ban on using the mercury in porosimeters

All the risks from both the use and waste phase would be totally eliminated. However, this option would also introduce high costs as mercury porosimeters would need to be replaced before the end of their service-life. For some applications several alternative

devices would be needed to cover the same range of pore size measurements and to measure all the parameters offered by a porosimeter. As no technically feasible alternatives are identified for some applications, it would no longer be possible to carry out certain types of measurements. However, the impacts of this are extremely difficult to assess. Due to lack of technically feasible alternatives, this option as such is not considered further. The following elements could be considered to reduce the negative impacts described above:

- long transitional period (e.g. 10 years) to allow users to adapt their quality control or research processes
- banning the use of mercury only in the porosimeters placed on the market after entry into force (i.e. ban placing on the market of mercury porosimeters)
- combination of above elements

This option with additional elements is further assessed in section E.2.

1b) Ban on using mercury in porosimeters with derogations for specific applications where technically feasible alternatives do not exist

Compared to 1a this option introduces lower costs as the impacts of not being able to carry out all types of measurements would be avoided. Likewise also the risk reduction capacity would be lower. As some laboratories are using porosimeters for several applications, this option might still introduce additional costs related to the need to buy additional devices to be used concurrently with the mercury porosimeter. The enforcement could be particularly problematic as mercury porosimeters would still be allowed, but only their use for specific applications would be restricted. In addition, it would be very difficult to go through all the applications to definitively assess the technical feasibility of alternatives, running the risk that some important applications could be banned. Thus, this option is not considered further. The additional elements described for option 1a could be included to this option as well.

1c) Ban on using mercury in porosimeters in specific applications

This option is the same as 1b, but allows banning only those uses for which technically feasible alternatives exist for sure. The risk reduction capacity depends on the amount of mercury used for applications with technically feasible alternatives. We have not been able to identify a single application or group of applications covering a significant share of measurements. As in option 1b, some laboratories are using porosimeters for several applications. Thus this option might introduce higher costs as there would be a need to buy additional devices to be used concurrently with the mercury porosimeter. In addition, the enforcement could be problematic if mercury porosimeters would be allowed but only their use for specific applications would be restricted. Thus, this option is not considered further. The additional elements described for option 1a could be included to this option as well.

Promoting appropriate waste handling of mercury

2) Setting waste handling requirements

Risks related to the waste phase of mercury originating from the use of porosimeters could be reduced by promoting appropriate waste handling. The current waste legislation requires treating mercury properly and there are no reasons to assume that

introducing similar requirements under REACH would impact the potential non-compliance significantly. However, according to available information there seem not to be problems with the compliance. Without any specific reasons the problems related to waste stage should be addressed through waste legislation and this option is not considered further. Nevertheless, the following two aspects to affect the waste stage were considered, but regarded highly impractical:

- The users of porosimeter could be obliged to deposit a pledge (x € per kg of Hg) which would be returned only when the mercury (including mercury in the samples) is returned to the supplier, and all the suppliers of mercury would need to adopt the system. The risk reduction capacity would be highly depending on the value of the pledge. Enforcement of this kind of scheme would be difficult, as mercury will be on the market for other applications than porosimetry without the pledge. In addition, some laboratories use mercury for other purposes than porosimeters as well and they would need to have separate fractions of mercury for different purposes. Setting this kind of system is regarded impractical for above mentioned reasons.
- Suppliers of porosimeters could be obliged to arrange take-back scheme for mercury used for porosimeters and the scheme would be obligatory for users. All the mercury for porosimeters would have to be purchased from the suppliers of porosimeters or from a company authorised by the supplier. The involvement of suppliers of porosimeters could make the enforcement easier. It would be also easier to inform these companies about the requirements. This scheme would include all the mercury containing waste fractions. Enforcement of this kind of system would be very difficult, as mercury will be on the market from other sources than the suppliers of porosimeters. Setting this kind of system is regarded impractical for above mentioned reasons.

Promoting appropriate handling of mercury during the use phase

3a) Setting use conditions

Laboratories have different safety measures in place to prevent emissions and exposure to mercury e.g. exhaust systems, mercury spill kits and fume hoods. This option would try to promote and codify current best practices to be used by all the users. Use conditions would reduce the risks related to use phase including also the in-house separation of mercury. With the available data it is difficult to estimate the risk reduction capacity and costs related to this option.

Occupational health legislation has already addressed the concern related to exposure at the workplace by setting an occupational exposure limit value for mercury (0.02 mg/m³). We have not identified reasons why a condition in Annex XVII entry would be needed to ensure that actors comply with this limit value. Thus this option is not assessed further.

3b) Setting monitoring requirements in the workplace

Laboratories have different safety measures in place to prevent exposure to mercury. Due to relatively high tonnages of mercury used and several steps of measuring with porosimeters where mercury is handled, relevant exposure may take place. To support

the implementing of the occupational exposure limit for mercury, monitoring requirement by monitoring batches or urine tests could be required.

As mentioned above, occupational health legislation has already addressed the concern related to exposure at the workplace by setting an occupational exposure limit value for mercury. We have not identified reasons why a condition in Annex XVII entry would be needed to ensure that actors comply with this limit value and this option is not assessed further.

Supporting further assessment of technical feasibility of the alternatives

4a) Information gathering

Due to challenges related to assessment of technical feasibility of the alternatives, it was not possible to conclude if technically feasible alternatives for all applications of mercury porosimeters exist or not. This option is aiming to support the collection of additional information to allow full assessment of both technical and economic feasibility by setting a requirement for the users of porosimeters to provide information to competent authorities of the Member States on the technical features needed in their field. This option is assessed further in the next Chapter.

In addition, the users of mercury porosimeters could be obliged to register themselves to competent authorities of Member States. This information could be later on used to collect further information.

4.2 Assessment of risk management options

4.2.1 Option 1: Restriction on the use of mercury in porosimeters that are placed on the market after 5 years of the entry into force

Adopting this restriction option would in practise mean that mercury porosimeters shall not be placed on the market after five years of the entry into force. The reason to introduce this as a use ban, rather than restricting the placing on the market of mercury porosimeters, is that at least one type of device can utilize both mercury and other liquids. Thus it would be possible to argue that the supplier would not be placing on the market mercury porosimeters but porosimeters in general. Nevertheless, to promote effective enforcement, it should be considered to ban also the placing on the market of mercury porosimeters (or porosimeter designed to be used with mercury), as it would be more practical to enforce the placing on the market of the devices than using them. The use of porosimeters placed on the market before the ban would become effective, would still be allowed.

4.2.1.1 Effectiveness

Risk reduction capacity

Following the approach described in Part B, the risk reduction capacity of this restriction option is described as the annual amount of mercury used in porosimeters. As the mercury is regenerated to be used again, the amount used does not reflect the risk reduction capacity for the waste phase. For that, the relevant figure is the amount

of mercury disposed annually as waste. For both indicators, the capacity is 1/10 of the annual amount in the first year the restriction is effective, assuming 10 years service-life for porosimeters. In 10 years the restriction would have its full effect and the risk reduction capacity would be the same as the annual amount. Using averages of ranges calculated above, the risk reduction capacity can be estimated to be rising from 0.2 to 2.3 tonnes per year for the waste phase and from 3.6 to 36 tonnes per year for the use phase. Nevertheless, the real emissions from the use of porosimeters are much lower due to relatively high rate of mercury being collected according to hazardous waste legislation and risk reduction measures already in place in laboratories.

Proportionality

Technical feasibility

Even though it has not been possible to fully assess the technical feasibility of the alternatives or combination of alternatives, different devices and methods are available to measure the porosity of the materials. In the product control, it seems that measurements with alternatives can offer adequate data to assure the quality even though the results would not be exactly the same as with mercury porosimeters. The five years transitional period for placing on the market and the possibility to continue using porosimeters already in use would allow users to adapt their quality control procedures.

Economic feasibility (including the costs)

As the technical feasibility of alternatives has not been fully established and the economic feasibility has not been assessed, it is not possible to assess the economic feasibility of this restriction option.

4.2.1.2 Practicality

Implementability and manageability

Because of the limited information on the technical and economic feasibility of alternatives, the implementability of this option is difficult to assess. Nevertheless, problems related to implementability and manageability should be significantly reduced by the five years transitional period and by the possibility to continue using existing devices.

Enforceability

The enforcement would in practice be done by enforcing the placing on the market of porosimeters, even though the restriction entry of this option is formulated to restrict the use of mercury. As there are only few suppliers of porosimeters in the EU, the enforcement should not be a problem.

4.2.1.4 Overall assessment of restriction option 1

Based on the limited information on the technical and economic feasibility of the alternatives it is not possible to draw conclusions on the proportionality of the restriction option. Even though it has not been possible to verify the technical feasibility of alternatives, it is not possible to rule out that technically feasible alternatives may exist. Also the risk reduction capacity of this option is difficult to assess. The comparison of the risk reduction capacity with other mercury measuring devices should not be done directly with annual tonnages, as the waste handling situation seem to be better for porosimeters and the risks related to the use phase seem to be higher.

4.2.2 Option 2: Information gathering with further assessment of the technical and economic feasibility

The assessment of the technical feasibility of the alternatives to mercury porosimeters is not finalised in the framework of this report due to the highly technical nature of the issue. The application areas where mercury porosimeters are used are very diverse and different features from the alternative devices might be required to get the desired results. This is naturally affecting the possibilities to transfer to the alternatives.

In depth assessment of the technical feasibility of the alternative devices would require involvement of both the suppliers of the different alternatives and the users from different application areas. As at least some alternative devices are new for the users of mercury porosimeters, it can be doubted if they would be able to directly argue whether an alternative is feasible without a detailed knowledge on the properties of devices. Thus a research program with possibly a workshop could be beneficial.

To support the further assessment of alternatives the users of mercury porosimeters could be required to provide information on their use as a requirement in the restriction entry. That information could include for instance the results (parameters) needed in each application area, the costs of measuring and also the argumentation on the technical feasibility of alternatives based on the descriptions provided in the questionnaire/reporting format. At the same time it would be possible to get a more detailed picture on the risks related to both use and waste phase of mercury.

4.2.2.1 Effectiveness

Risk reduction capacity

This restriction option does not have a significant risk reduction capacity without further regulatory action. Nevertheless, awareness of alternatives may lead to voluntary replacement of mercury porosimeters. The possible future risk reduction is naturally related to the outcome of the further assessment of the technical and economic feasibility of the alternatives and to the consequent actions taken on the

basis of this assessment. If the assessment later on concludes that feasible alternatives exist and a ban is introduced, the future risk reduction would be more or less similar to what is described for restriction option 1 above. It is difficult to estimate the quality of responses that would be received from the user especially related to technical feasibility of the alternatives. Thus it could be argued that the assessment of alternatives could be conducted without the legislative requirement and a voluntary involvement for instance in workshops might be more effective.

Proportionality (technical and economic feasibility)

As described above, the success of this option is related to the quality of data collected. It can be technically challenging to formulate the questions and additional information in a way that allows the users to provide useful information. To achieve a high response rate (compliance), it could be useful to require the users of mercury porosimeters to register themselves to competent authorities as a first step. At least some contact details can also be provided by the suppliers of porosimeters.

This option could support possible other efforts taken to assess the alternatives. The costs of information gathering are related to the time required for preparation of questionnaires and additional information, distributing the questionnaires, answering (time consumed by users) and analysing the data. These costs are not quantified in this report.

4.2.2.2 Practicality

The users of mercury porosimeters should be able to provide the requested information if the questionnaire and additional information is properly drafted. No specific problems related to implementability and manageability have been identified.

The enforcement of this option could be done in the margins of the general enforcements of the laboratories. Enforcement authorities could check if the users have provided the required information to Member State competent authorities when a mercury porosimeter is found in the laboratory. If the register of users would be established it could also be used for targeted enforcement of the users of the mercury porosimeters.

4.3 Comparison of the risk management options

The two restriction options described above are not comparable with each other in terms of risk reduction capacity, proportionality and practicality. The restriction option 1 is not regarded proportional due to uncertainties related to technical feasibility of alternatives. Restriction option 2 is not proposed either as the impact of having legal requirement to provide information does not automatically lead to receiving helpful data for the further assessment. Nevertheless, the information gathering combined to other suitable efforts to assess the alternatives could be useful.

4.4 The proposed restriction(s) and summary of the justifications

No restriction is proposed for mercury porosimeters due to high uncertainties in the technical feasibility of the alternatives. Consequently the economic feasibility was not assessed.

The waste handling of mercury used in porosimeters seems to be done in accordance with requirements of hazardous waste legislation. Nevertheless, due to relatively high tonnages of mercury needed for measurements with porosimeters, further assessment of the feasibility of alternatives could be beneficial.

Annex 8: Pycnometers

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1. Technical description of pycnometers

Pycnometers are used for accurately measuring the true and bulk densities of materials, by a volume displacement technique based on the fact that mercury at atmospheric pressure will not enter pores smaller than 15 microns in diameter. They are used for instance in battery separators, ceramic and fuel cells industry.

2. Description of release and exposure

As described in the approach to assess the risks related to measuring devices using mercury as described in Section B.4 of the main document, there is no single parameter to sufficiently describe the potential release and exposure from either the use or the waste phase. Waste management of mercury and mercury contaminated samples and other materials is one part of the normal operation of the laboratories performing measurements with these devices. There is no data available on the number of pycnometers in use in the EU, but according to Lassen et al. (2008) the annual use of mercury in pycnometers is estimated to be very small compared to porosimeters. In the stakeholder consultation, no response was received from the only identified producer of mercury pycnometers (based in the USA). According to a producer of mercury porosimeters (not pycnometers), the alternatives have already substituted mercury pycnometers in all the applications (Lassen et al., 2010). This indicates that at least the number of mercury pycnometers placed on the market in the EU annually is very low if not zero.

The mercury is not included in the pycnometers during the production of the devices. Thus the production phase is not relevant for potential release and exposure. The mercury used in measurements is cleaned and dried and returned to the reservoir of the device. The mercury does not end up in the sample, indicating that potential emissions from waste phase are small compared to the situation with porosimeters. (Lassen et al., 2008).

3. Available information on alternatives (Part C)

Alternatives using a gas replacement technique to measure the volume are available (Lassen et al., 2008). Inert gases such as helium or nitrogen are used as the replacement media. According to a producer of mercury porosimeters and non-mercury pycnometers, the alternatives have already substituted mercury in all the applications: *“As far as I know mercury is no more used in pycnometry as envelope or helium pycnometers have substituted mercury pycnometry in all the application.”* (Lassen et al., 2010).

The only identified producer of mercury pycnometers produces also the alternative, i.e. the gas pycnometer. According to a brochure of the producer, the application areas covered by the mercury pycnometer are also covered by gas pycnometers, and the

brochure does not mention any specific advantages of mercury pycnometry over the alternatives. These application areas include battery separators, ceramic and fuel cells industries. In addition gas pycnometers can be applied in automotive, chemical, pharmaceuticals, powder metallurgy, nonwovens and construction industries. (Porous Materials, 2010)

This producer of mercury pycnometers (based in the USA) did not provide a response in the stakeholder consultation.

There are no derogations for pycnometers in the national restriction for mercury in Sweden. Sweden has not indicated any problems due to the restriction of these devices, which can be seen as an indication that the alternatives are technically feasible.

4. Justification why the proposed restriction is the most appropriate Community-wide measure (Part E)

4.1 Identification and description of potential risk management options

4.1.1 Risk to be addressed – the baseline

As discussed in Part B, the annual amount of mercury used in measuring devices is used as an indicator of potential release and exposure in this report. For mercury pycnometers, a way to describe the risk reduction capacity is the amount of mercury bought annually by the users, but there is no data available on that. Nevertheless this amount is assumed to be very small compared to porosimeters. Based on information received from a producer of porosimeters, the market of mercury pycnometers in the EU is very small if existing at all (Lassen et al., 2010). Thus, restricting the placing on the market of the mercury porosimeters can be seen as codifying the current situation.

4.1.2 Options for restrictions

Considering the evidence supporting the technical feasibility of alternatives and the low number of (if any) mercury pycnometers sold annually, only one restriction option is considered, i.e. a ban on placing on the market of mercury pycnometers after 18 months of the entry into force. This can be seen more or less as codifying the current situation.

4.2 Assessment of risk management options

The available data suggests that technically feasible alternatives for mercury pycnometers are available. Furthermore, the number of mercury pycnometers placed on the market annually is low (if any) and thus the risk reduction capacity is very small (if any). Accordingly the compliance costs related to the proposed restriction are small (if any) as only few users would need to move away from pycnometers after

the end of their service life. The fact that replacement has already more or less happened, indicates that the alternatives should not be significantly more expensive than the mercury device.

4.3. The proposed restriction and summary of the justifications

Proposal:

The placing on the market of mercury pycnometers after 18 months of entry into force of the amendment of Annex XVII.

Summary of justification:

The main purpose of the proposed restrictions is to reduce the mercury pool in the society, thus avoiding negative impacts on human health and environment. Technically feasible alternatives to mercury pycnometers are available. The available data suggest that the replacement has already taken place which supports the conclusion that alternatives are also economically feasible.

Annex 9: Mercury metering device for the softening point determination⁹¹

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⁹¹ This mercury measuring device was identified in the very last stage of the preparation of Annex XV restriction report, and no questionnaire was sent to the producer in the stakeholder consultation. However the producer was contacted by phone to collect some information.

1. Technical description of mercury metering devices

The **softening point** is the temperature at which a material softens beyond some arbitrary softness (Wikipedia, 2010f). For a substance which does not have a definite melting point, it is the temperature at which viscous flow changes to plastic flow (answers.com, 2010).

For a bitumen it represents an index of its fluidity, the temperature at which a bitumen (used in roofing or road construction) softens or melts.

The softening point can be determined by several methods, depending on the type of the tested substance (carbonaceous substances, bitumen, resin, glass, foodstuff like cheese).

Mercury metering devices are used for measuring the softening point by the Kraemer-Sarnow method. The softening point of a material is the lowest temperature at which a mercury load deforms a sample under standardized conditions.

The Kraemer-Sarnow method is used for determining the softening points of resins and fusible carbonaceous materials and is carried out according to DIN 53180 from 1996, Binders for paints and varnishes - Determination of the softening temperature of resins and DIN 52025 from 2004, Testing of carbonaceous materials - Determination of the Kraemer-Sarnow softening point.

The Kraemer-Sarnow is the oldest method and uses a small glass tube that is open at both ends and the load is a small mercury drop (5g). The mercury drop is placed on a small disk made of the test material contained in a metal ring fixed at the lower end of a tube. The ensemble is warmed on a bath at a constant rate. The softening point is obtained as the Kraemer-Sarnow temperature (TKS) at which the mercury drop breaks through the softening material and falls.

2. Description of release and exposure

As described in the approach to assess the risks related to measuring devices using mercury as described in Section B.4 of the main document, there is no single parameter to sufficiently describe the potential release and exposure from either the use or the waste phase. There is no data available on the number of mercury metering devices currently used in the Kraemer-Sarnow method in the EU. Only one producer of mercury metering devices for the Kraemer-Sarnow method was identified in Europe. According to the producer, no devices have been sold in the past three or four years⁹². This indicates that the number of mercury metering devices placed on the market in the EU annually is very small (if any).

According to this producer, the mercury is not included in the mercury metering devices during their production. The mercury used in measurements can be cleaned and dried and returned to the reservoir of the device. Thus, the production phase is not relevant for potential release and exposure. The mercury ends up mixed with the sample, indicating that potential emissions from waste phase exist.

3. Available information on alternatives (Part C)

Alternatives using other techniques to measure the softening point are available. According to Benedek and Feldstein (2009) and a producer of mercury metering devices (Petrotest, 2010), the alternatives have already substituted mercury in all the applications.

The softening point can be determined at least by following methods:

The Ring and Ball method (R&B), carried out according to ASTM D 3461-76 and DIN ISO 4625; it is the most frequently used method to determine the softening point of resins (pavementinteractive.org). The resin is melted into a metal ring and left to cool. The ring is placed in a special metallic device, which is placed into a water or glycerol bath. A steel ball of given diameter and mass is placed on the ring and the bath is heated at a given rate. The temperature at which the ball forces the softening resin downward is noted as the softening point.

Mettler Softening Point method, carried out according to ASTM D 3461-76; it is the most recent method and it has the advantage to be automatic. The method measures the temperature at which the resin flows out of a sample cup under its own weight; the temperature is recorded when the first drop crosses the light path of a photocell; the mettler method is quite accurate and reproducible.

Plate-plate Stress Rheometer Test; the resin is placed between the two steel plates of a stress-controlled rheometer, maintaining a gap larger than 0,5 cm. The upper

⁹² This information was indicated in preliminary screening of the device, but could not be verified before the submission date of this report, but should be further investigated during the processing of this Annex XV report.

plate is oscillated at a given frequency, whereas the lower plate is heated. The variation of the storage and loss moduli as a function of the temperature is monitored. The softening temperature can be estimated from the temperature at the cross-over between the two moduli.

Vicat method or **Vicat hardness** is a method for the determination of the softening point for polycarbonates. The softening point is determined as the temperature at which the specimen is penetrated to a depth of 1 mm by a flat-ended needle with a 1 square mm circular or square cross-section. The determination of the softening point with the Vicat method can be carried out according to standards ASTM D 1525 and the equivalent ISO 306.

Although not widely used, other methods to determine the softening point exist, such as capillary method, the flow point, the drop point, and the Kofler method. In general, the R&B method provides the highest softening point, whereas the Mettler method provides the lowest softening point for a given resin. Therefore, always both methods should be given.

The alternative methods are widely used at least in petrochemical, chemical, building materials industry.

The only identified producer of mercury metering devices for the determination of the softening point also produces two other alternative devices.

4. Justification why the proposed restriction is the most appropriate Community-wide measure (Part E)

4.1 Identification and description of potential risk management options

4.1.1 Risk to be addressed – the baseline

As discussed in Part B, the annual amount of mercury used in measuring devices is used as an indicator of potential release and exposure in this report. For mercury metering devices, a way to describe the risk reduction capacity is the amount of mercury bought annually by the users, but there is no data available on that. Nevertheless this amount is assumed to be very small compared to porosimeters. Based on the preliminary screening⁹³, the market of mercury metering devices for this specific use in the EU is very small if existing at all. Thus, restricting the placing on the market of the mercury metering devices can be seen as codifying the current situation.

⁹³ This information was indicated in preliminary screening of the device, but could not be verified before the submission date of this report, but should be further investigated during the processing of this Annex XV report.

4.1.2 Options for restrictions

Considering the evidence supporting the technical feasibility of alternatives and the low number of (if any) mercury metering devices sold annually, only one restriction option is considered, i.e. a ban on placing on the market of the mercury metering devices for the determination of the softening point after 18 months of the entry into force. This can be seen more or less as codifying the current situation.

4.2 Assessment of risk management options

The available data suggests that technically feasible alternatives for mercury metering devices are available. Furthermore, the number of mercury metering devices for the determination of the softening point, placed on the market annually is low (if any) and thus the risk reduction capacity is very small (if any). Accordingly the compliance costs related to the proposed restriction are small (if any) as only few users would need to move away from mercury metering devices after the end of their service life. The fact that the alternatives, available from the same producer are preferred due to their accuracy, indicates that the alternatives should not be significantly more expensive than the mercury device.

4.3. The proposed restriction and summary of the justifications

Proposal:

The placing on the market of mercury metering devices for the determination of the softening point after 18 months of entry into force of the amendment of Annex XVII.

Summary of justification:

Technically feasible alternatives to mercury metering devices for the determination of the softening point are available. The available data suggest that the replacement has already taken place which supports the conclusion that alternatives are also economically feasible.

Appendices

All the following appendices are attached as separate documents:

Appendix 1: Classification and labelling

Appendix 2: Review of literature estimating the compliance costs, human health benefits and restoration costs of reduced mercury emissions to support assessment of the cost-effectiveness

Appendix 3: Services to support preparing an Annex XV restriction report on mercury containing measuring devices: Working notes based on stakeholder consultation






Appendix 4: Restriction of mercury in measuring devices under Regulation (EC) No 1907/2006 (REACH) in relation to restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS)

Appendix 5: Review on the availability of technically and economically feasible alternatives for mercury containing sphygmomanometers and other measuring devices for professional and industrial uses

Appendix 1: Classification and labelling

Mercury is included under the index number 080-001-00-0 in the Annex VI, Table 3.1 of CLP Regulation, *List of harmonised classification and labelling of hazardous substances* and Table 3.2 *List of harmonised classification and labelling of hazardous substances from Annex I to Directive 67/548/EEC*. The substance is classified according to Annexes I and IV of the 1st adaptation to technical and scientific progress of the CLP Regulation (Commission Regulation (EC) No 790/2009).

Index No: 080-001-00-0			
International Chemical Identification: mercury			
EC No: 231-106-7			
CAS No: 7439-97-6			
	Classification according to Annex IV of the Regulation (EC) No 790/2009, amending the Table 3.2 <i>List of harmonised classification and labelling of hazardous substances from Annex I to Directive 67//548/EEC, 31st ATP</i>	Classification and labelling according to CLP Regulation, 1st ATP from Annex I of the Regulation (EC) 790/2009	
		Hazard Class and Category Code(s)	Hazard statement Code(s)
Classification	Repr. Cat. 2; R61 T+; R26 T; R48/23 N; R50-53 Note E: The R phrases indicating specific effects on human health shall be preceded by the word 'Also'.	Repr. 1B: Reproductive toxicity, hazard category 1B Acute Tox. 2*: Acute toxicity, hazard category 1 (* meaning Minimum classification, see Annex VI, chapter 1.2.1 of the CLP Regulation) STOT RE 1: Specific target organ toxicity – repeated exposure, hazard category 1 Aquatic Acute 1: Hazardous to the aquatic environment, acute hazard category 1 Aquatic Chronic 1: Hazardous to the aquatic environment, chronic hazard category 1	H360D***: May damage fertility or the unborn child (***)meaning the general hazard statement can be replaced by the hazard statement indicating only the property of concern, where either fertility or developmental effects are proven to be not relevant, see Annex VI, chapter 1.2.3 of the CLP Regulation) H330: Fatal if inhaled H372**: Causes damage to organs (state all organs affected, if known) through prolonged or repeated exposure (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard) (** meaning Route of exposure cannot be excluded, see Annex VI, chapter 1.2.2 of the CLP Regulation) H400: Very toxic to aquatic life H410: Very toxic to aquatic life with long lasting effects

Labelling	Symbols	Pictogram, Signal Word Code(s)	Hazard Statement code(s)
	<p data-bbox="348 297 541 370">   </p> <p data-bbox="348 375 898 573"> Risk phrases: R61: May cause harm to the unborn child, R26: Very toxic by inhalation, R48/2: Toxic: danger of serious damage to health by prolonged exposure through inhalation, R50/53: Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment, </p> <p data-bbox="348 578 898 857"> S phrases: S53: Avoid exposure - obtain special instructions before use, S45: In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible), S60: This material and its container must be disposed of as hazardous waste, S61: Avoid release to the environment. Refer to special instructions/Safety data sheets. </p>	<p data-bbox="926 407 1283 431">GHS06: Acute toxicity (inhalation) </p> <p data-bbox="926 553 1304 578">GHS08: Reproductive toxicity, STOT </p> <p data-bbox="926 626 1262 651">GHS09: Hazardous to the aquatic </p> <p data-bbox="926 724 1325 821">environment</p> <ul data-bbox="1010 756 1325 821" style="list-style-type: none"> - Acute hazard category 1 - Chronic hazard category 2 <p data-bbox="926 862 1052 886">Dgr: Danger</p>	<p data-bbox="1457 310 1913 529">H360D***: May damage fertility or the unborn child (***)meaning the general hazard statement can be replaced by the hazard statement indicating only the property of concern, where either fertility or developmental effects are proven to be not relevant, see Annex VI, chapter 1.2.3 of the CLP Regulation)</p> <p data-bbox="1457 561 1671 586">H330: Fatal if inhaled</p> <p data-bbox="1457 626 1913 846">H372**: Causes damage to organs (state all organs affected, if known) through prolonged or repeated exposure (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard) (** meaning Route of exposure cannot be excluded, see Annex VI, chapter 1.2.2 of the CLP Regulation)</p> <p data-bbox="1457 878 1871 935">H410: Very toxic to aquatic life with long lasting effects</p>

Appendix 2: Review of literature estimating the compliance costs, human health benefits and restoration costs of reduced mercury emissions to support assessment of the cost-effectiveness

In this appendix the literature estimating the compliance costs and the human health benefits of reduced mercury emissions, as well as the restoration costs are summarised. There are many studies in which the compliance costs, damage costs, removal costs or other values have been estimated per kilogramme of mercury.

None of the compliance cost estimates for other policies are directly comparable with the cost of restricting mercury from measuring devices as proposed in this Annex XV restriction report. Furthermore, cost-effectiveness (cost per kg of mercury avoided or reduced) on its own does not reflect whether the costs introduced by a restriction are proportionate to the risks reduced. However, these other policies have been established to reduce the overall exposure of humans and the environment to mercury which is also the aim of the suggested restrictions. Therefore, it seems reasonable to infer that when the cost per kg of mercury not placed on the market is relatively low, proportionality of such a restriction is established.

Recognising the difficulty of establishing a point estimate for such thresholds these were established for purpose of this report to guide the assessment of the proportionality of suggested restriction for different devices. It is stressed that these thresholds are not to be used in isolation from the generic framework and approach taken in the development of this report and, therefore, should not be used in other contexts.

For the purposes of this analysis a benchmark of €10,000 /kg Hg has been regarded as indicating that proportionality of costs to the risks related to mercury is “well established”. On the other hand, it seems clear that there is an upper limit above which one can conclude that the proportionality has not been established. For the purposes of this analysis a benchmark of €100,000 / kg Hg was established. The range between the two benchmarks – i.e. these “borderline” cases – have been divided to two sections. If the compliance costs are below a threshold of €20,000/kg Hg it is regarded that the proportionality has been “fairly well” established. If the costs were below €100,000/kg Hg, the economic feasibility is “possibly established” for the purposes of this restriction report.

Table 1 summarises these ranges

Table 1: Ranges of cost-effectiveness applied in this restriction report to establish proportionality

Cost-effectiveness	Range per kg of mercury
Well established	Under €10,000
Fairly well established	€10,000- €20,000
Possibly established	€20,000-€100,000
Not established	Over €100,000

The basis for the thresholds established in Table 1 is described in the following sections. These thresholds can be applied as one criterion when the proportionality of the proposed restrictions is assessed.

1. COMPLIANCE COSTS OF REDUCING MERCURY

Hylander and Goodsite (2006) reviewed compliance costs of removing a kilogramme of mercury from different policies (Table 2). According to the reviewed studies the return of mercury in thermometers in Sweden in 1992-96 costs between €829 and €1047¹ per kg of mercury. These costs included the provision of information and collection, transport and deposition of mercury containing thermometers. The costs of additional working time of shop assistants and municipal officials were excluded. More importantly, the costs of purchasing alternative equipment were excluded, too. As at that time the price difference between mercury containing and mercury free thermometers was large, it is likely that the costs represent only a fraction of the overall compliance costs of replacing mercury in thermometers in Sweden.

Some other policies to reduce the amount of mercury in the society have been studied. For instance, the replacement of mercury containing items with mercury free items in Minnesota (US) were estimated to cost between €17 and €1745² per kg of mercury depending on the policy. The cost of collection of mercury and mercury compounds in school laboratories was estimated to be between €61 and €349³ per kg of mercury. (Jackson et al., 2000).

The compliance costs of amalgam⁴ separators per kg of mercury removed in Minnesota (US) have been estimated to be between €28,795 and €1,134,358 per kg of mercury removed (Jackson et al., 2000). However, ECHA did not have the possibility to examine in detail what is covered in these costs and consequently to what extent they are comparable with the costs of restricting the use of mercury in measuring devices.

Many Member States (e.g. Belgium, Denmark, Finland, Germany, Sweden and the UK) as well as Norway have national policies (either voluntary or legislative action) to encourage or require the use of amalgam separators at dentists. It should be noted that due to technical progress and the fact that amalgam separators have become standard equipment in dental care, the real costs of amalgam separators are likely to be now lower than in early 1990's. At the same time in the EU there is an overall declining trend in the amount of amalgam used to fill cavities⁶.

In Table 2, the costs of different policies to reduce mercury emissions are summarised.

³¹ From \$950 to \$1200 measured in 2004 US dollars

² From \$20 to \$2000 measured in 2004 US dollars

³ From \$70 to \$400 measured in 2004 US dollars

⁴ About half of dental amalgam is made of mercury
([http://en.wikipedia.org/wiki/Amalgam_\(dentistry\)#cite_note-1](http://en.wikipedia.org/wiki/Amalgam_(dentistry)#cite_note-1))

⁵ From \$33 000 to \$1 300 000 measured in 2004 US dollars

⁶ For instance, mercury free materials are used to fill cavities, and there is an overall reduction in caries in the EU) (eg. see Table 38.2 of World Bank, 2006).

