Mercury Inventory for New Zealand 2008

Prepared for the Ministry for the Environment by
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August 2009

Statement of Limitations

This report has been prepared for the Ministry for the Environment for the objectives and to the scope set out in the report. This report constitutes a technical report and is not Government policy. Any opinions expressed are those of the authors and Pattle Delamore Partners Limited. Use of the information in the report by any other party or for any other purpose is at that party's risk.

This report has drawn on opinions of others and data from the New Zealand and international literature on mercury-containing materials and devices, and mercury emissions from various natural and anthropogenic processes. The information has been accepted as provided and has not been independently checked. The data has been used in good faith but it could contain errors. Therefore PDP accepts no responsibility for errors in that data and consequent errors in derived emission estimates.

Information on the use of mercury, and natural and anthropogenic fate and transport of mercury, in New Zealand is incomplete. Accordingly, the inventory of emissions has gaps which, where possible, have been filled using overseas data, but in other cases must remain as gaps. The limitations of, and gaps in the data have been identified throughout the report.

In general, where there has been a choice in calculating estimates, New Zealand data has been preferred over overseas data, and official statistics or government reports preferred over other sources. Where there has been a range of such things as emission factors, mercury contents, and the like, middle values have been chosen for the calculations. Where UNEP Toolkit default emission factors have had to be used it is expected that these values will result in conservative (high) estimates.

The lack of reliable data may have resulted in over or under-estimates of particular types of emission sources, and of the natural and anthropogenic totals. While the major sources of natural and anthropogenic emissions are thought to have been accounted for, given the lack of reliable data for some sources it is not possible to estimate the likely error in the estimates.

Acknowledgements

A large number of people in a variety of organisations were consulted in compiling this report. Their assistance is acknowledged. People consulted include: Deborah Morley, Watercare Services Limited; Geoff Taylor, New Zealand Refinery Company; Chris Hendy, University of Waikato; David Craw, University of Otago; Dev Affleck, Mark Brockelsby, Nick Kim, Michelle Begbie and Marianna Tyler, Environment Waikato; John Reeve, New Zealand Food Safety Authority; David Gifford, New Zealand Steel; Joy Bier, Genesis Energy; Pieter Fransen, Waihi Gold Limited; Mark Wilhelm, Mercury Technology Services; Peter Robinson, Hill Laboratories Ltd; Richard Pointing, Lighting Council of New Zealand; Derek Richardson, Roger Henderson and Scott Kellner, Interwaste; Simon Court, Envirowaste; Trevor Berry, Solvent Refining Co; Craig Scarlett, New Zealand Aluminium Smelters Ltd and Nigel Newman, CRL Energy Ltd; Ed Murser, Carter Holt Harvey; Matthew Walker, TranzPower; Stephen Parker, Gas Association of New Zealand; Dr Brent Young, University of Auckland Chemical Engineering; Bill Armstrong, Todd Energy; Delia Tyson, Oceana Gold's Macraes Gold Mine; Craig Stevenson, Contact Energy Geothermal Group; Dominic McCarthy and Judy-Ann Ansen, Auckland Regional Council, Gary Bedford, Taranaki Regional Council; Jim Foye, Maritime New Zealand; Stewart Ross and Matt Vesey, Electricity Commission; Steve Todd and Dean Edwards, New Zealand Statistics; Rob McLaren, University of Otago; Andrew Holyoake, Lincoln University; David Jenkins, University of Auckland; Peter Wildbore, Massey University; Andrea McMillan, Otago University; Garth Wyllie, Cosmetic Toiletry and Fragrance Association of New Zealand; Paul Bonetti, Golden Bay Cement; Greg Flauter, Holcim; Stu Pickmore, Greg Olsen, Chris Cunningham and others from NIWA; Dr Graham Simes, New Zealand Dental Association; Julian Brown, Christchurch City Council; Bruce Collier, Wellington City Council; Paul Dunford, Napier City Council; Robert McCrone, Wellington Water Management Ltd; Grant Occleston, Auckland City Council; Kaye Eason, Veritec; Peter Clinton, Scion Forest Research Staff from Biolab, Merck Ltd, Global Science, and Ajax Fine Chemicals; Staff from the Cement and Concrete Association of New Zealand; Staff at Plastics New Zealand Inc; and Staff at Christchurch, Wellington, Dunedin and Auckland hospitals.

The inputs of Craig McCauley and Graeme Proffitt of Pattle Delamore Partners Limited in carrying out research, and reviewing and providing overall direction for the project, respectively, are also acknowledged.

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Executive Summary

This Mercury Inventory has been compiled as part of the information needed to inform the potential development of a product stewardship programme for lighting in New Zealand. In particular it is intended to assess the relative environmental impact of mercury-containing lamps, including the increased use of compact fluorescent lamps (CFL), compared to the impact of mercury from other natural and anthropogenic sources. The report has been prepared by Pattle Delamore Partners Limited on behalf of the Ministry for the Environment.

Mercury is a toxic, naturally occurring heavy metal. It occurs in three forms, elemental mercury (as a liquid or vapour), inorganic mercury compounds and organic mercury compounds. The most toxic form is the organic compound methylmercury.

Elemental mercury and inorganic and organic mercury compounds can be transformed in the environment from one form to another in a series of complex processes. In general, however, elemental mercury exists mostly in the atmosphere, while inorganic and organic mercury compounds exist mostly in land and water environments.

Sources of mercury in New Zealand fall broadly into two categories:

(a) Natural sources in land, soils, air and water and, notably in New Zealand, from volcanic and geothermal activity; and

(b) Anthropogenic sources from various industrial, chemical, medical and dental, electrical and domestic applications, including mercury-containing lighting equipment and lamps.

The total annual mercury emissions for New Zealand in 2008 have been estimated using the 2005 draft of the UNEP Mercury Toolkit to be 3,000 kg Hg/year, with roughly equal contributions from natural and anthropogenic sources. A lack of data means that some of the UNEP categories could not be estimated. Emissions from these sources are thought to be small. In addition, some industries considered major sources in the UNEP toolkit either do not exist in New Zealand, or are small.

The most significant natural sources of mercury were volcanic emissions, comprising 54% of natural emissions and 28% of total emissions. The most significant anthropogenic sources were combustion of fossil fuels (440 kg Hg/year) and geothermal power generation (350 kg Hg/year), representing 29% and 23% of the anthropogenic emissions, respectively. Other significant anthropogenic mercury sources included wastewater biosolids (180 kg Hg/year) and mercury-containing batteries (170 kg Hg/year).

Mercury-containing lamps are currently a small potential source of emissions, contributing approximately 50 kg/year which is only 3% of total anthropogenic emissions and less than 2% of overall mercury emissions from New Zealand. Compact fluorescent lamps currently make up about a third of potential emissions from mercury-containing lamps.

On a per capita basis, the total anthropogenic mercury inventories compiled for New Zealand, Ireland, Canada, the United States and the United Kingdom are comparable (of the order of 10^{-4} kg/person/year), whereas that of Denmark and Australia are an order of magnitude greater (10^{-3} kg/person/year). Excluding Australia's mercury releases from roads (which no other country has estimated), Australia's reported emissions are about twice those of New Zealand, the major difference being primary metal production.

Ten-year projections of the mercury emission have been calculated and the change in relative contribution of mercury from mercury-containing lamps has been assessed. This calculation has assumed emissions from New Zealand's natural mercury sources will remain the same.

There are considerable uncertainties with forecasting future anthropogenic emissions, related to such things as economic performance, the price of competing sources of energy and changes in policies with respect to mercury both in New Zealand and overseas. The predictions, being relative to current emissions, also have the same uncertainties as the current emission calculations.

Overall the anthropogenic mercury loads in 2018 are predicted to be 2,100 kg Hg/year an increase of 600 kg Hg/year or 40%, over 2008. Emissions from geothermal power generation (an increase of 190% to 1,020 kg Hg/year) are expected to be the largest contributor to anthropogenic mercury loads in 2018, followed by wastewater treatment (200 kg Hg/year) and dry cell batteries (170 kg Hg/yr). The geothermal power generation prediction is uncertain, however, being sensitive to the price and availability of competing sources of energy and relies on various power generators constructing power stations that they have indicated are, or may be, in the pipeline.

The contribution from mercury-containing lamps is estimated to remain about the same in absolute terms, assuming a high-use scenario for CFLs, and the mercury content of CFLs staying constant. In relative terms, this results in a halving of the contribution from mercury-containing lamps relative to the total mercury emissions. Compact fluorescent lamps will contribute only about half of the mercury from mercury-containing lamps.

With respect to the effects of mercury on the environment, most concern has been expressed globally over the accumulation of anthropogenic mercury from diffuse sources in aquatic ecosystems. Bioaccumulation and biomagnification of mercury may result in adverse effects on the aquatic animals and associated wildlife, but can also cause increased dietary intakes of mercury in the human population due to higher concentrations of methylmercury in fish.

There is limited evidence that mercury exposure is of concern in New Zealand, however. Apart from occupational exposure for a relatively small number of people (e.g. dental workers), dietary exposure through eating long-lived predatory marine species of fish, or fresh water fish caught in geothermal regions, is the most likely route for exposure. Dietary exposure to mercury may account for up to 54% of a person's total exposure to mercury and nearly all their exposure to methylmercury compounds. However, a number of studies have demonstrated that the benefits of eating a modest amount of fish outweigh the risks of exposure to methylmercury.

Mercury emitted from geothermal and industrial sources, the latter mainly from the combustion of coal and generation of geothermal power, is unlikely to pose any direct toxicity threats to humans. However, studies have shown that small increases in atmospheric loadings lead to a direct increase in the concentration of mercury in fish.

Exposure to mercury from broken CFLs will result in short-term exposure to mercury. However, exposure to broken lamps is of short duration and expected to be infrequent. It is thought that mercury exposure from broken CFLs poses minor or no direct threat to human health if prompt and proper clean up is carried out. Calculations using an extreme scenario of frequent breakages with improper clean-up techniques, suggests that an adult may be exposed to up to 4% of the World Health Organization's Provisional Tolerable Weekly Intake (PTWI), and an infant up to 8% of the WHO PTWI, but actual exposure is likely to be considerably less.

There is a variety of legislation and regulation controlling the use, storage and discharge of hazardous substances and safety within the workplace. However, apart from mercury and mercury-containing compounds having to be approved under the Hazardous Substances and New Organisms Act 1992, there are virtually no specific nationwide controls on mercury. The few specific regulatory controls are for work place exposure via approved codes of practice under the Health and Safety in Employment Act 1992 and controls on trade waste discharges to sewers under some local bylaws. New Zealand otherwise relies on various guidelines for air, water, landfills and biosolids.

Various overseas jurisdictions have specific statutory controls on mercury and, in general, it can be concluded that Europe and the United States are more advanced than New Zealand in imposing specific controls on mercury.

Introduction

This Mercury Inventory has been compiled for the Ministry for the Environment (MfE) as part of the information needed to inform the potential development of a product stewardship programme for lighting in New Zealand. The need for a product stewardship programme arose as a result of the Efficient Lighting Group's[1] New Zealand Efficient Lighting Strategy, which was released in 2008. The strategy recommended, in part, a large scale shift towards the use of energy efficient lamps in New Zealand, including compact fluorescent lamps. Increasing the use of energy efficient lamps caused concern about the impact on the environment from the disposal of mercury-containing lamps, thus warranting consideration of the need for a product stewardship programme.

Phase 1 of the product stewardship programme, which was completed in January 2008, and is entitled *New Zealand Lighting Industry Product Stewardship Scheme – Phase 1 Assessment and Review* (Stewardship Solutions, 2008), included an assessment of the current status of the lighting industry and its environmental impacts in New Zealand.

Prior to moving on to Phases II and III of the programme, some information gaps needed to be overcome. Specifically, the mercury contribution and associated environmental impact from mercury-containing lamps compared to the mercury contribution and associated environmental impact from other sources (natural and anthropogenic). This mercury inventory was commissioned to fill the information gaps.

This report aims to meet eight key objectives:

1. Summarise the general impact mercury poses on the environment.
2. Identify the various contributors of mercury to New Zealand's environment.
3. Present exposure scenarios for natural and anthropogenic sources.
4. Quantify New Zealand's total annual mercury load.
5. Compare anthropogenic mercury loads and total mercury loads to the mercury loads expected from certain types of lamps.
6. Assess the relative contribution of mercury from mercury lamps over the next ten years compared to anthropogenic mercury loads and total mercury loads.
7. Compare New Zealand's relative mercury hazard in relation to other countries.
8. Provide a summary statement of mercury pollution controls in New Zealand and overseas.

These key objectives have been addressed in five report sections. Section I provides a background into mercury in the New Zealand environment (Objective 1). It briefly details the different forms of mercury and outlines the different mercury pathways and transformations that occur between different sectors of the environment in New Zealand and globally (e.g. atmosphere, land and water). Section I concludes with some comments on mercury problems in the environment.

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[1] The Efficient Lighting Group was formed by the Electricity Commission, the Energy Efficiency and Conservation Authority and the Lighting Council New Zealand under a Terms of Reference that included the development of an 'integrated lighting strategy'.

Section II provides the mercury inventory for New Zealand. In this section, the various sources of mercury in New Zealand have been identified and quantified, including anthropogenic and natural, utilising the UNEP Toolkit (2005). Mercury from mercury-containing lamps is also quantified and a comparison of New Zealand's mercury emissions is made with six other OECD countries (Objectives 2, 4, 5 and 7). Section II relies heavily on information provided by various industries, various databases and the literature generally.

Data limitations were encountered when compiling the inventory. For example, no data was available to quantify the numbers of mercury-containing products in circulation in New Zealand, nor was any data available on the quantity of mercury in landfills. Consequently a complete inventory was not possible. Data limitations for particular items have been noted against the items.

Section III of the report outlines the risk associated with mercury in the environment. It presents different scenarios for significant environmental sources of mercury, both anthropogenic and non-anthropogenic and includes an assessment of the absolute and comparative environmental risks arising from these sources (Objective 3). It was not possible to compare New Zealand's risk with other countries, as data was not available in a form that allowed a ready comparison.

Section IV includes predictions of the relative mercury contributions from anthropogenic loads, and total mercury loads in ten years' time, and compares these with the expected load from mercury-containing lamps (Objective 6). The predictions are based on the contributions calculated in Section II of this report.

Section V summarises the different mercury pollution control mechanisms currently in place in New Zealand, and compares them with control practices that are used around the world (Objective 8).

Section I – Mercury in the New Zealand Environment

1 Introduction

Mercury is a naturally occurring, but very toxic metal that can have detrimental effects upon humans and other forms of life (biota) if not properly managed. This section 'sets the scene' by providing an overview of the mercury and mercury pathways in the environment. It draws on a review of the international literature and consultation with New Zealand industry experts and other authorities, to provide a short summary of the types of mercury that are present in the environment, and the impacts that mercury can have upon biota.

An overview of mercury circulation at both the global and national scale is also provided. The global mercury circulation pathway is presented in graphical form, and the transport and transformation of mercury throughout the environment is generally described.

This section also summarises in graphical form mercury pathways within the New Zealand environment. It explains the special features of mercury circulation patterns within New Zealand, which have a notable volcanic and geothermal component. It then briefly places in context the issues presented by the relative contribution of mercury-containing lamps to New Zealand's mercury flow, with further investigations and details on these matters to be presented in subsequent sections.

2 Mercury in the Environment

2.1 Forms of Mercury

Mercury (with the chemical symbol Hg) is a naturally occurring element. It exists in nature in many different chemical forms. In its elemental state, pure mercury is a liquid at room temperature. It is not common for mercury to be in this pure liquid form in nature. Instead it is generally found dispersed at very low concentrations (e.g. parts per billion) in soils, sediments, natural waters and the atmosphere, as well as plants and animals. The chemical forms of mercury in the environment include adsorbed mercury species, organic (carbon-containing) and inorganic compounds, and mercury vapour.

2.1.1 Elemental Mercury

Elemental or metallic mercury is a shiny, silver-white liquid metal. In this form mercury is expressed as Hg(0) or Hg^0, where the 0 denotes the oxidation state of the mercury atom (in this case uncharged). Elemental mercury can evaporate (volatilise) forming mercury vapour when it is exposed to air. Rates of evaporation increase with increasing temperature. Mercury vapour is colourless, odourless, and very toxic.

The inhalation of vapour is the prime route of exposure to elemental mercury (but not other forms) for humans. Concentrations of mercury in ordinary ambient air are too low to pose a significant exposure risk for humans. However, in cases of occupational exposure to elemental mercury, the risk of poisoning can be high. Mercury vapours are readily absorbed into the human body through the lungs and (at high concentrations) can go on to affect the nervous system, causing neurological and behavioural disorders (UNEP, 2008a). Once in the body, elemental mercury can oxidise to inorganic mercury and be retained in body tissues, including the brain and kidneys, for some months.

Traditionally, elemental mercury has been used in thermometers and barometers, dental amalgams, some electrical switches, and as a preservative in some medical preparations. More recently it has been used in lamps, electronics, and skin lightening creams (UNEP, 2008a). Elemental mercury is the most common form of mercury in the atmosphere.

2.1.2 Inorganic Mercury

Inorganic mercury compounds are more commonly found in nature than the elemental form of mercury. Mercury is a natural component of the Earth’s crust and exists (at some level) in all rocks, soils and sediments, usually as an inorganic compound. A major source of mercury in soils is from the parent rocks and minerals that are weathered to form the soil.

Mercury is mined as the inorganic mineral cinnabar, which is mercuric sulphide (HgS). Other common inorganic mercury compounds include mercuric oxide (HgO) and mercuric chloride ($HgCl_2$). The mercuric (doubly oxidised) form of mercury, for which there is a single mercury atom and an overall +2 charge (Hg(II)), readily forms salts, binding with negatively charged ions. This form of mercury also forms strong covalent (non-salt) bonds with sulphur, and organic matter, in the latter case leading to organic-mercury compounds of mercuric mercury (such as methylmercury). Some mercuric forms of mercury are soluble in water, such as $HgCl_2$, but mercury oxide and mercury sulphide compounds are insoluble in water. Due to their insolubility in water, these two inorganic forms of mercury act as mercury ‘sinks’ in the environment and effectively remove mercury from cycling within the biosphere.

Mercurous (singly oxidised Hg(I)) compounds form another group of inorganic mercury compounds. The mercurous form is diatomic (i.e. two mercury atoms) with an overall +2 charge ($Hg_2^{(2+)}$).

Inorganic mercury compounds may be less efficiently absorbed by living organisms when compared to elemental mercury vapour, depending on the inorganic compound the mercury atom is bound to. In humans, the majority of inorganic mercury comes from ordinary dietary sources, and absorption of this type of mercury through the gastrointestinal tract is not particularly efficient. Inorganic mercury can be passed to babies via breast milk, and therefore mercury exposure is a major concern for mothers with small infants (UNEP, 2008a).

In additional to ordinary dietary sources, humans may be exposed to inorganic mercury via dental amalgams and skin lightening creams, from products that use inorganic mercury salts, or during certain industrial activities e.g. mining and concrete and steel manufacture (UNEP, 2008a). Inorganic mercury was historically used as a fungicide, but this has been discontinued in many countries, including New Zealand (UNEP, 2008a).

2.1.3 Organic Mercury

Organic mercury compounds are formed when the mercury atom or inorganic mercury compound is bound to a carbon molecule. The most common form, and the form of most concern in terms of toxicity, is methylmercury (CH_3Hg^+). Like inorganic mercury compounds, organic mercury compounds can also exist as salts, such as methylmercury chloride (CH_3HgCl).

Organic mercury compounds are easily absorbed by fish in the aquatic environment (Hansen and Danscher, 1997). Once absorbed, these compounds can bioaccumulate in the body of fish (bioaccumulation is absorption of a substance by an organism at a greater rate than the organism can remove it). When smaller fish or other organisms containing organic mercury are consumed by a species higher up in the food chain, the concentration of mercury in the higher species (e.g. larger fish) increases, in a process called biomagnification. Of all the mercury forms, organic mercury poses the greatest risk to biota (living species). This is because methylmercury is more readily absorbed through the gastrointestinal tract and once inside, can migrate through cells which normally form a barrier to toxins. Methylmercury compounds can be transformed into compounds which cross the blood-brain and placental barriers, allowing mercury to react directly with brain and foetal cells (Choi and Grandjean, 2008). Once inside these barriers, mercury can also be oxidised to inorganic forms, effectively trapping it inside.

Humans are mainly exposed to organic mercury (in particular methylmercury), through the dietary consumption of fish. The highest levels of mercury are found in older predatory fish such as swordfish and tuna (UNEP, 2008a).

2.2 Mercury Pathways in the Environment

Elemental mercury and inorganic and organic mercury compounds can be transformed in the environment from one form to another in a series of complex processes (UNEP, 2008a). In general, however, elemental mercury exists mostly in the atmosphere, while inorganic and organic mercury compounds exist mostly in land and water environments. Transformation between different forms is a continual process, and can be caused by natural (e.g. microbial) and anthropogenic activities. The total amount of mercury in the various forms globally does not increase during these transformations, since mercury, as an element, cannot be created or destroyed.

While mercury cannot be destroyed, it can be transformed into non-bioavailable, non-water soluble chemical species (such as mercury sulphide and mercury oxide), and therefore can be removed from the biosphere into 'sinks'. An important sink is underwater sediments.

The transformations and transportation of mercury between forms and different areas of the environment are examined in further detail in the sections below. It is worth noting that, at present, little information is available for New Zealand on the residence time of mercury in any particular pathway. The chemical form of mercury will influence its residence time in any particular environmental compartment. Some of the transformation and transportation processes are poorly understood, and for some environmental forms of mercury, there are no estimates of residence time.

2.2.1 Global Mercury Circulation

Mercury moves freely throughout the globe in a complex combination of transformations and transport (Figure I-1). Mercury is emitted to the atmosphere by both anthropogenic and natural processes on land. In addition, mercury is emitted to the atmosphere directly from the ocean, in a process called evasion. Similarly, mercury is re-deposited to both the oceans and land from the atmosphere. Elemental mercury is highly mobile and can be transported and dispersed easily throughout the atmosphere. Elemental mercury is therefore less likely to be deposited close to its source than the ionic mercury compounds.

Ionic forms of mercury in the atmosphere are more reactive and soluble than elemental mercury, and are therefore more readily removed from the atmosphere by precipitation and dry deposition. Ionic forms of mercury tend to be deposited close to their emission sources, while elemental mercury may be transported far from its emission sources.

Mercury also moves from land to water via processes such as sedimentation, runoff and leaching. These processes can be of particular concern in areas of high industrial activity. Greater detail on how mercury is transformed within and between the different areas of the environment (air, land and water) is described in Section I-2.3.

2.2.2 General Mercury Pathways in New Zealand

The mercury pathways in New Zealand fit within the global pattern as described above. Fortunately, due to New Zealand's geographic isolation, it is not subject to the same level of anthropogenic mercury emissions sourced from neighbouring countries as is observed in Europe and North America. However, due to New Zealand's location on the convergence zone of two tectonic plates (Australian and Pacific), New Zealand has a natural mercury source that many other countries do not have, namely geothermal mercury emissions. White Island and, less frequently, Mt Ruapehu (Figure I-2), are two of New Zealand's more active volcanoes emitting mercury into the atmosphere. Geothermal areas situated elsewhere throughout the country also contribute to the total mercury emissions to air and water generated from New Zealand's land mass. The majority of these are in the Taupo Volcanic Zone in the Waikato and Eastern Bay of Plenty regions.