Table 2: Costs of reducing the emissions of mercury

Activity	Place and year	Cost (US\$/kg Hg)	<i>a</i>	Reduction potential	Reference
Return of Hg thermometers	Sweden, 1992–1996	950–1,200	<i>b</i>	Large	Rein and Hylander, 2000
Replace mercury-containing items	Minnesota, estimated 1999	20–2,000	<i>c</i>	Large	Jackson et al., 2000
Collect Hg and Hg compounds in school labs	Sweden, 1995–1999	70–400	<i>b</i>	Small	Rein and Hylander, 2000
Collect metallic Hg in school laboratories	Minnesota, estimated 1999	20	<i>c</i>	Large	Jackson et al., 2000
Collect Hg compounds in school laboratories	Minnesota, estimated 1999	1,400	<i>c</i>	Small	Jackson et al., 2000
Replacing Hg cells at chlor-alkali plants	USEPA, estimated 1996	10,100	<i>d</i>	Large	USEPA, 1997
Increase recycling of chairside traps in dentistry	Minnesota, estimated 1999	240		Medium	Jackson et al., 2000
Install amalgam separators	Minnesota, estimated 1999	33,000–1,300,000		Medium/ Large	Jackson et al., 2000
Replace dental amalgam fillings at dentists	Sweden, estimated 2004	129,000		Large	Hylander and Goodsite, 2006
Remove dental amalgam fillings at death	Sweden, estimated 2004	400		Large	Hylander and Goodsite, 2006
Flue gas cleaning with carbon at crematoria	Sweden, estimated 2004	170,000–340,000		Medium/ Large	Hylander and Goodsite, 2006
Flue gas cleaning with carbon at crematoria	UK, estimated 2004	29,000		Medium/ Large	Hylander and Goodsite, 2006; BBC News, 2005
Medical waste incinerators with scrubber	USEPA, estimated 1996	4,400–8,800		Medium/ Large	USEPA, 1997
Carbon injection into flue gases at waste incinerators	USEPA, estimated 1996	465–1,900		Medium/ Large	USEPA, 1997
Combined technologies at waste incineration	Uppsala, Sweden, 2004	40,000		Large	Hylander and Goodsite, 2006
Coal cleaning, conventional, chemical or both	Minnesota, estimated 1999	100,000–128,000		Large	Jackson et al., 2000
Carbon injection into flue gases at power plants	USEPA, estimated 1996	31,000–49,000	<i>e</i>	Large	USEPA, 1997
Carbon injection into flue gases at power plants	US Dep. Energy, estimated 1996	149,000–154,000	<i>e</i>	Large	Brown et al., 2000
Carbon injection into flue gases at power plants	Minnesota, estimated 1999	20,000–725,000		Large	Jackson et al., 2000
Combined technologies at power plants	USEPA, estimated 1996	11,000–61,000	<i>e</i>	Large	USEPA, 1997
Combined technologies at power plants	US Dep. Energy, estimated 1996	56,000–85,000	<i>e</i>	Large	Brown et al., 2000
Wind as replacement for energy from coal	Minnesota, estimated 1999	1,200,000–2,000,000		Large	Jackson et al., 2000

Source: Hylander and Goodsite (2006)

Notes

a Values in a range reflect differences across facilities of different sizes or at different recovery rates e.g. 90% or >95% of Hg recovered from flue gases, or other site-specific conditions.

b Cost calculated per kilogram Hg collected and includes costs for information, reimbursement for thermometers, and additional costs for collecting, transport and deposition, while costs for additional working time of shop assistants, municipal officials, etc. are excluded.

c Total cost per unit of Hg not emitted.

d Capital and electrical costs. Indirectly reduced Hg emissions caused by lower consumption of electricity from Hg emitting power plants have not been included. The costs increase if pollution occurred earlier needs extensive remediation.

e 90% reduction in mercury emissions. The EPA figures are based on a lower flue gas temperature when carbon is injected, thereby using the sorption capacity better, resulting in that only 2–34% active carbon is used compared to the DOE estimates.

Conclusion

Some of the compliance cost estimates are more relevant than others for the purposes of comparison with possible restrictions for mercury in measuring devices. It would seem that the costs of returning mercury containing thermometers and the collection of mercury containing equipment in school laboratories are more relevant as they relate to a similar approach than in restricting the placing on the market of mercury containing measuring devices. It should be noted that the costs between €829 and €1047 per kg of mercury seem to be only a fraction of the total compliance costs as they do not include the alternative (i.e. higher) costs related to mercury-free measuring devices.

It is more difficult to compare directly the costs of reducing mercury emissions to water or to the air by applying end-of-pipe abatement techniques vis-à-vis the costs of replacing mercury in measuring devices.

2. OTHER METHODS

2.1 Measuring human health benefits of reduced mercury exposure

Rice and Hammitt (2005) analysed very comprehensively the health benefits of reducing mercury emissions to air from coal-fired power plants in the United States. Reductions in mercury emissions were anticipated to decrease methyl mercury concentrations in fish, whose consumption is the primary pathway of human exposure to methyl mercury. The modelling analysis was based on EPA's analysis of Clear Skies Initiative. Table 3 gives the main results of Rice and Hammit (2005). The degree of certainty is discussed below.

The analysis accounted for potential changes in two health effects: cognitive abilities (i.e. changes in IQ⁷) and cardiovascular events. Overall, the health benefits of reducing mercury emissions range between about €5000 / kg Hg and €250,000 / kg Hg. The lowest benefits related to the development of the children (measured in IQ) while the higher benefits include also cardiovascular effects.

⁷ Using a cost-of-illness approach Rice and Hammitt (2005) estimated the value of a lost IQ point to be approximately \$16,500 (in 2000 dollars).

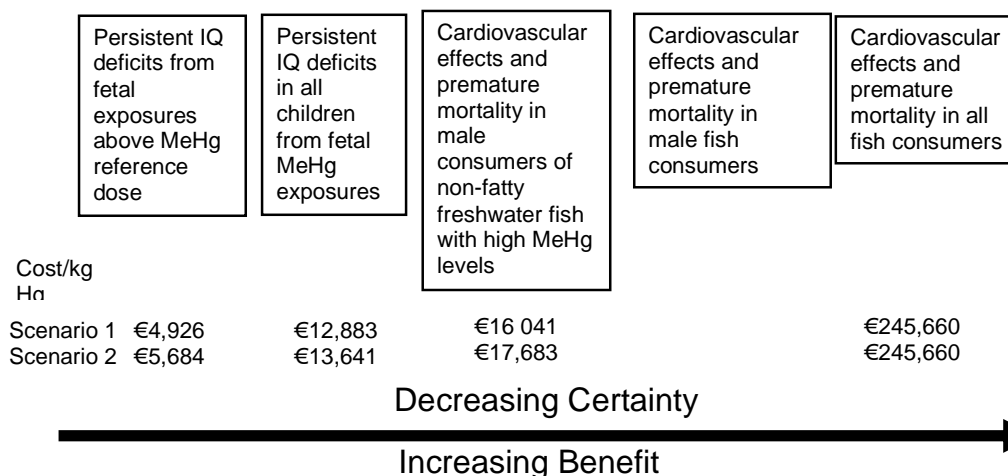
Table 3: Health benefits from reducing mercury emissions measured in € per kg of removed mercury, 2010 price level

Option		Scenario 1 (19.1 tonnes of Hg removed)	Scenario 2 (26.7 tonnes of Hg removed)	Degree of certainty
1	Cost of Illness estimates for persistent IQ deficits in children exposed above the reference dose in utero	€4,926 <i>(\$3,900)</i>	€5,684 <i>(\$4,500)</i>	Highest
2	As 1 but effects occur also below the reference dose	€12,883 <i>(\$10,200)</i>	€13,641 <i>(\$10,800)</i>	Fairly high
3	As 2 but also “males that consume non-fatty freshwater fish”, are assumed to have cardiovascular effects	€16 041 <i>(\$12,700)</i>	€17,683 <i>(\$14,000)</i>	Lower
4	As 3 but also <u>all</u> individuals are assumed to have cardiovascular effects	€229,873 <i>(\$182,000)</i>	€245,660 <i>(\$194,500)</i>	Lowest

Source: Page 193 in Rice and Hammitt (2005)

Note: The estimates in the study were given in US dollars 2000 price level and are given in *(italics)*. They have been converted to euros in 2010 price level by first converting the dollars to euros (i.e. ECUs) in 2000 and then using the EU's GDP deflator to bring them to 2010 price level. End note 1 gives the deflators and exchange rates used.

According to Rice and Hammit (2005) the neurological effects associated with *in utero* methylmercury exposures are well established and thus they considered these effects relatively certain “*On the other hand, while the studies that have evaluated the association of adult methylmercury exposures with cardiovascular events and premature mortality appear to be scientifically sound and the individual study results appear to be credible, they have not been subjected to a rigorous scientific analysis as a group.*” (Rice and Hammitt, 2005, p. 191) Although these relationships have been observed in several studies, there are also studies in which a relationship was not observed (Rice and Hammit 2005, p. 37). In other words, the degree of certainty is reduced the more health effects are included in the analysis. This has been illustrated in Table 3 as well as in Figure 1.

Figure 1: Spectrum of Certainty of Causal Association of Health Effect with Mercury Exposure with Estimated Benefit Overlay

Source: Adapted from Figure 12 of Rice and Hammitt (2005)

Spadaro and Rabl (2008) analysed the global average damages from mercury emissions. The cost of an IQ measured in US was applied in other countries in portion to GDP per capita and adjusted for the purchasing power parity (PPP). The resulting mean estimate of the global average of the marginal damage cost of mercury emissions was between €1,280 and €2,900⁸ per kg mercury emitted. Given that the world's PPP adjusted GDP is lower than the GDP in the US, the results at global level by Sparado and Rabl (2008) were close to those by Rice and Hammit (2005). For the EU, given that its GDP is relatively close to that of the US, the Rice and Hammit results are considered more relevant than those of Sparado and Rabl.

Swain et al. (2007) reviewed 11 studies that have provided quantification of the benefits of reducing mercury pollution. However, they did not relate the benefits to tonnes of mercury removed and thus, the results cannot be applied in the context of the regulation of mercury in measuring devices in the EU. As regards health endpoints most of the studies focused only on IQ. Consequently, these quantitative estimates of benefits related to reduced mercury use and emissions underestimate the full benefits of Hg reduction by excluding other health endpoints (see Table 1 above) as well as environmental endpoints. Authors argued that the economic valuation models used in these studies were quite similar, however, assumptions regarding the impact of decreased mercury emissions on the changes in methyl mercury levels in different types of fish, and the health effects considered, differed markedly. There are numerous uncertainties involved in evaluating policies for mercury reduction: including (i) changes in mercury deposition rates, (ii) changes in fish methyl mercury levels, (iii) changes in human intake of methyl mercury, (iv) changes in IQ due to exposure, and (v) changes in all-cause mortality and fatal and nonfatal heart attacks in adults. Much of the variability of economic benefit estimates in these studies is explained by differing assumptions made to response to uncertainties in the physical and health sciences of mercury and methyl mercury (Swain et al. 2007).

Conclusion

It can be concluded that many studies have estimated rather high values of reducing mercury emissions. These range from about €5,000 to €20,000 per kg Hg but could be much higher (e.g. €250,000), if the less certain cardiovascular effects are included. These values relate to emissions (to air) and are not directly comparable with the cost-effectiveness of reducing the amount of mercury placed on the market that is estimated in this report. The values relate to human health impacts, thus omitting the values of impacts that effect the environment as such.

2.2. Removing costs of mercury in Sweden

Hylander and Goodsite (2006) also reported several cases of the costs of removing mercury from deep sediments in Sweden. Some costs were actual, some planned or estimated. It is assumed that actual (rather than planned or estimated) costs reflect better the willingness of the society to reduce risks related mercury. Taking these actual costs as the basis the restoration costs in Örsörum Bay and Lake Thuringen have been between €8,726 and €21,815⁹ per kg of mercury.

The restoration costs cannot be compared with the compliance costs of restricting the placing on the market of mercury measuring devices, as the emissions take place mainly

⁸ From \$1500 to \$3400 per kg mercury emitted, measured in 2005 US dollars

⁹ From \$10 000 to \$25 000 measured in 2004 US dollars

during the waste phase and in a dispersive manner. Nevertheless, the costs give an order of magnitude in some specific cases of the value of removing mercury.

2.3. Special case – damage from mercury poisoning in Minamata, Japan

According to Hylander and Goodsite (2006) the (partial) compensation of victims of mercury poisoning in Minamata, Japan ranged between €5497 and €6544¹⁰ per kg of mercury. In this case there were also additional restoration costs of between €3927 and €4712¹¹ per kg mercury. If added together, the costs of compensating mercury emissions in the Minamata case ranged between €9,424 and €11,256 per kg of mercury. It should also be noted that the compensation costs relate to damage through poisoning in an extreme case and thus are likely to be an underestimate of society's willingness-to-pay to reduce mercury.

It should be noted that the Minamata case is unique and not directly comparable with the compliance costs of restricting the placing on the market of mercury measuring devices.

End note 1: GDP deflators and exchange rates used

	EU27 GDP deflator (Di), 2000 = 100	Exchange rates: US\$ in Euros	Coefficients for converting US\$ to € valued at 2010 (US\$/€) / (Di/D2010)
2000	100,0	1,0827	1,2630
2001	102,1	1,1166	1,2757
2002	104,6	1,0575	1,1791
2003	105,0	0,8840	0,9821
2004	107,5	0,8039	0,8726
2005	109,9	0,8038	0,8532
2006	112,5	0,7964	0,8260
2007	115,7	0,7297	0,7357
2008	116,2	0,6799	0,6829
2009	114,4	0,7169	0,7313
2010	116,7	0,6843	0,6843

Example: 100 US dollars measured in 2000 price level would be 1.2630 x 100 dollars, i.e. 1263 euros in 2010 price level

¹⁰ From \$6 300 to \$7 500 measured in 2004 US dollars

¹¹ From \$4 500 to \$5 400 measured in 2004 US dollars

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**Services to support preparing an Annex XV
restriction report on mercury containing
measuring devices**

**Results from the information gathering and
stakeholder consultation**

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Preface

The following appendix includes working notes prepared December 2009 to May 2010 to support ECHA in preparing an Annex XV restriction report on mercury containing measuring devices. The notes are not considered stand alone documents presenting a comprehensive view of the use of the equipment, but reflect the information that has been requested by ECHA for the preparation of the Annex XV report. It is therefore recommended to read the notes together with the relevant parts of the Annex XV report.

In addition to the working notes the consultant has provided an inception report including a review of the Concorde East/west (2009) report “Turning up the pressure: Phasing out mercury sphygmomanometers for professional use”; feedback on drafts prepared by ECHA and regular and *ad hoc* consultation on different technical matters regarding mercury containing measuring equipment.

1 Stakeholder consultation

A stakeholder consultation has been undertaken as part of the work under this contract. The objective of the consultation was mainly to identify the need and reasons for possible derogations to the proposed restriction and to collect input for the socioeconomic analysis such as information on the costs of alternatives and economic feasibility of replacement.

As part of the consultation, questionnaires were sent to identified manufacturers of mercury containing thermometers (including hydrometers and hygrometers), manometers, tensiometers, porosimeters and pycnometers, hanging drop electrodes (polarography), strain gauges and gyrocompasses. The questionnaires were tailored to each type of equipment. The questionnaires were sent by e-mail to contact persons (that had been identified and contacted previously by telephone), and followed up with a reminder by e-mail after some weeks. In a few cases it was not possible to identify a contact person by a telephone call and the questionnaire was sent to the company's general e-mail address.

For selected applications, where more information was requested by ECHA, the questionnaire was supplemented by telephone and e-mail contact to selected manufacturers and suppliers of mercury containing equipment, alternatives and test laboratories.

The list of manufacturers was based on the EU Mercury Study (Lassen et al., 2008) and it is deemed that the contacted manufacturers represent the majority of the manufacturing of the concerned equipment in the EU. For porosimeters the contacted manufacturers represent also nearly all of the equipment marketed in the EU, whereas for the other equipment a significant import from countries outside the EU may take place.

Manufacturers of reference electrodes have not been contacted by the consultant as it was decided that ECHA would contact the only identified manufacturer in the EU.

Producers of barometers were not contacted as the evidence that feasible alternatives exist was regarded to be so strong based on the earlier work. Nevertheless, it has been investigated in by contact to reference laboratories to what extent mercury barometers are still needed as reference instruments for calibration of other instruments.

Table 1 below lists the contacted companies and organisations.

Table 1 Contacted companies and organisations

Company	Questionnaire	Response obtained	Contacted by telephone or e-mail (apart from questionnaire contact)	Response obtained
Manufacturers of Hg thermometers				
Sika Dr Siebert und Kühn & Co. K, Germany	x	x		
Ludwig Schneider GmbH & Co. KG, Germany	x	x	x	x
AMARELL GmbH & Co. KG	x	x	x	x
ALLA FRANCE,	x	x		
Gusmini & Balconi S.R.L., Italy	x			
S. Brannan & Sons Ltd	x	x		
Russell Scientific Instruments Limited	x	x	x	x
SC Termodensitrom,	x			
Exatherm, Ltd., Czech Republic	x			
G H Zeal Ltd			x	x
Manufacturers and suppliers of alternative thermometers				
Carl A. Plesner A-S; Denmark			x	x
Kjærulf Pedersen a/s ; Denmark			x	x
Tempress A/S; Denmark			x	x
Bie & Berntsen A/S, Denmark			x	x
WIKA Alexander Wiegand SE & Co. KG; germany			x	x
Poulten Selfe & Lee Ltd, United Kingdom			x	x
Charnwood Instrumentation Services Ltd.			x	
Producers of porosimeters and pycnometers				
Micromeritics Instrument Corporation, U.S.A. (European branch contacted)	x	x	x	x

Company	Questionnaire	Response obtained	Contacted by telephone or e-mail (apart from questionnaire contact)	Response obtained
Porous Materials, Inc., USA	x			
QUANTACHROME INSTRUMENTS; USA (European branch contacted)	x		x	x
Thermo Fisher Scientific Inc.; USA (European branch contacted)	x		x	x
Users of porosimeters				
MOL Plc, Hungary			x	x
L'Istituto di Tecnologie Avanzate per l'Energia, Italy			x	x
Risoe, Denmark			x	x
Core Laboratories, UK			x	x
Producers of Hg manometers				
Giussani S.r.l., Italy	x			
Dwyer Instruments Limited, USA	x			
Sphygmomanometers (Hg and alternatives)				
Rudolf Riester GmbH; Germany	x	x	x	x
A.C. COSSOR & SON (SURGICAL) LTD, UK	x	x	x	x
Spengler , France	x			
Manufacturers and suppliers of gyrocompasses				
Kelvin Hughes Limited; UK	x		x	x
Raytheon Anschuetz GmbH; Germany			x	x
Points North Ltd. Scotland, UK			x	x
Strain gauges				
D. E. Hokanson, Inc., USA	x			
Kemikalieinspektionen, Sweden			x	x
Producers of Hg Tensiometers				
SDEC, France	x			

Company	Questionnaire	Response obtained	Contacted by telephone or e-mail (apart from questionnaire contact)	Response obtained
Producers of hanging drop electrodes				
Metrohm A/G, Switzerland	x	x	x	x
AMEL srl, Italy	x			
Reference and calibration laboratories, standard organisations				
Danish Technological Institute			x	x
Trescal A/S, Denmark			x	
Danish NMI (the National Metrology Institute)			x	x
Exova METECH A/S; Denmark			x	x
Danish Meteorological Institute, Denmark			x	x
National Physical Laboratory, UK			x	x
Pullman Instruments, UK			x	
Physikalisch-Technische Bundesanstalt (PTB), Germany			x	x
DIN-FAB, Germany			x	x
British Standards			x	x
BSI Committee Service Centre (CSC)			x	x
Material testing equipment				
Petrotest® Instruments GmbH & Co. KG, Germany			x	x
Stanhope-Seta, UK			x	x
AGA Appliances (stove with thermoindicator)				
AGA, UK				

2 Porosimeters

Porosimetry is an analytical technique used to determine various quantifiable aspects of a material's porous nature, such as pore diameter, total pore volume, surface area, and bulk and absolute densities.

Mercury intrusion porosimetry involves the intrusion of mercury at high pressure into a material through the use of a porosimeter. The pore size can be determined based on the external pressure needed to force the liquid into a pore against the opposing force of the liquid's surface tension. See Lassen et al. (2008) report for more details about the technique.

2.1 Analysis procedures

The following short description of the analysis procedure is based on the Operators Manual to AutoPore IV 9500 from Micromeritics and a demonstration of the analysis using this porosimeter provided by a laboratory using the equipment for analyses. Somewhat different procedures may be used by the use of other equipment (more details are referred to in operator's manuals from individual equipment providers). This description focuses on what happens to the mercury in the procedure.

A step-by-step description of the operating procedure this set out below as well as a photo illustration of the device below. In this laboratory the porosimeter was connected to an exhaust and not placed in a fume hut – it may be different in other laboratories.



The sample cells used in most mercury porosimeters are designated penetrometers (Thermo Scientific uses the term dilatometers). The penetrometer consists of metal stem and a glass sample bulb where the sample is placed during the measurements.

All photos by COWI

- 1 Before the analyses: The reservoir in the porosimeter is filled with mercury. The porosimeter requires approximately 2.3 kg of mercury (minimum) to begin analyses and the reservoir can contain a maximum of 5.4 kg. Each analysis may extract from 3 mL (= approx. 40 g mercury) to 15 mL (app. 120 g) of mercury from the reservoir depending on the penetrometer and sample size used.
- 2 The penetrometer is weighed. The sample (specimen) is placed in the glass sample bulb of the penetrometer and the total weight of penetrometer + sample is determined.
- 3 The penetrometer is loaded in the low pressure port of the porosimeter for analysis of large pores (3.6 to 360 μm).
- 4 The penetrometer is evacuated and backfilled automatically with mercury through the stem of the penetrometer. The mercury extends the entire length of the penetrometer and fills the bulb and stem.
- 5 As pressure increases, mercury moves into the sample's pores, vacating the stem. The mercury moves from the stem into the sample bulb and further into the pores. Pore volume data are calculated by determining the volume of mercury remaining in the penetrometer stem. The volume of mercury in the penetrometer's stem is measured by determining the penetrometer's electrical capacitance. The result of the analysis is basically a dataset of different pressures versus volumes of mercury pressed into the specimen.
- 6 The penetrometer (still filled with mercury) is removed from the low pressure port and placed in a balance for determination of the weight of penetrometer + sample + mercury. (The weighing may be done after step 7 instead.)
- 7 The penetrometer is loaded in the high pressure port for analysis of small pores (0.005 to 6 μm) and step 4 and 5 are repeated.
- 8 The penetrometer is removed from the high pressure port and transferred to a fume hood (this may vary by laboratory).
- 9 A plug on the top of penetrometer is unscrewed and the mercury is drained through the stem into a container for slightly contaminated mercury.
- 10 The sample is poured into a container for mercury contaminated waste.
- 11 The penetrometer is cleaned with solvents in order to remove mercury droplets, oil and grease.
- 12 In some laboratories the contaminated mercury is regenerated by a cleaning for reuse. The number of analyses that can be run using the same mercury depends on the mercury oxidation status. Some laboratories indicate they reuse the mercury 5-10 times, others that they reuse the mercury more than 5-10 times and that the mercury is renewed by the amount added in

replacement of mercury being lost in the samples. The oxidation rate depends on the porous materials analysis, typically metal-based materials, may accelerate the oxidation process.

Steps 9-12 may be different in the way that the mercury is regenerated immediately after the analysis. The following description is based on the Instruction Manual, "Use of Cleaning Kit for Mercury" from Thermo Scientific PN 317 130 44, Revision June 2007. The mercury cleaner is a pyrex glass siphon device allowing removal by decanting both solid and powdered sample residues from the mercury.

- 1 Open the penetrometer (termed a 'dilatometer' in the manual) containing the mercury and pour the mercury and sample into a metal filter in the siphon container.
- 2 The sample remained inside the filter is transferred into a container for mercury contaminated waste
- 3 The mercury, passed through the filter, is further cleaned by slow decantation in the siphon and will be collected on the bottom of the siphon vessel passing through a solvent layer.
- 4 The penetrometer is cleaned with a brush and solvents in order to remove mercury droplets, oil and grease. All parts of the dilatometer is immersed into the solvent for 10 - 20 minutes.

Photo illustration from a laboratory visited

The following photos illustrate some of the procedures in a visited laboratory. The laboratory purchases annually about 30 kg of mercury from a mercury recycling company which also receive the contaminated mercury from the laboratory.

Note that some types of porosimeters are smaller and may be operated on a laboratory bench e.g. Thermo Scientific Pascal 140.



The penetrometer is removed from the high pressure chamber of the porosimeter (AutoPore IV 9500 from Micromeritics).

Note the exhaust at the right of the photo. The porosimeter is designed so it can be connected to a ventilation system that pulls ambient air over the counter, through the instrument and out a duct at the rear.

The black box on the top of the porosimeter is a mercury spill kit. The laboratory did not have any incidents with spills at least the last two years and the spill kit had been in use (the personnel had only been working with the equipment for two years).



A small mercury droplet on the penetrometer stem is wiped into the dish for collecting mercury. The dish contain approximately 3 mm of oil to prevent the escape of mercury vapours.

The mercury reservoir is located in the upper right corner of the photo. When filling the reservoir the black cap is removed and the mercury is filled in from a small container. The reservoir is filled when the instrument indicates that the level is low. Mercury is purchased in small containers holding exactly the quantity needed for filling the reservoir.



The mercury-filled penetrometer is being weighed. The penetrometer is placed in the plastic container in the front of the photo when moved between the porosimeter, the balance and the fume hood where it is emptied and cleaned.



The penetrometer before the top screw is removed and the mercury is drained into a container for slightly contaminated mercury. The penetrometer holds about 3 ml (40 g) of mercury.

In this laboratory the contaminated mercury is disposed of for recycling and no internal regeneration of the mercury takes place.

The operation takes place in a fume hood.



The mercury has been drained from the penetrometer and the specimen (with some mercury pressed into it) is poured into a container for mixed mercury waste.

The operation takes place in a fume hood.

This waste fraction is disposed of as mercury waste to a hazardous waste company via the laboratory's general hazard-

ous waste system.



The penetrometer is cleaned for remaining mercury, oil and grease using a solvent and Mercury Collector Replacement Pads (Sigma Aldrich). The pads are used to remove small droplets of mercury from the surface of the penetrometer. The waste from the cleaning operation is disposed of as mercury waste to a hazardous waste company via the laboratory's general hazardous waste system.

Other procedures using other equipment

For porosimeters from other manufacturers somewhat different methods may be used.

For the Pascal porosimeters from Thermo Scientific, the sample cells, designated dilatometers, consist of two glass sections connectable by means of a rectified conical joint. Except for the Pascal 140 model, the degassing and mercury filling are performed before the analysis in a mercury filling unit (Duplex Dilatometer filling device). The Pascal porosimeters seems not to be equipped for direct connection to an exhaust system (e.g. not indicated in the PASCAL 240 Series. "Instruction Manual. Mercury Porosimeter"). The Pascal 140 is a low-pressure porosimeter and has only one port for analysis of the full range of poresizes that can be determined with the instrument.

Some equipment is not connected directly to an exhaust. As an example the new Autopore IV 9520 from Micromeritics is equipped with a fan and a mercury filter and do not need to be exhausted externally. Obviously the releases to the surroundings via the exhaust would be smaller with this setup, but no data are available on actual releases through the exhaust.

2.2 Possible mercury releases from the use of porosimeters and precautions

The following release routes of mercury may be considered:

- 1 Releases from the porosimeter through the exhaust of the porosimeter. From mercury spilled by filling of container, droplets on penetrometer, cleaning of valves, cleaning of high pressure tank, etc.

- 2 Releases from the fume hood through the exhaust of the fume hood. From mercury spilled or directly evaporated by emptying and cleaning the penetrometer and mercury spilled or directly evaporated by regenerating the mercury. Mercury releases from small droplets on gloves, cleaning pads, etc.
- 3 Release from the fume hood through the drain of the sink (if the fume hood has a sink). From mercury spilled by emptying and cleaning the penetrometer, mercury spilled by regenerating the mercury, from small droplets on gloves, cleaning pads, etc. the mercury may inter into a sink in the fume hood.
- 4 Releases from the laboratory's general ventilation system. From mercury spills outside the fume hood or porosimeter.
- 5 Long term releases from mercury contaminated waste. All mercury contaminated waste (>0.1 % w/w) has to be disposed of as hazardous waste, in accordance with EU waste regulation.
- 6 Releases from recycling of mercury by recycling companies.
- 7 Mercury in solvent disposed of as solvent waste. Mercury is not dissolved in the solvents and the waste solvent seems not to be considered mercury containing.

No data has been available for quantification of any of the releases.

2.2.1 Releases from the porosimeter through the exhaust

It is assumed that all types of porosimeters are equipped for connection to an exhaust systems or the air around the porosimeter otherwise is removed by a ventilation systems. It is assumed that the laboratories in general do not have specific mercury filters on the ventilation system and that most of the ventilated mercury is released to the surroundings.

Under normal operation, without any accidental spills, the releases to the ventilation system are considered to be negligible. The main releases would be associated with the possible spills.

The manuals of the porosimeters include a number of instructions in order to prevent spills and mercury going into parts of the porosimeter. The following is, if not mentioned otherwise, based in the instruction manual for the AutoPore IV 9500 from Micromeritics. Notes of the author of this document in square-brackets.

Incident	Instructions
Spill by filling the container or droplets spilled from the penetrometer	Any mercury spilled on the counter tray should be wiped into the drain hole in the tray, from which it will fall into a collector (mercury spill dish) and be covered by a layer of oil.
Mercury releases from the mercury spill dish	Pour approximately 1.0 to 2.0 cubic centimetres of oil into the container to prevent the mercury from vaporizing. If mercury accumulates in the dish, remove it by removing the cover and extracting the mercury with the syringe accessory.
Broken penetrometer – mercury in high pressure chamber	Should a penetrometer be broken and mercury spilled in a high pressure chamber, the glass and mercury should be removed immediately
Explosion of the penetrometer	No situation is known where pressure has caused an explosion or other dangerous reaction in a material while being evaluated by mercury porosimetry. Nevertheless, it is well to be aware of such a possibility should azides or perchlorates, for example, be considered for testing
Mercury going into the vacuum pump	Should operator error or malfunction draw mercury toward the vacuum system, the mercury will be collected in a protecting reservoir (mercury trap) with a capacity sufficient to retain all the mercury in the system at one time. A warning buzzer will signal that mercury transfer has occurred. This reservoir should be drained immediately. If, instead, more mercury is added and the error persists, subsequent quantities of mercury cannot be retained. The vacuum pump and other components will then be subject to damage Drain excess mercury from the trap into the reservoir. Remove the plug extending down from the mercury trap. Refer to Draining Spilled Mercury Dish later in this chapter. Position a container beneath the trap before removing the plug. [Porosimeters from Quantachrome are equipped with a cold trap]
Spill from low pressure port	Never remove a penetrometer or blank plug from the low pressure port when the Hg Drained indicator is not illuminated. Doing so could allow mercury to spill from the low pressure port. [further instructions on troubleshooting in manual] Mercury overfill in low pressure port [detailed instructions on troubleshooting in case of mercury overfill in the manual]
Mercury spill from the penetrometer	If the assembly is not to be placed immediately in the high pressure chamber, store it with the stem upward so that none of the mercury will be spilled.
Mercury released from the high pressure chamber	The high pressure fluid should be changed if mercury is spilled into a high pressure chamber; small drops of

Incident	Instructions
	mercury in the bottom of the chamber can cause erroneous results
Mercury releases from valves	[maintenance instructions] Make sure all mercury is below drain valves. Evacuate the reservoir and open the drain and fill valves with the low pressure manifold at atmospheric pressure. Failure to do so could result in a mercury spill. Hold a container below the valves to capture any retained mercury.

2.2.2 Releases from the fume hood

Based on the information gathered during one laboratory visit and three telephone interviews, it is assumed that handling of the penetrometers after analysis is done in a fume hood to prevent exposure of the personnel.

Incident	Instructions
Spill when pouring mercury and sample from the penetrometer	Place the mercury waste container in a shallow pan of water in case of spills. If there is any mercury in the bottom of the detergent solution, dispose of the solution properly. Do not tilt the penetrometer while removing the nut. Hold the penetrometer upright to avoid spilling mercury.

The major source of releases would be from the handling of the penetrometer and the mercury waste after the analysis. Whereas spills only happen occasionally during analysis mercury may evaporate from the handling of the penetrometer after each analysis. The minimisation of releases is mainly a question of good general laboratory procedures – for example, not leaving small droplets in the bottom of the fume hood, containers, tools and gloves.