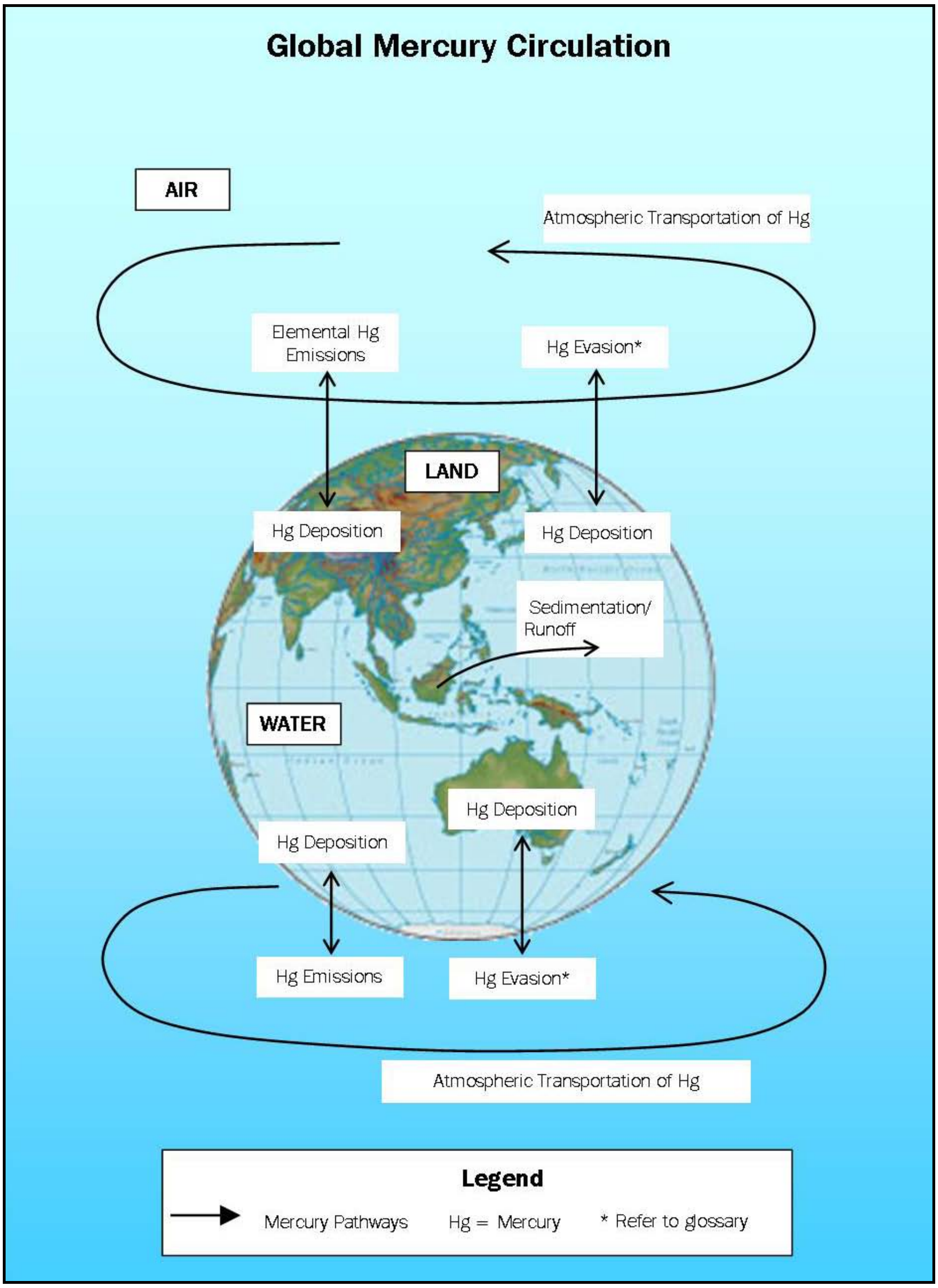

Figure I-1: Global mercury circulation

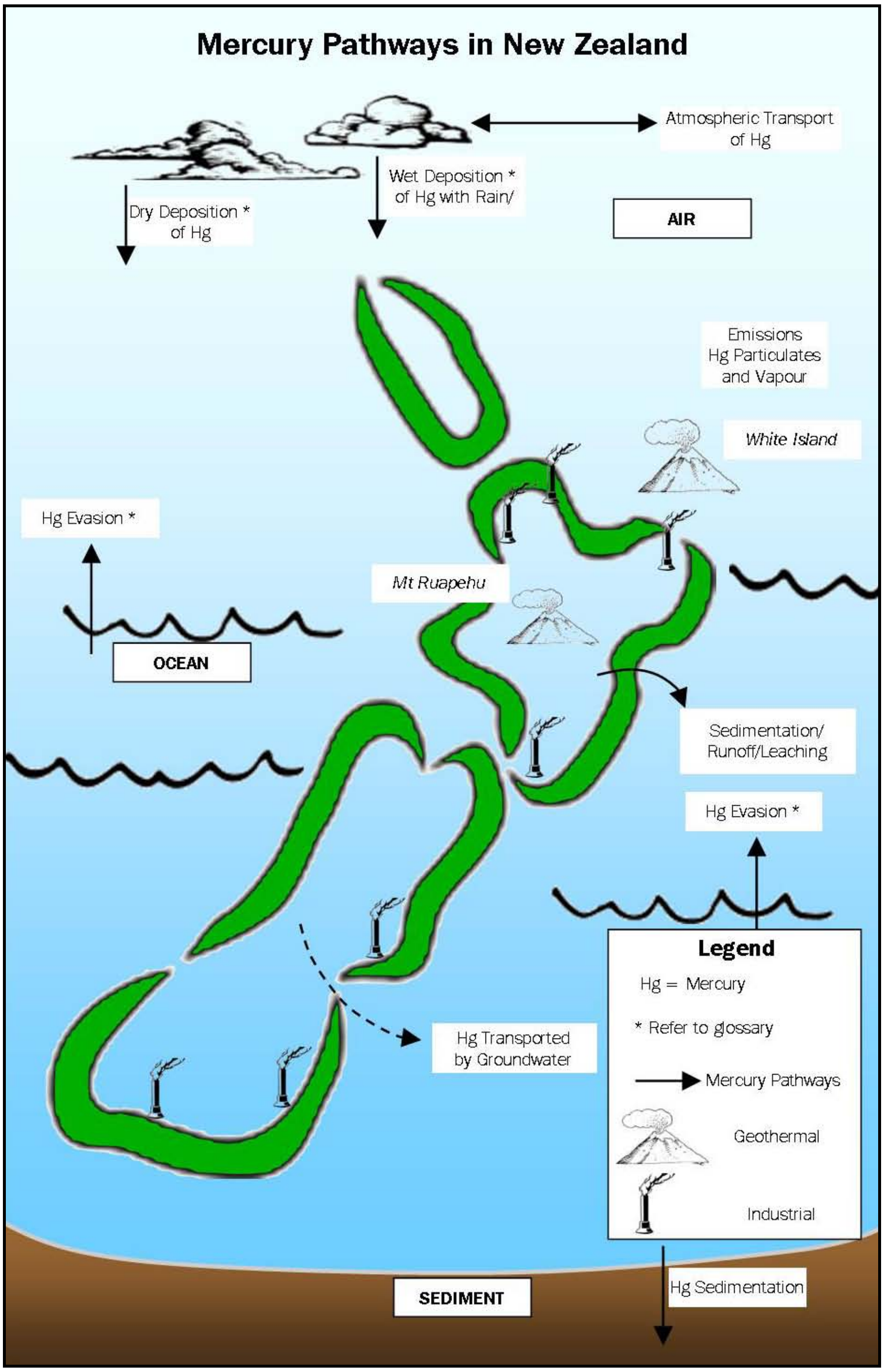

Figure I-2: Mercury pathways in New Zealand

Anthropogenic sources of mercury in New Zealand include air emissions from industrial activities, such as cement and steel manufacturing, geothermal power generation and coal combustion. These are all thought to be important sources of mercury into the environment. Additional sources include the incorrect disposal of mercury-containing items such as some electrical switches, medical equipment, electronic equipment, some dry cell batteries, some thermometers, fluorescent tubes, mercury-vapour discharge lamps and compact fluorescent lamps (CFL).

2.3 Transformations of Mercury in the Environment

The biogeochemical mercury pathways that occur in the environment are outlined in Figure I-3. A biogeochemical pathway is used to show how mercury moves through the living parts of the earth (biosphere) and non-living parts of the earth (lithosphere, atmosphere, and hydrosphere). An understanding of these pathways is important to understanding how mercury can be a risk to living species, including humans.

Mercury is transformed between different forms by two main types of reactions, oxidation-reduction and methylation-demethylation. Oxidation-reduction reactions refer to the loss of electrons (an increase in the oxidation state of mercury) and gain of electrons (reduction in the oxidation state of mercury). Methylation-demethylation is the process of gaining and losing a methyl group (CH_3). Methylation is primarily assisted by microorganisms (bacteria) under oxygen-poor (anaerobic) conditions that exist in sediments and soils (State of Utah, 2009). However, the process of methylation can be carried out by chemical processes that do not involve living organisms (abiotic processes) (UNEP, 2002). Oxidation-reduction reactions can occur in all areas of the environment, whilst methylation-demethylation reactions more commonly occur in the water and land environments.

A description of the transformations and transportation of mercury forms within the atmosphere, land and water environments follows.

2.3.1 Atmosphere

There are many different physical and chemical transformations and reactions occurring between the various mercury compounds that exist in the atmosphere. Mercury enters the atmosphere from various natural and anthropogenic sources. Volcanoes, for example, emit particulate mercury in mercury-containing minerals and salts, and elemental mercury as vapour. Industry and mining also emit these forms of mercury, and can also emit other more complex forms of mercury compounds.

Once emitted to the atmosphere, elemental mercury can be readily circulated within it, or oxidised to inorganic (Hg(II)) compounds. These compounds can be similarly reduced back to elemental mercury in the atmosphere. The form mercury adopts in the atmosphere dictates its mobility and distribution potential, and this has consequences for the control of mercury emissions.

Mercury from the atmosphere can be deposited to land or water by either “wet” or “dry” deposition. Wet deposition occurs when mercury is dissolved into water droplets (either by rain or other types of precipitation) and returned to land or water. The process of wet deposition is efficient at removing divalent (soluble) forms of mercury from the air. Dry deposition is where mercury is removed via settling and scavenging processes (such as absorption onto plant foliage or chemical reactions with other gaseous compounds and suspended particulate matter). Dry deposition is more likely to remove particulate forms of mercury from the ambient air, and can also remove gaseous mercury forms.

About 80% of the total mercury in the atmosphere is in the form of elemental mercury vapours (Wang *et al*, 2004). Due to its high volatility, elemental mercury can remain in the atmosphere for 1 to 2 years, which results in the long range transport of mercury across country borders as part of the global circulation of mercury (Lin and Pehkonen, 1999). Compared to Hg(0), Hg(II) has a much shorter lifetime in the atmosphere; from several days to a few weeks (Lin and Pehkonen, 1999).

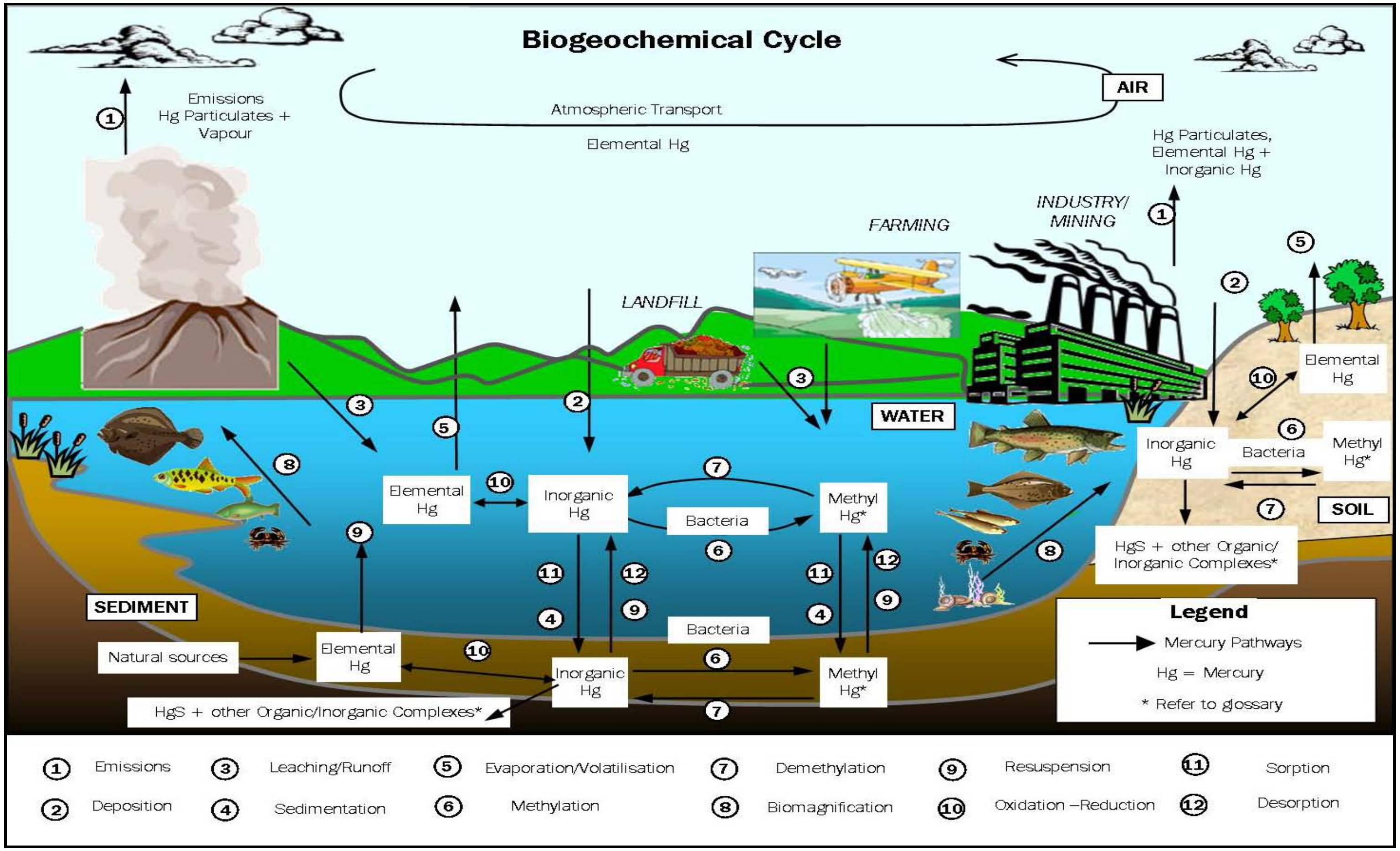

Figure I-3: Mercury biogeochemical cycle

2.3.2 Land

As previously described in Section I-2.1.2, mercury exists naturally in the land environment, for example in the mineral cinnabar (HgS) or as a trace component in all sedimentary, igneous and metamorphic rocks. Mercury compounds in the land/soil environment can also be a result of atmospheric deposition. Mercury compounds in the soil can undergo oxidation-reduction reactions, where oxidised mercury Hg(II) can be reduced to elemental mercury, Hg(0). This reaction can then be followed by volatilisation of elemental mercury, where mercury is re-emitted to the atmosphere, or can be followed by leaching or runoff, where Hg(0) is transported to the water environment.

In the soil layer, mercury can also form complexes with inorganic and organic compounds via a series of reactions including methylation. The formation of mercury complexes can make the mercury less mobile, causing it to remain in the soil for long periods of time.

The mobility of mercury in the soil layer depends on many factors. It can be mobilised if attached to organic matter that is subsequently washed into waterways by runoff (UNEP, 2002), or if it binds to soluble compounds; or conversely, it can be immobilised if it is strongly bound to insoluble compounds. In areas of soils with high levels of mercury accumulation, mercury can continue to be released into other environments for long periods of time (UNEP, 2002). The average residence time of mercury in soil has been estimated as being in the order of 1,000 years (NRC, 1979).

2.3.3 Water

Mercury enters the waterways via deposition of particles or ionic compounds from the atmosphere, runoff and erosion from the land surface, leaching from landfills, geothermal inputs, combustion and industrial discharges. Once in the water environment, mercury undergoes similar oxidation-reduction, sorption-desorption processes on to mineral surfaces and organic matter, and methylation-demethylation reactions as occur in the land environment.

In a similar manner to the land environment, elemental mercury can be evaporated back to the atmosphere directly from water (this process is also called evasion) or it can be oxidised to form Mercury(II). This ionic form of mercury can then be either reduced back to elemental mercury and again evaporate to the atmosphere, or it can form methylmercury. Mercury(II) can also form complexes with organic matter or be sorbed onto suspended particulate matter within the water environment. Mercury(II) complexes are thought to be the dominant form in which mercury is found in natural waters. Mercury(II) complexes can be transported over very long distances (Lin and Pehkonen, 1999).

The methylation reactions in the water environment are of particular concern due to the bioaccumulation of methylmercury in aquatic species. As a result, top-level predators acquire greater body burdens of mercury than the fish they consume. Bioaccumulation and biomagnification within the food chain can result in top-level predators (fish-eating fish, birds and humans) having bioaccumulation factors of the order of 10 million (Sigel and H. Sigel, 1997). In other words, concentrations within the bodies of these predators can be 10 million times higher than the environments in which they live.

Both oxidised mercury(II) and methylmercury can be deposited into the underlying sediments, where similar processes and transformations occur as those described for the land environment.

Sediments at the bottom of water bodies can act as mercury sinks from which mercury can be distributed back into circulation for many years after initial deposition (UNEP, 2002).

The residence time of mercury in the oceans is up to 3,200 years, while the average residence time of mercury in oceanic sediments is in the order of 250 million years (NRC, 1979).

2.4 Mercury Problems in the Environment

2.4.1 Anthropogenic (Man-Made) Transformations of Mercury

Many of the transformations of mercury between the different parts of the environment are caused by anthropogenic or man-made processes and activities. It is estimated that approximately one third of mercury currently emitted to the atmosphere is sourced from anthropogenic or man-made activities (UNEP, 2008b).

Over the years, humans have mined and used mercury in many different products ranging from electrical switches, batteries, thermometers, medical equipment, dental amalgams, fluorescent tubes, discharge lamps and, more recently, in energy-efficient lamps. In addition to these intentional uses, humans have carried out various activities that cause unintentional mercury emissions. Such activities include fossil fuel combustion, mining and metal extraction, chloralkali production (used to produce chlorine gas and caustic soda used in many chemical and industrial processes), and waste incineration. These anthropogenic activities have increased atmospheric concentrations of mercury by a factor of three, on average, since pre-industrial times (UNEP, 2008b).

Greater emissions caused by anthropogenic or man-made activities are of concern when mercury is re-deposited to both the ocean and land environments and converted to toxic organic mercury compounds. As previously described, these transformations (such as methylation forming methylmercury), are mostly assisted by bacteria under oxygen-poor conditions. Such bacterial transformations in landfill soils, for example, can act to mobilise mercury from mercury-containing products such as crushed lamps into water and the food chain, presenting a risk to humans and other living organisms.

2.4.2 Potential Mercury Problems in New Zealand

The general mercury pathways in New Zealand’s environment were described in Section I-2.2. Mercury emissions in New Zealand are derived from a mix of both anthropogenic and natural sources, with mercury from geothermal activity notable in many places throughout the country. The breakdown of the various sources is discussed in Section III.

As mercury is a toxic, too much mercury can potentially result in a number of adverse effects. These include:

- Toxicity to plants (aquatic plants, grass, herbage or crops);
- Toxicity to micro-organisms (including toxicity to soil microbes which fix nitrogen from the atmosphere);
- Toxicity to higher animals (fish, grazing stock, wildlife);

- Increased dietary intakes in the human population (mainly linked to more mercury in fish);
- The exceedance of food standards in plant or animal products grown on mercury-enriched soil;
- The creation of contaminated sediments and contaminated land, with associated effects, to humans, animals and plant life; and
- Risk of contamination of groundwater or potable water.

Of these, most global concern has been over the issue of accumulation of anthropogenic mercury from diffuse sources in aquatic ecosystems. This concern is most strongly felt in large continental areas with significant industry, such as the United States and continental Europe. Bioaccumulation and biomagnification of mercury may result in adverse effects on the aquatic animals and associated wildlife, but can also cause increased dietary intakes of mercury in the human population due to higher concentrations of methylmercury in fish. The greatest proportions of anthropogenic loadings of mercury in the global environment are generated by fossil fuels, industrial, and mining activity. When added to natural loadings, these artificial loadings may present a risk to the environment.

In practice, mercury concentrations in the New Zealand environment are sufficiently low that it is rare to encounter the adverse effects listed above. Section III of this report provides more information regarding these risks associated with mercury emissions in New Zealand.

There is limited evidence of problems from mercury in New Zealand. However, with respect to fish the New Zealand Food Safety Authority (NZFSA) has issued precautionary advice for pregnant women to limit their consumption of long-lived and predatory fish species at the top of the marine food chain (e.g. school shark, bluefin tuna), and trout caught from lakes in geothermal areas.

For trout, mercury concentrations in fish caught in North Island geothermally-influenced lakes are significantly greater than those of trout caught in other lakes (e.g. Kim, 1995). A section of at least one lake bed (Lake Waikare in the Waikato region) is contaminated with mercury, to levels that may prevent germination of aquatic plants, as a result of a natural geothermal spring in the lake.

Some geographically localised areas of elevated mercury exists as a result of industrial activities. Some specific areas of potential concern are:

- Operation of the Wairakei Geothermal Power station causing a local discharge of additional mercury to Lake Aratiatia (Timperly and Hill, 1997), Lake Ohakuri (Rumsby and Coombes, 2008) and other hydrolakes along the Waikato River;
- Elevated levels of heavy metals (including mercury) prevent plant growth and entering local waterways at some old mine tailings disposal sites, such as the Tui Mine site at Mt Te Aroha; and
- Sediments of the lower Firth of Thames known to have higher levels of mercury than those of comparable harbours. Two possible sources are historic mining activities on the Coromandel Peninsula, and organic-mercury drainage from the Hauraki peatlands (Kim, 2007).

Monitoring of coastal marine sediments in some locations has revealed some areas of elevated mercury concentrations which exceed ANZECC (2000) Interim Sediment Quality Guidelines-low (ISQG-low) values, possibly from run-off from urban areas. These include some areas of the Waitemata and Manukau Harbours in Auckland (McHugh and Reed, 2006) and Wellington Harbour (Stephenson *et al*, 2008).

It should be noted that there is generally little evidence for *actual* adverse environmental effects from mercury in most of the cases cited above.

The disposal of mercury-containing consumer products, (especially CFLs) into landfills has been raised as a potential concern. At this stage there is no well-recognised waste disposal facility to deal with used lamps New Zealand. Most commonly, these lamps are disposed of with household refuse to landfill. It is estimated that 98% of mercury-containing lamps are disposed to the 60 landfills that currently operate in New Zealand, with only 2% recycled. This means approximately 5,400,000 lamps are disposed of to landfill each year (Stewardship Solutions, 2008).

The effect of this and past disposal of mercury-containing consumer products into many closed landfills which were not up to current landfill standards, is not known. Much of the mercury in current and closed landfills is probably in bound forms. Modern landfills are also lined to contain leachate and have leachate collection and treatment systems. It is therefore probable that there is very limited release of mercury from closed and operating landfills.

The potential impact on the environment from discharges of mercury from landfills is examined in greater detail in Section III-3.4 of this report.

3 Conclusion

Mercury is a toxic, naturally occurring heavy metal. It occurs in three forms, elemental mercury (as a liquid or vapour), inorganic mercury compounds and organic mercury compounds. It is readily transformed from elemental and inorganic forms into its most toxic form, the organic compound methylmercury, by soil bacteria in oxygen-poor conditions.

Elemental mercury and inorganic and organic mercury compounds can be transformed in the environment from one form to another in a series of complex processes. In general, however, elemental mercury exists mostly in the atmosphere, while inorganic and organic mercury compounds exist mostly in land and water environments.

Sources of mercury in New Zealand fall broadly into two categories:

(a) Natural sources in land, soils, air and water and, notably in New Zealand, from volcanic and geothermal activity; and

(b) Anthropogenic sources from various industrial, chemical, medical and dental, electrical and domestic applications, including mercury-containing lighting equipment and lamps.

Globally, most concern has been expressed over the accumulation of anthropogenic mercury from diffuse sources in aquatic ecosystems. Bioaccumulation and biomagnification of mercury may result in adverse effects on the aquatic animals and associated wildlife, but can also cause increased dietary intakes of mercury in the human population due to higher concentrations of methylmercury in fish.

There is limited evidence that mercury exposure is of concern in New Zealand. Apart from occupational exposure in some specific occupations (dental workers), eating long-lived predatory fish, or fresh water fish caught in geothermal regions, is the most likely route for mercury exposure in New Zealand.

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Section II – Mercury Contributors

1 Introduction

This section of the report aims to identify and quantify, where possible, both the natural and anthropogenic contributors of mercury in New Zealand as of 2008. The United Nations Environmental Programme (UNEP) *Toolkit for identification and quantification of mercury releases* (UNEP, 2005) (henceforth referred to as the UNEP Toolkit) has been employed for this analysis. The sub-sections outlining the anthropogenic sources follow the categories and numbering system provided in the UNEP Toolkit.

This section commences with a brief methodology of the identification and quantification process (Section II-2). This is followed by a description and quantification, where possible, of the natural sources of mercury, followed by the anthropogenic sources. The assessment includes discussion on mercury-containing food, in particular fish species in New Zealand.

A number of sources identified in the UNEP Toolkit could not be quantified because of a lack of data. These are discussed in Section II-4.

Finally, in Section II-6, the mercury emissions for New Zealand are compared with six other OECD (Organisation for Economic Cooperation and Development) countries, being Ireland, Denmark, Canada, Australia, the United States, and the United Kingdom.

2 Methodology

The UNEP (2005) *Toolkit for identification and quantification of mercury releases* was employed to carry out this analysis (UNEP Toolkit). The UNEP Toolkit was generated as a guidance tool to assist countries in managing mercury pollution as part of the UNEP's Mercury Programme. The programme was established following the UNEP (2002) *Mercury Assessment Report* to the UNEP Governing Council in 2003, which stated that there was reason to warrant further international action to minimise the effects on humans and wildlife from the release of mercury in the environment. The UNEP established the programme for mercury with the role of encouraging countries "to adopt goals and take actions, to identify exposed populations, minimise exposures through outreach efforts, and reduce anthropogenic mercury releases" (UNEP, 2005).

The Toolkit allows standardised mercury reporting for regions and countries and therefore comparable mercury datasets. It was hoped that the generation of the toolkit, and subsequent adoption of the toolkit by countries around the world would lead to establishing a global picture of mercury emissions and therefore assist in prioritising actions to control and reduce mercury emissions (UNEP, 2005).

The Toolkit is in "Pilot Draft" form. An update of the toolkit was due to have been released but was not available at the time of carrying out this inventory. The Toolkit was used for the New Zealand mercury inventory as it represents international best practise in mercury emissions reporting.

Acquisition of data needed to complete the Toolkit required making contact with various industries within New Zealand, including the lamp industry, mining, petroleum, steel, cement and lime industries, medical and dental industries, and power generation and transmission companies, to obtain their estimates of mercury content in their raw materials or products so as to calculate emissions. Her Majesty's Customs and New Zealand Statistics were also contacted for data on mercury and mercury-containing product imports into New Zealand. Energy statistics relevant to the use of coal, natural gas and liquid fuels, and generation of geothermal power, were sourced from the Ministry of Economic Development (MED) and the Electricity Commission.

Scientific information sources searched included scientific publications and periodicals, UNEP Mercury programme on-line sources, and similar sources from other countries, such as the United States Environmental Protection Agency (US EPA) and European Commission mercury programmes.