It should be noted that the releases of mercury from the processes is a function of the total quantity of mercury used for the analysis and not the amount of new purchased mercury.

2.2.3 Releases from the laboratory's general ventilation system

Mercury spills on the floor of the laboratory or from stored mercury may be lost to the environment through the laboratory's general ventilation system. The following instructions are given in the manual for the AutoPore IV 9500 together with some mere general information on proper handling of mercury and mercury health effects.

Incident	Instructions
Spill of mercury e.g. by droplets from the penetrometer or by dropping the penetrometer or mercury containers on the floor	<p>[No instructions on precautions by moving the penetrometer between the workplaces: porosimeter, balance, fume hood]</p> <p>Mercury spills should be cleaned immediately and thoroughly by mechanical, chemical or other appropriate means. Micromeritics uses and recommends that you use plastic or rubber gloves and a small vacuum pump equipped with a mercury vapour absorbing filter on the exhaust and a vacuum probe with a mercury trap on the inlet for efficient pick-up of small mercury particles in cleaning mercury spills. Afterwards, the spill area should be swabbed with a mercury decontaminant and allowed to dry.</p>
Mercury releases from storage of mercury	<p>Open containers for storage of mercury in the work area should be covered with an aqueous or an oil layer and kept at ambient temperatures to prevent vaporization.</p> <p>Because of permeability of polyethylene or plastic bottles to mercury vapor, thick glass bottles, stainless steel or cast iron containers are recommended for storing mercury.</p> <p>To avoid dangerous chemical reactions, mercury should not be stored with acetylene, fulminic acid, ammonia and oxalic acid.</p>
Mercury releases from mercury contaminated clothing	Clothing contaminated with mercury should be stored in vapour-proof containers pending removal for laundering.

The manual do not mention that mercury storage in open containers should be kept at a minimum, and only placed in ventilated areas.

2.2.4 Clean up of spill

Different methods are used for cleaning up of mercury spill. One example is the QuikVac portable mercury spill vacuum.



The Mercury QuikVac portable mercury spill vacuum from Micromeritics. *“The Mercury QuikVac is the ideal tool for collecting both liquid mercury and mercury-contaminated particulate matter. Its compact size and light weight make it perfect for laboratory applications. The activated carbon filter traps the mercury vapors and exhausts clean, safe air back into the laboratory. Use it in and around vent hoods, and other areas where mercury spills may occur.”*

Source: www.micromeritics.com

2.2.5 Experience of interviewed laboratories

Four laboratories have been interviewed with a focus on procedures that may lead to exposure of personnel and releases to the environment. The following information has been obtained:

Laboratory 1:

- In about 1/50 measurements a small droplet escaped the penetrometer typically because of improper filling when new materials were tested. The droplet was wiped into the mercury spill dish. In order to prevent any drip the penetrometer was kept in a container when moved from one place to another.
- By changing of the vacuum pump a visible amount of mercury was found in the valves of the pump.
- It happens that mercury is found in the high pressure port, but not often.
- No experience with broken or dropped mercury filled penetrometers. It happens that penetrometers break by the cleaning after the mercury has been removed.
- No experience with any accidents (major spills e.g. by dropping of penetrometers or explosion of penetrometers).
- Porosimeter connected to exhaust, penetrometer emptied and cleaned under fume hood.

Laboratory 2:

- No experience with broken or dropped mercury filled penetrometers. No experience with any accidents.
- The porosimeter was in this laboratory not connected directly to the exhaust (ventilation system) and not placed under a fume hood.
- Penetrometer emptied and cleaned and mercury filtered under fume hood.
- Could not describe any mercury revealed by maintenance as the maintenance was provided by the equipment supplier.

Laboratory 3:

- One incidence of broken mercury filled penetrometers.
- Old porosimeter connected to exhaust; new porosimeter equipped with fan and mercury filter and not vented externally.

- It happens that mercury is spilled. Cleaned with the use of a mercury spill kit.
- It happens that mercury is found in high pressure port, but not often
- Penetrometer is emptied and cleaned and the mercury was filtered without the use of fume hood. Urine check of personnel every half to one year – no indication of exposure.

Laboratory 4

- Penetrometer filled, emptied and cleaned and mercury filtered under fume hood.
- It happens that mercury end up in the high pressure autoclave (high pressure port), at the bottom of the autoclave.
- It happens that mercury-filled penetrometers breaks by the handling, but it is very rarely

All laboratories

All the laboratories had specific procedures for clean up of mercury spills. The procedures are slightly different. One example: “...we use polyethylene scoop and relevant brush for collecting the majority of the spilled mercury and we have a special mercury collector which allows to collect the small drops of mercury and then we chemically treat the surface contaminated by tiny mercury drops by spreading them with sulphur. The operator (technician) wears appropriate coat, shoes, gloves and protective screen”.

2.2.6 Safety recommendations of the IUPAC Working Group

The IUPAC Working Group on “Liquid intrusion and alternative methods for the characterization of macroporous materials” has addressed the safety of using mercury porosimeters (Provisional document dated of 15th February 2010). Besides recommending checking country specific regulations and recommendations regarding occupational safety and health the groups provides the following guidelines:

- “ (i) *The operator should use appropriate personal protective clothing and equipment effective in preventing skin contact with mercury*
- (ii) *Always work with mercury over a spill tray. Keep all containers with mercury sealed when not in use. Waste mercury in any work area must be in spill trays covered with oil.*
- (iii) *Ensure that containers of mercury are securely capped when not actually being poured from, or into. Handle containers of mercury, including sam-*

ple cells, in a well-ventilated area. It is strongly recommended to clean mercury porosimeter measurement cells in a fume hood.

- (iv) Use the mercury vapor traps supplied on the equipment and never override or disable any safety device.*
- (v) If at all possible any operation with mercury should be performed in a separate room with proper ventilation and less 'lab-traffic'. A so-called "Tacky Mat" outside the Mercury Test area...on which mercury porosimeter users must step with both feet, when exiting the Mercury test area is also recommended.*

...it is advisable to periodically check the actual concentration for instance by monitor badges which are worn by the operator of the mercury porosimeter. This test should be performed at least annually, but always after a spill has occurred. All mercury spills should be cleaned immediately and thoroughly by mechanical, chemical, or other appropriate means.

Individuals dealing with the clean-up need to wear a respirator, and of course protective clothing effective in preventing skin contact with mercury.

It is not only from environmental standpoint important to stress, that used mercury should be recycled, i.e., it can be send to appropriate institutions/companies which specialize in the recycling of mercury, i.e. re-distilled (i.e. triple distilled) mercury can be used again in mercury porosimetry applications."

2.2.7 Safety measures in place in one visited laboratory in DK

The measures in place in the laboratory visited for this study can be summarised as follows:

- The porosimeter is connected to an exhaust system.
- The operator use appropriate personal protective clothing for preventing skin contact with mercury, and has been trained in the use of the equipment.
- The porosimeter is maintained in accordance with the manual and in case of malfunction the instructions of the manual (described above) are followed.
- The porosimeter is equipped with a dish for collecting mercury. The mercury in the dish is covered by oil to prevent evaporation and the collection dish is emptied regularly.
- The porosimeter is equipped with a mercury trap for preventing mercury going into the vacuum pump.

- In case of spill of mercury in high pressure port the mercury is removed from the port.
- When moving the mercury filled penetrometer between different work-places it is kept in an open container to prevent spill.
- In case of improper filling of the penetrometer, the penetrometer is checked for droplets before transferred to the balance for weighing. Droplets are collected in the collection dish of the porosimeter
- Mercury for filling the porosimeters is supplied in containers with exactly the amount needed for one filling, in order to reduce the risk of spill by the filling.
- A mercury spill kit for immediate response in case of spill is placed at the workplace. The personnel have been informed to follow the instructions on the use of the spill kit.
- Mercury and mercury waste is kept in capped containers and only opened when mercury is poured from, or into the container.
- Handling of penetrometer after analysis takes place in a fume hood. All handling takes place over a spill tray to prevent spill in the bottom of the fume hood. The spill tray is cleaned after handling each penetrometer.
- Contaminated material from cleaning of the penetrometers is collected in plastic bags for mercury waste and the bags are placed in a container.
- Contaminated/oxidized mercury and mercury containing samples are placed in closed containers kept in a fume hood.
- Contaminated mercury is disposed of for external recycling.
- Mercury contaminated samples and other waste is disposed of as hazardous waste via the laboratory's general hazardous waste system.

In addition to the measures above, the authors of this note suggests that the following measures could be considered:

- Any operation with mercury should be performed in a separate room with a minimum throughput of other laboratory personnel
- All operations should be kept close proximity in a "Mercury Test area" with proper ventilation. When leaving the area, porosimeter users must step with both feet on a so-called "tacky mat".
- Contaminated samples should be disposed of for recycling of the mercury.
- A respirator for use in case of spill should be kept near to the working area

- The actual mercury concentration should be periodically checked.
- The ventilation from the fume hood and porosimeter should be equipped with a mercury filter [has to be further investigated whether relevant].

No data on actual concentrations in outlet air have been available. As mentioned consideration may be made of the requirement for mercury specific filters on the exhaust. However, it would be relevant to first measure actual concentrations in the outlet air.

No data on actual mercury concentrations in the air of the laboratories has been obtained. None of the visited or interviewed laboratories had any data.

Waste containing > 0.1% mercury is considered hazardous in the EU and should be disposed of accordingly. The contaminated samples in general contain > 0.1% mercury whereas it is not clear whether waste from the cleaning of the penetrometers also contain > 0.1%.

2.2.8 Quantification of releases

No data have been available on the possible mercury releases through the laboratories' ventilation systems. Data on mercury concentration in the ventilation air from laboratories using porosimeters may be available, but have not been identified.

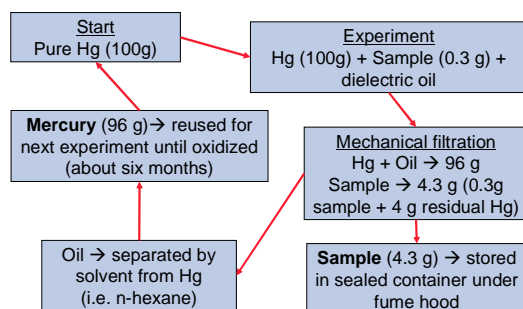
The data do not allow calculation of the releases on the basis of the known mercury input and outputs.

The main source of mercury releases from the laboratories using porosimeters is assumed to be from the fume hood where penetrometers are emptied and the mercury regenerated.

2.3 Mercury flow

The mercury flow through the process is highly dependent on whether internal recovery and recycling takes place in the laboratory and the types of samples (for example, if the samples are powders a larger amount of mercury will be disposed of with the samples).

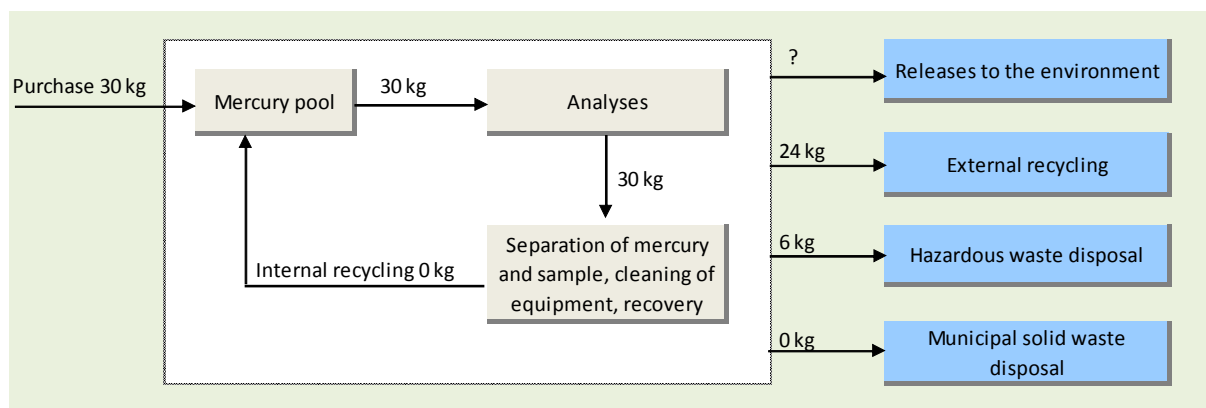
The following flowchart from Thermofisher Scientific indicated the overall flow of mercury (Thermofisher, 2009).



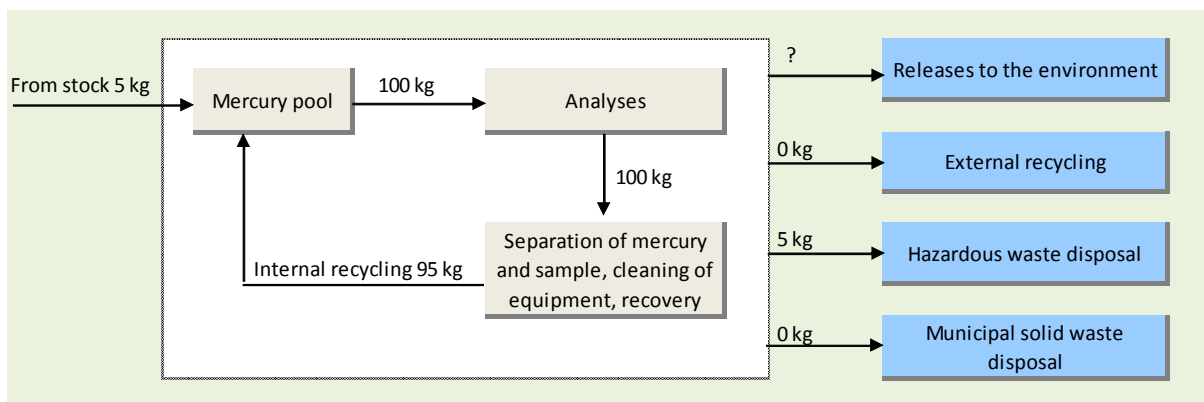
According to this scheme, for each 100 g of mercury used in the analysis, 4.3 g ends up in the waste with the sample and has to be replaced by new mercury. It is indicated that the mercury is reused for about six months. It is in this description not clear what happens to the mercury when it is oxidized.

More generalised flowcharts showing the annual flow are presented below. Examples of three interviewed laboratories and the total EU wide flow is shown (the latter based on data presented in ECHA Annex XV draft report). Note that in the case internal recovery takes place, a larger proportion of the mercury outflow will be as hazardous waste. For one laboratory, an accurate mass balance could not be established on the basis of the available information. The flowcharts do not address the issue of occupational exposure, which potentially may take place at all stages. All quantities are in kg/year.

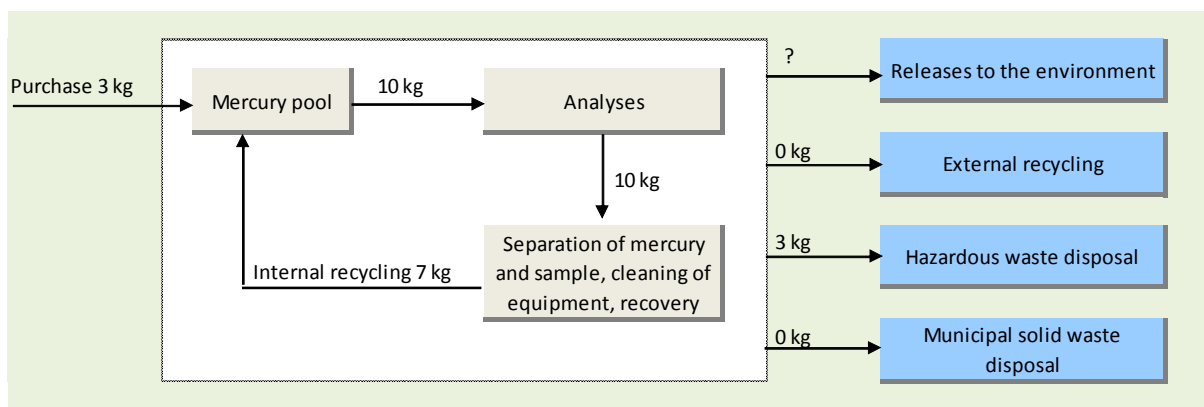
Laboratory 1: No internal recovery. About 20% of the mercury follows the sample and other waste whereas 80% of the mercury is disposed of for external recycling.



Laboratory 2: Mercury is on average recovered and recycled about 20 times. No oxidized mercury for external recycling. For each analysis about 5% of mercury is disposed of with the samples. Mercury is not purchased as the laboratory holds a large stock of pure mercury.



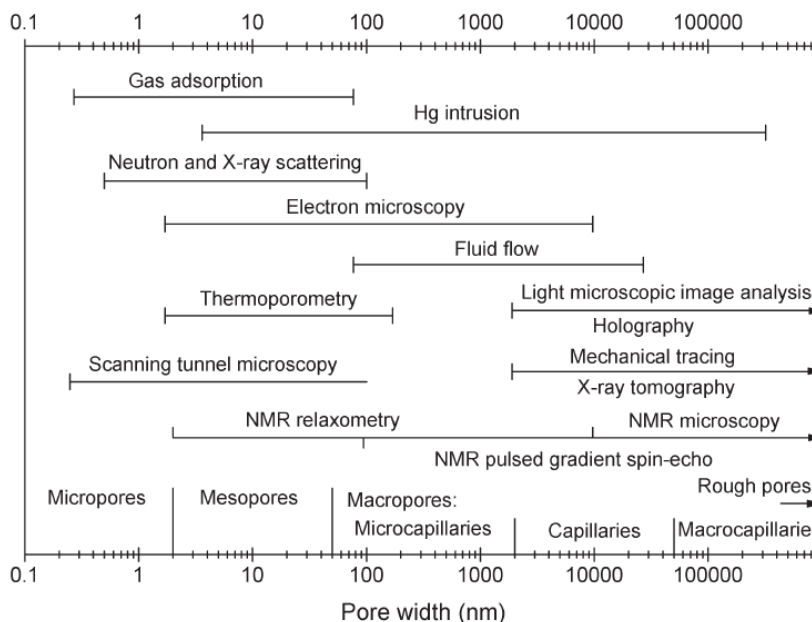
Laboratory 3: The mercury is on average recovered and recycled about 3 times. On average 25% of mercury is disposed of with samples, but it varies greatly with the porosity of the samples. All mercury is disposed of as hazardous waste.



2.4 Availability of alternatives

A number of techniques for characterizing porous materials are applied. The different techniques provide different parameters and can be applied for different pore sizes. An overview of measuring ranges for different techniques, based on a 1997 report is shown below (NIST, 2006):

Figure 1 Measuring ranges of methods for pore size determination (NIST, 2006, after Meyer 1997)¹



Most of the techniques are rather supplementary to the mercury intrusion porosimetry than actual alternatives, as they measure other parameters.

As indicated in the 2008 EU mercury report at least one company, Porous Materials inc. (U.S.A.), manufactures equipment which is specifically marketed as alternatives to mercury porosimeters:

- Mercury-free intrusion porosimetry (water intrusion).
- Mercury-free extrusion porosimetry;

The following table shows some characteristics of the different techniques according to Porous Materials.

¹ Porosity and Specific Surface Area Measurements for Solid Materials. National Institute of Standards and Technology Special Publication 960-17. September, 2006.
http://www.nist.gov/public_affairs/practiceguides/SP960-17_RPG_Porosity1.pdf

Table 2 Characteristics of mercury porosimeters, liquid extrusion porosimeters and water intrusion porosimeters (Based on Porous Materials)

	Characteristics	Mercury intrusion porosimeter	Liquid extrusion porosimeter	Water intrusion porosimeter
Pore structure characterization	Mean pore size	x	x	x
	Pore size distribution	x	x	x
	Total pore volume	x	x	x
	Liquid permeability		x	
	Porosimetry surface area	x	x	x
	Bulk density	x		x
	Absolute density	x		
	Particle size distribution	x		
Sample characteristics	Pore size range	0.0035 - 500 μm	0.05 - 2000 μm	0.001-20 μm
	Surface area range	1-100	not indicated	1-100
	Dead end and through-pores	x		x
	Special sample characteristics	indicated as N/A	not indicated	Hydrophobic
Applications	Automotive industry	x	x	x
	Battery/fuel cell industry	x		x
	Ceramic industry	x	x	x
	Chemical industry	x		x
	Filtration industry	x	x	
	Geotextiles/textiles industry		x	
	Nonwovens industry		x	
	Paper industry	x		x
	Pharmaceutical/medical industry	x	x	x
	Powder metallurgy industry	x	x	x

Mercury-free intrusion porosimetry

The Water Intrusion Porosimeter offers an alternative to mercury porosimetry for hydrophobic samples only (samples not wetted by water). According to Porous Materials the Water Intrusion Porosimeter performs a wide array of tests including total pore volume, pore volume distribution, mean pore size, and bulk density. According to the manufacturer, the water intrusion porosimeter is ideal

for quality control of hydrophobic materials, as tests are non-destructive and less than 10 minutes in length.

The availability of alternatives has been addressed by the IUPAC Working Group on “Liquid intrusion and alternative methods for the characterization of macroporous materials” (Provisional document (dated 15th February 2010)

According to the IUPAC review a major problem when using water intrusion in hydrophobic materials is that the wetting behaviour of water depends on details of the surface chemistry of the test material and consequently the contact angle of water is very often not known. The review does not provide any conclusion regarding the applicability of the method.

According to the specifications for the Aquapore water porosimeter, the porosimeter can be applied for pore sizes of 0.0005 - 20 μm .

According to the presentation from Thermofisher Scientific the hydrophobic materials cover less than 5% of applications and the determination of analytical parameters is difficult and a long surface treatment is needed.

No information has been received upon request from Porous Materials on the actual applications of the water intrusion porosimeter and the specific applications where the mercury porosimeter could be replaced. No data have been available indicating whether the same users typically analyse both hydrophobic and hydrophilic samples and in this case would need both a water intrusion and a mercury intrusion porosimeter. Porous Material market about porosimeters which can be used for both mercury and water porosimetry (Mercury/Nonmercury Intrusion Porosimeter) and a porosimeter exclusively for water porosimetry (Water Intrusion Porosimeter (Aquapore)).

Mercury-free extrusion porosimetry

The mercury-free liquid extrusion porosimetry applies a different principle than the intrusion porosimetry. Whereas the intrusion methodology measures the pressure needed for the intrusion of the liquid into the sample, the extrusion porosimetry measure the porosity of the material by the pressure needed for pressing a wetting liquid that spontaneously has filled the pores out of the material.

The IUPAC review uses the term “liquid porosimetry” for this analytical method (IUPAC, 2010). The method is employed by the TRI/Autoporosimeter™ from TRI/Princeton (USA) and the liquid extrusion porosimeter produced by Porous Material. (USA)

TRI/Princeton mention about the instrument that it “*provides accurate measurements of pore size distributions in the range of pore radii 1 to 1000 microns and, unlike mercury porosimetry, is applicable to fragile, soft and deformable materials.*”

According to the IUPAC review the method measures not only the surface area, pore volume, and pore size distribution, but also the actual uptake and retention

capillary pressure at different liquid content, θ , and the liquid uptake/drainage hysteresis.

The review does not discuss in detail the applicability and limitations of the method as compared to mercury intrusion porosimetry. It reaches the conclusion that *“As long as the main objective is the assessment of a pore volume and a pore-size distribution (with the acceptance of simplifying assumptions about the uniform shape of the pores), methods like liquid or contact porosimetry and water desorption calorimetry certainly deserve being developed”*. And *“Now, these methods are still far behind mercury intrusion porosimetry in terms of experience and know-how gathered about the experiment with a variety of materials.”*

The presentation from Thermofisher Scientific (2009) indicated that the technique involves a very expensive gravimetric technique and that the technique has a limited pore size range. As described above the TRI/Princeton instrument is limited to the 1-1000 μm range whereas Porous Materials indicate a range of 0.06-1000 μm for their instrument.

Development of methods for product control

Mercury is currently used for both research and product quality control (QC/QA) in production of different materials e.g. particle filters for diesel motors.

For product control (ensuring a uniform material quality), it may be possible to develop methods where only a few parameters are analysed as an indicator of the desired quality and these parameters could be determined using alternative methods. In the presentation by Thermofisher Scientific it is indicated that three years would be needed for validation and re-calibration of QC/QA procedures and four years would be needed for development of new certified reference materials (such as BAM and NIST reference materials) for the results validation. The presentation does not indicate which methods may be used for the product control.

2.4.1 Questionnaire results

Mercury porosimeters are used for analysis if pore sizes in the range of 0.003 to 400 micrometers in materials used in many sectors. The table below shows applications for which technically feasible alternatives are not considered to exist, as answered by one manufacturer of mercury porosimeters. Two of the manufacturers did not answer the questionnaire as they considered the questions being answered by the IUPAC review (IUPAC 2010).

Table 3 Applications of mercury in porosimetry for which *technically* feasible alternatives are not regarded to exist (answer from one manufacturer)

Application of mercury porosimeter	Sectors	Potential alternatives	Reasons for these alternatives of not being technically feasible ⁽¹⁾
Particle filters (PM10) for diesel motors	Automotive	none	Very large pores must be measured, fast and inexpensive experiments for QC/QA in production
Heterogeneous catalyst supports	Catalysis	none	Pores in the upper meso and lower macro range typically from 4 to 500 nm, need a lot of info not given by other techniques
Battery separators, anode and cathodes	Energy	none	Anodes and cathodes should be treated as a non wetted surfaces. Difficult and long preparation, not practical for QC/QA purposes
Fuel cell matrix	Energy	none	Very large pores
Drugs support for controlled release	pharma	none	Soluble in water
Bones replacement ceramics	Medicine	none	Very large pores
Particle size analysis of solvable materials	General	none	Difficult sample preparation and difficult de-aggregation of particles
Cements, Concrete	Building materials	None	Impossible to use wetting liquid, cements reacts with water
Frost resistance determination of exterior materials	Building materials	none	Pores in the lower macropore range (below 1 micron)
Raw materials for ceramics	Ceramics		
Moulding for ceramics preparation	ceramics	none	Small pores must be carefully determined
Refractory materials heat transfer properties	Industrial ovens	none	
Soil and rocks drainage properties	Geology, agricultural		
Resins and polymers raw materials	Plastic		
Geological samples	General	None known	Pore structures need to be characterized
Gas & Oil recovery	Energy	none	Pore structure of reservoir rocks to determine how to best extract the most natural gas and oil
Ceramic Insulators	General	None	Determine pore structure related to strength of materials and dielectric qualities
Dental Ceramics	Medical	None	Detemine pore structure and strength of dental materials
Paper products	General	None for the range used	Determine paper coating properties and paper porosity

Note: QC/QA = Product Quality Control/Quality Assurance

2.5 Standards

The table below shows some of the main standards for mercury porosimetry and their application in different sectors (based on the response from one manufacturer). The manufacturer consulted mentioned that a number of U.S., European and Japanese patents specify the use of mercury porosimetry for testing products. Many manufacturing companies have internal procedures for production of materials which specify the use of mercury porosimetry because no other equivalent method exists for determining the same information.

Table 4 Analysis for which national or international standards prescribe the use of mercury porosimeters

Analysis	Industrial sectors	Standard	Alternatives that potentially may be used for the analysis if the standard is changed*1
Standard Test Method for Interior Porosity of (PolyVinyl Chloride) (PVC) Resins	Plastic	ASTM D2873-94(1999)e1	
Standard Test Method for Determination of Pore Volume and Pore Volume Distribution of Soil and Rock	Geology, agricultural	ASTM D4404-84(1998)e1	
Standard Test Method for Determining Pore Volume Distribution of Catalysts	Catalysis	ASTM D4284-03	
Standard Test Method for Bulk Density and Porosity of Granular Refractory Materials	Ovens	ASTM C493-98	
Porosity and pore size distribution of materials	General	BS 7591-1:1992	
Evaluation of Pore Size Distribution and Porosity of Materials by Mercury Porosimetry and Gas Adsorption - Part 1: Mercury Porosimetry	General	ISO 15901-1	
European Pharmacopoeia	Pharma	07/2008:20932	
Pore volume distribution and specific surface area	General	DIN 66133	
Bulk and tap density (Roh und Schüttdichte)	General	DIN 51065	
Density of granules	Powders	DIN EN 993-17	

*1 The column is empty as the answerer considers that no alternatives are available.

2.6 Key cost elements

For a comparison of cost elements between mercury porosimetry and alternatives, information has been requested from manufacturers. The table below is based on the answer from the same manufacturer as previous the tables.

Two alternatives are indicated - each considered for a specific application:

- Flow porometer (only for membranes): pore size (passing through).
- Water porosimeter (only for hydrophobic materials): pore size and volume.

Table 5 Key costs elements for a comparison of mercury porosimetry with alternative methods

	Mercury porosimeter	Alternative
Measured properties	Pore size and pore volume distribution, specific pore volume, % porosity, intra-inter particle porosity, envelope, bulk and apparent density, particle size distribution, specific surface area and area distribution, compressibility, tortuosity, permeability, frost resistance factor, surface fractal dimension	Flow porometer (only for membranes): pore size (passing through) Water porosimeter (only for hydrophobic materials): pore size and volume
Typical price of meter (factory gate price without VAT in €)	20.000 euro to 40.000 euro depending on configuration	Porometer → from 25.000 euro to 50.000 euro depending on brand and model
Typical number of analysis per year – industrial setting	1000 to 3000	Don't know
Typical number of analysis per year – research	150 to 1000	Don't know
Average lifetime of porosimeter (in years)	20 years (depends on availability of spares)	Don't know
Recurrent costs per analysis (excl. salary) (€/analysis) (specify)	About 30 euro per analysis	Don't know
Average time needed for one analysis including sample preparation (minutes)	From 30 to 90 minutes depending on material and pressure range required	Don't know
Costs of waste disposal (€/analysis)	Estimated about 1 euro per analysis	Don't know
Other factors influencing the costs estimates (specify):	Lab safety (fume hood, tools for handling mercury, etc), personnel training, regular service (needed max 2 service inspection per year), periodic BioAssay of personnel to make sure no mercury exposure has occurred.	Don't know

3 Pycnometers

From consultation for this study one manufacturer of mercury porosimeter and pycnometers has answered that “*As far as I know mercury is no more used in pycnometry as envelope or helium pycnometers have substituted mercury pycnometry in all the application.*” The other three contacted manufacturers has not responded to this part.

Mercury pycnometers are still marketed by Porous Materials, USA.
http://www.pmiapp.com/products/mercury_pycnometer.html

Porous Materials has not answered the questionnaire and subsequent requests by email and telephone.

4 Thermometers

4.1 Introduction

The following chapter is drafted on the basis of information obtained by a questionnaire sent to nine manufacturers of mercury thermometers in early 2010 and an extract from the report “*Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society*” (Lassen et al. 2008) (referred to as the 2008 EU Mercury Report in the following). Furthermore, seven manufacturers and suppliers of non-mercury thermometers have been contacted by telephone and e-mail.

Six manufacturers, from Germany, the UK and France, have answered the questionnaire (which is included in Section 11). Several of the manufacturers only filled in a few of the tables in the questionnaire. The questionnaire responses have been followed up with additional questions by extensive e-mail correspondence with the manufacturers which has been most informative.

Mercury thermometers may, in principle, be used for manual reading of all temperatures in the interval from the freezing point of mercury, -39°C , up to about 800°C , with an accuracy of 0.01°C . For measurements at lower temperatures, down to -58°C , a mercury-thallium thermometer may be used, while for even lower temperatures hydrocarbons such as toluene or pentane are used. For temperatures higher than 800°C , thermometers with a gallium filling are used.

Three types of mercury-containing thermometers have traditionally been used in the EU:

- Mercury-in-glass thermometers:
 - Medical thermometers;
 - Ambient temperature thermometers (wall thermometers);

- Minimum-maximum thermometers (Six's thermometers) and maximum thermometers;
 - Laboratory thermometers;
 - Thermometers for combustion and industrial processes.
- Mechanical mercury thermometers with a dial; and
 - Contact thermometers (electric thermoregulators – these are covered by the RoHS directive and were not addressed by the questionnaire and are not further addressed in this note).

Furthermore, mercury-in-glass thermometers may be used as a part of other measuring equipment, among these:

- Hygrometers (to measure humidity). A mercury hygrometer consists of two mercury thermometers mounted together, one of which has a cloth wick over its bulb and is called a wet-bulb thermometer.
- Hydrometers (to measure density or specific gravity of a liquid). Some hydrometers have a mercury thermometer inside the hydrometer for simultaneous reading of the temperature.

The most common mercury thermometers consist of mercury encased in a thin glass tube that rises and falls (expands and contracts) with temperature. This thermometer has traditionally been widely used as a fever thermometer, in laboratories, as an ambient temperature thermometer and for temperature monitoring of machines, combustion processes and industrial processes.

The mercury content of thermometers used by laboratories and in industry ranges from 1 to 20 g Hg per thermometer, with an average content of 3-4 g.

Mercury dial thermometers consist of a mercury filled metal tube with a bourdon coil and a pen or needle for reading the temperature. They are applied mostly in the process industry and for marine applications. Similar thermometers for high temperature measurements, e.g. in foundry applications for measurements of the temperature of diesel exhaust, are also referred to as pyrometers. For remote control of large engines or combustion processes, thermometers consisting of a sensor on the machine and a mercury-filled capillary up to 40 m long connecting the sensor to a gauge in the control room have been and may still be in use. The mercury content ranged from about 5 to 200 g (Maag *et al.* 1996). These thermometers have mainly been used for marine engines and within the power sector.

In their questionnaire responses, manufacturers have pointed to the need for derogations for three application areas of mercury thermometers, each of which will be addressed in this note:

- Thermometers used for combustion and industrial processes measuring at temperatures >200°C.

- Thermometers used in laboratories and other applications where a resolution of 0.1 °C and better is needed (one manufacturer mentions 0.5 °C resolution while the remaining answered 0.1 °C).
- Hygrometers.

The discussion about availability and feasibility of alternatives is different for the three application areas and they are consequently addressed separately in the following.

None of the manufacturers have pointed at minimum-maximum thermometers (Six's thermometers) or thermometers for measuring temperatures <200°C at a resolution of >0.5 °C as essential uses.

Minimum-maximum thermometers

Minimum-maximum thermometers with mercury are still marketed, but thermometers with mercury-free filling are available at similar prices or lower (see e.g.

http://www.brannanshop.co.uk/acatalog/maximum_minimum_thermometers.html#18). Electronic minimum-maximum thermometers are readily available at somewhat higher prices.

Other thermometers

Non-mercury thermometers for measuring temperatures <200°C at a resolution of >0.5 °C are readily available at prices similar to or lower than the price of the mercury thermometers. A check by a Danish supplier of thermometers for laboratories revealed that the prices of the non-mercury thermometers were about 10% lower than the price of mercury thermometers for the same range and resolution.

Maximum thermometers

Maximum thermometers are used to measure the maximum daily temperatures or the maximum temperature of a process. The thermometer has a small area where the glass tube is narrowed and works by the same principle as the fever thermometer. When the temperature begins to drop, the constriction prevents the mercury from flowing back down the tube. The mercury will not move back down the tube until the thermometer is shaken.

Maximum thermometers have been specifically mentioned by one manufacturer as an essential application. Maximum thermometers are available for different ranges and resolutions. For ranges including low temperatures, a mercury-thallium alloy is used. Mercury maximum thermometers are provided by several manufacturers, with a resolution down to 0.1°C e.g. “maximum precision thermometers for shaking, enclosed scale” in a catalogue from Ludwig Schneider (<http://www.ludwig-schneider.de/>). The maximum thermometers with high resolution are included in the general applications of thermometers mentioned below.

4.2 Thermometers used for combustion and in industrial processes

Technical feasibility of alternatives

For temperatures below 200-250°C, mercury-free liquid-in-glass thermometers and electronic thermometers are the most common replacement for the mercury thermometers used in industrial processes. Mercury-free liquid-in-glass thermometers are, in general, not suitable for accurate measurements at 0.1°C resolution, but in the industrial processes it is generally not necessary to measure the temperature at this level of precision.

The following discussion thus concerns thermometers for the range of 200-800°C.

The main alternatives are:

- **Dial thermometers.** These thermometers may consist of a liquid- or air-filled metal cylinder with a dial for manual reading. Another type is a bimetallic dial thermometer that senses and indicates temperature using a bimetallic coil, which consists of two dissimilar metals bonded together. These materials have different coefficients of thermal expansion and, when subjected to temperature change, rotate the coil.
- **Thermocouples:** These thermometers consist of two lengths of dissimilar metals, joined at one end to form a measuring junction. Each length, referred to as a thermoelement, develops a voltage (or more accurately, a thermoelectric electromotive force) along its length wherever the thermoelement passes through a temperature gradient. Different thermocouple types can be used for applications in temperature ranges from -40°C to +1800°C. Thin-film resistance thermometers provide accuracy over a wide temperature range (from -200°C to 850°C). Electronic thermometers are used throughout industry for automatic temperature measurements. For some applications, e.g. diesel engines for marine applications, the automatic measurements may be supplemented with mechanical thermometers for manual reading.
- **Platinum resistance thermometers (PRTs)** rely on the known variation of electrical resistance with temperature of a specially constructed resistor to convert temperature into a measurable electrical property. Different type e.g Pt 100, Pt 200, Pt 500, and Pt 1000.
- **Gallium thermometers.** These are applied today for high range thermometers where the upper temperature is 750°C or higher. Thermometers with a gallium filling are e.g. available for the range 0-1,050 °C with 5 °C resolution or 0 – 800 °C with 2°C resolution. (See for example <http://www.amarell.de/thermometers/quartzglassthermometers.htm>)

Table 6 shows the merged response from three manufacturers of the mercury thermometers comparing the mercury thermometers with three alternatives: thermocouples, dial thermometers and gallium thermometers. According to the

responses, the thermocouple and dial thermometers alternatives suffer from aging which results in decreasing accuracy and more frequent re-calibration. Furthermore, they need additional power supply and there will be some requirement for modified/additional installations in existing facilities. A UK thermometer manufacturer stated previously for the EU Stakeholder Consultation that adequate alternatives and technologies already exist for this application area (referred to in the 2008 EU mercury report).

According to the information in the table, dial thermometers have the disadvantage in large diesel engines of being sensitive to vibration. Contrary to this, Danish suppliers of thermometers indicated – for a previous study in 2006 – that for measurements in engines, the mercury-in-glass thermometers have the disadvantage that droplets may be introduced by the vibrations from the engine, if the thermometer is not held vertically (Lassen and Maag 2006). Furthermore long mercury-in-glass thermometers have the disadvantage that they can easily break when handled. Mercury thermometers used for combustion and industrial processes have been banned for many years in Denmark and the study concluded, on the basis of information from market actors, that it was unlikely that mercury thermometers would be reintroduced even if they were no longer banned (Lassen and Maag 2006).

Gallium thermometers

For the gallium thermometer no reasons for these alternatives not being technically feasible were mentioned, but in Table 7 it is indicated that it is difficult to manufacture gallium thermometers, resulting in high prices for these thermometers. One manufacturer indicates that they have used liquid gallium in thermometers for the high temperature range above 750 °C for more than 80 years. They have subsequently been contacted for obtaining more information which is included in the following.

The contacted company use today pure gallium, as experiments with gallium-indium gave no useful results. According to the manufacturer, working with gallium is very difficult because it melts only at 30 °C and the thermometer cannot be filled - unlike mercury - in large numbers and under high-vacuum conditions. Each thermometer has to be individually filled, which is a costly operation.

The filling has to be done at high temperatures. The gallium thermometers produced today with a wide temperature range are made of heat resistant quartz glass with a coarse capillary, and in this case there are no specific problems with the temperature.

According to the manufacturer, however, this type of glass is not suitable for precision thermometers which have to comply with certain specific requirements. For the precision thermometers a special type of glass is used, and this glass is only suitable for working at temperatures up to 480 °C which is close to the working temperature used by filling of the gallium. For many types of gallium thermometers this leads to a large amount of waste from the manufacturing process. An example of a precision thermometer is shown in table 8 with a price of about 20 times that of the similar mercury thermometer.

In solid-stem thermometers the gallium thermometer has, except for minor differences in the size of the bulb, the same dimensions as the mercury thermometer. They seem in principle to be suitable for retrofit (although at higher prices), but the manufacturer indicates that they would not comply with the thermometer manufacturing standards.

Fever thermometers filled with an alloy of gallium, indium and tin (galinstan), are widely marketed. In order to avoid the galinstan wetting the glass, the inner tube of the thermometer must be coated by gallium oxide. No examples of the use of this alloy for thermometers used in industry or laboratories have been identified.

Retrofit

One particular problem, mentioned in Table 6, is the need for modified/additional installations in existing facilities if spare mercury thermometers are no longer available. Mercury-free replacement thermometers (spare parts) that will fit into the existing installations are often not available. In the marine sector in Denmark this problem has to some extent been solved by buying spare mercury thermometers abroad.

In Sweden mercury thermometers have been banned since 1991 with a few exemptions. In an investigation of a general mercury ban, the Swedish authorities address the question of retrofitting: *“A large number of mercury thermometers are fitted in autoclaves, and warming cabinets used in laboratories and in health care. When the thermometers have been broken or no longer register correctly, the equipment has been modified to allow the installation of, for example, a thermocouple, or the thermometer has been replaced with a more modern digital temperature-measuring device. These two techniques offer certain advantages as regards automation and the collection/recording of data. There are probably still several thousand mercury thermometers in autoclaves, and warming cabinets, which will be replaced as they become unserviceable.”* (Kemi 2004)

No information has been made available on the typical cost for retrofitting existing installations in order to be able to use mercury-free alternatives. The actual costs will be highly dependent on the timing of a restriction.

A Danish manufacturer of thermometers indicates that the company often provides thermometers (both PT100 and dial) which are adjusted to a specific machinery (specific length and diameter) and that the price of these is only slightly higher than the standard thermometer. The screw thread is typically 1/2” on all thermometers. The company indicates that they know of examples where mercury thermometers may be used as spare parts in the marine industry, but have never heard about it in other sectors. In Danish industry there has been a focus on automatic reading which has been the driver for changing to electronic equipment - this may be different in other Member States.

Table 6 Applications of mercury thermometers for combustion and industrial processes for which no technically feasible alternatives are regarded to exist (based on answers from three manufacturers of mercury thermometers for industrial processes)

Application of thermometer	Sector	Potential alternatives	Reasons for these alternatives not being technically feasible
Temperature >200°C	Industry	- Thermocouple - RTD (Resistance Temperature Device)	- Aging -> decreasing accuracy -> frequent recalibration - Requires electric indicator (digital or analogue) - Requires additional power supply - Requires modified/additional installations in existing facilities
Temperature >200°C	Industry	Dial thermometer	- Aging -> decreasing accuracy -> frequent recalibration - Requires modified/additional installations in existing facilities
Temperature >200°C	Industry	Gallium thermometers	-
Temperature >200°C	Engineering Large Diesel engines	Thermocouple	- Aging -> decreasing accuracy -> frequent recalibration - Requires electric indicator (digital or analogue) - Requires additional power supply - Requires modified/additional installations in existing facilities
Temperature >200°C	Engineering Large Diesel engines	Dial thermometer	- Aging -> decreasing accuracy -> frequent recalibration - Vibration resistance may be a problem - Requires modified/additional installations in existing facilities

Economic feasibility

According to the responses from three manufacturers of mercury thermometers the price of alternative thermometers is 3-5 times the price of the mercury thermometers (Table 7). For electronic thermometers this is the price of the probe and the cost of the data acquisition system is in addition to this.

Table 7 Applications of mercury thermometers for combustion and industrial processes for which technically feasible alternatives exist, but these are not regarded as economically feasible (based on answers from three manufacturers of mercury thermometers for industrial processes)

Application of thermometer	Sector	Available technically feasible alternatives	Price of alternatives as compared to mercury thermometer	Other reasons for these alternatives of not being economically feasible
Temperature >200°C	Industry Engineering Large Diesel engines	Dial thermometer	3 - 5 times more	<ul style="list-style-type: none"> - High investments for replacement of all mercury filled industrial glass thermometers in existing facilities - (Re-)Installation costs - Costs for re-calibration - Energy costs for extra power (Thermocouple/RTD) - For local power supply disposal of batteries after service life - Cost of additional indicator (Thermocouple)
		Thermocouple RTD (Resistance Temperature Device)	3 - 5 times more + cost for additional indicator (3 - 4 x cost of the thermometer)	
		Gallium	5 times	

The manufacturers point to the fact that electrical sensors and indicators for temperature measurement make the measurement dependent on an external power supply. For safety reasons there will, in certain applications, be a need for measurements which are not dependent on an external power supply.

As an example in the marine sector, insurance contracts in Denmark prescribe that the engines be equipped with thermometers which can work without external power (Lassen and Maag 2006). Manual dial thermometers can be used for this purpose and they often serve as a back-up for electrical thermometers with automatic reading.

The dial thermometer is the meter which can most immediately be compared with the mercury industrial thermometer as it is used for manual reading and does not need an additional data acquisition system.

Table 8 shows some cost elements for three different types of thermometers according to a manufacturer of thermometers for industrial processes. The company also supplies non-mercury thermometers.

According to the manufacturer the major difference influencing the cost estimate is the indicated average lifetime of the equipment. It is indicated by the manufacturer that the mercury thermometer has an average lifetime of >25 years, whereas the lifetime is only 1-2 years for the dial thermometer.

The manufacturer indicates in the response that 7,629 pieces were sold in the EU in 2009, but these figures seem to concern the specific manufacturer only. In the 2008 EU mercury report it is roughly estimated that the EU market for mercury thermometers used in industry is around 50,000 - 100,000 pieces per year.

Table 8 Comparison of mercury industrial high-temperature thermometer, up to 600 °C with alternatives (answer from one manufacturer of mercury thermometers for industrial processes)

Type of thermometer	Industrial thermometer	Thermocouple with display	Dial thermometer
Typical price of thermometer (factory gate price without VAT in €)	30 - 60 EUR	150 - 200 EUR	100 - 150 EUR
Typical mercury content	3.5g/piece	-	-
Number of thermometers sold annually in the EU (best estimate)	12,550 pieces in 2008 7,629 pieces in 2009 *1		
Average lifetime	> 25 years	5 years	1- 2 years
Costs of calibration	-	100 - 150 EUR	-
Frequency of calibration	> 25 years	12 - 24 month	
Other recurrent costs (specify):	-		
Other factors influencing the costs estimates (specify):	-		

*1 Consultants note: It is not clear whether the figures only include thermometers produced by the specific manufacturer

Table 9 shows data on possible alternatives according to a major global manufacturer of alternative thermometers. The manufacturer does not supply mercury thermometers and cannot compare the prices of mercury thermometers for the same application.

For the electrical systems, prices and lifetime are for the sensors (or probes) only. A thermometer system consists of the sensor, a transmitter (which can be analogue or digital) and a data reader. Furthermore, a digital temperature indicator for manual reading may be connected to the thermometer. The prices and lifetimes indicated in table 9 are for the sensor only. The transmitter may process data from more than one sensor, and the data reader may also read data from other types of sensors e.g. pressure gauges.

The lifetime of the probe is generally shorter than for the rest of the system, as the probes are often placed in more harsh environments (vibration, temperature, humidity, corrosive gases, etc.). The manufacturer was not able to provide average lifetimes for all thermometers and the indicated lifetimes relate to the range of lifetimes, which are dependent on the environment where the thermometer is placed.

Table 9 Possible alternatives to mercury thermometers in industrial processes (answer from one major German manufacturer of non-mercury thermometers for industrial processes)

Temperature measurement systems	Measurement Range °C	Accuracy °C	Average Lifetime Years	Calibration Frequency Months	Basic List Price €
Mechanical systems					
Bi-metal thermometers	-70 ... +500	acc. to DIN EN 13190	1-5	6-12	> 105
Gas actuated thermometers	-200 ... +600	acc. to DIN EN 13190	1-5	6-12	> 170
Electrical systems					
Resistance thermometers *2	-200 ... +600	acc. to DIN EN 60751	1-10	6-24	> 110
Thermocouples *2	-200 ... +1200 (standard)	acc. to DIN EN 60584	1-5	6-24	> 85
	-0 ... +1700 (special)	acc. to DIN EN 60584	1-2	6-24	no data

*1 List price for basic configuration – higher prices for special configurations. The list price indicates the price the customer has to pay excl. VAT.

*2 Prices are for the probe (sensor) only. The system consists of a transmitter and an indicator which can transmit and read more thermometers and other measuring equipment. The average lifetime is for the probe alone.

Prices

The price of a typical mercury thermometer for industry is reported to be 30 - 60 EUR (Table 8) and this may be used as the baseline price. The price includes the casing for the thermometer.

Prices of **mechanical systems** allow for a straightforward comparison with mercury thermometers as the mechanical thermometers represent a 1:1 substitution. The manufacturers of mercury thermometers have indicated that the prices of mechanical thermometers are typically 3-5 times the price of mercury thermometers. The prices indicated in table 9 for mechanical systems are quite well in accordance with the price of the dial thermometer in table 8 although the prices in table 7 are “factory gate prices” and the prices in table 9 are minimum list prices for the end-customer. For a previous Danish study it was indicated that the price of the dial thermometer was some 2-4 times the price of the mer-

cury thermometers (Lassen and Maag 2006). We consider that the 3-5 times indicated by the manufacturers of mercury thermometers is the best available estimate.

For **electronic systems** the price of the sensor is reported to be 3-5 times the price of mercury thermometers. Table 8 indicates that the cost of the systems would be 3-4 times the cost of the thermometer (it was not indicated whether it is 3-4 times the price of the sensor or the mercury thermometer). No data have been made available to estimate how the price of the data acquisition systems can be allocated to the individual thermometers. For the previous Danish study it was reported that the price of PT100 resistance machine thermometers was in the order of 10 times that of a simple mercury-in-glass machine thermometer (Lassen and Maag 2006). It is estimated to be very difficult to obtain a better estimate as the electronic systems consist of several elements with different lifetimes (the data reader typically has a longer lifetime than the sensors). Based on the available data a price of the electronic thermometers of 5-15 times the mercury thermometers seems reasonable, but it should be noted that the thermometers are not comparable. The driver for replacing the mercury thermometers with electronic systems is the advantage of electronic reading which apparently for many customers offsets the extra costs of the thermometers. It should be noted that the electronic thermometers typically have to be recalibrated shortly after they are put into use.

Lifetimes

The average lifetime for the dial thermometer is indicated by the mercury thermometer manufacturer to be 1-2 years (Table 8) whereas the manufacturer of alternatives indicates 1-5 years for mechanical systems depending on the environment (Table 9). A Danish manufacturer of mechanical thermometers estimates the typical lifetime of bimetallic thermometers at 2-5 years and of gas-filled thermometers at 5-10 years. It seems reasonable to use a range of 2-5 years as a best estimate for the mechanical systems.

For electronic systems the estimated lifetimes concern the sensors only. Data in table 8 suggest a lifetime of 5 years for a thermocouple while data in table 9 suggests 1-5 years for the thermocouples and 1-10 years for the resistance thermometers. A major Danish manufacturer of PT100 temperature sensors for industry, diesel engines and laboratories estimates that the typical lifetime of PT100 resistance sensors used in industry at temperatures up to 800°C is 5-10 years. The maximum guaranteed lifetime for some applications is 5 years, but usually the guarantee time is shorter. In very harsh environments with higher temperatures (e.g. waste incinerators) the lifetime of the probes is <0.5 year. Based on the available data a typical lifetime for the electronic sensors of 3-6 years seems reasonable.

The average lifetime of mercury thermometers is indicated to be >25 years. No data are available on the breakage rate of the thermometers but the >25 years seems rather to be the technical lifetime than the actual lifetime. According to a major manufacturer of mercury thermometers, it is realistic to assume an average lifetime of 10-15 years.

Calibration frequency and costs

According to the answers from manufacturers of mercury thermometers, the electronic equipment needs frequent calibration to guarantee accurate measurement values, i.e. to ensure congruence of actual and indicated values. According to these manufacturers, industrial glass thermometers do not need frequent recalibration because its glass capillary keeps its accuracy for 30 years or more. The frequency of recalibration required for mercury thermometers is indicated in Table 8 to be >25 years.

The actual calibration frequencies will probably be dependent on the procedures set up by the users in their quality management system.

In the UK British Standard BS 1041 Section 2.1 (Guide to selection and use of liquid-in-glass thermometers) recommends that verification of the ice point should take place at least annually and that complete re-calibration should take place at intervals of not more than five years². The Danish National Reference Laboratory for temperature reports that the frequency for calibration of mercury thermometers in Denmark has typically been once per 3-5 years. The calibration frequency is not only dependent on the equipment, but also the seriousness of inaccurate temperature measurements and in many industries the equipment is calibrated more often to be on the safe side. According to a major manufacturer of mercury thermometers the calibration certificates of thermometers from this company are valid for a maximum of 5 years. The manufacturer estimates that calibration once every 3-5 years would be typical.

One manufacturer points to the requirements for calibration according to the ISO 9001 quality management standard. The ISO 9001 standard does, however, not set up specific frequencies for calibration of equipment, but require that the company define procedures. The actual frequencies will be different for different companies.

According to the information in Table 8, the calibration frequency of the alternative mechanical system is 6-12 months while the frequency for the electronic systems is 6-24 months. A Danish supplier of PT100 and dial thermometers recommends calibration once a year but reports that 95% of the customers do not calibrate the mechanical dial thermometers because they are mainly used as a backup for the electronic thermometers for automatic reading.

According to a Danish manufacturer it is typically necessary to recalibrate the probe after installation where the probe is "aged" by changing the temperature about 10 times. After the aging process, the probe is often stable for some 5 years and does not drift by more than 0.1°C. Many customers calibrate the thermometers every year because it is required by their quality management system.

It seems appropriate to assume that both mechanical and electronic equipment is calibrated once a year.

² http://www.brannan.co.uk/products/cal_index.html.

For the cost estimates it is of high importance how the calibration is done. Table 8 indicates a price of 100 - 150 EUR for the calibration of an electronic thermometer. For this study the cost of calibration, done by a certified laboratory in Denmark, is reported to be about 200-300 EUR with the highest prices for calibration of high precision thermometers. The cost of a calibration depends on the number of calibration points used. A price of 200 EUR has been reported by a major German manufacturer of electronic thermometers. With a traceable certificate the cost of calibration from the manufacturer is about 350 EUR.

The cost of calibration is higher than the cost of new sensors, but used equipment is more stable than new equipment. All interviewees indicate that the cost of calibration is a significant cost element and is of importance when comparing mercury thermometers with alternatives.

Different procedures may be applied for the calibration of the thermometers:

- The thermometers are sent to a certified laboratory for calibration;
- A reference thermometer is sent for calibration by a certified laboratory; while the other thermometers are calibrated in-house. Different temperature calibration instruments are marketed for in-house use.
- The thermometers are calibrated by mobile units providing on-site calibration of the company's pressure and temperature instruments.

According to a Danish reference laboratory it varies whether the companies prefer to do the calibration in-house or have all equipment calibrated at the laboratory. For in-house calibration it is necessary to have the appropriate equipment and facilities and to have trained personnel, and therefore some companies find it more cost efficient to outsource the calibration. This indicates that the actual costs of in-house calibration may not be much less than calibration at a laboratory.

A cost element of importance is also to what extent it is necessary to stop production when the equipment is calibrated. As an example is it common in the Danish dairy industry to stop the production for one week, while all equipment is being calibrated and maintained.

No information has been made available on costs of the option with the mobile unit. The price is based on used man-hours and transport costs and varies considerably.

To obtain a better estimate on actual calibration costs it would be necessary to obtain information on total annual costs of calibration and total number of thermometers for a number of companies.

4.3 Thermometers used in laboratories and other applications

This section addresses thermometers used in laboratories and other applications where a resolution of 0.1 °C and better is needed. For convenience the term “laboratory thermometers” is used for all types. For thermometers of a resolution of 0.2 °C or less, non-mercury liquid-in-glass thermometers are available.

The following alternatives to mercury thermometer with high resolution are marketed today:

- **Platinum resistance thermometers (PRTs)** and **thermistors** both rely on the known variation of electrical resistance with temperature of a specially constructed resistor to convert temperature into a measurable electrical property. Thermistors have stabilities approaching a few thousandths of a degree Celsius per year when properly constructed, and are highly sensitive (approximately 4% change in resistance per degree Celsius). However, the usable temperature range is limited to not more than 100°C for a single thermistor, and the approximate maximum temperature of use is 110°C (Ripple and Strouse 2005). The best stability is obtained with thermistors coated or encapsulated in glass. Platinum resistors have a substantially wider operating range compared to thermistors, but they have a sensitivity 10 times smaller (approximately 0.4% change in resistance per degree Celsius).
- **Thermocouples (TCs)** consist of two lengths of dissimilar metals, joined at one end to form a measuring junction. Each length, referred to as a thermoelement, develops a voltage (or more accurately, a thermoelectric electromotive force) along its length wherever the thermoelement passes through a temperature gradient (Ripple and Strouse 2005). Different thermocouple types can be used for applications in temperature ranges from -40°C to +1800°C. Thin-film resistance thermometers provide accuracy over a wide temperature range (from -200°C to 850°C).
- **Gallium thermometers** may be used for some applications, but the thermometers seem to be produced for this purpose today in only very limited numbers.
- **Liquid-in-glass thermometers with an organic filling** (PerformaTherm™).

One of the manufacturers points to the fact that people mix resolution and accuracy. A digital thermometer showing the temperature with a resolution of 0.1°C, does not necessarily measure the temperature with an accuracy of 0.1°C. However, if properly calibrated the best electronic thermometers in general have a high accuracy, and the discussion about their use more concerns the need for frequent calibration.

The responses provided (Table 10 and Table 11) confirm the existing information: that the questions regarding the suitability of alternatives concern meas-

urements at a resolution of 0.1°C or better and the drawbacks of alternatives are the price and stability of the probes. One of the has responded with an extensive list of thermometers with different application areas, but these areas are covered by the general description in the tables below.

The responses indicate that that these thermometers are used within a wide range of sectors: scientific research, breeding, the environmental sector, and the chemical, petroleum, pharmaceutical, medical, and food sectors.

Thermometers with a resolution of 0.5°C.

In principle thermometers with non-mercury fillings can be used down to a resolution of 0.2°C. However, one manufacturer points to the need for mercury thermometers for specific measurements even at 0.5°C. An example is an instrument for flash-point determination, where the different expansion coefficient and response time of the non-mercury filling would result in incorrect determination of the temperature. In this case another setup would be needed if non-mercury thermometers had to be used.

PerformaTherm

One liquid-in-glass thermometer with an organic filling, with a resolution of 0.1°C, has been introduced. According to the manufacturer, the PerformaTherm™ thermometers from Miller & Weber Inc, USA, meet the ASTM standards for accuracy, tolerance and uncertainty. Each thermometer is supplied with a two-page report of calibration. According to the manufacturer the proprietary blue liquid is biodegradable, nontoxic, noncaustic, and nonhazardous. About 15 different ASTM thermometers are available. The thermometers have the same dimensions as similar mercury thermometers.

The maximum temperature of the thermometers is 105 °C. The limited temperature range has been mentioned as an obstacle for its use.

The liquid of the thermometer has, according to the manual, a tendency to separate, especially during storage or transit and needs to be rejoined using cooling methods. According to a supplier the column has a tendency to separate during shipping and when stored in a horizontal position, whereas this does not happen when the thermometer is stored in a vertical position (e.g. placed within equipment). The column can be reunited in the laboratory by a specific procedure.

According to information obtained from some users in the petrochemical industry the slower response time and the separation of the liquid are serious restraints for the use of the thermometers for applications such as fuel specifications (including freezing point of jet fuels and flash point of diesel). It has not been possible to identify any scientific papers evaluating the performance and limitations of the PerformaTherm thermometers.

According to the web-site of Miller & Weber Inc, PerformaTherm is also supplied for the food industry with a so-called HACCP [hazard analysis and critical control points] Compliance Kit.

A supplier of PerformaTherm™ on the EU market has been asked for further information on the use of the thermometers in the EU. Sales to date have reportedly been very limited due to supply limitations and it has not been possible to obtain an evaluation of the use of these thermometers in different sectors.

No information on calibration frequency has been provided. According to the supplier mentioned above the frequency is normally determined by the quality management procedures of the users.

The price of PerformaTherm ASTM thermometers is 2-3 times the price of ASTM mercury-filled thermometers with the same specification, produced by Miller & Weber Inc.

Table 10 Applications of mercury laboratory thermometers for which technically feasible alternatives are not regarded to exist (based on answers from two manufacturers of mercury thermometers for industrial processes)

Application of thermometer	Sector	Potential alternatives	Reasons for these alternatives of not being technically feasible
Temperature total range but with accuracy and resolution of 0.1°C or better	R&D, Quality Control, Breeding, Calibration, equipment control for ISO QMS, FDA, Standard methods Environmental, Water, Food, methods	Thermocouple RTD (Resistance Temperature Device) Gallium filling	3-5 times higher prices + cost for additional indicator (3...4 x cost of the thermometer) 10-15 times the price of the Hg thermometers. Limited measurement range, many failures during manufacturing, therefore, difficult to calculate price
Impossible to list all applications	Chemical Petroleum Food (Lab. Not consumers) research	Digital but with limits about accuracy due to stability of the probe	When speaking about high precision (0.1°C and more), the stability of the probe moves and the thermometer becomes not sufficiently accurate. The user cannot see that the accuracy has changed. The only way is to control regularly the thermometer, which is costly.
Different thermometers with a resolution of 0,5°C or better or for measurements above 250°C Thermometers made in accordance with specific standards [reference is made to the full response indicating a wide range of different thermometer types for different applications]	Science and research, quality control, chemical, pharmaceutical and medical engineering	Thermometer with mercury-free fluids Electronic thermometer	Thermometers with mercury-free fluids not applicable at higher resolution than 0.5 °C and above 200°C. Significantly slower temperature response of glass thermometers with mercury-free fluids may lead to erroneous evaluation of measurement results Electronic thermometers can in some cases not be used because of the structure of their temperature and chemical resistant sensor housing No calibration with a validity of 15 years possible.

Economic feasibility

Manufacturers of mercury thermometers point to a number of cost elements that are of importance for assessing the economic feasibility of alternatives (Table 11).

Table 11 Applications of mercury laboratory thermometers for which technically feasible alternatives exist, but these are not regarded as economically feasible (based on answers from two manufacturers of mercury thermometers for industrial processes)

Application of thermometer	Sector	Available technically feasible alternatives	Price of alternatives as compared to mercury thermometer	Other reasons for these alternatives of not being economically feasible
Temperature total range but with accuracy and resolution of 0,1 °C and better	R&D, Quality Control, Breeding, Calibration, equipment control for ISO QMS, FDA, Standard methods Environmental, Water, Food, methods	Thermocouple RTD (Resistance Temperature Device)	3 ... 5 times more + cost for additional indicator (3...4 x cost of the thermometer)	<ul style="list-style-type: none"> - High investments for replacement of all mercury filled industrial glass thermometers in existing facilities - (Re-)Installation costs - Costs for re-calibration - Energy costs for extra power (Thermocouple/RTD) - For local power supply disposal of batteries after service life - Cost of additional indicator (Thermocouple)

The manufacturers have provided different examples for the comparison of a thermometer for general measurements in laboratories at resolution of 0.1 °C and alternatives (Table 12, Table 13 and Table 14). Several manufacturers have mentioned that such a thing as “a typical thermometer” for this application does not exist as a wide range of different thermometers are manufactured.

The number of thermometers sold again seems to indicate the numbers sold by the specific manufacturer and not the total EU market, and furthermore only seems to cover the specific thermometer type.

According to the 2008 EU mercury study the total market for mercury-in-glass thermometers was estimated at 200,000 - 400,000 thermometers. It is not indicated how many of these are thermometers with a resolution of 0.1 °C. For more specific market data it would be necessary to make a detailed market analysis with collection of data from all manufacturers.

Table 12 Comparison of thermometer for general measurements in laboratories at resolution of 0.1 °C and alternatives (based on one manufacturer response)

Type of thermometer	Precision mercury thermometer	Thermocouple + Instrument	RTD (Resistance Temperature Device) + Instrument
Typical price of thermometer (factory gate price without VAT in €)	80	600	300
Typical mercury content per thermometer (g/item)	4	0	0
Number of thermometers sold annually for general applications in laboratories in the EU (best estimate)	-	-	
Average lifetime (in years)	30	3	3
Costs of calibration (€ per calibration)	70	70	70
Frequency of calibration (per year)		1	1
Other recurrent costs (specify) (€/year/item):			
Other factors influencing the costs estimates (specify):		Power/Batteries	Power/Batteries

*1 Consultants note: It is not clear whether the figures only include thermometers produced by the specific manufacturer

Table 13 Comparison of thermometer for general measurements in laboratories at resolution of 0.1 °C and alternatives (based on one manufacturer response)

Type of thermometer	Mercury laboratory thermometer, government tested with verification certificate *2 0 - 50 °C Resolution 0,1°C	Electronic thermometer with Pt 1000 4-conductor probe -20+150 0,1°C Resolution 0,001 °C
Typical price of thermometer (factory gate price without VAT in €)	37	826
Typical mercury content per thermometer (g/item)	3	0
Number of thermometers sold annually for general applications in laboratories in the EU (best estimate) *1	650	25
Average lifetime (in years)	Unlimited	3 - 5 years
Costs of calibration (€ per calibration)	154	266
Frequency of calibration (per year)	Validity of calibration 15 years	At least every year
Other recurrent costs (specify) (€/year/item):	None	Batteries
Other factors influencing the costs estimates (specify):	None	Additional calibration points Accessories, power supply, software, etc.