3 Sources of Mercury

As outlined in Section I, in New Zealand mercury is released into the environment by both natural and anthropogenic (man-made) sources. Mercury is a naturally occurring element that can either be completely inert within the earth (i.e. within the mineral cinnabar), or in an active form when emitted into the atmosphere from volcanoes and other geothermal sources, from the soil, or discharged to water.

Anthropogenic emissions occur from products that intentionally contain mercury, such as lamps, some dry cell batteries and thermometers, and those in which mercury is present as a minor impurity, such as some fertilisers and accumulated in sewage sludges. Commercial products involving intentional mercury use are theoretically ‘safe’ until they are broken or thrown away, after which the mercury content may be released into the environment.

Anthropogenic sources of mercury also include emissions that occur as a by-product of certain industrial and manufacturing processes e.g. mining and processing of ore, and cement manufacturing. Trace levels of mercury can exist in the raw material and be mobilised and released during processing. Mercury is also released from fuels (e.g. coal) used as a raw material or source of heat in the processing.

3.1 Natural Sources

There are three main natural sources of mercury in New Zealand; volcanoes, volatilisation (emissions to air) from soils and emissions from other geothermal sources to the atmosphere, soil and water, in order of decreasing emissions. Volcanic emissions are estimated to average 800 kg/year (Nriagu, 2003), emissions from soils are estimated to be 500 kg/year (Eckley and Branfireun, 2008; Kuiken *et al*, 2008; Carpi and Lindberg, 1998; Gustin *et a.*, 2008; Erickisen *et a*,, 2006; Tsiros and Dimopoulos, 2003 and Nriagu, 1989) and other geothermal emissions are estimated to be 194 kg/year (Simmons and Brown, 2007; Timperley and Hill, 1997). The total from these sources is approximately 1,500 kg/yr (rounded to two significant figures).

It should be noted that the discharges from geothermal and volcanic discharges of mercury are highly variable. A moderate size eruption such as those observed from Mount Ruapehu from time to time can emit between 100 to 200 kg Hg/day. A single larger eruptive event could potentially double the average annual flux of mercury emitted from natural sources (Nriagu and Baker, 2003; Gustin *et al*, 2008).

A minor source of mercury is forest fires. Plants contain a small amount of mercury which is released to the atmosphere on combustion. Some research has been done on mercury emissions from forest fires in Oceania (Pirrone *et al*, 1996). Based on this research the amount of mercury released from forest fires in New Zealand (excluding wood burning for heating purposes) is likely to be very low (less than 10 kg/year) when compared to other natural sources.

Biogenic emissions are from the biologically mediated processes in both the terrestrial and marine environments. These processes may contribute a significant proportion of the total mercury emissions to the atmosphere (Nriagu, 1989; Lindberg *et al*, 1998), however, there are no reliable estimates regarding the amount of mercury emitted from biogenic sources within New Zealand. Therefore this report may underestimate the total amount of mercury released from natural sources.

Figure II-1 shows the proportions and total from natural sources (forest fires sources are omitted as being negligible relative to the other sources).

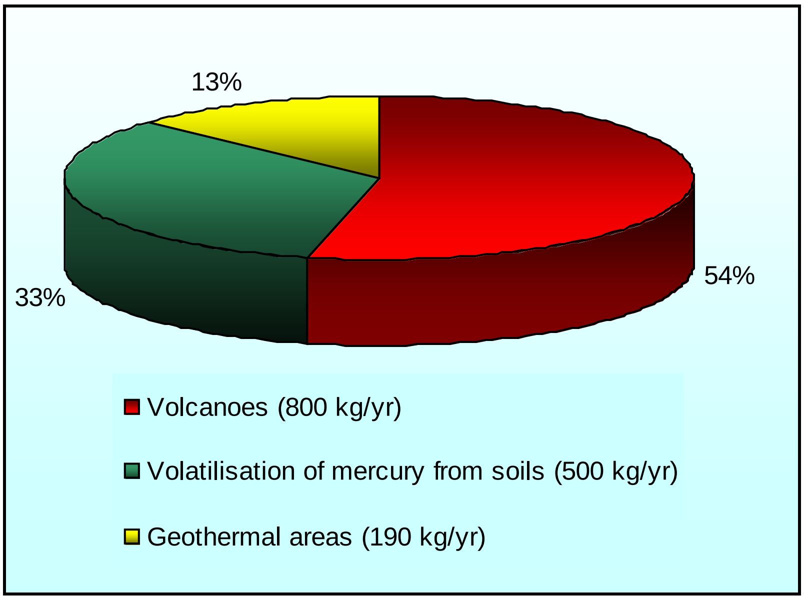


Figure II-1: Natural sources of mercury emissions in New Zealand

3.2 Anthropogenic Sources

Mercury emissions and other releases from anthropogenic sources in New Zealand that were able to be quantified are estimated to total approximately 1,400 kg/yr. The breakdown of individual sources follows.

The classification of anthropogenic sources closely follows that provided in the UNEP Toolkit (2005). Each section heading relates to the appropriate chapter from the Toolkit. For example, the extraction and use of fuels/energy sources refers to Chapter 5.1 in the toolkit, with the Toolkit chapter number appended to each section heading in brackets.

Some anthropogenic sources of emissions could not be quantified and therefore could not be included in the estimated total given above. Sources that could not be quantified are listed in Section II-4 of this report.

Where information on mercury emission rates was not available to calculate totals for specific suspected emitters in New Zealand, UNEP default emissions factors were used.

3.2.1 Extraction and Use of Fuels/Energy Sources (5.1)

The extraction and use of fuels and energy sources includes coal combustion (including for power generation); extraction, refining and use of petroleum oil; use of natural gas and other fossil fuels; biomass power and heat production; and geothermal power production.

Coal

In the UNEP Toolkit (2005), coal combustion has been split into coal combustion and coal washing. Coal washing is used to remove the non-coal mineral content of the coal so it burns more efficiently. In New Zealand, coal washing does occur but no information could be obtained to determine how much mercury is released during this process, as it is not measured. It is thought that the amounts of mercury would be negligible, especially since this process is carefully managed (CRL Energy Limited, pers.com, February 2009).

Coal combustion occurs when coal is burnt to generate energy. This process can thermally release any mercury that is contained in the coal in trace concentrations. The average mercury content in New Zealand coals is estimated to be of 0.13 mg/kg (Moore *et al*, 2005)). Mercury from coal combustion is mostly released in the gaseous form (UNEP, 2005).

Huntly Power Station is estimated to emit up to 216 kg Hg/year (Environment Waikato, pers.com, February 2009). Huntly Power Station is responsible for 92% of New Zealand's coal-fired power generation (Ministry of Economic Development, 2008), therefore, nationally, coal combustion for power supply is estimated to emit 237 kg Hg/year.

Coal combustion occurs in other industries in New Zealand in addition to power stations, in particular steel making, cement manufacturing, the dairy industry, and meat processing. Based on coal-use statistics (Ministry of Economic Development, 2008), the mass of mercury emitted from each of these non-power station sources, except cement and steel manufacturing, is estimated to be: dairy industry (39 kg Hg/year), meat processing (16 kg Hg/year) and other industry (7 kg Hg/year), or a total of 62 kg/year.

A similar calculation was carried out for the cement industry, resulting in an emission estimate of 22 kg Hg/year. However, specific mercury emission data is available for part of the cement industry and this has been used in favour of the coal combustion-based estimate (Section II-3.2.3). Similarly, emissions from coal used in steel manufacturing have been accounted for in the steel-industry-specific calculations in Section II-3.2.2.

Oil

The Ministry of Economic Development's energy data file (MED, 2008) was used to establish the quantities of various petroleum products used in New Zealand, whether refined in New Zealand or imported as refined products. Average mercury contents were then obtained from the international literature, for the most part, to calculate mercury emissions from petroleum products. Little New Zealand-specific data was available on the mercury content of crude oil or liquid fuels, but this was used where available.

For crude oil refined in New Zealand, it was assumed that all the mercury in the crude oil is released either during refining or during subsequent use in vehicles, aircraft, boats and ships or for heating purposes. In other words, it was assumed none of the mercury was captured during the refining process, but either occurred as air emissions during refining, or as air emissions when used as a refined fuel. For imported refined product, an estimate of the mercury content in the product was used.

International concentrations of mercury in crude oil average 10 ppb, but with some values as high as 30,000 ppb (Pirrone *et al*, 2001, as cited in UNEP, 2005). In 2008 approximately 6.2 billion litres of fuels were used in New Zealand. Approximately 70% of that total was processed by New Zealand Refinery Company Limited (NZRC) at Marsden Point and 30% was imported as refined product (NZRC, pers. com. March 2009).

NZRC was contacted to obtain information on mercury within their crude oil feedstock. They reported that of the 36 shipments received at Marsden Point, only four had mercury determinations on their chemical assays. According to NZRC, these assays indicated a mercury content of 30.2 kg in the four shipments. NZRC advised that mercury determinations were undertaken on these four shipments because they were from sources known to contain high mercury and the other shipments were from sources which were not expected to contain elevated concentrations of mercury.

An approximate mass of 80 kg Hg/yr is estimated to be emitted from the refining of oil and use of liquid fuels in New Zealand. A number of assumptions were made to arrive at this estimate:

- In the absence of information on shipment size, it was assumed the four shipments with mercury assays represent 11% (4 out of 36) of the total crude oil shipped into Marsden Point (i.e. all shipments were assumed to be same size).
- The four shipments of high mercury crude oil resulted in 30.2 kg of mercury being emitted in New Zealand.
- The crude oil not analysed at NZRC (assumed to be 89% of the total crude imported into Marsden Point) had an average concentration 10 ppb.
- That approximately 55% of the mercury in crude oil is lost during the refining process (Wilhelm, 2001). If the crude starts out with an average of 10 ppb then refined petroleum products imported into New Zealand have an average concentration of 4.5 ppb.
- That the fuel used for international air and maritime transport from New Zealand (this was able to be quantified from the MED data) does not contribute significantly to New Zealand total mercury emissions, as most is discharged outside New Zealand's territorial boundaries.

Natural gas

The Maui natural gas field off the coast of Taranaki supplies about 80% of New Zealand's total gas requirements (Contact Energy Ltd, 2009). According to Shell Todd Oil Services, mercury has never been detected in natural gas in New Zealand (Shell Todd Oil Services, pers. com. February 2009), although it is unclear whether mercury is routinely tested for, or (when tested) what analytical detection limit was. It is probable that the gas does in fact contain low concentrations of mercury, and it is estimated that 60 kg Hg/year could be released into the environment from the combustion of natural gas in New Zealand.

This is based on 4.7 x 10^9 m^3 of natural gas being used in New Zealand in 2008 (MED, 2008) and assuming the average mercury concentration in natural gas is 13 µg/m^3 (geometric mean of reported mercury concentrations in natural gas from a variety of international sources (Ceccarelli *et al*, 1993; Chen *et al*, 2000; Chongprasith *et al*, 2001; Isensee, 1982; Mirsra *et al*, 1993; Ozerova *et al*, 1974; Ozerova, 1975 and Tunn, 1973).

Biomass combustion

Many countries still rely on combustion of biomass e.g. wood for power and heat generation (UNEP, 2005). As mercury is a naturally occurring element, it will be present in trace levels in wood, depending on soil and atmospheric concentrations of mercury.

An estimated 2,085,061 tonnes of wood was burned for home heating in the year 2004 (Wilton, 2005). However, concentrations of mercury have not been measured in New Zealand trees or wood products. Overseas literature (Pang, 1997) has reported a concentration range of 0.20 – 37 mg Hg/tonne. Based on this range, there is a potential release of 0.4 – 77 kg of Hg/year in

New Zealand. Assuming an average concentration of 5 mg/tonne would yield 10.4 kg Hg emissions/year for 2004. It is likely more wood was used in 2008 than 2004, however given the uncertainty in mercury content of wood, the 2004 estimate is considered reasonably representative of the likely 2008 emissions.

As noted earlier, forest fire emissions are thought to be less than 10 kg Hg/year.

Geothermal electricity generation

Geothermal electricity production sites in New Zealand include Wairakei Power Station and Broadlands-Ohaaki Power Station (New Zealand Institute of Chemistry, 1998). Wairakei Geothermal Power Station discharges approximately 46.5 kg Hg/year (Timperley and Hill, 1997) directly into the Waikato River and discharges approximately 72.5 kg Hg/year into the atmosphere (Contact Energy, 2009). Simmons and Brown (2007) estimated that approximately 38 kg Hg/year is discharged via the Ohaaki geothermal field. Unlike Wairakei, spent geothermal fluid from Ohaaki is reinjected into the ground and therefore does not contribute to emissions to the nearby Waikato River.

The Contact Energy resource consent application for the Te Mihi project indicates that the Poihipi (55MW installed capacity) and the Rotokawa (33 MW installed capacity) geothermal power stations discharge approximately 35 kg Hg/year and 23 kg Hg/year respectively (C. Stevenson, 2009). Several other geothermal power stations have an installed capacity of approximately 240 MW (Ngawha, Kawerau, Mokai – MED, 2008). Based on the information for Wairakei (operating at an annual average of 155MW), Ohaaki (operating at 40MW), Poihipi and Rotokawa it is estimated these other stations could contribute an additional 140 kg Hg/year. Therefore, mercury emissions from geothermal electricity generation may result in up to 350 kg mercury being released each year.