*1 Consultants note: It is not clear whether the figures only include thermometers produced by the specific manufacturer

*2 Means that the precision of the thermometer is tested by an independent test laboratory.

Table 14 Comparison of thermometer for general measurements in laboratories at resolution of 0.05 °C and alternatives (based on one manufacturer response)

Type of thermometer	ASTM 44C mercury thermometer with official certificate +18.6 – 21.4 °C Resolution 0.05°C	ASTM 44C gallium thermometer with official certificate 18.6 – 21.4 °C Resolution 0.05°C	Electronic thermometer with Pt 1000 4-conductor probe -20+150 Resolution 0.001°C
Typical price of thermometer (factory gate price without VAT in €)	54	810	826
Typical mercury content	11 g /piece	0	0
Number of thermometers sold annually for general applications in laboratories in the EU (best estimate) *1	100	1	25
Average lifetime	Unlimited	Unlimited	3 - 5 years
Costs of calibration (€)	143,-	143,-	202,-
Frequency of calibration	Validity of calibration 15 years	Validity of calibration 15 years	At least every year
Other recurrent costs (specify):	0	0	Batteries

*1 Consultants note: It is not clear whether the figures only include thermometers produced by the specific manufacturer

Lifetime

The costs estimates are very sensitive to the indicated differences in average lifetime. It is not clear from the answers whether the lifetime of the electronic equipment only concerns the lifetime of the probe or the lifetime of both probe and data logger.

The manufacturers have indicated that the lifetime of the mercury thermometers is unlimited (two manufacturers) or 30 years (one manufacturer) whereas the lifetime of the electronic thermometers is 3-5 years. Manufacturers of electronic thermometers used in industry have indicated lifetimes of 5-10 years for the probe and this would probably also be true for the electronic thermometers used in laboratories.

The actual lifetime will depend on the actual use of the equipment as it is a question of how often the equipment is dropped. The actual lifetime of mercury thermometers is certainly not unlimited (as then there would be no market for replacement thermometers), but it has not been possible to identify any information on the actual lifetime. A possible way to reach an estimate would be to ask large users about their stock of thermometers and annual purchase of new equipment, but it would be rather time consuming to reach a robust estimate.

Calibration

According to the tables above one manufacturer indicates that the mercury thermometers do not need calibration while the other indicates a 15 year validity of calibration. Both indicate that the electronic alternatives need to be calibrated once a year and this has also been confirmed by suppliers of electronic thermometers.

In laboratories the frequency of calibration is, however, often determined by the quality management system. In many laboratories the frequency is 1-2 calibrations per year independent of thermometer type.

The mercury thermometer is very stable unless it is subject to physical damage and it is necessary to check the thermometer by physical inspection.

According to a Danish certified test laboratory mercury thermometers are usually calibrated every 3-5 years.

The calibration/check of a mercury thermometer consists of two steps as described by an instrumentation service provider

(<http://www.instrumentationservices.net/mercury-thermometers.php>):

- **“Physical inspection.** *The thermometer is physically inspected on arrival as we look for a broken mercury column or cracked glass. If it appears to be OK we will measure the dimensions to ensure that it meets with the required specifications: BS, ASTM, or IP.*
- **Calibration.** *The thermometer is then placed in a calibration bath at the depth required by the type of thermometer that we are calibrating. We compare the readings of the thermometer against a high accuracy AC bridge thermometer using two reference probes. Any corrections that need to be made are noted on the certificate.”*

As discussed for the industry thermometers, the thermometers used in laboratories may either be sent to a certified laboratory for calibration or calibrated in-house using a calibrated reference thermometer which is calibrated at a test laboratory. The costs are expected to be more or less the same as described for industry thermometers.

Shipping

The tables above do not include information on shipping costs. One supplier of thermometers mention that the costs of shipping of the thermometers if shipped by air freight is significant. If the shipped package includes one mercury thermometers the shipping costs typically increase by some 200 €. When shipping large numbers of thermometers from the manufacturers to suppliers the extra shipping costs per thermometer may be low, but the extra costs may be significant when the suppliers ship one or a few thermometers to a customer. One supplier indicates that this is one of the reasons that the supplier has been looking for mercury-free alternatives for the oil refinery sector.

Field testing of flammable liquids

A recent article from ASTM (ASTM 2009), which discussed the possible replacement of mercury thermometers, points at a specific application where the use of a non-electric device may be of advantage.

The custody transfer of oil and natural gas, for example, commodities that are bought and sold by volume at a stated temperature, require regular field temperature measurements to verify quantities. In such situations mercury thermometers remain the 'gold standard' according to the American Petroleum Institute in Washington, D.C. The representative of the institute notes that when temperature measurement devices are used for calibrations and measurements in the field, the environment may involve potentially flammable atmospheres and liquids that can accumulate static charges, and safety becomes an issue. Because mercury in glass thermometers have no electrical safety issues and are inherently safer than alternative devices, they will be used for such purposes until an alternative is felt to be trustworthy and safe

4.4 Hygrometers

One manufacturer has indicated that economically feasible alternatives are not available for whirling hygrometers (also known as sling psychrometers) as the price of alternatives (electronic instrument using PT100) is about 10 times the price of the mercury hygrometer. Another manufacturer has indicated that technically feasible alternatives are not available for some applications of hygrometers. The two answers are merged in Table 15. The manufacturers did not provide further information for the socioeconomic assessment of replacing this equipment.

For most applications, alternatives to mercury are spirit-filled hygrometers and electronic hygrometers which are marketed at approximately the same as the price of mercury hygrometers.

The manufacturers do not indicate specific applications of the hygrometers for which alternatives are not available or for which very expensive electronic device is needed. Hygrometers have been banned in Denmark for many years and through requests to laboratories calibrating this kind of equipment it has not been possible to identify any applications for which it has been difficult to replace the mercury hygrometers.

Prices of hygrometers from one of the responding manufacturer's web retail shop are as follows:

- Non-mercury liquid filled hygrometer: 19 € (excl. VAT)
- Dial hygrometer: 9 € (excl. VAT)
- Mercury whirling hygrometers: 59-78 € (excl. VAT)
- Digital temperature and humidity meters: 67-72 € (excl. VAT)

The digital meters are, in the retail shop, indicated as ideal for use in science, industry and engineering. The data does not indicate that electronic devices should be more expensive than mercury hygrometers, and the economics of replacing mercury hygrometers has not been further investigated.

Table 15 Applications of mercury laboratory thermometers for which technically feasible alternatives exist, but these are not regarded as economically feasible (based on answers from two manufacturers of mercury thermometers for industrial processes)

Application of thermometer	Sector	Available technically feasible alternatives	Price of alternatives as compared to mercury thermometer	Reasons for these alternatives of not being economically feasible
Whirling Hygrometer (measurement of humidity using wet and dry bulb method) Also known as "Psychrometer"	Environmental Monitoring Meteorology	Electronic instrument using PT100	Estimated figure 10:1 (ten times more expensive)	
Psychrometer	Meteorological control stations and Institutes	Thermometer with mercury-free fluids Electronic thermometer		Thermometer with mercury-free fluids not applicable at higher resolution than 0.5 °C and above 200°C. Significantly slower temperature response of glass thermometers with mercury-free fluids may lead to erroneous evaluation of measurement results Electronic thermometers can in some cases not be used because of the structure of their temperature and chemical resistant sensor housing.

4.5 Derogations proposed by manufacturers

As part of the questionnaire, manufacturers of thermometers have been asked to propose phrasing of derogations. Some manufacturers replied with the same phrasings. The replies are collected in Table 16.

Table 16 Derogations proposed by manufacturers of mercury thermometers

Proposed derogations			
Application area	Phrasing of derogation	Time frame of derogation	Justification for the derogation
Industrial thermometers	Thermometers containing mercury that are used for temperatures > 200°C	unlimited	Technically and economically feasible alternatives not available. Typical mercury content: approx. 3.5g/piece -> total consumption of approx. 100 kg/year *2
Precision thermometers	Thermometers containing mercury that are used for temperatures > 200°C with accuracy and resolution of 0.1 °C and better *1	unlimited	Technically and economically feasible alternatives not available. Typical mercury content: approx. 3.5g/pce -> total consumption of approx. 100 kg/year *2
Precision thermometers	All thermometers with a higher resolution than 1 °C All thermometers whose range exceeds 200°C All thermometers tailored to specific equipment	unlimited	All non-mercury thermometer fillings have shortcomings: wetting liquids from distillation, ionic liquids separate and remain in particles sticking to the inside of the capillary. Gallium tends to lubricate the process and is extremely difficult to work with. All non-mercury liquids are used only in very limited temperature ranges. Electronic thermometers behave differently to glass thermometers, and cannot be used everywhere where temperature measurements are essential because of its design. There are currently no calibratable instruments on the market to reach anywhere near the reliable accuracy of a precision thermometer. Both non-mercury glass thermometers and electronic thermometers can lead to much slower response and to erroneous and incorrect evaluations of measurement results.

*1 Consultants comment: Probably a mistake - considering the rest of the questionnaire the phrasing should rather be "Thermometers containing mercury that are used for temperatures > 200°C and thermometers with an accuracy and resolution of 0.1 °C and better"

*2 The quantities represent Germany only and the data are in reasonable agreement with the quantities estimated in the EU Mercury Report.

4.6 Standards

An issue that may hamper the replacement of mercury thermometers is that many test methods standards make reference to the use of mercury thermometers.

In the discussion of standards it is essential to distinguish between two types of standards:

- Standards with the technical specifications of thermometers such as *ASTM E1 - 07 Standard Specification for ASTM Liquid-in-Glass Thermometers*.
- Test method standards that prescribe the use of specific thermometers. As an example the *ASTM D93 - 10 Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester* prescribes that the temperature is measured with a thermometer in accordance with *ASTM E1 Specification for ASTM Liquid-in-Glass Thermometers* or an electronic temperature device with similar temperature response as the mercury thermometers.

Standards with the technical specifications of mercury thermometers are further described in section 4.7.2.

This section concerns standards used for laboratory use. To the knowledge of the authors standards used in meteorology prescribing the use of mercury thermometers have not been raised as an issue by stakeholders. In Denmark and Sweden the use of mercury thermometers in meteorology has been restricted for many years, without any reported discussion of the issue with standards.

4.6.1 Standards prescribing the use of mercury thermometers

Traditionally many standards have prescribed that the temperature should be determined by the use of mercury thermometers. A number of standards for analysis and materials testing still make reference to the use of mercury thermometers, but many new versions of the standards allow for the use of electronic devices with similar accuracy and temperature response.

Relevant standards used for materials testing are issued by ISO (International), CEN (European) and different national standardisation organisations including ASTM International (widely used in Europe), DIN (Germany) and IP/BS (UK) (IP = Institute of Petroleum, now the Energy Institute). For analysis within the pharmaceutical sector the European Pharmacopoeia prescribes the use of specific thermometers for some tests (see later).

The main areas identified in which standards refer to the use of mercury thermometers are listed below. Please note that for many standards alternative (i.e. non-mercury) thermometers may be used, as discussed later in this section.

For flash point determination in the petrochemical sector, all identified standards from the standards organisations ISO/EN (ISO and CEN develop standards together within this area), ASTM and IP are listed. Further, some national standards may exist.

For the other applications of thermometers, except pharmaceutical industry, only the ASTM standards are listed in the table. It is assumed that for most of the thermometer use areas similar standards are issued from the other standardization organisations. However, only the ASTM International web-site indicates specifically in the summary of the standards that the standards make reference to the liquid-in-glass thermometers. For other standards it is necessary to buy the standards to obtain this information.

A search on the ASTM International website revealed more than one hundred ASTM standards making reference to ASTM E1 *Specification for ASTM Liquid-in-Glass Thermometers*. ASTM E1 defines thermometers with the following liquids depending on the type and temperature range of the thermometer:

- Mercury,
- mercury thallium eutectic alloy, and
- toluene or other suitable liquid coloured with a permanent red dye.

The standards from ASTM International are widely used in the petrochemical and chemical industries in Europe and more than one hundred different types of ASTM E1 mercury thermometers are marketed by major manufacturers of mercury thermometers.

For non-mercury alternatives to E1 thermometers, E1 and some analysis standards make reference to ASTM E2251 *Standard Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids*. Some standards make direct references to ASTM E2251 e.g. ASTM D1795 - 96(2007)e1 *Standard Test Method for Intrinsic Viscosity of Cellulose*. The reason is that less accuracy is permissible for these methods and the temperature to be measured is within the range of the alternative liquid-in-glass thermometers.

The list of standards in Table 17 is not exhaustive, but illustrates the sectors where the standards are applied and gives examples of test parameters.

The main part of the identified standards is for materials testing in the petrochemical industry, paint and varnishes industry, polymer industry and other chemicals industry. No standards used in the pulp and paper industry making reference to ASTM E1 were identified as all standards for this sector make reference to the non-mercury thermometers. The ASTM standards for product control are to some extent applied in Europe together with the ISO, CEN and national standards.

Further, examples of standards for analysis of environmental samples are listed in Table 17. These standards may not be applied in the EU, but are included for illustration. It has not been possible within the scope of this work to identify similar laboratory standards applied in the EU.

In some instances the thermometers are used as parts of hydrometers (determination of density and gravity) and hygrometers (determination of humidity).

Table 17 Examples of standards making reference to the use of mercury thermometers

Sector	Test parameter	Examples of standards
Petrochemical industry	Flash-point with closed cup - Pensky-Martens method	<p>ASTM D93 - 10 Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester</p> <p>EN ISO 2719:2002 Determination of flash point - Pensky-Martens closed cup method</p> <p>IP 34: Determination of flash point - Pensky-Martens closed cup method</p> <p>IP 35: Determination of open flash and fire point - Pensky-Martens method</p>
	Flash-Point with Closed Cup - other methods	<p>EN ISO 1516:2002 Determination of flash/no flash - Closed cup equilibrium method</p> <p>EN ISO 1523 :2002 Determination of flash point - Closed cup equilibrium method</p> <p>EN ISO 3679:2004 Determination of flash point - Rapid equilibrium closed cup method</p> <p>EN ISO 3680:2004 Determination of flash/no flash - Rapid equilibrium closed cup method</p> <p>EN ISO 13736 :2008 Determination of flash point - Abel closed-cup method</p> <p>ASTM D56 - 05 Standard Test Method for Flash Point by Tag Closed Cup Tester</p> <p>ASTM D3278 - 96(2004)e1 Standard Test Methods for Flash Point of Liquids by Small Scale Closed-Cup Apparatus.</p> <p>ASTM D3828 - 09 Standard Test Methods for Flash Point by Small Scale Closed Cup Tester</p> <p>ASTM D3934 - 90(2007) Standard Test Method for Flash/No Flash Test-Equilibrium Method by a Closed-Cup Apparatus</p> <p>ASTM D3941 - 90(2007) Standard Test Method for Flash Point by the Equilibrium Method With a Closed-Cup Apparatus</p> <p>IP 170: Determination of flash point — Abel closed-cup method</p> <p>IP 491: Determination of flash/no flash - Closed cup equilibrium method</p> <p>IP 491: Determination of flash/no flash - Closed cup equilibrium method</p> <p>DIN 51755-1 Testing of Mineral Oils and Other Combustible Liquids; Determination of Flash Point by the Closed Tester according to Abel-Pensky</p>

Sector	Test parameter	Examples of standards
		<p>IP 492: Determination of flash point - Closed cup equilibrium method</p> <p>IP 534: Determination of flash point – Small scale closed cup ramp method</p>
	Flash- and fire-point with open cup	<p>EN ISO 2592:2001 Determination of flash and fire points - Cleveland open cup method</p> <p>ASTM D92 - 05a Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester</p> <p>ASTM D1310 - 01(2007) Standard Test Method for Flash Point and Fire Point of Liquids by Tag Open-Cup Apparatus</p> <p>IP 36: Determination of flash and fire points - Cleveland open cup method</p>
	Viscosity	ASTM D445 - 09 Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
	Distillation	ASTM D86 - 09e1 Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure
	Saybolt viscosity	ASTM D88 - 07 Standard Test Method for Saybolt Viscosity
	Pour point	ASTM D97 - 09 Standard Test Method for Pour Point of Petroleum Products
	Boiling point	ASTM D1120 - 08 Standard Test Method for Boiling Point of Engine Coolants
	Freezing point	ASTM D2386 - 06 Standard Test Method for Freezing Point of Aviation Fuels
	Cloud point	ASTM D2500 - 09 Standard Test Method for Cloud Point of Petroleum Products
	Dropping point	ASTM D566 - 02(2009) Standard Test Method for Dropping Point of Lubricating Grease
	Softening point	ASTM D2319 / D2319M - 98(2008)e1 Standard Test Method for Softening Point of Pitch (Cube-in-Air Method)
	Filterability	ASTM D4539 - 09 Standard Test Method for Filterability of Diesel Fuels by Low-Temperature Flow Test (LTFT)
	Density	ASTM D1298 - 99(2005) Standard Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
	Gravity	ASTM D287 - 92(2006) Standard Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)
	Vapour pressure	ASTM D323 - 08 Standard Test Method for Vapor Pressure of Petroleum Products (Reid Method)
	Heat of combustion	ASTM D4809 - 09a Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)

Sector	Test parameter	Examples of standards
	Oxidation stability	ASTM D4742 - 08e1 Standard Test Method for Oxidation Stability of Gasoline Automotive Engine Oils by Thin-Film Oxygen Uptake (TFOUT) ASTM D7098 - 08e1 Standard Test Method for Oxidation Stability of Lubricants by Thin-Film Oxygen Uptake (TFOUT) Catalyst B
	Foaming Characteristics	ASTM D892 - 06e1 Standard Test Method for Foaming Characteristics of Lubricating Oils
	Residues	ASTM D2158 - 05 Standard Test Method for Residues in Liquefied Petroleum (LP) Gases ASTM D524 - 09 Standard Test Method for Ramsbottom Carbon Residue of Petroleum Products
	Corrosiveness	ASTM D130 - 04e1 Standard Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test ASTM D4310 - 09 Standard Test Method for Determination of Sludging and Corrosion Tendencies of Inhibited Mineral Oils
	Refractive index	ASTM D1747 - 09 Standard Test Method for Refractive Index of Viscous Materials
Paint, inks and varnished	Flash point	EN ISO 1523 :2002 Determination of flash point - Closed cup equilibrium method ASTM D1310 - 01(2007) Standard Test Method for Flash Point and Fire Point of Liquids by Tag Open-Cup Apparatus
	Viscosity	ASTM D4212 - 99(2005) Standard Test Method for Viscosity by Dip-Type Viscosity Cups ASTM D1200 - 94(2005) Standard Test Method for Viscosity by Ford Viscosity Cup
	Distillation range	ASTM D1078 - 05 Standard Test Method for Distillation Range of Volatile Organic Liquids ASTM D850 - 03(2008)e1 Standard Test Method for Distillation of Industrial Aromatic Hydrocarbons and Related Materials
	Nonvolatile content	ASTM D4713 - 92(2007) Standard Test Methods for Nonvolatile Content of Heatset and Liquid Printing Ink Systems
	Physical/chemical properties of materials	ASTM D740 - 05 Standard Specification for Methyl Ethyl Ketone ASTM D5958 - 99(2005)e1 Standard Practices for Preparation of Oil-Based Ink Resin Solutions
Polymers	Softening stability	ASTM D1525 - 09 Standard Test Method for Vicat Softening Temperature of Plastics
	Viscosity	ASTM D1601 - 99(2004) Standard Test Method for Dilute Solution Viscosity of Ethylene Polymers ASTM D1823 - 95(2009) Standard Test Method for Apparent Viscosity of Plastics and Organosols at High Shear Rates by Extrusion Viscometer ASTM D4878 - 08 Standard Test Methods for Polyurethane Raw Materials: Determination of Viscosity of Polyols

Sector	Test parameter	Examples of standards
	Gravity	ASTM D4659 - 09 Standard Test Methods for Polyurethane Raw Materials: Determination of Specific Gravity of Isocyanates
	Density	ASTM D1817 - 05 Standard Test Method for Rubber Chemicals—Density
	Shrinkage	ASTM D2732 - 08 Standard Test Method for Unrestrained Linear Thermal Shrinkage of Plastic Film and Sheeting
	Deflection temperature	ASTM D648 - 07 Standard Test Method for Deflection Temperature of Plastics Under Flexural Load in the Edgewise Position
	Rheological properties	ASTM D2196 - 05 Standard Test Methods for Rheological Properties of Non-Newtonian Materials by Rotational (Brookfield type) Viscometer
	Physical/chemical properties of materials	ASTM D1755 - 09 Standard Specification for Poly(Vinyl Chloride) Resins ASTM D2195 - 05 Standard Test Methods for Pentaerythritol ASTM D1045 - 08 Standard Test Methods for Sampling and Testing Plasticizers Used in Plastics ASTM D4830 - 98(2006) Standard Test Methods for Characterizing Thermoplastic Fabrics Used in Roofing and Waterproofing ASTM D1619 - 03(2008) Standard Test Methods for Carbon Black—Sulfur Content ASTM D301 - 95(2004) Standard Test Methods for Soluble Cellulose Nitrate ASTM D4028 - 07 Standard Specification for Solar Screening Woven from Vinyl-Coated Fiber Glass Yarn
Other chemical industry	Physical/chemical properties of materials	ASTM E224 - 08 Standard Test Methods for Analysis of Hydrochloric Acid ASTM E223 - 08 Standard Test Methods for Analysis of Sulfuric Acid ASTM D914 - 00(2006) Standard Test Methods for Ethylcellulose ASTM D3716 - 99(2008) Standard Test Methods for Use of Emulsion Polymers in Floor Polishes ASTM D889 - 99(2009) Standard Test Method for Volatile Oil in Rosin ASTM D5249 - 95(2006) Standard Specification for Backer Material for Use with Cold- and Hot-Applied Joint Sealants in Portland-Cement Concrete and Asphalt Joints
	Viscosity	ASTM D1986 - 91(2007) Standard Test Method for Determining the Apparent Viscosity of Polyethylene Wax
	Gravity	ASTM D891 - 09 Standard Test Methods for Specific Gravity, Apparent, of Liquid Industrial Chemicals
	Cloud point	ASTM D2024 - 09 Standard Test Method for Cloud Point of Non-ionic Surfactants

Sector	Test parameter	Examples of standards
Mineral resources industry	Swell Index	ASTM D5890 - 06 Standard Test Method for Swell Index of Clay Mineral Component of Geosynthetic Clay Liners
	Physical/chemical properties of materials	ASTM D5249 - 95(2006) Standard Specification for Backer Material for Use with Cold- and Hot-Applied Joint Sealants in Portland-Cement Concrete and Asphalt Joints
Other sectors	Different	ISO 15267:1998 Animal and vegetable fats and oils -- Flashpoint limit test using Pensky-Martens closed cup flash tester ASTM F482 - 09 Standard Practice for Corrosion of Aircraft Metals by Total Immersion in Maintenance Chemicals ASTM F558 - 06 Standard Test Method for Measuring Air Performance Characteristics of Vacuum Cleaners
Test of environmental samples	Dispersive characteristics	ASTM D6572 - 06 Standard Test Methods for Determining Dispersive Characteristics of Clayey Soils by the Crumb Test
	pH	ASTM D5015 - 02(2008) Standard Test Method for pH of Atmospheric Wet Deposition Samples by Electrometric Determination
	Humidity	ASTM E337 - 02(2007) Standard Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)
	Electrical conductivity and resistivity	ASTM D1125 - 95(2009) Standard Test Methods for Electrical Conductivity and Resistivity of Water
	Nitrogen oxides in the atmosphere	ASTM D3608 - 95(2005) Standard Test Method for Nitrogen Oxides (Combined) Content in the Atmosphere by the Griess-Saltzman Reaction ASTM D1607 - 91(2005) Standard Test Method for Nitrogen Dioxide Content of the Atmosphere (Griess-Saltzman Reaction)
	Mercaptan in the atmosphere	ASTM D2913 - 96(2007) Standard Test Method for Mercaptan Content of the Atmosphere
Pharmaceutical industry	Drop point	European Pharmacopoeia section section 2.2.17

According to the information obtained from suppliers of apparatus for materials testing, at least the ISO/EN and ASTM standards used for materials control in the petrochemical sector in general, allow the use of electronic thermometers. According to suppliers of equipment for determination of flash point and viscosity and equipment for distillation across sectors, at least for flash point and viscosity, the standards also allow for the use of electronic thermometers.

The flash point determination, which has been mentioned as one of the areas where it was particularly difficult to replace the mercury thermometers are discussed in more detail below.

Flash point determination

Flash point is used in shipping and safety regulations to define flammable and combustible materials. Is it used also in the determination of flammability and explosivity for classification and labelling?

A number of standards for determination of the flash point of fuels, greasing oils, paint and varnishes and other chemicals exist. ISO 1523 is used in United Nations Recommendations for Transportation of Dangerous Goods and in the International Civil Aviation Organization (ICAO) regulations and for similar regulations in the International Maritime Dangerous Goods (IMDG) code.

Currently many (if not all) standards allow for the use of electronic devices with similar temperature response as the mercury thermometers.

As an example the ASTM D93-10 *Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester* specifies regarding the temperature measuring device: “*Thermometer having a range as shown as follows and conforming to the requirements prescribed in Specification E1 or in Annex A3, or an electronic temperature measuring device, such as resistance thermometers or thermocouples. The device shall exhibit the same temperature response as the mercury thermometers.*”

<i>Temperature Range</i>	<i>Thermometer Number</i>	
	<i>ASTM</i>	<i>IP</i>
<i>−5 to +110°C (20 to 230°F)</i>	<i>9C (9F)</i>	<i>15C</i>
<i>+10 to 200°C (50 to 392°F)</i>	<i>88C (88F)</i>	<i>101C</i>
<i>+90 to 370°C (200 to 700°F)</i>	<i>10C (10F)</i>	<i>16C”</i>

Mercury thermometers made in accordance with ASTM D1, 9C are marketed for flash point determination in accordance with ASTM D93, but this does not imply that only these thermometers can be used.

The ASTM D93-10 makes specific reference to the ASTM E1 Liquid-in-Glass Thermometers, but not to standards for the electronic devices. For the electronic devices it is only mentioned that the temperature response shall be similar to the response of the liquid-in-glass thermometers.

Similarly, the ISO 2719 standard *Determination of flash point — Pensky-Martens closed cup method* does not require that the temperature is measured with a mercury thermometer.

Section 6.2 on thermometers specifies that thermometers should conform to the specifications in Annex C of the standard, but adds: “*NOTE Other types of temperature-measuring devices may be used, provided that they meet the requirements for accuracy and have the same response as the thermometers specified in annex C.*”

Annex C specifies three types of thermometers (low, medium and high range) which are indicated to correspond to the IP thermometers IP 15C, 16C and 101C and the ASTM thermometers ASTM 9C, 10C and 88C. The accuracy of the thermometers is indicated in the annex.

Whereas the ASTM standard only opens for the use of electronic devices, any thermometer which can meet the requirements for accuracy and response can be used according to the ISO 2719 standard.

On request from the consultant a member of the ISO/CEN working group on flash point determination has provided the following information on the requirements of the different ISO standards for flash point determination. In practice all these standards allow for the use of other types of thermometers.

Standard	Requirements as to the use of thermometers
EN ISO 2719 Determination of flash point - Pensky-Martens closed cup method:	Allows for other types of thermometers
EN ISO: 13736 Determination of flash point - Abel closed-cup method (currently under revision):	Edition 1997 allows for automated equipment
EN ISO 3679 Determination of flash point - Rapid equilibrium closed cup method (currently under revision):	Edition 2004 allows for temperature measuring devices other than mercury thermometers
EN ISO 3680 Determination of flash/no flash - Rapid equilibrium closed cup method (currently under revision):	Edition 2004 allows for temperature measuring devices other than mercury thermometers
EN ISO 1523: Determination of flash point - Closed cup equilibrium method	Edition 2002 - no extra equipment is described; only a different procedure is given; equipment according to EN ISO 13736, EN ISO 2719, DIN 51755 part 1, ASTM D56 is allowed
EN ISO 1516: Determination of flash/no flash - Closed cup equilibrium method	Edition 2002 - no extra equipment is described; only a different procedure is given; equipment according to EN ISO 13736, EN ISO 2719, DIN 51755 part 1, ASTM D56 is allowed

Apparatus for materials testing

Equipment for flash point determination is today marketed as both manual apparatus with mercury thermometers or and as automatic apparatus with electronic thermometers. The electronic thermometers are electronically corrected for replicating the response time of the specified mercury thermometer.

A UK manufacturer of test apparatus e.g. supply a thermometer with a PT 100 probe for distillation control which “...uses a unique simulation program that replicates the characteristics of mercury-in-glass ASTM 7C/F or 8C/F thermometers, including the time lag and thermal history”³. This specific thermometer can be used in accordance with ISO 3405, ASTM D86, ASTM D850 and a number of other standards.

³ <http://www.stanhope-seta.co.uk/product.asp?ID=2405&bShowDetail=true>

According to a major German manufacturer of test apparatus nearly all customers in Germany today use the automatic apparatus for flash point determination, while the manual apparatus is mainly requested by customers with relatively few measurements per week. The price of the electronic apparatus (about 12,000 €) is about 5 times the price of the manual apparatus with mercury thermometers.

Automatic equipment with electronic thermometers is today available for most material tests within the petrochemical industry. For some test equipment, however, the development of automatic devices may still be pending. For some test equipment some of the manufactures only market the manual equipment while others have both manual and automatic in their product range.

Table 18 lists examples of test equipment with PT-100 electronic thermometer from the product catalogues of two major manufactures of test equipment.

Table 18 Examples of apparatus for materials testing in accordance with standards provided with electronic PT-100 temperature device (based on the web page of two major manufactures of the apparatus)

Equipment for determination of:	Standards	Name of ISO standard
Flash-point – closed cup	ISO 15267 ASTM D93	Flash Point by Pensky-Martens Method
	EN ISO 13736	Determination of flash point -- Abel closed-cup method
	ISO 1523	Determination of flash point -- Closed cup equilibrium method
Flash-point – open cup	EN ISO 2592 ASTM D92	Determination of flash and fire points -- Cleveland open cup method
Viscosity	ISO 3104 ASTM D445-IP71	Kinematic Viscosity of Transparent and Opaque Liquids and the Calculation of Dynamic Viscosity
Gum content	ISO 6246 ASTM D381-IP 131	Petroleum products -- Gum content of light and middle distillate fuels -- Jet evaporation method
Distillation temperature	ISO 3405 ASTM D86 ASTM D 850 - ASTM D 1078	Petroleum products -- Determination of distillation characteristics at atmospheric pressure
Softening point	ISO 4625-1 EN 1427 ASTM D 36 EN 1238 ASTM E 28	Binders for paints and varnishes -- Determination of softening point -- Part 1: Ring-and-ball method

Changing of standards

Although the standards allow for the use of electronic devices with similar characteristics it may be relevant to change the standards, as in many cases the electronic devices would be able to measure the temperature more accurately and currently have to be modified in order to replicate the mercury thermometers.

The general principles for replacing mercury thermometers are discussed by Ripple and Strouse (2005) in an ASTM paper. According to that paper many hundreds of ASTM test methods relied on ASTM liquid-in-glass (LiG) thermometers or ASTM Liquid-in-Glass Thermometers with Low-Hazard Precision Liquid (E 2251).

At the moment a process of replacing mercury-in-glass thermometers in ASTM test methods is ongoing (ASTM 2009). In total 853 consensus documents from 94 different technical committees are being reviewed (ASTM 2008).

A recent paper from ASTM discusses some of the issues of changing the standards (ASTM 2009), which also explains why it may sometimes be difficult to replicate the response of the mercury thermometers. According to the paper, the goal of the thermometer designs was often to provide consistent results among the parties. To that end, the designs were often manipulated for optimal repeatability or ease of use within the method, not necessarily for accuracy. Examples of this manipulation include establishing arbitrary emergent stem temperature assignments for partial immersion thermometers (for example, ASTM 5C/5F cloud and pour thermometers), or use of expanded bulb thermometers in tests (thermometers conditioned at their highest temperature before use, for example, ASTM 56C and ASTM 117C calorimetric thermometers).

In many ASTM test methods, the use of an alternative temperature measurement device may provide more accurate temperature measurements but may not reproduce the previously accepted values of the test method. Switching to an electronic alternative might introduce a new bias in the method. In general, because of the unique design manipulations of the ASTM E1 thermometers, results produced by alternative temperature measurement devices in apparatus built for ASTM mercury-in-glass thermometers will not be directly comparable to results obtained using the ASTM E1 thermometer(s) specified in the test method. For some test methods, electronic thermometers are marketed with simulations for replicating the response of the mercury thermometers. Currently, such equipment seems not to have been developed for all test methods, in particular for which there have been no incentives for the development of the automatic test apparatus.

In many cases the best solution seems to be to change the standards to take advantage of the better characteristics of the electronic devices. ECHA has made direct contact to ASTM regarding the process of changing the standards and the ASTM process will not be discussed further here.

According to the European experts contacted no similar process is ongoing in ISO or CEN.

National standards

According to German experts in the field at least for the testing within the petrochemical sector the DIN standards are today replaced by the corresponding EN ISO standards except for one standard, DIN 51755. DIN 51755, requiring the use of mercury thermometers, is mentioned in several community legislation such as Commission Regulation (EC) No 1031/2008 of 19 September 2008.

IP standards, issued by the British Energy Institute are widely used in the petrochemical sector. Under the Phoenix agreement from 2006 the Energy Institute (EI), and the American Petroleum Institute (API) work together with the aim of producing joint API/EI standards in all areas of petroleum measurement.

Information on standards issued by other Member States has been beyond the current contract.

Indication of standards on thermometers

The Dutch mercury regulation⁴ includes a derogation for “*a mercury thermometer exclusively intended to perform specific analytical tests according to established standards;*”

According to the explanatory notes of the regulation “*Section j discusses mercury thermometers which are explicitly prescribed in international standards, such as ASTM, DIN, BS. These thermometers can easily be distinguished from other thermometers, because they are specially designed for the application of a particular standard and the number of that standard is written on the thermometers*”.

The latter seems to be incorrect. According to information from a leading German mercury thermometer manufacturer contacted for this study, in some cases, as also described in section 4.6.2, the standard for the manufacturing of the thermometer is written on the thermometer (e.g. ASTM E1, 12F). This may give an indication of the analysis for which the thermometer is going to be used (e.g. the 12F is indicated in the standard as “density wide range”) and consequently the number indicated the standard prescribing the thermometer. But the number of the standard the thermometer is designed for is not indicated. The indication of thermometer type on the thermometer applies to the ASTM thermometers, but is in general not the case for thermometers made in conformity with a specific DIN standard. The standard for the manufacturing of the thermometer e.g. DIN 12775 is usually indicated in the technical specifications of the thermometer, but not written on the thermometer.

⁴ English translation of "Besluit kwikhoudende producten Wms 1998". Bulletin of Acts and Decrees of the Kingdom of the Netherlands No. 553

According to information from one manufacturer 60-80 % of the thermometers used in the laboratories in the EU are used for measurements where the procedure prescribes either: 1) that the thermometers used conform to a specific standard or 2) more widely prescribes that the thermometers should be a standard thermometer (without specifying the standard). In some sectors e.g. the petrochemical industry or pharmaceutical industry it applies to nearly 100% of the thermometers. No data are available indicating the percentage of thermometers used in accordance with standards prescribing a specific thermometer.

Test methods for implementation of REACH

The new Swedish mercury regulation has an exemption for mercury thermometers for flash point determination until 31/12/2013 with reference to Directive 67/548/EEC (http://www.kemi.se/templates/Page____5487.aspx).

Directive 67/548/EEC specified in Annex XV methods for determination of flash point. As concern the flash point test method the description in the annex has been transferred without changes to Council Regulation (EC) No 440/2008 of 30 May 2008 laying down test methods pursuant to Regulation (EC) No 1907/2006 (REACH)⁵. The Regulation No 440/2008 does not specifically prescribe mercury thermometers for flash point determination but prescribes that “Only the methods which can give the temperature of the flash -point may be used for a notification.” The regulation lists a number of standards for reference. The exact wording is as follows:

“1.6.3. Performance of the test

1.6.3.1. Equilibrium method

See ISO 1516, ISO 3680, ISO 1523, ISO 3679.

1.6.3.2. Non-equilibrium method

Abel apparatus:

See BS 2000 part 170, NF M07-011, NF T66-009.

Abel-Pensky apparatus:

See EN 57, DIN 51755 part 1 (for temperatures from 5 to 65 °C), DIN 51755 part 2 (for temperatures below 5 °C), NF M07-036.

Tag apparatus:

See ASTM D 56.

Pensky-Martens apparatus:

⁵ <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:142:0001:0739:EN:PDF>

See ISO 2719, EN 11, DIN 51758, ASTM D 93, BS 2000-34, NF M07-019”.

Most of these standards likely allow for the use of electronic thermometers with similar response as the mercury thermometers, but it has not been possible within the scope of this contract to consult all these standards.

On one instance the Regulation specifically prescribes the use of mercury thermometers. The Regulation specifies under A1 “Melting/freezing temperature” that “*Only those thermometers should be used which fulfil the requirements of the following or equivalent standards: ASTM E 1-71, DIN 12770, JIS K 8001.*” The two first standards are standards on liquid-in-glass thermometers while the latter is a Japanese standard on “General rule for test methods of reagents”. [ASTM E 1-71 does not exist but may be the 1971 version of ASTM E 1] Under the procedure it is further mentioned that “*The filled capillary tube is placed in the bath so that the middle part of the mercury bulb of the thermometer....*”.

Test methods for implementation of Commission Regulation (EC) No 1031/2008

Commission Regulation (EC) No 1031/2008 of 19 September 2008 amending Annex I to Council Regulation (EEC) No 2658/87 on the tariff and statistical nomenclature and on the Common Customs Tariff makes reference to a German test method for flash point determination. According to the method DIN 51755 the temperature shall be determined by the use of mercury thermometers.

Page 191 of Regulation 1031/2998 states:

“(b) ‘white spirit’ (subheading 2710 11 21) means special spirits as defined in paragraph (a) above with a flash-point higher than 21 °C by the Abel-Pensky method (1);” and the footnote specifies...

“(1) The term ‘Abel-Pensky method’ means method DIN (Deutsche Industrienorm) 51755 — März 1974 published by the DNA (Deutsche Normenausschuss), Berlin 15.”

European and national Pharmacopoeias

The European Pharmacopoeia is a single reference work for the quality control of medicines in Europe. The Pharmacopoeia consists of a large number of monographs addressing different issues. Several legal texts make the European Pharmacopoeia mandatory, first of all a Convention elaborated by the Council of Europe on the Elaboration of a European Pharmacopoeia and European Union directives 2001/82/EC, 2001/83/EC and 2003/63/EC (amended). The work on monographs is allocated by the European Pharmacopoeia Commission to specially constituted groups of experts and working parties. According to information at the website of the European Directorate for the Quality of Medicines and Health Care an update of a monograph takes at least 2 years.

An example of test equipment marketed with reference to the European Pharmacopoeia is a drop point apparatus with a mercury thermometer⁶. This is the only for which it has been possible to identify a direct reference to the European Pharmacopoeia and the drop point determination. Furthermore, the drop point test is the only test method mentioned by the market actors contacted for this study.

The drop point test is described in the monograph no. 33 of the European Pharmacopoeia.

The European Pharmacopoeia 5.0 from 2005 mention e.g. for 2.2.17 drop point:” *The apparatus (see Figure 2.2.17.-1) consists of 2 metal sheaths (A) and (B) screwed together. Sheath (A) is fixed to a mercury thermometer*”. The latest update of the Pharmacopoeia has not been available to the consultant within the time frame of this activity and has not been consulted.

The International Pharmacopoeia published by WHO (2008) makes reference to the use of mercury thermometers in one section. The Pharmacopoeia comprises a collection of recommended procedures for analysis and specifications for the determination of pharmaceutical substances that is intended to serve as source material for reference or adaptation by any WHO Member State wishing to establish pharmaceutical requirements. In the chapter on Methods of Analysis it is in the section of melting temperature and melting range stated that: “*Standardized thermometers should cover the range -10 to +360 °C, the length of one degree on the scale being not less than 0.8 mm. These thermometers should preferably be of the mercury-in-glass, solid-stem type with a cylindrical bulb and made of approved thermometric glass suitable for the range covered; each thermometer should have a safety chamber*”. A search of the International Pharmacopoeia revealed that the mercury thermometers are mentioned in the section on melting point and melting range only.

4.6.2 Standards with technical specification of thermometers

The questionnaire sent to manufacturers included a question regarding which national or international standards prescribe the use of mercury thermometers.

The question seems to have been unclear as none of the manufacturers replied to the question, but instead replied with information on the standards the thermometers have to comply with (Table 19) and the sectors where these thermometers are used.

The objective of the question – to clarify the sectors in which analysis standards are used that prescribe that temperature is measured by the use of mercury thermometers - was consequently not met. Answers from the manufacturers are collected in Table 19.

⁶ http://www.stanhope-seta.co.uk/catalogue/11610-0_pharmacopoeia_drop_point.pdf

In any case, the Table 19 shows a wide range of standards for the manufacturing of thermometers. For most applications the manufacturers indicated that alternatives are not available, but the meaning is here that none of the alternatives would comply with the standards for the mercury thermometers. It should not be interpreted that alternatives are not available for measuring the temperature in the specified range.

Table 19 also includes international standards (ISO), German (DIN), American (ASTM), British (BS, IP and STPTC) and French (AFNOR) standards. National standards are probably used in many other Member States.

One manufacturer indicated that in France the petroleum industry uses ASTM (American) or IP (British) standards.

One manufacturer mentioned that the list of thermometers connected with all standards is very long (hundreds), as every thermometer has its own specification and the manufacturer does not consider it possible to make reference to every standard and industrial sector.

Subsequently, one manufacturer was contacted for more information but, according to their response, manufacturers of the thermometers would usually not have the information on the analysis standards prescribing the use of the thermometers.

Table 19 Standards for thermometers and alternatives as reported by manufacturers of thermometers

Analysis	Industrial sector	Standard	Thermometer standard referred to by the standard	Alternatives that potentially may be used for the analysis if the standard is changed
Calorimeter Thermometer	Industry, University, R&D, Control Institutions,	DIN 12771 ISO 651 BS 791	Temperature > 200°C and acc. 0.1°C	no alternatives available
Precision Thermometer	Industry, University, R&D, Control Institutions,	DIN 12775 DIN 12778 DIN 12781	Temperature > 200°C and acc. 0.1°C	no alternatives available
Precision thermometers acc. To Allihn	Industry, University, R&D, Control Institutions.	DIN 12776	Temperature > 200°C and acc. 0.1°C	no alternatives available
Precision thermometer sets, Anschütz, DIN 12777	Laboratory, Industry, University, Control Institutions Pharmacies,	DIN 12777	Measuring range Accuracy Dimensions	No alternatives available

Analysis	Industrial sector	Standard	Thermometer standard referred to by the standard	Alternatives that potentially may be used for the analysis if the standard is changed
Distillation thermometer	Industry, University, R&D, Control Institutions.	DIN 12779 DIN 12784	Temperature > 200°C and acc. 0.1°C	no alternatives available
Precision thermometer for viscosimeter Flash-point thermometers	Industry, University, R&D, Control Institutions.	DIN 12785	Temperature > 200°C and acc. 0.1°C	no alternatives available
Softening point thermometers	Laboratory, Petroeoleum- Industry	DIN 12785, ASTM 15C ASTM 16C	Measuring range Accuracy Dimensions	No alternatives available
Breaking point thermometers	Laboratory, Industry	DIN 12785 IP 42C	Measuring range Accuracy Dimensions	No alternatives available
Determination of the distillation	Laboratory, Industry	DIN 12785 ASTM 7C ASTM 8C	Measuring range Accuracy Dimensions	No alternatives available
Thermometer sets according to Dr. Otte	Laboratory, Industry, University, Control Institutions	DIN 12786	Measuring range Accuracy Dimensions	No alternatives available
Precision adjusting thermometers acc. To Beckmann	Industry, University, R&D, Control Institutions,	DIN 12789 ASTM 115	Temperature > 200°C and acc. 0.1°C	no alternatives available
Contact Thermometer	Industry, University, R&D, Control Institutions.	DIN 12878	Temperature > 200°C and acc. 0.1°C	no alternatives available
Straight stem large thermometers	Industry, Chemical, pharmaceutical industry	DIN 16174	Measuring range Accuracy Dimensions	No alternatives available
Angle stem, large thermometers	Industry, Chemical, pharmaceutical industry,	DIN 16175	Measuring range Accuracy Dimensions	No alternatives available

Analysis	Industrial sector	Standard	Thermometer standard referred to by the standard	Alternatives that potentially may be used for the analysis if the standard is changed
Engine thermometers	Marine Industry, Power plants, Diesel Engine manufacturer, Chemical, pharmaceutical Industry	DIN 16181 DIN 16182 DIN 16185 DIN 16186 DIN 16189 DIN 16190 DIN 16191 - 16195	Temperature > 200°C and acc. 0.1°C	no alternatives available
Meteorological extreme thermometers, DIN	Meteorology	DIN 58654	Measuring range Accuracy Dimensions	No alternatives available
Psychrometer August, DIN	Meteorology	DIN 58660	Measuring range Accuracy Dimensions	No alternatives available
Aspiration psychrometers, Assmann	Meteorology	DIN 58661	Measuring range Accuracy Dimensions	No alternatives available
Depth thermometers	Meteorology	DIN 58664	Measuring range Accuracy Dimensions	No alternatives available
Soil thermometers, DIN 58 655	Meteorology	DIN 58665	Measuring range Accuracy Dimensions	No alternatives available
Precision thermometer	Industry, University, R&D, Control Institutions.	BS 593 BS1365 BS1704 /ANSI BS1900 ISO R653 ISO R654 ISO R655 ISO R656 ISO R1770 ISO R1771	Temperature > 200°C and acc. 0.1°C	no alternatives available

Analysis	Industrial sector	Standard	Thermometer standard referred to by the standard	Alternatives that potentially may be used for the analysis if the standard is changed
BS 593 laboratory thermometer	Laboratory, Industry	BS 593 A10C – F400C	Measuring range Accuracy Dimensions	No alternatives available
Meteorological Thermometers	Meteorology	BS 692	Measuring range Accuracy Dimensions	No alternatives available
BS 1704 general purpose thermometers	Laboratory, Industry	BS 1704 A/total – H/75	Measuring range Accuracy Dimensions	No alternatives available
Secondary Reference BS 1900	Laboratory, Industry,	BS 1900, SR5/20C – SR6 – 102C	Measuring range Accuracy Dimensions	No alternatives available
-	Oil industry, scientific analysis	BS 2000	Mercury in glass Laboratory thermometer	PT100
-	Oil industry, scientific analysis	IP	Mercury in glass Laboratory thermometer	PT100
-	Oil industry, scientific analysis; various	ASTM E1-07	Mercury in glass Laboratory thermometer	PT100
Precision thermometer	Industry, University, R&D, Control Institutions.	ASTM 1C/F- 133C/F	Temperature > 200°C and acc. 0.1°C	no alternatives available
Adjustable range thermometers, Beckmann	Laboratory, University, Control Institutions	ASTM 115C	Measuring range Accuracy Dimensions	No alternatives available
ASTM thermometers	Laboratories for mineral analysis, Petroleum industry	ASTM 1C/F – 137C/F	Measuring range Accuracy Dimensions	No alternatives available
Special thermometers According to ISO ,	Laboratory, Industry, University, Control Institutions	ISO 655, ISO 656	Measuring range Accuracy Dimensions	No alternatives available

Analysis	Industrial sector	Standard	Thermometer standard referred to by the standard	Alternatives that potentially may be used for the analysis if the standard is changed
IP thermometers	Laboratories for mineral analysis, Petroleum industry	IP 1C – 102C	Measuring range Accuracy Dimensions	No alternatives available
S.T.P.T.C. thermometers	Laboratories for mineral analysis, Industry	STPTC T 1d – T 26d	Measuring range Accuracy Dimensions	No alternatives available
Short range short stem BS 1365	Laboratory, Industry,	SA 55C – SB 220 C	Measuring range Accuracy Dimensions	No alternatives available
Thermometers AFNOR	Laboratories for mineral analysis, Industry	AFNOR STL/0,1 – STL 2/	Measuring range Accuracy Dimensions	No alternatives available

4.7 Other information

One manufacturer mention in their questionnaire response that European manufacturers of glass thermometers employ approximately 800-1,000 employees for the production of mercury filled glass thermometers. In the 2008 EU Mercury Report it is estimated that some 1,000-1,500 people may be employed in this industry.

One manufacturer mentions that they sell a decontamination kit which is an amalgam (probably a metal powder which can form an amalgam). According to the manufacturer, when a thermometer is broken, this amalgam decontaminates up to 99% of the mercury. They sell the KIT with an empty hermetic box, so that the user can put the amalgam containing the mercury inside the box.

Some thermometers are produced with an outer plastic sheet to prevent loss of mercury in case the thermometer is broken.

5 Sphygmomanometers

The following chapter is not a structured note, but a collection of information obtained from manufacturers of sphygmomanometers. The information feeds into Annex XV report prepared by ECHA.

Table 20 Basic information for the socioeconomic analysis.

	Mercury sphygmomanometer			Shock-resistant aneroid sphygmomanometer			Manual (auscultatory) electronic sphygmomanometer		
	A	B	C	A	B	C	A	B	C
Manufacturer									
Name of equipment used as example	Diplomat Nova	Ac-coson Dekam et table model		R1- shock- proof	Ac- coson Duplex hand model			Ac- coson greenli ght 300	
Price of meter in 2010 (factory gate price without VAT in €)	39.70	39		36.20	30			110	
Average lifetime of sphygmomanometer (in years)	10	10		10	5			15	
Manufacturer's recommendations regarding calibration frequency (years between calibrations)	5 years	2 years		5 years	1 years			4 years	
Typical price of calibration and maintenance (in € per calibration)	15	20		15	20			20	
Expected trends in prices for the period 2010-2020 (2020 prices in percentage of 2010 prices)	+ 12%	+60%		+ 12%	+50%			+25%	
Expected trend in quantity of mercury containing sphygmomanometers sold in EU without further legislative action (quantity sold in 2020)	35,000	-50% (COWI: corre- sponds to 22.500)		Not appli- cable	Not appli- cable		Not appli- cable	Not appli- cable	

Table 21 shows the different views of the manufacturers as to the equipment expected to replace the mercury devices.

Table 21 Manufacturers' views of the percentage of market share of different alternatives if existing mercury containing sphygmomanometers would be replaced.

	Shock-resistant aneroid sphygmomanometers			Manual (auscultatory) electronic sphygmomanometers			Oscillometric sphygmomanometers			
	Manufacturer	A	B	C	A	B	C	A	B	C
Percentage	75 *1	50		3	40		22	10		

*1(including non shock-resistant aneroid devices)

5.1 Comments and additional information from manufacturers

A: In many large size emerging markets as China, India, Indonesia physicians still prefer mercury devices because aneroid devices made in the Far East do not deliver reliable readings. Despite inferior quality of aneroid devices made in the Far East there are already significant quantities in the EU market because of low market entry barriers (CE registration) compared to other registration requirements in China, USA, Japan, Brazil, etc.

If the current mercury devices will be replaced by low quality aneroid devices there is a risk of unreliable blood-pressure readings.

B: No comment

C: No answer

5.2 Additional information

Besides the questionnaire the manufacturers have been asked about the need for topping up mercury when the sphygmomanometers are calibrated.

B: "In my experience we do not find devices need topping up with mercury. In all cases for us, we do not top up mercury, as we do not see a need for it. What we do is replace all the mercury with new, and send the old mercury to our specialist recycler"

From the Concorde report⁷ reviewed as part of the work under this contract: In one Czech hospital, of a total of about 180 mercury sphygmomanometers in use, one interviewee reported that about 40 of the sphygmomanometers need topping up every year, suggesting pervasive and continual slow mercury emis-

⁷ Concorde 2009. Turning up the pressure: Phasing out mercury sphygmomanometers for professional use. Concorde East/West for European Environment Bureau.

sions to the air. Among the several Hungarian hospitals interviewed, some 10-20 percent of the mercury sphygmomanometers appeared to need mercury added each year, and in Greek hospitals around 2-3 percent.

6 Hanging drop electrodes

Two companies have been addressed with a questionnaire concerning the use of mercury hanging electrodes in polarography. Only one company answered.

The use of mercury in polarography is briefly described in the 2008 EU mercury report. The total mercury use in the EU for this application is estimated at 0.1-0.5 t/year. For a DG Enterprise mercury workshop on 28 April 2009, Metrohm (with 50% of the global market share) estimated the total global consumption at 0.25-0.35 t/year. Each unit uses on average 100 -150 g per year.

In the 2008 EU mercury report it is indicated that this equipment was banned in Sweden based on a 2004 report from the Swedish Chemicals Inspectorate mentioning that polarographs for professional measuring could be placed on the market until 31 December 2007. However the Inspectorate has answered our questions regarding alternatives to polarographs “*It is a matter of interpretation whether the use of mercury in these instrument were allowed or not under the previous Swedish legislation. Our view would probably be that they were not, but it was never tried. Under the current Swedish legislation it is allowed with reference to and subject to the conditions of the Reach restriction derogation for scientific research and development. A study in 2004 indicated no alternatives, but only a few users in Sweden (5 to 10?). To reduce mercury consumption the size of the drops have been diminished (range of a few microlitres in 2003)*”.

6.1 Technical feasibility

According to the manufacturer, the use of mercury electrodes has been quite stable for a number of years. The table below lists major and important examples of applications. The list is not exhaustive, as the manufacturer see customers use the instrumentation for an extremely widespread range of applications.

For a number of applications the manufacturer indicates that no alternatives are available. For a detailed investigation of possible alternatives it would be necessary to contact a number of manufacturers of other types of analysis instruments, in order to clarify whether these methods could in fact generate useful analysis results.

Table 22 Applications of mercury in polarography for which no technically feasible alternatives are not regarded to exist

Application of polarography with hanging drop mercury electrodes	Sector	Potential alternatives	Reasons for these alternatives of not being technically feasible ⁽¹⁾
Metal speciation in natural water samples	Environmental research (and monitoring)	Combined techniques: <ul style="list-style-type: none"> • LC + ICP-MS • SPE + e.g. AAS • ... 	<ul style="list-style-type: none"> • Limited mobility • Laboratory infrastructure required • Not all applications can be replaced
Complexation capacity of natural waters, competitive ligand exchange methods	Environmental research	Unknown	
Toxic metals in sea water	Environmental research (and monitoring)	<ul style="list-style-type: none"> • AAS • ICP 	<ul style="list-style-type: none"> • Problems with salt matrix in spectroscopic instruments • Limited mobility
Iodide in brine	Chloralkali electrolysis (mercury-free membrane technology)	ICP	<ul style="list-style-type: none"> • Problems with salt matrix • Lower sensitivity
Trace metal impurities in process solutions	Metal production (e.g. zinc smelters)	<ul style="list-style-type: none"> • AAS • ICP 	<ul style="list-style-type: none"> • Laboratory infrastructure required • Not suitable for use in production environment
Organic components in plating solutions	Metal production (e.g. copper smelters, metal foil production for electronics industry)	Unknown	
Lead in electroless nickel baths	Electronics industry	<ul style="list-style-type: none"> • AAS • ICP 	<ul style="list-style-type: none"> • Spectroscopic methods do not give reliable results (Total lead with AAS, "active" lead ions with VA)
Fe(II) content in iron sucrose injection solutions	Pharmaceutical	Unknown	
Elemental sulfur in gasoline	Petrochemical	Unknown	

Additional information:

Abbreviations

LC – Liquid chromatography

ICP – Inductive coupled plasma

ICP-MS – Inductive coupled plasma – mass spectrometry

AAS – Atomic absorption spectroscopy

SPE – Solid phase extraction

6.2 Economic feasibility

The listed reasons for the alternatives not being economically feasible is a copy of the reasons not being technically feasible and mainly concerns the need for laboratory infrastructure (probably meaning that different advanced laboratory equipment is needed).

Table 23 Applications of mercury polarography for which technically feasible alternatives exist, but these are not regarded as economically feasible

Application of polarography with hanging drop mercury electrodes	Sector	Available technically feasible alternatives	Reasons for these alternatives of not being economically feasible
Metal speciation in natural water samples	Environmental research (and monitoring)	Combined techniques: <ul style="list-style-type: none"> • LC + ICP-MS • SPE + e.g. AAS • ... 	<ul style="list-style-type: none"> • Limited mobility • Laboratory infrastructure required • Not all applications can be replaced
Toxic metals in sea water	Environmental research (and monitoring)	<ul style="list-style-type: none"> • AAS • ICP 	<ul style="list-style-type: none"> • Problems with salt matrix in spectroscopic instruments • Limited mobility
Iodide in brine	Chloralkali electrolysis (mercury-free membrane technology)	ICP	<ul style="list-style-type: none"> • Problems with salt matrix • Lower sensitivity
Trace metal impurities in process solutions	Metal production (e.g. zinc smelters)	<ul style="list-style-type: none"> • AAS • ICP 	<ul style="list-style-type: none"> • Laboratory infrastructure required • Not suitable for use in production environment

6.3 Derogations

The manufacturer does not propose any phrasing of derogations but clearly indicated the need for derogations.

6.4 Standards

The manufacturer has provided an extensive list of standards for the use of polarographic methods. Many of the standards describe the methodology, in cases where polarography is used for e.g. the determination of lead and cadmium contents of zinc (ISO 713). The presence of the standard does not imply that lead and cadmium contents of zinc cannot be determined with other methods.

It is not clear to what extent the polarographic methods are prescribed e.g. by regulation or to what extent the methods are obligatory e.g. for product control in some sectors. A closer investigation will be necessary if this is to be clarified but is out of the scope of the current contract.

Comparison of polarography with alternative techniques

The manufacturer provides the following estimates for the comparison of mercury polarographs with other instrument. It would be necessary to contact manufacturers of equipment for the alternative methods if the estimates need to be verified. This is beyond the scope of the current contract.

Table 24 Comparison of polarography with alternative techniques

	Mercury polarographs	Alternative 1 Atomic absorption spectroscopy (AAS)	Alternative 2 Inductive coupled plasma (ICP) spectrometers with <ul style="list-style-type: none"> • Optical emission detection (OES) or <ul style="list-style-type: none"> • Mass spectrometric detection (MS)
Application area	Electroactive substances: <ul style="list-style-type: none"> • Transition metal ions (ionic content) • Anions • Organic substances 	Metals (elemental content)	Metals and non-metallic elements (elemental content)
Typical price of the total instrument (factory gate price without VAT in €)	>= EUR 20,000	Estimated: > EUR 40,000 (Graphite furnace instrument, cheaper flame emission instruments lack sensitivity)	Estimated: > EUR 40,000 to EUR 100,000

	Mercury polarographs	Alternative 1 Atomic absorption spectroscopy (AAS)	Alternative 2 Inductive coupled plasma (ICP) spectrometers with <ul style="list-style-type: none"> Optical emission detection (OES) or <ul style="list-style-type: none"> Mass spectrometric detection (MS)
Laboratory infrastructure required	Nitrogen gas supply (Gas cylinder, size typical 10 – 50 L)	Gas supply (types depending on application), fume exhaust installations	Argon supply (very high consumption, fume exhaust installations)
Average lifetime of instrument (in years)	Min. 10 years according to our experience	Unknown	Unknown
Typical number of analyses per year with full time operation	Extremely varying on users requirements, from 100 to 5,000	Several 1,000 samples p.a. possible	Several 1,000 samples p.a. possible
Recurrent costs per instrument in normal use (€ per year)	EUR 2,000 – 2,500	Unknown Costly accessories are lamps, graphite furnaces	Unknown We have been reported that users spend often EUR 20,000 – 30,000 p.a. only for argon gas. Additional costs come on top.
Recurrent cost per analysis (€ per analysis)	In average typically around EUR 1 per analysis	Unknown	Unknown
Other factors influencing the costs estimates (specify):	Special applications <ul style="list-style-type: none"> Special chemicals Ultrapure chemicals 		
Total mercury use for the application in the EU in 2009	Estimate: 100 – 180 kg		
Expected total mercury use in the EU for the application in 2020 without further legislative action	Expected: 80 – 150 kg due to partial replacement with mercury-free alternatives		

7 Use of mercury equipment for calibration

In order to make a preliminary assessment of the need of mercury devices for calibration of other measuring devices different national reference laboratories in Denmark and the National Physical Laboratory in the UK were contacted.

It would be possible to go further on with this issue by a request to The European Association of National Metrology Institutes (EURAMET), but this has been beyond the scope of the current contract. EURAMET is a Regional Metrology Organisation (RMO) of Europe. It coordinates the cooperation of National Metrology Institutes (NMI) of Europe in fields like research in metrology, traceability of measurements to the SI units, international recognition of national measurement standards and of the Calibration and Measurement Capabilities (CMC) of its members. (<http://www.euramet.org/>)

EURAMET has committees on “Thermometry” and “Mass and Related Quantities” (includes pressure).

7.1 Barometers

In Denmark accurate electronic barometers based on the "vibrating cylinder transducer" principle are usually used for calibration purposes. The Danish Meteorological Institute has today only one mercury barometer, "the institute reference", which is rarely used for certain calibration purposes. It is our impression that similar national references are used in other Member States.

Mercury calibration barometers are produced by Dr. Alfred Müller Meteorologische Instrumente KG, Germany. The barometers are often referred to as Fuess-Müller instruments. http://www.rfuess-mueller.de/html/mercury_barometers.html

It has been beyond the scope of the assistance to try to identify other manufacturers.

An article indicating that Japanese Meteorological Agency has adopted a Vaisala electronic barometer for replacement of the old mercury reference can be found at:

http://www.vaisala.com/files/Japan_Meteorological_Agency_adopts_Vaisala_barometers.pdf

7.2 Manometers

In Denmark electronic manometers are usually used for calibration purposes.

However, one institution holds a mercury reference manometer for calibration of other precision meters. The manometer has a 6 m mercury column with 5-10 kg mercury. The manometer is read with a laser and data are processed electronically. The mercury is changed occasionally as it needs to be 100% pure. The mercury is not directly exposed to the air and the operator could not explain how the mercury is contaminated (probably some diffusion of oxygen or other gases). The meter was originally used by the air force for calibration of height meters, but is today used for many calibration purposes.

According to the institution the manometer is the only mercury reference in Scandinavia. It is produced and maintained by Bavaria Avionic Technology GmbH, Germany (the company could not be readily found at the Internet).

Similar equipment is produced by Schwien in the USA, and marketed in the EU: <http://www.chell-instruments.co.uk/schwien/schwien.htm>.

The Model 1025LX Super Schwien Manometer is a laboratory-grade precision primary pressure standard designed to provide highly accurate, stable, absolute or differential pressures: <http://www.schwien.com/>.

It has been beyond the scope of the assistance to try to identify other manufacturers.

According to an answer from the National Physical Laboratory (NPL) in the UK there would be no need for mercury manometers and barometers. Large area piston-cylinder arrangements (pressure balances) are able to give a similar level of performance, albeit requiring a lot of effort.

7.3 Gas flow meters

At least three institutions in Denmark hold mercury-containing gas flow meters for calibration of flow meters and controllers for gases. Mercury is in the equipment used in a frictionless sealing (mercury sealed piston). The piston prover is a volumetric calibration device consisting of a precision bore borosilicate glass tube and a mercury sealed piston. The meter can be used for measuring flows to a maximum of 10 l/minute. When a gas flow enters into the vertically-mounted glass tube the piston will move upwards. A number of sensors have been mounted along the wall of the tube to detect the presence of the piston. The volume between these sensors has been calibrated and is therefore a fixed known volume. Together with the travel time, pressure and temperature in the glass tube, the flow at reference conditions can be calculated

The meters with mercury are today produced in the Netherlands by Bronkhorst High-Tech B.V.
http://www.bronkhorst.com/en/products/calibration_equipment/fluical_bench-top_calibration_system/

It has been beyond the scope of the assistance to try to identify other manufacturers.

7.4 Thermometers

In Denmark the laboratories accredited for calibration of thermometers typically use platinum resistance thermometers for calibration of other thermometers. No national mercury reference has been identified in Denmark.

For the calibration of some thermometers mercury triple-point cells are used. The triple point of mercury is one of the defining fixed-points of the International Temperature Scale of 1990. The triple point of mercury occurs at a temperature of -38.8344 °C and a pressure of 0.2 mPa. It may be questioned to what extent the triple-point cell in itself can be considered a measuring device.

Triple-point cells are among others manufacturer by the National Physical Laboratory, UK. <http://www.npl.co.uk/engineering-measurements/thermal/temperature/products-and-services/supply-of-temperature-fixed-points-for-the-calibration-of-standard-platinum-resistance-thermometers-and-thermocouples>

7.5 Sphygmomanometers

The assessment of SCENIHR 2009 clearly states that mercury sphygmomanometers are not essential for calibration purposes: *"No, they are not essential as reference devices for the metrological verification (calibration) needed to ensure the accuracy of the measurement of the blood pressure devices. In general, more accurate manometers are available for metrological verification."*
p. 31

8 Gyrocompasses

A UK based supplier (contacted in the UK and Denmark) indicates that they are not themselves manufacturer of the gyros and they are not aware whether any of the gyros in use today contain mercury.