Summary of fuels and energy sources

The results for the extraction and use of fuels and energy sources for New Zealand are provided in Table II-1 and Figure II-2 below.

Table II-1: Contribution from extraction and use of fuels/energy sources

Fuel Source	**Mercury Emissions (kg Hg/year)**
Coal Combustion- Power plants	240
Geothermal	350
Coal Combustion - other	60
Oil Refining	80
Combustion of Natural Gas	60
Biomass Combustion	10
Total	800

Note: Results have been rounded to nearest 10.

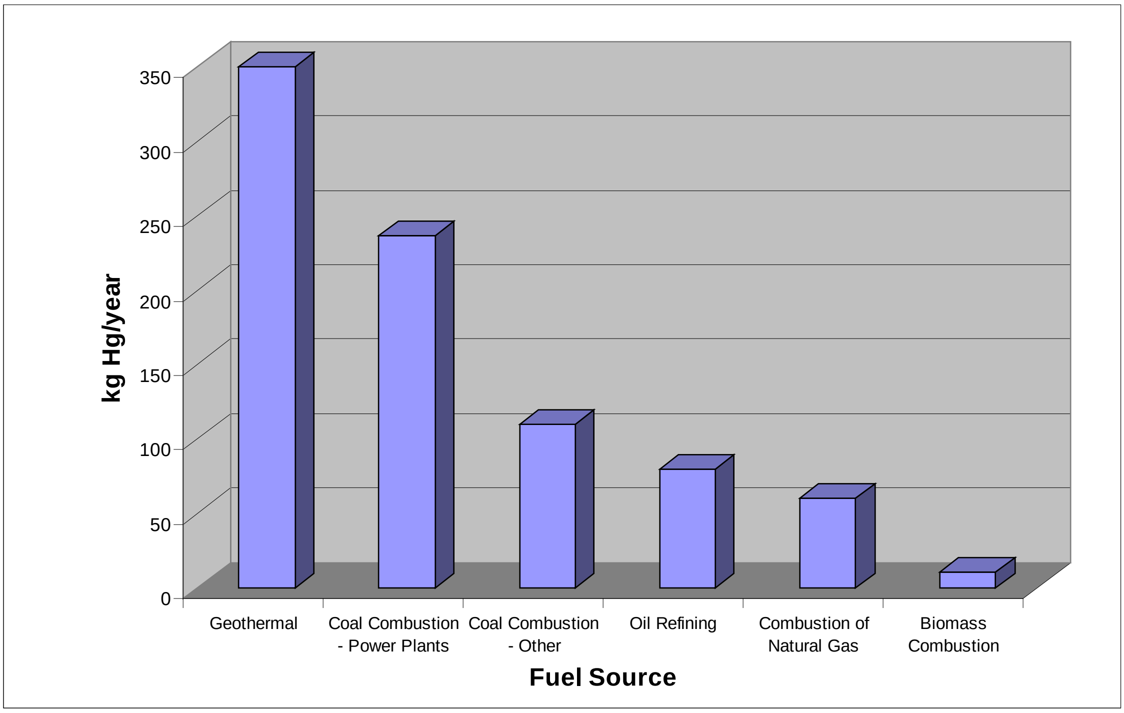


Figure II-2: Contribution from extraction and use of fuels/energy sources

3.2.2 Primary (Virgin) Metal Production (5.2)

Primary (virgin) metal production includes extraction and processing of mercury, zinc, copper, lead, aluminium and other non-ferrous metals. It also includes gold and silver extraction by processes including the mercury amalgamation process, and primary ferrous metal production. Mercury emissions from primary metal production can occur when mining mercury itself, or where mercury is present as an impurity in the ore being mined. There is no mercury ore mining in New Zealand, although historic mining was carried out.

Mining and processing of minerals in New Zealand currently includes gold extraction (Waihi Mine, Waihi and Macraes Mine, Otago), aluminium processing at Tiwai Point in Southland and primary ferrous metal production (New Zealand Steel at Glenbrook).

Mercury is sometimes used around the world intentionally for recovering gold from the crushed ore or alluvial deposits. This can contribute to mercury emissions. In New Zealand, however, this process is no longer carried out at a commercial scale, with cyanide being used for gold extraction since the late 1800s (New Zealand Institute of Chemistry, 1998; MED, 2004). The much higher efficiencies using the cyanide leaching process (90% of gold recovered compared with 45% using the mercury amalgam process) meant that it rapidly became the major extraction process for large scale commercial mining.

The use of mercury amalgam may still occasionally occur for small-scale artisanal or hobby gold mining, but it is expected that its use has largely been discontinued in New Zealand. No data exists, and therefore no estimate can be made, for the use of mercury in small-scale gold mining in New Zealand.

Approximately 11 tonnes of gold is produced per year in New Zealand (Crown Minerals, 2007) equating to very minor mercury emissions from the ore (0.2 kg/Hg/year). Concentration of mercury in wastewater at Waihi gold mine (Waikato region) has been below the practical quantitation limit (PQL) of 0.0008 ppm and similarly at Macraes gold mine (Otago region) the mercury concentrations in the tailings are below the PQL of 0.021 mg/kg. As the mercury content is low in the tailings, and also as it is not very leachable, the concentration of mercury resulting in the discharge overall from the gold mines is likely to be very small (less than 1 kg).

Aluminium is manufactured in one location in New Zealand at the Tiwai Aluminium Smelter near Bluff. The raw material for aluminium manufacture is the mineral bauxite, which contains small amounts of mercury. However, bauxite is not refined in New Zealand, being carried out in Australia prior to export to New Zealand. The refining process involves extracting alumina (aluminium oxide) from the bauxite. During this process the majority of the mercury in the bauxite would be removed. The alumina is then transported to New Zealand where the smelting using electricity is undertaken. New Zealand Aluminium Smelters Limited (NZASL) confirmed that there has been no detectable mercury in their raw materials imported from overseas (NZASL, pers. com, March 2009). No information is available regarding emissions, as resource consents for the site do not require any mercury monitoring in either the waste materials or in the receiving environment.

All of New Zealand’s primary ferrous metal production occurs at Glenbrook, near Auckland, using iron sand as the raw material. No mercury emission data was available for the mill and the UNEP default emission rate was used. It is estimated that approximately 26 kg/Hg/year of mercury is emitted from primary ferrous metal production, using an emission rate of 0.04 g Hg/tonne of steel (UNEP, 2008). The total steel production from Glenbrook is 650,000 tonnes per year (New Zealand Steel, pers.com, February 2009).

It is not clear whether the UNEP emission rate includes emissions from coal and coke used in the smelting process, or whether it is for emissions from the iron ore. However it has been assumed the emission rate is all-inclusive so as not to double count. It should also be noted that the Glenbrook mill uses a unique electric smelting process for the iron sands, resulting in less coal use than conventional mills, which use coal as a source of heat and as a source of carbon to convert iron to steel. This may mean that the UNEP emissions rate results in an over-estimate.

The contributions of mercury from primary metal production in New Zealand found in this study are displayed in Table II-2 and Figure II-3.

Table II-2: Contribution from primary (virgin) metal production

Primary Metal Production	Mercury Emissions (kg Hg/year)
Ferrous	26
Gold	<1
Aluminium (smelting from alumina)	0

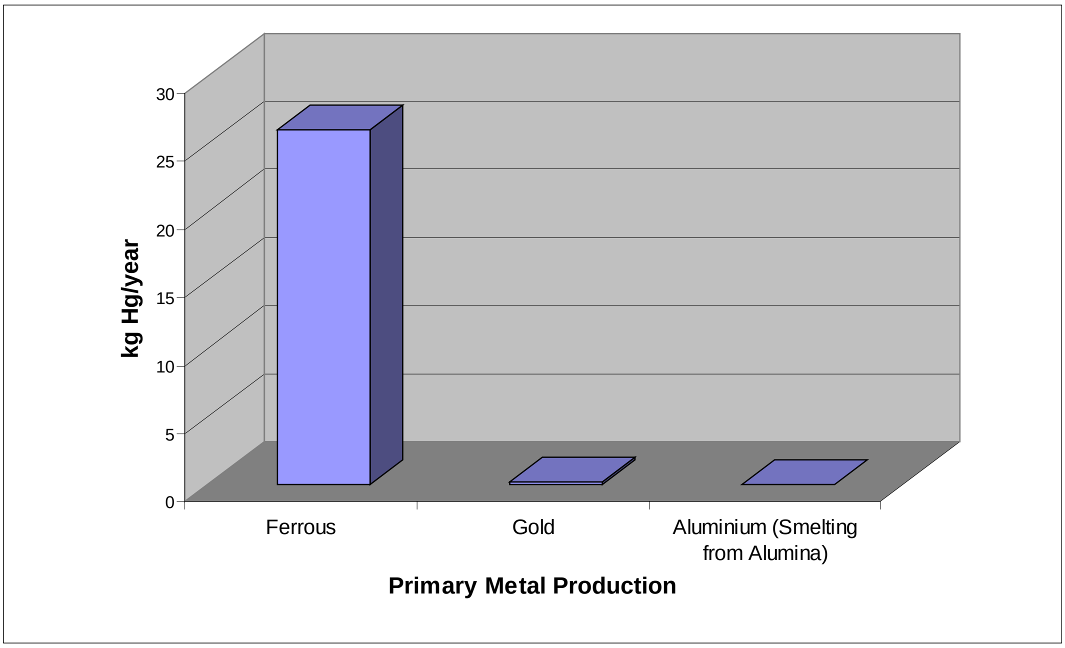


Figure II-3: Contribution from primary (virgin) metal production

3.2.3 Production of Other Minerals and Materials with Mercury Impurities (5.3)

The UNEP Toolkit (2005) refers to other minerals and materials with mercury impurities such as cement production, pulp and paper production, burnt lime production, and light weight aggregate kilns. Cement, pulp and paper, and burnt lime are all produced in New Zealand.

Cement

Cement is produced at two locations under two brands: Holcim's Milburn brand in Westport and Golden Bay Cement in Whangarei. Mercury is routinely monitored twice annually by Holcim and is reported in their annual report. No information was available for Golden Bay.

The average mercury emission at Holcim's Westport plant to air was 0.002 g/tonne of cement produced in 2007 but averaged about 0.007 in the preceding three years (Holcim, 2007). Holcim's international average is 0.02 g/tonne (Holcim, 2009). Holcim's production of cementitious material (clinker) was 458,000 tonnes in 2007, with about 510,000 tonnes of cement being produced. At an average of 0.007 g Hg/tonne the Westport works would have emitted 3.2 kg Hg/year in 2007. The Westport plant operates at close to capacity. The 2008 mercury emission rate is expected to have been similar.

New Zealand produces a total of 1,120,000 tonnes of cement per year (Cement and Concrete Association of New Zealand, pers. com, February 2009), with Golden Bay's share about 600,000 tonnes. Using the UNEP (2008) default emission factor of 0.1 g Hg/tonne/year for Golden Bay's production, results in a mercury release rate of 60 kg Hg/year.

The majority of the mercury emitted is from the fuels used in the cement making process (UNEP, 2008), principally coal. Given the estimated mercury emissions from coal use for the entire cement industry amounted to only 22 kg/year, based on the average mercury content for New Zealand coals (and ignoring pollution control equipment that will remove some mercury with particulate material), the estimate for Golden Bay of 60 kg/year using default emissions factors appears to be high. A better figure is probably of the order of 10 kg/year (i.e. roughly half 22 kg/year), therefore a total combined figure of 13.2 kg Hg/year has been used for Golden Bay and Holcim.

Pulp and paper

Pulp and paper manufacturing is a source of mercury emissions, from trace levels of mercury in the wood raw material, in fuels used for energy production, and in the chemicals applied in the processes (UNEP, 2005). A particular contributor in plants overseas is the manufacture of chlorine and caustic soda using the mercury cell chlor-alkali process. The chlor-alkali process is no longer used in New Zealand and elemental chlorine is no longer used for bleaching pulp and paper because of environmental concerns.

Pulp and paper manufacturing in New Zealand occurs mostly at plants in the North Island under the Carter Holt Harvey (CHH) and Pan Pacific Forest Industries brands (Pan Pacific). CHH operates the Kinleith and Tasman pulp mills at Tokoroa and Kawerau, respectively, with a combined production of 530,000 tonnes per year. Pan Pacific operates a pulp mill at Whirinaki near Napier, with a capacity of 260,000 tonnes per year.

CHH stated that mercury emissions are not currently monitored at any of the CHH plants (CHH, pers. com. February 2009). However, such monitoring has been carried out in the past. UNEP (2005) does not provide default emission factors for the pulp industry, because of a lack of data. Consequently, mercury emissions for the pulp industry have not been calculated, but are expected to be small (based on United States data presented in UNEP (2005)). Emissions from fuel sources have been accounted for elsewhere.