The CMZ 700 gyro, to which reference was made in the 2008 EU study report, was in fact not produced by Kelvin Hughes as was indicated in the report, but the actual manufacturer was the Japanese company Yokogawa. According to the UK supplier, the new types from Yokogawa do not contain mercury.

A supplier in Scotland supplies gyrocompasses of the following brands: SG BROWN (TSS), ROBERTSON, Sperry, ANSCHUTZ (Raytheon), YOKOGAWA and TOKIMEC. According to the supplier, new equipment from these suppliers should not contain mercury.

A German manufacturer has been asked about a MSDS of the liquid used instead of Hg in their gyrocompasses. They answer that *“Our compass system has a totally different technology. So our so called "Supporting Liquid" can not be used instead of mercury. This liquid is water based and contains some components which increase the electrical conductivity. The liquid is harmless.”*.

Regarding refilling or topping up of mercury, neither of the two UK suppliers have any information on alternatives which could be used instead of mercury in existing equipment.

From a German company we have been informed that YOKOGAWA probably has a replacement kit for replacement of mercury in existing gyrocompasses, but this has not been further investigated.

9 Manometers, tensiometers and strain gauges

No replies to the questionnaires were obtained from manufacturers of manometers, tensiometers and strain gauges.

10 References

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11 Example of questionnaire

Questionnaire prepared by COWI A/S for the European Chemicals Agency, ECHA.
Please address any questions regarding the questionnaire to Carsten Lassen, COWI at crl@cowi.dk.

Please return your completed questionnaire by e-mail to crl@cowi.dk before 15th February 2010. Kindly e-mail any questions to the same e-mail address.

Any reports or other additional information available in hard copy only, can be mailed to COWI A/S, Jens Chr. Skous Vej 9, DK-8000 Aarhus C, Denmark. Attn. Carsten Lassen

Contact information	
Company name	
Contact address of company	
Web site	
Contact person	
Telephone number of contact person	
E-mail address of contact person	
Date	
Additional company names and contact persons (in case the questionnaire is completed by several companies jointly)	

This questionnaire requests information about the use of mercury thermometers. The information is intended to be used by the European Chemicals Agency (ECHA) when preparing an Annex XV restriction dossier related to mercury containing measuring devices. Please also include any relevant information regarding thermometers used in hygrometers or hydrometers.

Filling in the tables

In order to be able to compile and compare the data across companies we have prepared a number of tables for a consistent reporting of the information. In case you have only partial information, please fill in what is available and leave other cells open.

Some relevant information may not fit into the tables, and in this case we would appreciate if you add this information under "additional information" or enclose the original documents. You do not need to care about the lay-out of information pasted into the questionnaire, as long as it is clearly readable and understandable.

Please add extra rows to the tables as necessary.

Supplementary material

Product brochures, or other material addressing the subjects raised in the questions below, may be of great value for the preparation of the dossier. Please submit such material to us, or supply specific links to where this material can be found on public Internet sites.

1. Essential uses of mercury thermometers

Applications of mercury thermometers for which technically feasible alternatives exist, but these are not regarded as economically feasible				
Application of thermometer	Sector	Available technically feasible alternatives	Price of alternatives as compared to mercury thermometer	Other reasons for these alternatives of not being economically feasible

Additional information:

Possible derogations

For the assessment we are interested in your views if there is a need for derogations and how the derogation could be phrased. Your suggestions are considered initial thoughts only and we would like to note that you may change your view later.

Proposed derogations			
Application area	Phrasing of derogation	Time frame of derogation	Justification for the derogation

Additional information:

2. Analysis standards prescribing the use of mercury thermometers

A large number of mercury thermometers are marketed with reference to different analysis standards e.g. different standards from ASTM, DIN or BS. The objective of the table below is to obtain an overview of which sectors and application areas are covered by standards specifically prescribing the use of mercury thermometers. Further the objective is to obtain an indication of to what extent national standards are used for the analysis concerned in the different Member States. We suggest that you at least fill in the table for the national standards used in your country.

Analysis for which national or international standards prescribe the use of mercury thermometers				
Analysis	Industrial sector	Standard	Thermometer standard referred to by the standard	Alternatives that potentially may be used for the analysis if the standard is changed

Additional information:

3. Basic information used for socioeconomic assessment

For the socioeconomic assessment we are seeking information that could be used as cases in the comparison between mercury thermometers and alternatives.

We are aware that hundreds of different mercury thermometers are marketed and the cases should preferably be a “representative” thermometer case and a case where replacement is expected to be relatively difficult and expensive. As a “representative thermometer” a thermometer for general measurements in laboratories at resolution of 0.1 °C in laboratories has been selected. If you have information about more than two alternatives, please fill in a separate sheet.

Application: Thermometer for general measurements in laboratories at resolution of 0.1 °C in laboratories			
	Mercury thermometer	Alternative 1 (please specify):	Alternative 2 (please specify):
Type of thermometer			
Typical price of thermometer (factory gate price without VAT in €)			
Typical mercury content per thermometer (g/item)			
Number of thermometers sold annually for general applications in laboratories in the EU (best estimate)			
Average lifetime (in years)			
Costs of calibration (€ per calibration)			
Frequency of calibration (per year)			

Application: Thermometer for general measurements in laboratories at resolution of 0.1 °C in laboratories			
Other recurrent costs (specify) (€/year/item):			
Other factors influencing the costs estimates (specify):			

Additional information:

Please provide an example of applications where you consider the replacement to be relatively expensive. If you have several examples, please fill in a separate sheet.

Application (please specify):			
	Mercury thermometer	Alternative 1 (please specify):	Alternative 2 (please specify):
Type of thermometer			
Typical price of thermometer (factory gate price without VAT in €)			
Typical mercury content			
Number of thermometers sold annually for general applications in laboratories in the EU (best estimate)			
Average lifetime			
Costs of calibration			
Frequency of calibration			
Other recurrent costs (specify):			
Other factors influencing the costs estimates (specify):			

Additional information:

4: Any other information and comments

Please add any further information you may find essential for the assessment

Appendix 4: Restriction of mercury in measuring devices under Regulation (EC) No 1907/2006 (REACH) in relation to restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS)

This appendix clarifies which measuring devices containing mercury fall within the scope of Directive 2002/95/EC (RoHS Directive) as it stands now and as foreseen in its proposed recast¹. It explains which devices are not covered in the current proposal for a restriction of mercury in measuring devices under the REACH Regulation because they are within the scope of the proposed recast of the RoHS Directive.

Electrical and electronic equipment is not covered

Several mercury containing measuring devices are dependent on electric currents in order to work properly, and thus fall under the definition of ‘electrical and electronic equipment’ in the RoHS Directive². This Directive does not contain a specific provision concerning the relationship to the REACH Regulation, nor vice-versa. However, Article 2(2) of the RoHS Directive provides that it shall apply without prejudice to Community legislation on safety and health requirements and specific Community waste management legislation. Similarly Article 2(4)(a) of the REACH Regulation provides that it shall apply without prejudice to workplace and environmental legislation. Thus, in principle both regulations are applicable in parallel. That being said, and acknowledging the differences of the respective legal instruments (Directive vs. Regulation), it appears, however, that the scope of the RoHS Directive affects the REACH Regulation.

To ensure regulatory coherence and consistency, mercury containing measuring devices falling under the definition of ‘electrical and electronic equipment’ should not be subjected to restriction under the REACH Regulation. Instead, the RoHS Directive should be regarded as sufficiently covering those devices constituting to some extent *lex specialis* in relation to the REACH Regulation.

This approach would be in line with recital 1 of the Directive 2007/51/EC that introduced the restriction on mercury in measuring devices, now subject to revision and reads: “*The Commission communication of 28 January 2005 on the Community strategy concerning mercury, which considered all uses of mercury, concluded that it would be appropriate to introduce Community-level marketing restrictions on certain **non-electrical or non-electronic** measuring and control equipment containing mercury, which is the main mercury product group not covered by Community action so far.*” (emphasis added).

¹ Proposal for a Directive of the European Parliament and of the Council on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast), COM(2008) 809 final.

² ‘*electrical and electronic equipment*’ or ‘*EEE*’ means equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields falling under the categories set out in Annex IA to Directive 2002/96/EC (WEEE) and designed for use with a voltage rating not exceeding 1 000 volts for alternating current and 1 500 volts for direct current (Directive 2002/95/EC).

Mercury containing measuring devices & RoHS

The RoHS Directive requires that new equipment put on the market does not include mercury. However, it currently does not cover ‘monitoring and control instruments’³ and ‘medical devices’⁴ which are not listed in the reference to Annex IA to Directive 2002/96/EC (WEEE) in Article 2(1) RoHS Directive. To ensure legal consistency and clarity of the obligations it could be regarded as more appropriate to revise this omission in RoHS rather than to introduce a new restriction under another piece of legislation such as the REACH Regulation. In fact, Article 2 of the proposed RoHS recast¹ includes the above mentioned currently omitted categories in its scope, and consequently the devices listed below would be covered by the RoHS Directive in the future if adopted in the proposed version.

The RoHS Directive presents with regard to mercury in these listed measuring devices an equally effective measure as a restriction under REACH. Having all obligations related to mercury in electrical and electronic equipment in one piece of legislation would be clearer for actors that need to comply with the obligations. This could be seen beneficial also for the enforceability and monitoring of the fulfilment of these obligations.

It should be noted that the proposed RoHS recast foresees a specific exemption for reference electrodes⁵, and that potentially other such exemptions might be added during the legislative procedure. It could lead to inconsistencies if ‘electrical and electronic equipment’ would be assessed in the restriction report for mercury in measuring devices under the legal framework of REACH.

List of mercury measuring devices using electric currents

The following mercury containing measuring devices were considered to be dependent on currents or electromagnetic fields in order to work properly, and are therefore not covered by the current proposal for a restriction of mercury in measuring devices:

1) Gyrocompasses/heading indicator

A gyrocompass is a compass that finds true north by using an (electrically powered) fast-spinning wheel whose axle is free to take any orientation. This orientation changes much less in response to a given external torque than it would without the large angular momentum associated with the gyroscope's high rate of spin. Without this electrical driven spin the device would not function properly. Gyrocompasses are widely used on ships and aircraft (called ‘heading indicator’ in that case), and can contain mercury.

³ Directive 2002/96/EC mentions under ‘monitoring and control instruments’: smoke detectors; heating regulators; thermostats; measuring, weighing or adjusting appliances for household or as laboratory equipment; and other monitoring and control instruments used in industrial installations (e.g. in control panels).

⁴ Directive 2002/96/EC mentions under ‘medical devices’: radiotherapy equipment; cardiology; dialysis; pulmonary ventilators; nuclear medicine; laboratory equipment for in-vitro diagnosis; analysers; freezers; fertilization tests; and other appliances for detecting, preventing, monitoring, treating, alleviating illness, injury or disability.

⁵ Annex VI lists applications exempted from the ban in Article 4(1) as regards Categories 8 and 9 contains an item 1d: “Mercury in reference electrodes: low chloride mercury chloride, mercury sulphate and mercury oxide”

2) Reference electrodes

Mercury-containing reference electrodes are used for a variety of measurements. A reference electrode provides a stable potential whatever the measurement conditions. They are considered to be 'electrical and electronical equipment' (as confirmed by the exemption in the proposal for recast of RoHS).

3) Calibration devices for gas flow meters

Calibrators of gas flow meters based on a mercury sealed piston prover have sensors in the tube that detect the presence of the piston. The volume between these sensors has been calibrated and is therefore a fixed known volume. Together with the travel time, pressure and temperature in the glass tube, the flow at reference conditions can be calculated. Thus electric current is essential for the proper functioning of the device.

4) Mercury tilt switches

Mercury tilt switches are small tubes with electrical contacts at one end of the tube. As the tube tilts, the mercury collects at the lower end, providing a conductive path to complete the circuit. When the switch is tilted back, the circuit is broken. Mercury tilt switches are used in some medical devices and laboratory equipment, motion/vibration sensors, float switches and level switches, in certain clocks, lifeboats, and thermostats⁶.

5) Thermoregulators

A thermoregulator (also designated contact thermometer or accustat) is a kind of thermostat, but applies another principle than the thermostats described under tilt switches. A glass stem which contains twin capillary bores connects to a sensitive mercury filled bulb. Attached to a rider is a contact wire that extends into the capillary bore

⁶ A temperature-response sensor, which is coupled to a mechanical means of activating a mercury tilt switch. The temperature-response sensor is typically either a thermocouple, resistance temperature detector (RTD), or gas activated bourdon tube.

REVIEW ON THE AVAILABILITY OF TECHNICALLY AND ECONOMICALLY FEASIBLE ALTERNATIVES FOR MERCURY CONTAINING SPHYGMOMANOMETERS AND OTHER MEASURING DEVICES FOR PROFESSIONAL AND INDUSTRIAL USES

1. INTRODUCTION-SCOPE OF THE REVIEW

In its Communication of 28 January 2005 on the Community strategy concerning mercury¹, the Commission concluded that it would be appropriate to introduce Community-level marketing restrictions on certain non-electrical or non-electronic measuring and control equipment containing mercury. The European Commission made a study concerning the risks from the use of mercury-based measuring devices² and taking into account technical and economic feasibility of alternatives. The outcome of this investigation indicated that marketing and use restrictions should cover those measuring devices that are intended for sale to the general public and also all fever thermometers. The Commission adopted a proposal for restrictions on 21 January 2006³. During the adoption of the restrictions by the European Parliament and the Council, it was decided that the restrictions should not include:

- (a) the import of measuring devices containing mercury that are more than 50 years old; this concerns either antiques or cultural goods as defined in Council Regulation (EEC) No 3911/92 considering that such trade is limited in extent and seems to pose no risk to human health or the environment;
- (b) mercury-containing devices for healthcare (in particular, sphygmomanometers for measuring blood pressure and strain gauges) on the basis of their essential use in the treatment of specific medical cases.

The final restrictions were adopted in Directive 2007/51/EC of the European Parliament and the Council⁴. The Directive contains a review clause indicating that: *By 3 October 2009 the Commission shall carry out a review of the availability of reliable safer alternatives that are technically and economically feasible for mercury-containing sphygmomanometers and other measuring devices in healthcare and in other professional and industrial uses. On the basis of this review or as soon as new information on reliable safer alternatives for sphygmomanometers and other measuring devices containing mercury becomes available, the Commission shall, if appropriate, present a legislative proposal to extend the current restrictions to sphygmomanometers and other measuring devices in healthcare and in other professional and industrial uses...*

Directive 2007/51/EC has been incorporated into Annex XVII of the REACH Regulation⁵ since 1 June 2009. This document contains the information and results of consultations of stakeholders conducted by the Commission until today. Consequently, the review will have to be accomplished by the European Chemical Agency (ECHA) according to REACH procedures.

¹ Available at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2005:0020:FIN:EN:PDF>

² Available at: <http://ec.europa.eu/enterprise/chemicals/docs/studies/rpa-mercury.pdf>

³ Available at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2006:0069:FIN:en:PDF>

⁴ OJ L57, 3.10.2007, p.13.

⁵ OJ L 396, 30.12.2006, p. 1.

2. BACKGROUND INFORMATION ON THE CURRENT USES OF MERCURY CONTAINING DEVICES IN HEALTHCARE AND IN OTHER PROFESSIONAL-INDUSTRIAL APPLICATIONS.

Following the investigation of the Commission and consultation with all interested parties, the use of mercury containing measuring devices in healthcare and in other professional and industrial applications has been identified. It should be noted that significant input (e.g socio-economic data, availability of alternatives) for the purposes of this review had been provided by a study “*Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society*”, commissioned by DG Environment in the framework of the Community Strategy on Mercury. The final report was submitted in September 2008⁶ and contained a separate section concerning the mercury measuring devices for professional uses and feasibility of their substitution. Table 1 provides a summary of the mercury consumption in some professional/industrial uses of mercury measuring devices as recorded in the report.

Table 1: Mercury consumption in certain measuring devices for professional/industrial uses for 2007 (source: COWI report-2008)

Application	Consumption	
	Tonnes Hg/year	In %
Other mercury-in-glass thermometers	0.6 - 1.2	10.2% - 8.9%
Thermometers with dial	0.1 - 0.3	1.7% - 2.2%
Manometers	0.03 - 0.3	0.5% - 2.2%
Barometers	2 - 5	34.1% - 36.9%
Sphygmomanometers	3 - 6	51.1% - 44.3%
Hygrometers	0.01 - 0.1	0.2% - 0.7%
Tensiometers	0.01 - 0.1	0.2% - 0.7%
Gyrocompasses	0.005 - 0.025	0.1% - 0.2%
Reference electrodes	0.005 - 0.015	0.1% - 0.1%
Hanging drop electrodes	0.1 - 0.5	1.7% - 3.7%
Other uses	0.01 - 0.1	0.2% - 0.1%
Porosimetry		
Total	5.87 – 13.55	100%

⁶ “: Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society” (COWI A/S, Concorde East West, 2008)

Available at: <http://ec.europa.eu/environment/chemicals/mercury/index.htm>

2.1 Mercury measuring devices in Healthcare

2.1.1 Mercury containing Sphygmomanometers

Mercury sphygmomanometers have been used for more than 100 years and are still considered by many to be the “gold standard” of blood pressure measurements, although their market has been steadily decreasing in recent years in certain Member States due to legal (Sweden, Lithuania) or voluntary (e.g. Denmark, Netherlands) phase-out. Mercury sphygmomanometers manufactured in the EU typically contain 85 to 100 g mercury per instrument. The total EU-wide annual mercury consumption in sphygmomanometers for 2006 was estimated at 3-6 tonnes in 30,000 - 60,000 units, most of which were sold mainly to general practitioners.

Three manufacturers of mercury containing sphygmomanometers in the EU have been identified (Rudolf Riester GmbH & Co. KG-Germany, A.C.Cossor & Son Limited-UK and PiC Indolor- Italy) whereas several brands are also imported from non-EU countries including Japan, USA and China. There is a significant export of mercury containing sphygmomanometers manufactured within the EU to countries outside the EU. European-made sphygmomanometers are in demand because they are considered to be of higher quality by customers, and are more resistant to breakage and release of mercury. It is estimated that annual exports comprise at least 60,000-90,000 units corresponding to a content of 5-8 tonnes of mercury.

Market shares of mercury containing sphygmomanometer and the level of substitution vary among Member States. Italy, the UK and certain new Member States constitute the largest market for mercury containing sphygmomanometers within the EU, whereas in other Member States these account for 10% or less of the total market for manual blood pressure measurement devices. Information for the main alternative devices (e.g electronic and aneroid sphygmomanometers) is given in section 4 of this report.

2.1.2 Mercury containing Strain gauges

Mercury strain gauges are used for blood flow and blood pressure measurements in body parts, mainly for diagnosing certain kinds of arteriosclerosis, and are based on a technique called strain gauge plethysmography. Considering that one major global producer of strain gauges consumed 946 grams of mercury in 2004 for production of strain gauges, it can be concluded that total EU consumption for this application may be insignificant in comparison to the amount of mercury used in sphygmomanometers. It should be noted that even in Member States that have phased out mercury containing sphygmomanometers, a certain number of strain gauges is still in use for diagnosis and monitoring of arteriosclerosis in patients (~200 devices in Sweden and ~100 in Denmark).

2.2 Other mercury containing measuring devices for professional or industrial uses

2.2.1 Mercury containing Thermometers

The following types of mercury-containing thermometers have traditionally been used in the EU:

(a) Mercury-in-glass thermometers:

- Medical thermometers;
- Ambient temperature thermometers (wall thermometers);

- Laboratory thermometers;
- Thermometers for combustion and industrial processes.
- Minimum-Maximum thermometers.

(b) Mechanical mercury thermometers with a dial

As the use of mercury in medical thermometers is now banned in the EU, further focus is given to other professional uses of mercury thermometers such as in laboratories and for specific purposes in the industry, for which the mercury consumption is estimated in the order of 0.6-1.2 tonnes per year (half of which is used in thermometers for research, and the rest for industrial and marine applications). Mercury has been widely replaced by alternatives, but mercury-in-glass thermometers seem to hold a significant market share for some specific applications. The mercury content of marketed mercury-in-steel dial thermometers used in industry and marine applications is estimated at 0.1-0.3 tonnes mercury per year.

2.2.2. Mercury containing Porosimeters

Porosimeters are used for measuring porosity, i.e. the void spaces in a material. Mercury porosimeters are typically applied for materials with pore diameters in the range of 0.0036 μm to 1 mm. EU manufacturers of porosimeters argue strongly that mercury intrusion porosimetry (MIP) has been the unique reliable and established technique for the macropore analysis for at least 30 years, as being a fast, easy to use technique with relatively inexpensive instrumentation, a wide range of pore size / pore volume measurements and well established safety procedures and recycling processes. According to the COWI-Concorde (2008) report, the total number of porosimeters in the EU is estimated at ~2000, with a total amount of mercury used estimated with high uncertainty at 10-100 tonnes per year.

2.2.3. Mercury containing Electrodes

Hanging drop electrodes in polarography are mainly used to analyse trace elements in water and environmental samples. The typical mercury use for such an instrument is ~140 gr / year. On that basis it is roughly estimated that the EU-wide mercury consumption for this application in 2007 was 0.1-0.5 tonne per year. Mercury electrodes for polarography are banned in Sweden but are exempted from a ban imposed by Norway in measuring devices until 31 December 2010.

Reference electrodes are used for a variety of measurements mainly for research purposes. It is estimated that the total mercury use in electrodes for medical equipment is ~ 2-10 kg/year and in monitoring and control instruments at about 3 kg/year, indicating a total EU mercury use at 0.005-0.015 tonnes.

2.2.4 Mercury containing Manometers

Manometers measure the difference in gas pressure between the measured environment and a reference. Mercury-containing manometers are mostly U-shaped glass or plastic tubes for laboratory use and intended for special industrial applications mainly for pressure measurements in the heating and ventilation sector. Although it is not easy to obtain a precise estimate of the current use of mercury for new manometers, the total EU consumption of mercury for filling new manometers is roughly estimated in the order of 0.03-0.30 tonnes per year.

2.2.5 Mercury containing Barometers

Barometers measure atmospheric pressure and are used for a number of professional applications, such as in weather stations (e.g. Meteorological Institutes), airports and airfields, and on ships. Compared to sphygmomanometers and thermometers, mercury containing barometers account for a minor part of mercury in measuring devices for professional uses which is estimated at 0.1-0.5 tonnes per year in the EU area. Mercury containing barometers for professional applications today hold a very small market share, as alternatives are available for all applications.

2.2.6 Other mercury containing measuring devices of minor use

- (a) Tensiometers mainly used for research applications to determine the level of soil moisture tension (soil water potential). According to the COWI-Concorde (2008) report, the only one EU manufacturer informed that sales of mercury tensiometers have been in the range of 10-15 instruments per year and production would be discontinued in 2009.
- (b) Hydrometers measure the density or specific gravity of a liquid. Mercury is deemed not to be used in the bulk of hydrometers in the EU today.
- (c) Gyrocompasses find true north by using a fast-spinning wheel and friction forces in order to exploit the rotation of the Earth. EU annual mercury consumption for filling new gyrocompasses are in the order of 0.005-0.025 tonnes.
- (d) Coulter counters are used for automated counting and measuring the size of microscopic particles. The total mercury content of new Coulter counters on the EU market is assumed to be below a few kg, if any.

In total it is estimated that the mercury consumption in the above-mentioned “minor applications” is in the range of 0.01- 0.1 tonne per year.

3. CONSULTATIONS WITH STAKEHOLDERS

In summer 2008, DG-Enterprise & Industry has launched a consultation with Member States and other interested stakeholders. More specifically, questionnaires were prepared and circulated to the Members of the Commission Experts Working Group on Limitation of Chemicals (LWG) and to the Experts Working Group on Medical Devices (MDEG) asking them to provide input concerning:

- the availability of alternatives to mercury-containing sphygmomanometers in the Member States and whether these are adequately validated and calibrated;
- essential uses of mercury-containing sphygmomanometers that are required in Member States (e.g. treatment of special medical conditions);
- other mercury-containing measuring devices used for research and in industrial uses and the availability of alternatives for such devices.

In addition, the Commission sent the questionnaires to interested NGOs, industry trade associations, and scientific organisations requesting them to submit any information (reports of relevant studies/clinical trials etc.) which would be helpful for the purposes of the review. It should be noted that all responses of Member States, as well as the received material from

other stakeholders (statement, reports, scientific papers) are available on CIRCA⁷. Moreover, a list of the most important submissions is given in Appendix 2. A summary of the outcome of this consultation is presented below.

3.1 Feedback from Member States and other interested parties

(a) Positions of Member States:

There was no clear consensus within the MEDG. A number of Member States (MT, FI, DE, HU, UK and IT) claimed that mercury-containing sphygmomanometers are still essential, either for calibration purposes or the treatment of special health conditions, whereas others (IE, NL, PL and SE) were of the opinion that there are technically and economically viable alternatives for all uses.

Within the LWG, most responding Member States (LV, SE, NL, NO and FR) claimed that mercury-containing sphygmomanometers are no longer necessary and have already been replaced. However, DE and IT argued that mercury-containing sphygmomanometers should be kept for calibration purposes, while UK and FI strongly opposed an EU ban of mercury-containing sphygmomanometers stressing that these are indispensable for the treatment of certain medical conditions.

(b) Scientific organisations

The Commission also invited medical organisations to provide their expert advice concerning the substitution of mercury-containing sphygmomanometers in healthcare. The European Society of Hypertension (ESH) replied that properly validated electronic instruments (but not the aneroid devices) could serve as reliable substitutes to mercury containing-sphygmomanometers. However, ESH claimed that automated devices are not accurate for blood measurements in patients with arrhythmia, and that mercury-containing sphygmomanometers are also still essential for the calibration of electronic devices. The European Board and College of the Obstetrics and Gynecology (EBCOG) has also committed to consult the International Society for the Study of Hypertension in Pregnancy (ISSHP), in order to advise the Commission on the need for Hg-containing sphygmomanometers for the treatment of hypertension in obstetrics(No input has been received from EBCOG until the time of completion of this report)

(c) NGOs

The Commission has received input from various NGOs (European Environmental Bureau - EEB, Health and Environmental Alliance – Health Care Without Harm-HCWH) including recent reports concerning the existence of safer alternatives to mercury-containing measuring devices in healthcare as well as recent publications from clinical journals and other worldwide initiatives. All NGOs strongly recommend that mercury-containing sphygmomanometers should be banned in the EU, considering that these devices can pose a risk to human health and the environment during use and as waste and that adequate alternatives are already available in the European market.

⁷http://circa.europa.eu/Members/irc/enterprise/lmudsp/library?l=/thematic_folder/mercury_follow_up&vm=detail&sb=Title

(d) Industry associations

The European Committee of Radiological, Electromedical and Healthcare Industry (COCIR) and the US-based Association for Advancement of Medical Instrumentation (AAMI) both claim that mercury-containing sphygmomanometers must not be banned from either practical use or from calibration purposes because they provide the most accurate reading possible today. Concerning the environmental impacts, COCIR stresses that the amount of mercury released by these devices, assuming there are spills, is negligible when compared to other sources of mercury releases, in particular industrial sources.

Input was also received from individual companies such as (a) COSSOR, a UK manufacturer of both mercury containing and mercury free sphygmomanometers, provided information on accuracy and limitations of each type of sphygmomanometers, and (b) Russell Scientific Instruments Limited who defended the use of mercury in a limited number of highly specialised professional uses such as thermometers (e.g “retort thermometers” for canning industry) and barometers (used by amateur meteorologists or breeders of reptiles and birds).

3.2 Commission Workshop on mercury in measuring devices for professional/industrial uses (April 2009)

Though the Commission consultation with stakeholders yielded a good amount of information concerning the mercury based sphygmomanometers, there was only limited input concerning the mercury containing measuring devices for other professional/industrial uses in the EU. Therefore, in order to establish a broader knowledge base for the other uses but also further develop the information on healthcare sphygmomanometers, DG Enterprise and Industry organised a workshop in Brussels in April 2009. Apart from NGOs and Member States (experts from both LWG and Medical Authorities) who recalled their above-mentioned positions, representatives of European industry were also invited to attend the workshop and present more information on the remaining applications of mercury containing measuring devices (e.g. porosimetry, polarography) and the feasibility of alternatives.

Some information of the presentations and the subsequent discussion between the participants are given in section 4 where the main arguments on feasibility of alternatives to mercury containing devices are developed. In addition more details about the actual discussions and positions are described in the Minutes of the workshop available at: http://circa.europa.eu/Members/irc/enterprise/lmudsp/library?l=/thematic_folder/mercury_follow_up&vm=detailed&sb=Title.

Concerning mercury containing measuring devices for professional and industrial uses, discussions revealed that these mainly concern quite specialised and rather small-scale applications, which probably do not significantly contribute to exposure of consumers or release to the environment. It seems that while the mercury consumption can be quite high, e.g in porosimeters, the number of such devices for use in the EU is limited and they are typically used in laboratories with well established control procedures on safety at the work place and management of dangerous waste, so that most of the mercury can be recycled and reused. On the issue of mercury recycling in porosimetry, the Commission has carried out a consultation with the industry, the outcome of which is presented and discussed in section 4.2.2.

Concerning sphygmomanometers, the workshop discussions provided much useful information to confirm that there is an ongoing tendency for substitution of mercury-

containing sphygmomanometers, and that where such substitution has occurred the experience has been uniformly positive. Nevertheless, in some Member States where substitution has not yet occurred, concerns remain on calibration, validation, and on the treatment of certain medical conditions, which could at least in part be due to user-related preferences and habits, as well as lack of knowledge or training for using mercury-free sphygmomanometers.

3.3 EEB Conference on mercury in measuring devices for professional/industrial uses (June 2009)

A Conference was organized in Brussels (18 June 2009) by the NGOs (EEB-HCWH) entitled “EU Mercury phase out in measuring and control equipment”. The meeting was attended by medical doctors in the EU and US, hospital representatives, experts in validation and calibration issues, manufacturers of mercury containing and mercury-free measuring devices, trade unions, NGOs and representatives of UN organisations. The Commission services participated as well. The presentations of the Conference are available at: http://www.zeromercury.org/EU_developments/090618_Meas_Dev_conference.html.

EEB and HCWH have also prepared a report from the Conference⁸ summarizing the outcome and main conclusions of the discussions.

In this Conference, the EEB presented its study ‘*Turning up the pressure-Phasing out mercury sphygmomanometers for professional uses*’. The report⁹ highlights real-life experiences of European hospitals that purchase and/or use mercury-containing and mercury-free sphygmomanometers. By means of a survey of the experiences of a number of European hospitals, this study has observed that most of the hospitals in a few EU Member States have completely phased out mercury-containing sphygmomanometers – some of them more than ten years ago. A smaller number of hospitals insists that mercury sphygmomanometers are still necessary, or at least see no immediate need to phase them out. The EEB report indicated that it is technically and economically feasible to make the transition to mercury-free sphygmomanometers that are available on the market and are approved by professional bodies, including for special cases like pre-eclampsia and hypertension.

At the EEB Conference there were also presentations about the UNEP/WHO initiatives at global level concerning restrictions of the use of mercury-containing measuring devices. According to a 2008 UNEP study¹⁰ (“*Report on the major mercury-containing products and processes, their substitutes and experience in switching to mercury-free products and processes*”) several countries - not only European (Sweden, Netherlands, Norway etc.) but also worldwide (e.g. Brazil, USA) - have successfully demonstrated the availability and utilisation of mercury free alternatives (such as digital or electronic and aneroid sphygmomanometers). The only remaining challenges are the direct costs or high price of some alternatives especially in developing countries and the need for the alternatives to have a regular calibration.

⁸ available at: http://www.zeromercury.org/EU_developments/091104EEB-HCWH-Meas-Dev-Conf-Rep.pdf

⁹ Publication-Report ‘Turning up the pressure : Phasing out Mercury Sphygmomanometers for professional use Concorde East/West (Commissioned and Published by European Environmental Bureau, 2009)
http://www.zeromercury.org/SphygReport_EEB_Final-A5_11Jun2009.pdf

¹⁰ available at: <http://www.chem.unep.ch/mercury/OEWG2/documents/g72/>

4 DISCUSSION ON AVAILABILITY OF ALTERNATIVES TO MERCURY-CONTAINING DEVICES FOR PROFESSIONAL/INDUSTRIAL USES

4.1 Alternatives to mercury-containing measuring devices in healthcare

4.1.1 Availability of mercury-free sphygmomanometers

For more than a century, blood pressure has been measured worldwide both in clinical practice and medical research by the auscultation technique using mercury containing sphygmomanometers together with a stethoscope to listen to the various sounds of blood flow as pressure is released from an inflatable cuff placed around the arm. The advantages and disadvantages of mercury-containing sphygmomanometers have been extensively discussed in the medical literature. Compared to other measuring devices, the main advantages of the mercury-containing sphygmomanometers are the following:

- they are relatively easy to use by people who are trained and practiced in using this instrument,
- they are relatively stable (i.e. they typically do not need to be calibrated more than once every two years),
- they may be used with virtually any medical condition,
- they are relatively easy to repair so that they may have a long lifetime,
- it is fairly easy to see when they are not functioning properly, and
- even the cheapest models may be expected to be reasonably reliable.