Lime

Production of burnt lime (otherwise known as quick lime) and hydrated (slaked) lime involves heating limestone at high temperatures in kilns. Mercury is expected to be present in very small quantities in the limestone and in some of the fuels. Production of burnt and hydrated lime is distinct from producing agricultural lime, which is simply crushed limestone rock. Although no data is available, production of agricultural lime is not expected to release significant quantities of mercury (i.e. <1% of total mercury emissions).

Much of the lime manufactured in New Zealand is produced by subsidiaries of Holcim (150,000 tonnes) however mercury emissions from lime production are not monitored by Holcim. Total burnt lime production in New Zealand amounted to approximately 175,000 tonnes in 2008 (back-calculated from carbon dioxide emission calculations, MfE, 2009).

No default emission factors are provided in UNEP (2005) for lime production. Average United States emission factors of 9 mg/tonne of lime produced for coal-fired kilns are reported in UNEP (2005). Applying this factor to 175,000 tonnes, results in mercury emissions of about 1.6 kg/year. Most of this will have been accounted in the coal combustion emissions, above. Given the apparent smallness of the non-fuel component of emissions, and the uncertainties in the emission factors, the non-fuel component has been ignored, arriving at an approximate emission rate of 1.4 kg Hg/year.

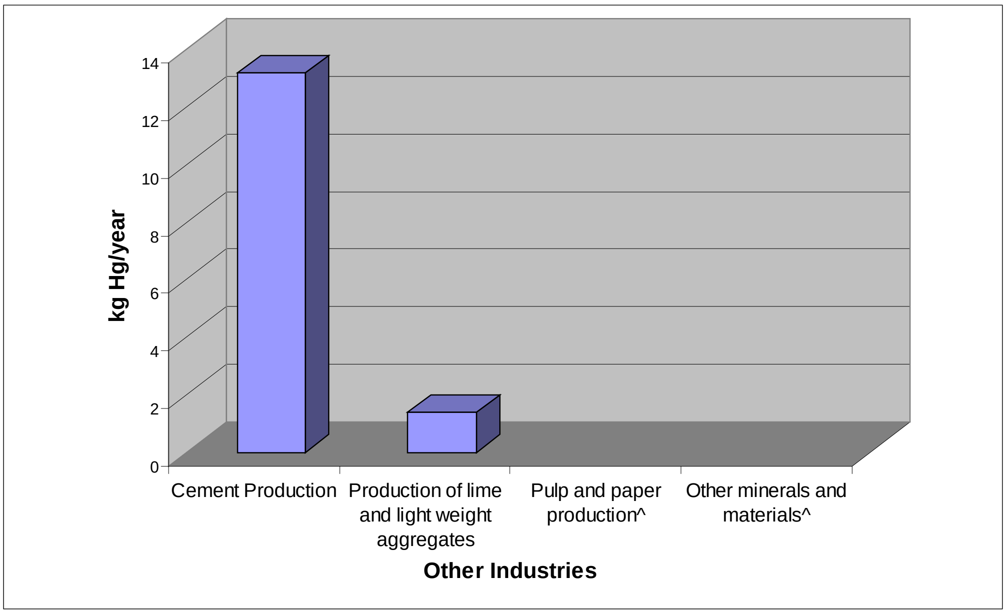
Other non ferrous products mined in New Zealand include, but are not limited, to aggregate and sand, limestone, dolomite, pumice, amorphous silica and iron sands. It is expected that mercury releases into the environment from the mining of these materials is minimal. Note that agricultural chemicals e.g. superphosphate are covered in Section II-3.2.5.

Table II-3 and Figure II-4 provide the data for mercury contributions from the cement industry in New Zealand. Due to uncertain data it was not possible to include contributions from industries which produce pulp and paper, and other minerals.

Table II-3: Contribution from production of other minerals and materials with mercury impurities

Other Industries	**Mercury Emissions (kg Hg/year)**
Cement production	13
Production of lime and light weight aggregates	1
Pulp and paper production	Data unavailable

Note: Results have been rounded to two significant figures.



^ No data available but thought to be small.

Figure II-4: Contribution of production of other minerals and materials with mercury impurities

3.2.4 Intentional Use of Mercury in Industrial Processes (5.4)

Mercury has been used in the past in a variety of industrial processes, including chlor-alkali production, vinyl-chloride-monomer production and acetaldehyde production (UNEP, 2005).

Chlor-alkali production – the process used to produce caustic soda ($NaOH$) and chlorine (Cl_2) – was historically used in New Zealand in pulp and paper mills. Mercury cells are employed in the chlor-alkali process. These can be a major source of mercury to the environment as mercury can be contained in the caustic soda and in waste products, mercury spills and leaks can occur, and mercury can escape as fugitive emissions (USEPA, 2003). Carter Holt Harvey had 21 mercury cell electrolysers in New Zealand but all of these were decommissioned about twenty years ago (Chemical Processes in New Zealand, 1998; Carter Holt Harvey, pers. com. 2009).

No other intentional use of mercury in industrial processes is known to occur in New Zealand, therefore no emissions can be reported.

3.2.5 Consumer Products with Intentional Use of Mercury (5.5)

A wide variety of consumer products historically contained mercury and some products still contain mercury. Common examples are thermometers, electrical switches and lamps. Mercury is also used in several types of batteries (in particular button batteries for small devices such as hearing aids), and pre-2003 antilock braking systems (ABS). Mercury is also a trace compound in electrical and electronic waste streams, where it is used in thermostats, sensors, relays, switching equipment and in liquid crystal displays (LCDs). All of these consumer products are still currently imported into and used in New Zealand.

Lamps

Mercury-containing lamps include linear fluorescent tubes (LFL), compact fluorescent lamps (CFL), high pressure mercury vapour lamps, high-pressure sodium lamps and metal halide lamps. In this inventory, the latter three lamps have been combined into one category, and are often grouped as high intensity discharge (HID) lamps. Members of Lighting Council New Zealand (LCNZ) imported 3,248,439 fluorescent tube lamps (type T12, T8 and T5), 2,522,190 compact fluorescent lamps (CFL/I and CFL/E), and 347,020 of other types of mercury-containing lamps into New Zealand in 2007.

The LCNZ members have various market shares in each light category; 93% of LFL imports, 96% of CFL-e [2] and 95% of HID, but only 46% of the CFL-i market (Stewardship Solutions, 2008). The market share percentages have been used to calculate the total number of mercury-containing lamps imported in order to calculate the total mercury content. Manufacture of lamps no longer occurs in New Zealand (the last factory having closed in 2000) therefore import data should represent all lamps now sold in New Zealand.

Using an average mercury concentration of 12 mg Hg/lamp for T12 fluorescent tube lamps (Jang, 2004), 4 mg Hg/lamp for T8 fluorescent tube lamps, 5 mg Hg/lamp for T5 fluorescent tube lamps and 50 mg Hg/lamp respectively for each of the other types of lamp (UNEP, 2005; Stewardship Solutions, 2008) gives a total potential mercury release rate of approximately 50.3 kg Hg/year. This assumes that the same numbers of lamps as are imported into New Zealand are disposed of each year. This assumption will be conservative. While publicity over recent years promoting CFL use has increased imports, given the typical long life of energy-efficient lamps, many of these lamps will still be in use.

Approximately 2% of mercury-containing lamps in New Zealand are recycled in Australia (Interwaste, pers.com, February 2009), with the remaining going to landfill. Therefore, the

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[2] There are two different types of compact fluorescent lamps: CFL-i and CFL-e. CFL-i lamps have an integrated ballast, while CFL-e lamps have non-integrated, or external ballast.

mercury release rate of 50.3 kg Hg/year should be reduced slightly to 49.3 kg Hg/year (i.e. 98% of 50.3 kg Hg/year).

Thermometers

Due to a lack of data, the number imported and quantity of mercury thermometers in circulation in New Zealand households cannot be quantified. In the past, mercury-containing clinical thermometers were common in households, however many will have been replaced with digital thermometers. It is expected that a proportion of the mercury thermometers remaining in circulation will be broken each year, releasing mercury into the environment within households and to landfills through disposal of the remains. This cannot be quantified on the available data.

Switches

Mercury is a component in many electrical switches such as displacement/plunger relays and tilt switches. Small electrical switches may contain 3.5 g of mercury, while larger industrial switches may contain as much as 3.5 kg of mercury (Draft Wisconsin Mercury Sourcebook, 1997). Mercury-containing switches are found in some cars in tilt switches for the boot light (although boot switches may also be mechanical). Each switch contains approximately 0.8 g of mercury (Ecology Centre Great Lakes United University of Tennessee, 2001). Such switches account for more than 99% of the mercury used in automobiles in the United States (Ecology Centre Great Lakes United University of Tennessee, 2001). It is not known how common such switches are in the New Zealand vehicle fleet.

United States data suggests that most non-US car manufacturers stopped using mercury in their cars' lighting systems in 1993 and US manufacturers did the same in 2002. About 67.5 million switches are still used in older cars and trucks in the United States. This suggests that mercury switches in cars will mainly be from US imports, which are uncommon in New Zealand, or other cars older than 1993. Light vehicle fleet statistics for December 2007 show that about 23% of passenger cars and light commercial in New Zealand were manufactured before 1993 (Ministry of Transport, 2009). The fleet statistics also show that 107,000 pre-1993 light vehicles left the fleet in the year to December 2007. However, this is based on vehicles not being relicensed for more than a year, and will overestimate the number of vehicles being scrapped (rather than just being taken off the road) by an unknown amount.

It is expected a similar number of pre-1993 vehicle will have left the fleet in 2008. If all of these cars contained one mercury boot-light switch and each switch contained 0.8g, then a maximum 86 kg of mercury was potentially released into the environment. However, as there is no information on the number of pre-2003 cars with mercury tilt switches, it is not possible to calculate the actual amount of mercury potentially released from these switches. It is known that many Japanese cars (e.g. Toyota, Nissan, Mitsubishi, Subaru), which make up a large proportion of New Zealand's fleet, do not contain mercury tilt switches[3].

For cars that do contain tilt switches, the switches could have been recovered during dismantling and disposed of appropriately, been disposed of to landfills where much of the mercury either remains in the devices or is bound up within the landfill, or remained in the scrap metal from where it may have been released during crushing of cars or during secondary steel production. However, much of New Zealand's scrap steel is exported, with the result that any mercury in the scrap will also be exported. Therefore, all that can be said with respect to mercury tilt switches is that perhaps a few to some tens of kilograms could have been emitted

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[3] See http://www.elvsolutions.org/educational.html

into the New Zealand environment in 2008. Given the uncertainties, a value has not been included in the inventory calculation.

Mercury switches are also found in some older ABS vehicle braking systems. Such systems are present in only some vehicle models, and only some systems prior to 2003 were mercury-containing. Two to three mercury-containing switches were used per ABS acceleration sensor and each switch has approximately 1 g of mercury (Clean Car Campaign, 2001). Calculating a total mercury release rate from vehicles in New Zealand would involve quantifying the number of vehicles in New Zealand manufactured and imported prior to 2003 with mercury-containing ABS systems, and then determining the number of switches in each vehicle. Such research has not been attempted. However, it is possible that thousands of pre-2003 ABS-equipped cars have been imported each year over a number of years, with each car containing up to a few grams of mercury. This would amount to several to tens of kilograms of mercury being imported in the braking systems each year. Many of those cars will still be on the road and therefore emissions will be minimal. However, as the cars get older it can be assumed that the cars will be taken off the road and dismantled at the rate of tens of thousands per year. At that stage, several kilograms of mercury could have been released into the environment if the switches are not safely disposed of.

The Ministry of Transport estimates that 158,000 light vehicles (cars and light commercial vehicles) left the vehicle fleet in 2007 (Ministry of Transport, 2009). The average age of vehicles leaving the fleet in 2007 was 17.5 years (i.e. built in 1989), with more than half the vehicles being older than that. While there is a range of ages scrapped, on average, few cars of that age will have mercury-containing ABS braking systems as ABS systems were generally only installed in higher priced or luxury cars of that age and then not all cars with ABS systems contained mercury. Few Japanese car models had such switches[4].

For the purposes of getting a feel for the potential quantities of mercury from ABS braking systems, if it is assumed that 5% of the vehicles taken off the road in 2008 had ABS brakes and each system contained 3 g of mercury, then this amounts to 23.7 kg of mercury having the potential to be released to the environment each year. Again, such a value has such high uncertainties that it has not been used in the inventory calculation.

Batteries

There are several different types of batteries that contain mercury. These include ‘button cells’ of silver oxide, zinc air and mercury oxide composition, in addition to some alkaline, and zinc carbon batteries. Silver oxide batteries are used in devices such as watches and calculators, zinc air and mercury oxide batteries are used in hearing aids, alkaline batteries are for general purposes, and zinc carbon batteries are commonly used in smoke alarms and clocks (Gershman, Brickner and Bratton, Inc., 1992 as cited in Draft Wisconsin Mercury Sourcebook, 1997).

There is no production of mercury-containing batteries in New Zealand. Data obtained from Customs New Zealand and Statistics New Zealand for battery imports was used to estimate the number of batteries used in New Zealand (Table II-4).