As a result, and certainly also because most medical personnel are familiar with these instruments, they are still considered by many to be the “gold standard” for blood pressure measurement. In fact, the vast majority of information on population blood pressure - secular trends, progression to hypertension, and prognostic implications - has so far been obtained with the use of mercury sphygmomanometers. However, the various hazards and costs associated with the life-cycle of mercury in a sphygmomanometer may be significant. Moreover, reports from hospitals and family practices have suggested that many mercury-containing sphygmomanometers are defective and with very poor maintenance.

Alternatives to mercury-containing sphygmomanometers on the market can roughly be divided into the following groups:

(I) Blood measuring devices based on the auscultatory technique, such as:

(a) Aneroid sphygmomanometers for manual reading

The manual aneroid sphygmomanometer works in a similar way to the mercury-containing sphygmomanometer, but with an aneroid gauge that replaces the mercury-containing manometer. While the accuracy and reliability of the aneroid manometer vary with the design and quality of the device, several aneroid mechanical sphygmomanometers have been validated for clinical use, meeting the criteria of the protocols of the British Hypertension Society (BHS). However, these devices are very sensitive to mechanical shock, easily susceptible to damage and calibration drift, particularly if they are portable, leading sometimes to inaccurate measurements. It is therefore recommended that these devices undergo a metrological check at least annually, although the implementation of this

recommendation appears unlikely, especially in primary care. A recent UK study¹¹ in a primary care setting has shown that more than 50% of aneroid devices had a calibration error > 3 mm Hg compared to only 8% of mercury and automated devices combined.

(b) Manual digital sphygmomanometers

These devices measure the pressure in the cuff with an electrical transducer. They have the disadvantage that electrical power is required.

A relatively new type of “manual digital” sphygmomanometer marketed as an alternative to mercury-containing sphygmomanometers and as a reference manometer, combines an electronic manometer with a dial for manual reading. One such device, manufactured by A.C. Cossor & Son (Surgical) Ltd in the UK, performs an auto-calibration to zero each time it is switched on, and meets the criteria of the International Protocol for blood pressure measuring devices in adults (BHS). Although such devices are suitable for patients where clinical conditions may preclude the use of automated oscillometric devices (such as arrhythmia and pre-eclampsia), their reading cannot be assumed to be equivalent to the reading of a mercury column so that validation is required prior to their introduction on the market.

As stated in the COWI-Concorde (2008) report, aneroid and digital sphygmomanometers are widely sold in the Member States for application by general medical practitioners and in hospitals, which comprise the main market for sphygmomanometers today. An evaluation by the UK Medical Agency (MHRA) noted that the decreasing cost of automated devices, together with the improved reliability of aneroid devices and the introduction of manual digital sphygmomanometers are leading to a further reduction in the use of mercury-containing sphygmomanometers.

(II) Blood measuring devices based on the oscillometric technique

Oscillometry measures only mean pulsation in arterial pressure and then uses software algorithms to calculate the systolic and diastolic values. The types of instruments using this principle are:

(a) Semi-automated devices

Semi-automated electronic blood pressure devices have undergone extensive development during recent years, and a large number of different devices are marketed today. They typically use the oscillometric technique and include an electronic monitor with a pressure sensor, a digital display, an upper arm cuff and a hand-operated inflation bulb. The semi-automated electronic devices are today standard for home/self assessment in many Member States and are also widely used by general medical practitioners. The European Society of Hypertension has noted that for self-assessment, electronic devices using oscillometry are becoming more popular and are replacing the auscultatory technique. The electronic devices require less training and are easier to use by patients with infirmities such as arthritis and deafness.

(b) Automated devices

¹¹ Coleman AJ, Steel SD, Ashworth M, Vowler SL, Shennan A. Accuracy of the pressure scale of sphygmomanometers in clinical use within primary care. *Blood Press Monit* 2005; 10:181-188

Oscillometry is usually used by automated devices to determine blood pressure by analysing the pressures transmitted through arterial oscillations/vibrations that occur during cuff inflation and/or deflation. For “fully” automated measurements in hospitals, more advanced equipment, which often combines the measurement of blood pressure with monitoring of temperature, heart rate and blood oxygen level, is often used.

An accurate automated oscillometric sphygmomanometer is capable of providing printouts of systolic, diastolic and mean blood pressure, together with heart rate and the time and date of measurement, eliminating errors of interpretation and abolishing observer bias and terminal digit preference. Another advantage of automated measurement is the ability of such devices to store data for later analysis.

However, a drawback of the sphygmomanometers based on the oscillometric technique is that their accuracy is limited in special patient groups such as the elderly and those with vascular diseases that influence the oscillometric signal including diabetes, arrhythmias, and pre-eclampsia. It should also be noted that doctors are commonly uneasy about trusting algorithmic methods, which are guarded as a proprietary secret by manufacturers. In addition, the accuracy of automated oscillometric devices is user dependent as these are commonly used at home by untrained individuals.

Other considerations on substitution of mercury-containing sphygmomanometers

Concerning the cost of alternative devices, a recent EEB survey which is reflected in the Concorde (2009) report, revealed that standard EU prices are in the order of € 40-60 for a validated mercury-free sphygmomanometer, while the cost of a mercury containing sphygmomanometer, where available, was generally cited at € 50-80. High variation was indicated in the COWI-Concorde (2008) report, with a price difference between European produced alternatives and mercury containing sphygmomanometer ranging from € 0 (€ 60 for both types) for shock-proof conventional aneroid sphygmomanometers, to approximately € 100 for high performance sphygmomanometers with electronic gauges. The total extra costs to the users in the EU of purchasing alternatives can thus be estimated at € 0-6,000,000 per year depending on which alternative is chosen.

As previously mentioned, the recent EEB survey in a number of European hospitals (an overview is given in Table 2 below) concerning the use of mercury-containing sphygmomanometers and their level of substitution noted that *'overall, nearly 90 percent of the sphygmomanometers used in these hospitals were found to be mercury-free, and 75 percent of the hospitals investigated no longer use mercury-containing sphygmomanometers – some already for more than 10 years.* Only a small number of hospitals insist that mercury-containing sphygmomanometers are still necessary, or at least see no immediate need to phase them out. Moreover, many hospitals in other Member States are merely waiting for the old mercury containing instruments to wear out.

Table 2: Results of the EEB survey on the use of mercury-containing and mercury-free sphygmomanometers in European hospitals (source: 2009 Concorde report)

Country	Number of hospitals investigated	Number of beds*	Total sphygs*	Mercury sphygs*	Mercury-free sphygs*	Hospitals with only mercury-free sphygs
Czech Repub	4	3,279	1,235	838	397	0

France	4	4,035	1,120	12	1,100	3
Germany	29	16,000	4,000	0	4,000	29
Greece	2	1,050	190	120	70	0
Hungary	5	4,375	315	115	200	1
Italy	3	1810	480	240	240	1
Spain	5	2,785	860	0	860	5
United Kingdom	3	4,700	1,700	90	1,610	2
Total	55	38,034	9,900	1,413	8,487	41
Hg vs. Hg-free				14%	86%	75%
Total without Germany	26	22,034	5,900	1,413	4,487	12
Hg vs. Hg-free				24%	76%	46%

4.1.2 Opinion of SCENIHR on the feasibility of substitution of mercury-containing sphygmomanometers in healthcare (2009)

Following the workshop in April 2009, in order to address the remaining concerns and considering that the health and safety of patients is critical, DG Enterprise and Industry has requested in March 2009 an opinion of the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) concerning the feasibility of the substitution of mercury-containing sphygmomanometers in the healthcare sector.

SCENIHR was requested to examine whether the replacement of mercury-containing blood-pressure measuring devices (sphygmomanometers) would endanger proper healthcare including for specific groups of patients. SCENIHR was asked to comment on the essential use of mercury-containing sphygmomanometers as reference devices for (a) calibration (or technical verification) which is the regular metrological testing needed to ensure the accuracy of the blood pressure devices and (b) clinical validation which is the independent device accuracy assessment within a clinical setting commonly required before routine clinical use.

Based on the existing literature review and the information provided by the Commission and stakeholders and following a public call for information (which yielded additional relevant clinical/scientific evidence submitted by interested parties) SCENIHR adopted its opinion in September 2009¹².

In brief, SCENIHR concluded the following concerning the feasibility of alternatives:

- (a) The mercury-containing sphygmomanometer is disappearing from use and there are many alternative devices available to replace it. Blood pressure measurement by a trained observer, using a mercury-containing sphygmomanometer or a validated auscultatory alternative, remains the most accurate and reliable form of indirect blood pressure measurement. The alternative devices using auscultation (e.g aneroid or digital) have similar limitations as the mercury-containing sphygmomanometers regarding the observer bias associated with auscultation itself.

¹² The opinion is available at: http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_025.pdf

- (b) Even though oscillometric instruments are not considered as true "alternatives" to mercury-containing sphygmomanometers because they operate under a completely different principle, in practice these instruments do replace mercury-containing sphygmomanometers, in spite of their accuracy limitation which makes them insufficient for clinical use.

Overall, SCENIHR summarized their opinion by providing the following replies to the specific questions of the Commission's mandate:

1. *Is there sufficient evidence to demonstrate that mercury-free blood pressure measuring devices (aneroid or electronic instruments) are reliable substitutes for mercury-containing sphygmomanometers?*

Yes. There is sufficient scientific evidence that mercury-free blood pressure measuring devices (when clinically validated) are generally reliable substitutes for mercury-containing sphygmomanometers in routine clinical practice. These alternative devices include both auscultatory devices requiring an observer and automated oscillometric devices for which some instructions are required.

2. *Have mercury-free sphygmomanometers been adequately validated over a wide range of blood pressures, ages and clinical conditions to allow routine use in hospitals and outpatient settings?*

Yes. Clinically validated, auscultatory non-mercury devices are equivalent to mercury-containing sphygmomanometers. For the oscillometric devices the situation is different as these devices have mainly been clinically validated in adult populations including a wide range of blood pressure but not in a wide range of ages and clinical conditions.

3. *Have mercury-free sphygmomanometers been adequately validated for the diagnosis of hypertension in specific clinical conditions (arrhythmia, pre-eclampsia in obstetrics etc.)?*

Yes. Clinically validated, auscultatory non-mercury devices are equivalent to mercury-containing sphygmomanometers, and are thus suitable for the specific groups of patients. In addition, some oscillometric devices have achieved accuracy in certain conditions although in others, like arrhythmias, the auscultation technique is necessary. Moreover, there is a need for more clinical validation of oscillometric devices to make them usable in specific groups of patients, including elderly patients, children and pre-eclamptic women.

4. *Are mercury-containing sphygmomanometers essential as reference devices for validation of long-term clinical epidemiological studies enrolling patients with hypertension?*

Yes. Mercury-containing sphygmomanometers are considered essential as reference devices for the clinical validation of the alternatives. For on-going, long-term epidemiological studies currently using mercury sphygmomanometers it is advisable not to change the method of measurement. Therefore, it will be necessary to keep mercury sphygmomanometers available in order to compare them with the alternatives in these studies.

5. *Are mercury-containing sphygmomanometers essential for calibration of mercury-free sphygmomanometers, when the latter are used for routine diagnostic purposes?*

No, they are not essential as reference devices for the metrological verification (calibration) needed to ensure the accuracy of the measurement of the blood pressure devices. In general, more accurate mercury free manometers are available for metrological verification.

6. *Is SCENIHR aware of any adverse effects for patients' health due to the replacement of mercury-containing sphygmomanometers by mercury-free alternatives?*

No evidence was found for adverse effects for patients' health in clinical settings due to the replacement of mercury-containing sphygmomanometers by validated mercury-free alternatives. There are adequate alternatives in most clinical condition/setting. In special conditions, such as pre-eclampsia, non-mercury auscultatory devices should be preferred until further validation of oscillometric devices.

4.1.3 Availability of alternatives to mercury-containing strain gauges

Available alternatives to mercury-containing strain gauges are:

- Strain gauges with indium-gallium;
- Photo cell or laser-Doppler techniques.

According to a 2005 survey of the Swedish Chemical Agency (KEMI), although mercury equipment is now being successfully replaced by these alternative techniques, the reason why equipment containing mercury is still in use in Sweden is mainly not medical but economic. The mercury-containing tube is developed to function together with complex electronic measuring equipment that costs more than € 20.000 and has a life span of 10-15 years. Therefore, although the mercury free products are fully competitive with mercury equipment on a price basis and on functionality, hospitals hesitate to invest in a new system unless the existing system breaks.

Moreover, as indicated by COWI-Concorde (2008), mercury-containing strain gauge plethysmographs are mostly used for research purposes. There is at present no alternative to mercury-containing plethysmographs in research where absolute blood flow in arms and legs is examined.

4.2 Alternatives for other mercury-containing measuring devices for professional/ industrial uses

4.2.1 Availability of alternatives for mercury-containing thermometers

A number of different types of mercury-free thermometers are marketed in the EU, among which:

(I) Mercury-free liquid-in-glass thermometers

The liquid-in-glass thermometer is the most common replacement of the mercury-in-glass thermometer at temperatures up to 250°C at a very similar price. Most mercury-free liquid-in-glass thermometers can directly replace mercury-containing room temperature thermometers but are not suitable for accurate measurements at 0.1°C resolution.

(II) Dial thermometers

These thermometers are available for measuring temperatures in the range between about 70°C to 600°C and have typically replaced mercury-in-glass thermometers for the temperature range above 250°C, e.g. for measuring the temperature of exhaust gases of diesel engines. The price of a typical dial thermometer for a diesel engine is 2-4 times the price of a similar mercury-containing thermometer.

(III) Electronic thermometers

Electronic thermometers with a digital display and/or automatic data logging make up an increasing part of the thermometer market. The most common types are based on thermocouples, thermistors or resistance probes. The available electronic thermometers for laboratory use are generally more accurate than mercury-containing thermometers, if properly calibrated, which has to be done more often than with mercury-containing thermometers. However, the price of platinum resistance machine thermometers is of the order of 10 times the price of a simple mercury-in-glass machine thermometer (although price comparisons are complicated by the fact that the electronic thermometers typically consist of two separate parts: a probe (sensor) and a data logger).

For most industrial applications, electronic thermometers are replacing mercury thermometers due to the advantages of automatic reading. However, in laboratories and for some very specific applications in industry mercury-containing thermometers are still widely used. There are, in fact, 2 major constraints acting as a barrier to phasing out mercury-containing thermometers for laboratory use: (a) the higher cost of available alternatives (b) the fact that some international standards (e.g. DIN-Germany, PI-UK and ASTM-USA) widely used in in the EU and elsewhere, prescribe the use of mercury-containing thermometers for laboratory use.

4.2.2 Availability of alternatives for mercury containing porosimeters (and information on mercury recycling in porosimetry)

(a) Alternative mercury-free techniques

The two main alternatives to mercury intrusion porosimetry (MIP) techniques are:

- Mercury-free extrusion porosimetry:

This technique can only measure pore sizes within the range 0.06 µm - 1000 µm, but it does not work with dead-end pores and requires that one side of the sample is cut to a plane surface (which in some cases is not desirable).

- Mercury-free water intrusion porosimetry:

This technique can only be applied on hydrophobic (water-rejecting) materials, covers less than 5% of all applications and is a difficult and time-consuming surface treatment.

Other limitations of the alternatives techniques are: high prices of some of the components (i.e. gravimetric methods) or the long experiment time, lack of comparability with MIP, lack of international standards such as ISO or DIN etc.

(b) Mercury recycling in MIP

Following the discussions at the Commission workshop of April 2009, NGO's voiced doubts concerning the lack of data on the degree of recycling actually practiced by users of mercury porosimeters. DG Enterprise and Industry then approached the leading EU porosimeter manufacturers (ThermoFisher, Micromeritics and Quantachrome) covering together > 80% of the EU market) to ask for their assistance in surveying their customers (e.g. companies,

research institutes, etc.) on their use of mercury in MIP and on the extent of mercury recycling currently practiced.

In July 2009, questionnaires prepared by the Commission were sent to the users of mercury porosimeters in the EU, requesting information concerning the amount of mercury they have in stock to be used in porosimetry, the amount they recycle or dispose as waste or keep stock as oxidized, as well as the amounts of new mercury they buy per year. Information was also asked on the cost of new mercury and if they recycle the mercury in-house.

The consultation was completed in early September 2009 and yielded replies from 70 users of mercury porosimeters in the EU, of which ~65% were from university/research centers and ~35% from industrial laboratories. These account for ~10 % of mercury porosimetry users in the EU according to estimations of the manufacturers. In terms of geographical distribution, most replies were received from Germany (16) followed by France (15), Spain (14), UK (11), Italy (5), Netherlands and Belgium (3), and Hungary, Finland and Austria (1).

Appendix-1 contains the information received from the respondents (in anonymous form). The detailed replies received could be made available to ECHA on request.

According to the replies, the total amount of mercury bought by the respondents is ~ 0.52 tonnes/year, a number which if extrapolated for the total of EU users is ~ 5.2 tonnes/year. This is the amount of new mercury supplied to users each year. It should be noted that this value is lower than the range of values given in the 2008 COWI report (10-100 tonnes of mercury consumed in porosimetry/year in the EU)

The consultants having worked on the earlier studies on mercury uses (Concorde/COWI) have indicated that a level of mercury recycling around 80 % would be close to their expectations and in any case quite higher than the recycling rate of mercury in other sectors.

The price of new mercury (column 7 of Appendix 1) was found to vary enormously (from 21 to 480 € with an average value of ~93 €) depending on where and from whom the customer buys it, what quality of mercury, and in what quantities. It could be that the quite high prices correspond to very expensive extra pure distilled mercury. The costs of recycling and disposal (columns 8 and 9 of Appendix 1) also vary widely depending on quantities, country, method, etc.

4.2.3 Availability of alternatives to mercury containing electrodes

There are a few alternative techniques to mercury polarography for determination of trace metals such as: IC-ICP-MS (Ion chromatography coupled to inductively coupled plasma mass spectrometry) and SPE-AAS (Solid Phase Extraction coupled to Atomic Absorption Spectroscopy). However, according to industry stakeholders, these have certain limitations such as: high purchase and running costs, limited mobility, specific laboratory infrastructure required, problems with some sample matrices (e.g. sea water, pure chemicals) etc.

Concerning the reference mercury-containing electrodes (e.g for pH measurements), these have mostly been replaced by electrodes based on silver/silver chloride. However these can be detrimentally affected by sulphides and can be unsuitable as reference electrodes for chemical analysis of chloride or silver concentrations.

4.2.4 Availability of alternatives to mercury-containing manometers

Electronic (or digital) manometers serve as main alternatives to mercury containing manometers and are widely used by industry for automatic and remote control.

According to a report from the Danish EPA in 2006¹³, although the price of electronic manometers is estimated to be about 3-4 times the price of a mercury-containing manometer for similar pressure range, the electronic manometers have the advantage of automatic measurements and for this reason they cannot be directly compared to mercury-containing manometers. Moreover, a digital manometer can also be more precise than a mercury-containing manometer if properly calibrated. Laboratories calibrating manometers may still use mercury-containing manometers as reference instruments. As indicated in the COWI-Concorde (2008) report, according to a European manufacturer of mercury-containing manometers, there is no application for which mercury-containing manometers cannot be replaced by other devices.

4.2.5 Availability of alternatives to mercury-containing barometers

A number of alternatives to mercury-containing barometers are marketed today in the EU. For professional applications, alternatives are mainly electronic devices which are as precise as mercury-containing barometers such as:

- Electronic barometers (e.g. aneroid displacement transducers, digital piezo-resistive barometers or cylindrical resonator barometers),
- Electronic resistance or capacitance barometers.

According to the Guidelines from the World Meteorological Organisation (WMO 2006) there is an increasing move away from the use of mercury-containing barometers (due to the fact that mercury vapour is highly toxic and corrosive, mercury-containing barometers are delicate, difficult to transport clean and maintain etc.) to the use of electronic alternatives, which present many advantages. It should be noted that the price of mercury-containing barometers is generally higher or similar to the price of electronic barometers.

4.2.6 Alternatives for other mercury-containing measuring devices of minor use

- (a) Tensiometers: Mercury-containing tensiometers can, for all applications, be replaced by other types such as electronic tensiometers and tensiometers with mechanical bourdon.
- (b) Gyrocompass: Mercury-free gyrocompasses have been available for many years and are used on all types of vessels and for the same applications as mercury-containing gyrocompasses. These gyrocompasses use a mercury-free liquid consisting of surfactants and other harmless organic compounds.
- (c) Coulter counters: Alternatives with mercury-free gauges are available on the market.

¹³ Alternatives to mercury-containing measuring devices (EPA, Denmark, 2006)
<http://www2.mst.dk/udgiv/publications/2006/87-7052-133-6/pdf/87-7052-134-4.pdf>

5. PRELIMINARY CONCLUSIONS OF THE CURRENT INVESTIGATION

5.1 Sphygmomanometers in healthcare

(I) Following consultation with stakeholders and the investigations by SCENIHR, it can be concluded that mercury-containing sphygmomanometers are being steadily phased out in the EU (in particular for clinical use in hospitals) and are replaced by existing cost-effective alternatives. The fact that auscultatory rather than oscillometry technique may be preferable for high accuracy of blood pressure measurements for certain patient groups (pregnant women, persons with diabetics etc.) does not necessarily mean that mercury-containing devices are required. Indeed, several Member States (e.g Netherlands, Sweden, Denmark) have reported their positive experience over a long period with the use of mercury-free sphygmomanometers under all conditions. The majority of the existing market for mercury-containing sphygmomanometers now seems to be made up of (older) general practitioners, who consider them as the most accurate in recording blood pressure being also very experienced in their use.

(II) No matter what type of blood pressure measurement device is used, both aneroid and mercury-containing sphygmomanometers must be calibrated regularly in order to avoid errors in blood pressure measurement and consequently the diagnosis and treatment of hypertension. On the issue of calibration, manufacturers underline that a digital manometer should be used as the calibration standard rather than a mercury-containing manometer. Furthermore, SCENIHR concluded that mercury-containing manometers are not appropriate to be used as reference manometers, given their poor resolution.

(III) According to SCENIHR, given the important contribution over the years by mercury-containing manometers to the present knowledge on hypertension as a risk factor and to its control by treatment, and because of their continuing use as standard reference devices for the clinical evaluation of aneroid and automated blood pressure measuring devices, *it might be important to keep mercury manometers as a reference tools, available only in a few accredited centres around the world to perform clinical validation studies of new devices.*

5.2 Other mercury-containing measuring devices for professional/industrial uses

(I) Existing evidence and consultations reveal that mercury porosimeters and mercury electrodes in polarography are still essential for certain professional/industrial uses due to technical limitations of their existing alternatives. In particular for porosimetry, it appears that given the use of mercury porosimeters for essential professional uses and the rather high level of mercury recycling performed by their users, such mercury use may not pose an unacceptable risk to human health or the environment and therefore should remain possible in the EU.

(II) Though substitution of certain mercury containing devices (strain gauges for blood measurements, thermometers for laboratory/industrial uses) seems technically feasible, it may still be difficult to achieve full replacement in the short term due to considerably higher cost of the existing alternatives.

(III) For the rest of mercury-containing measuring devices (manometers, barometers, tensiometers etc.) there are already available technically and economically feasible alternatives in the EU and therefore their current professional/industrial applications could be phased out without particular problems.

6. LIST OF ABBREVIATIONS

AAMI: Association for Advancement of Medical Instrumentation

BHS: British Hypertension Society

COCIR: Committee of Radiological, Electromedical and Healthcare Industry

EBCOG: European Board and College of the Obstetrics and Gynecology

ECHA: European Chemical Agency

EEB: European Environmental Bureau

EPA: Environmental Protection Agency

ESH: European Society of Hypertension

HCWH: Health Care Without Harm

IC-ICP-MS: Ion chromatography coupled to inductively coupled plasma mass spectrometry

ISO: International Standardization Organization

ISSHP: International Society for the Study of Hypertension in Pregnancy

KEMI: Swedish Chemical Agency

LWG: Limitation Working Group

MDEG: Medical Devices Expert Group

MIP: Mercury Intrusion Porosimetry

NGOs: Non-Governmental Organisations

REACH: Registration Evaluation Authorisation of Chemicals

SCENIHR: Scientific Committee on Emerging and Newly Identified Health Risks

SPE-AAS: Solid Phase Extraction coupled to Atomic Absorption Spectroscopy

UNEP: United Nations Environment Programme

WMO: World Meteorological Organisation

7. APPENDICES

(I) Summary table of the Commission's consultation concerning the Hg recycling level in porosimetry.

Summary of results of COM consultation concerning recycling

on mercury porosimetry

<i>Code</i>	<i>Stock of Hg for use in porosimetry (kg)</i>	<i>New Hg bought (kg/y)</i>	<i>Recycled Hg (kg/y)</i>	<i>Hg disposed as waste (kg/y)</i>	<i>Stock of oxidised Hg in-house (kg)</i>	<i>Price of New Hg (€/kg)</i>	<i>Cost of recycled Hg (€/kg)</i>	<i>Cost of disposed Hg waste (€/kg)</i>
1	40.0	1.0	10.0	0.1	0.2	150.0	15.0	10.0
2	15.0	2.0	5.0	2.0	0.0	220.0	----	4.0
3	15.0	1.0	0.0	0.0	1.0	30.0	----	----
4	8.0	0.0	4.0	0.0	0.0	----	550.0	----
5	9.0	1.0	1.0	1.0	2.0	----	----	----
6	22.0	0.0	20.0	2.3	0.0	----	----	----
7	10.0	0.0	0.0	0.0	0.0	----	----	----
8	17.0	43.0	17.0	67*	0.0	27.0	----	15.0
9	3.0	0.0	3.0	0.0	0.0	----	----	----
10	30.0	40.0	40.0	0.0	0.0	37.0	6.5	----
11	6.0	0.0	6.0	0.0	0.0	----	22.0	----
12	13.5	7.0	0.0	7.0	0.0	21.0	----	4.5
13	10.0	12.0	60.0	0.3	20.0	37.3	34.8	8.8
14	24.0	8.0	0.0	8.0	0.0	90.0	----	90.0
15	10.0	1.0	6.0	1.0	0.0	218.3	----	2.5
16	11.0	0.0	1.0	0.4	0.0	----	----	10.0
17	22.5	0.0	22.5	0.0	0.0	----	----	----
18	30.0	105.0	105.0	0.2	0.0	45	10	0.2
19	4.0	6.0	2.0	0.0	0.0	340.0	----	----
20	400*	0.0	50.0	5.0	60.0	----	----	80.0
21	50.0	0.0	15.0	1.0	20.0	----	44.0	----
22	20.0	0.0	5.0	0.0	0.5	----	8.0	----
23	16.0	12.0	4.0	12.0	1.0	38.0	----	0.5
24	3.0	0.0	95.0	5.0	0.0	----	----	----
25	20.0	2.0	0.0	0.0	0.0	30.0	----	----
26	15.0	0.5	10.0	0.0	10.0	47.1	15.1	4.6
27	40.0	0.0	30.0	0.0	0.0	----	14.0	----
28	8.0	0.0	7.0	1.0	0.0	----	----	6.9
29	173.0	0.0	14.0	1.0	0.2	----	----	3.4

30	5.0	8.8	8.8	0.0	2.5	53.0	2.0	0.0
31	10.0	40.0	40.0	0.0	0.0	37.8	10.0	----
32	27.0	1.0	54.0	1.0	0.0	47.0	----	15.0
33	4.0	20.0	16.0	0.0	0.0	40.0	7.0	----
34	10.0	0.0	5.0	1.0	0.0	----	----	3.7
35	4.0	4.0	1.0	0.0	1.0	----	----	----
36	5.0	1.0	1.0	0.0	0.0	150.0	60.0	----
37	16.0	12.0	20.0	8.0	0.0	55.0	18.0	20.0
38	6.0	9.0	0.0	9.0	0.0	76.0	----	----
39	10.0	5.0	5.0	5.0	5.0	24.2	----	----
40	5.0	0.5	0.5	0.5	0.0	----	----	----
41	6.0	1.0	0.0	1.0	0.0	79.0	----	----
42	6.5	6.5	7.0	0.4	0.0	62.0	33.0	----
43	17.5	0.5	20.0	0.1	7.5	55.0	15.0	17.0
44	40.0	10.0	0.0	0.0	0.0	87.8	----	----
45	6.0	3.0	0.0	3.0	3.0	77.0	----	3.3
46	12.0	0.0	18.0	0.0	5.0	45.7	15.1	----
47	15.0	0.5	15.0	0.5	0.0	1000*	15.1	----
48	10.0	10.0	10.0	0.0	0.0	25.0	9.0	----
49	14.0	0.0	1.0	0.0	0.0	----	----	----
50	1.5	2.5	0.0	1.5	1.0	230.0	----	----
51	4.0	6.0	0.0	6.0	0.0	484.6	----	4.0
52	39.0	0.0	20.0	0.3	0.0	----	13.0	13.0
53	18.0	0.0	18.0	0.5	0.0	0.0	61.0	----
54	0.5	5.0	20.0	0.0	0.0	150.0	1.6	----
55	6.0	0.5	0.5	0.5	0.5	----	----	----
56	10.0	0.0	0.0	0.1	0.0	----	----	----
57	6.0	0.0	0.0	0.0	0.0	----	----	----
58	3.0	36.0	36.0	0.0	0.0	33.0	6.0	----
59	10.0	0.0	9.0	1.0	5.0	37.0	6.5	----
60	10.0	3.0	7.0	3.0	0.0	137.0	----	----
61	20.0	1.0	10.0	0.0	0.0	90.0	24.0	----
62	30.0	30.0	14.0	16.5	0.0	35.0	25.0	1.2
63	1.0	0.1	0.9	0.1	0.0	----	----	----

64	10.0	10.0	10.0	0.0	0.0	37.3	6.5	4.0
65	20.0	4.0	4.0	4.0	0.0	15.0	15.0	----
66	20.0	0.0	15.0	3.0	0.0	----	15.0	17.0
67	51.0	2.0	200*	1.9	0.0	43.2	13.3	4.5
68	12.0	10.0	10.0	0.0	0.0	89.2	4.6	----
69	7.5	2.5	2.0	0.5	2.5	88.0	----	----
70	10.0	2.0	10.0	0.0	0.0	341.0	40.0	----
Average	17.2	7.2	13.6	1.7	2.1	93.3	35.2	13.2
Total	1138	479	941	114	148	not applicable	not applicable	not applicable
<p>The values indicated by (*) were excluded from analysis (as considered to be unrepresentative) All the price information is converted to €. If the answer is presented as range of values, an average is reported in the table.</p>								

(II) List of material available on circa

http://circa.europa.eu/Members/irc/enterprise/lmudsp/library?l=/thematic_folder/mercury_fol_low_up&vm=detailed&sb=Title

1. ESH Guidelines for home BP, J.Hypertension (2007).
2. Minutes and presentations of the Commission Mercury Workshop (April 2009).
3. Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society (COWI, 2008).
4. Alternatives to mercury-containing measuring devices (COWI 2006, EPA Denmark)
5. Mercury-free blood pressure measurement equipment (KEMI, Sweden, 2005).
6. Blood pressure monitors and sphygmomanometers. (MHRA, UK, 2005).
7. Mercury-free Health Care. Med.J.World (2008).
8. The global movement for Mercury free healthcare (HCWH, 2007).
9. Blood pressure measurement – is it good enough for accurate diagnosis of hypertension? (Current Controlled Trials in Cardiovascular Medicine, 2006).
10. Mercury in Healthcare (WHO, 2005).
11. End of an Era. The phase-out of Mercury Blood Measuring Devices. HCWH (2008).
12. Positions of (a) Member States (DE, FI, IE, IT, LA, LU, NL, PL, SE, HU, UK) and (b) associated industry (COCIR, AAMI, Russels Scientific) (c) NGOs (EEB, HCWH).
13. An Assessment of the Future Levels of Demand for Mercury in the UK. RPA (2009).
14. Report of the Independent Advisory Group on Blood Pressure Monitoring in Clinical Practice (BMP monitoring 2005)
15. Report from the EEB Conférence : EU Mercury phase-out in Measuring and Control Equipment (June, 2009).
16. The following indicative list of scientific publications:

Markandu et al. (2001); O' Brien (2000, 2003, 2005); O' Brien et al. (2005); Parati et al. (2006); Parati et al. (2008); Pickering et al. (2005); Pater (2005); Colloquit and Jones, 2002; Canzanello et al. (2001);Reinders et al. (2003) etc.