The data obtained from Customs included the quantity and gross weight of the batteries. Unfortunately this gross weight includes the packaging and therefore the data could not be used to accurately calculate the weight of each cell. For the smaller cells (less than an external volume of 300 cm^3) cell weights have been applied from other references and from information

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[4] See http://www.elvsolutions.org/educational.html

from battery retailers. For the larger cells (greater than an external volume of 300 cm^3) the customs data was used as it was assumed the packaging on these larger batteries would comprise only a small percentage of the weight.

The quantity of mercury in each category of imported batteries was calculated by multiplying the number of cells by their respective average individual weight and by the percentage of mercury estimated to be present in each cell. This approach may be an overestimate the amount of mercury that mercury contain but the information on actual mercury concentrations in batteries in New Zealand does not exist to better quantify the value.

It is assumed the majority of small batteries are disposed of in domestic rubbish to landfill, with the amount imported each year the same as the amount disposed of. The resulting release rate from batteries is estimated to be 168 kg Hg/year. This is significantly smaller than the 1,500 kg Hg/year estimate obtained when using the UNEP Toolkit (2005), but as the estimate is based on import data it is considered to be more accurate than the Toolkit value.

Table II-4: Annual contribution of mercury in batteries in New Zealand

Battery Type	Description	Estimated wt% of Hg(2)	Quantity(1)	Average Weight of individual cell (kg)	Assumed Weight (Quantity*Weight) (kg)	Quantity of Hg (kg)
Mercuric Oxide	Primary; of an external volume not exceeding 300 cm^3	33%	59,240	0.001(3)	59	20
Silver Oxide	Primary; of an external volume not exceeding 300 cm^3	1%	994,984	0.001(4)	995	10
Zinc Air	Primary; of an external volume not exceeding 300 cm^3	1%	5,761,039	0.001(6)	6,417	64
Zinc Air	*Primary; of an external volume exceeding 300 cm^3*	1%	97,651	0.001(5)	91	1
Alkaline (Mn-Dioxide)	Primary; of an external volume not exceeding 300 cm^3	0.01255%	41,322,632	0.012(7)	497,938	62
Alkaline (Mn-Dioxide)	*Primary; of an external volume exceeding 300 cm^3*	0.01255%	638,766	0.129(5)	82,385	10
				TOTAL		170

Notes:

(1) New Zealand Customs data, 2008.

(2) Tchobanoglous, G and Kreith, F (2002).

(3) Assumed average weight of button cell.

(4) Assumed average weight of Silver Oxide cell Source Aquino, J (1995).

(5) Individual weights were calculated from customs data.

(6) Geometric mean calculated from weights provided on Alibaba.com

(7) Individual weight calculated from an assumed range of weights from 1.1 g to 23 g of alkaline batteries.

Results have been rounded to two significant figures.

Electrical and electronics

Mercury is a trace compound in electrical and electronic waste streams, where it is used in thermostats, sensors, relays, switching equipment and in LCD displays (including TVs and computer monitors) (Horne and Gertsakis, 2006). Horne and Gertsakis (2006) estimate the average mercury content in computer parts to be roughly 0.002%, whereas Morf *et al* (2007) estimates the average mercury in all electrical and electronic waste to be approximately 0.68 mg/kg (0.000007%). Morf *et al* (2007) found there was a high degree of variability in the concentration of mercury they tested in different waste streams, which they thought was due to mercury point sources (such as lamps, switches and batteries) being present in some waste streams.

LCD TVs and computer monitors are potential source of mercury in electrical and electronic waste (besides batteries, switches and fluorescent lamps) (Asari, *et al*, 2008). LCD TVs can contain as much as 150 mg of mercury and LCD monitors may contain approximately 50 mg of mercury (Aari, *et al*, 2008). However, New Zealand Custom data does not allow quantification of the amount of mercury entering New Zealand via these two products. Given the relatively recent introduction of LCD monitors, it is expected few such monitors are being disposed of to landfill in New Zealand but the numbers may increase. If an average TV or computer LCD monitor contains 100 mg mercury, 10,000 monitors would have to be scrapped to equate to 1 kg of mercury each year. This suggests the amount emitted is small relative to some other mercury sources.

Agricultural chemicals

Mercury has been used in the past in biocides and pesticides, particularly on seed grain and in other agricultural areas (UNEP, 2002). This use of mercury has been discontinued in many countries (UNEP, 2008). The Hazardous Substances (Pesticides) Transfer Notice 2004 (as amended) from the Environmental Risk Management Authority (ERMA) has no reference to mercury and therefore it is likely New Zealand has also discontinued use of mercury in such products.

Mercury has been identified in some fertilisers internationally, with an estimated concentration of 0.03 mg/kg (McBride and Spiers, 2001). Trace levels of mercury are contained in the phosphate rock used to manufacture superphosphate, a commonly used fertilizer in New Zealand. Superphosphate use in New Zealand is approximately 1,270,000 tonnes per year (Statistics New Zealand, 2008), resulting in an approximate release to the environment of 38 kg Hg/year.

Paint

Mercury compounds, in common with other heavy metal compounds, have historically been used as paint pigments. Paint is both produced and imported into New Zealand. However, a representative of Resene New Zealand Limited was unaware of any mercury within their paint. Mercury in paint was banned in the United States by the US EPA in 1991 (see http://www.epa.gov/mercury/consumer.htm#pai). Further investigation into mercury in paint has not been pursued, but it is possible some older paint on New Zealand buildings contains some mercury.

Pharmaceuticals and cosmetics

Mercury is known to have been used historically in pharmaceuticals and cosmetic products. A representative from the New Zealand Pharmaceutical Society of New Zealand stated that, to the best of his knowledge, mercury was no longer used in pharmaceuticals in New Zealand. Historically, however, mercury was used as a component in diuretics in the 1950s, and also in mercurochrome for abrasions.

Mercury is also widely used in ophthalmic solutions as a preservative (for example, in eye drops as 10 ppm thiomersal or 10 ppm phenyl mercuric chloride, and in contact-lens cleaning solution as thiomersal) and mercury compounds are used as antimicrobial preservatives in many medical solutions such as antibiotics or vaccination agents. Table II-5 provides a list of various mercury compounds which have been used for therapeutic uses internationally, and many of these would have also been used in New Zealand.

A representative from the Cosmetic, Toiletry and Fragrant Association confirmed that all cosmetics in New Zealand are to conform to the Cosmetic Products Group Standard 2006, issued by ERMA, which aligns with European Union directive levels, and therefore should not contain any mercury (Cosmetic, Toiletry and Fragrant Association, pers. com, February 2009). However, some skin lightening creams with small amounts of mercury may be available in New Zealand (10-50 kg Hg/tonne from UNEP Toolkit default value).

Table II-5: Mercury compounds that have been used as therapeutic agents (adapted from N. Kim, 1995)

Therapeutic use	Mercury compound
Antibacterial	Merbromin
	Mercuric succinimide
	Mercuric sulphide, red
	Mercurous acetate
	Mercurous iodide
Antiseptic	Mercurous chloride
Antisyphilitic	Mercurous chloride
	Organo-mercurials
Cathartic	Mercurous chloride
	Mercury mass
Diagnostic aid (renal function)	Merisoprol ^{197}Hg
Disinfectant	Mercurophen
Diuretic	Meralluride
	Mercamphamide
	Mercaptomerin, sodium
	Mercumallylic acid
	Mercumatilin, sodium
	Mercurous chloride
	Mersalyl
Ectoparasiticide	Mercuric oleate
Local antiseptic	Mercuric sodium *p*-phenolsulphonate
	Mercurophen
	Mercurous chloride
Topical anti-infective	Meralein sodium
Topical antiseptic	Mercuric chloride
	Mercuric chloride, ammoniated
	Mercuric cyanide
	Mercuric iodide, red
	Mercuric oxide, red
	Mercuric oxycyanide
	Mercuric salicylate
Topical antiseptic (opthalmic)	Mercuric oxide, yellow

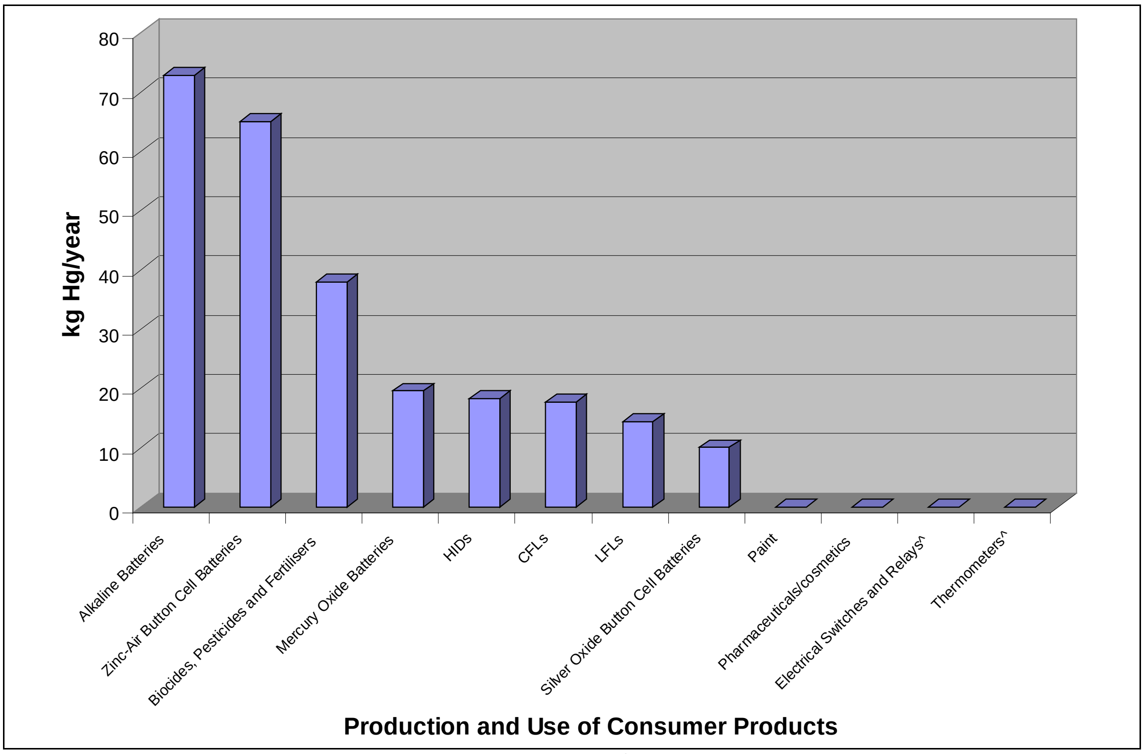
Consumer products summary

Table II-6 and Figure II-5 provide a summary of the estimated mercury contribution from consumer products in New Zealand.

Table II-6: Contribution from consumer products with intentional use of mercury

Consumer Product	Mercury Emissions (kg Hg/year)
Alkaline batteries	73
Zinc-air batteries	65
Biocides, pesticides and fertilisers	38
Mercury oxide batteries	20
High intensity discharge (HID) lamps	18
Compact linear fluorescents (CFL)	18
Linear fluorescent linear (LFL)	14
Silver oxide button cell batteries	10
Paint	0
Pharmaceuticals and cosmetics	0
Electrical switches and relays	Data not available
Thermometers	Data not available
Total	250

Note: Results have been rounded to two significant figures.



^ Data unavailable in New Zealand, and therefore emissions have not been calculated.

Figure II-5: Contribution from consumer products with intentional use of mercury

3.2.6 Other Intentional Products/Process Uses (5.6)

Other intentional products and uses described in the UNEP Toolkit include dental amalgams, medical equipment, laboratory chemicals and equipment, cultural uses, educational uses and miscellaneous (tanning, pigments etc.).

The medical and laboratory equipment listed in the UNEP Toolkit includes a number of items such as blood pressure monitors, thermometers, blood gas analyzers, coulter counters, centrifuges, and electron microscopes. No attempt has been made to quantify the number of such items in New Zealand laboratories or how much mercury they might contain. For example, while many organisations have replaced mercury in glass thermometers with digital instruments, mercury thermometers are still available from equipment suppliers and used for some purposes (e.g. climate stations).

There is no reliable information on how much mercury might be disposed of from decommissioned or broken items each year. It is suggested that, as all of these items would only be used in commercial or research laboratories, they would be disposed of appropriately and not in landfills at the end of their life. In this section therefore, a qualitative review of disposal of mercury-containing equipment in some major research and health facilities in New Zealand has been carried out.

Mercury is contained in various medical devices in particular sphygmomanometers (blood pressure monitors). Auckland, Wellington, Christchurch, and Dunedin hospitals were all contacted to determine the quantity of mercury-containing items still held and the disposal methods used by each hospital of such products. Wellington and Dunedin hospitals reported that the majority of mercury-containing items had been phased-out five years ago. Christchurch and Auckland hospitals have been phasing items out over the past three to five years. The hospitals all reported that during the phasing out process, a suitable hazardous waste contractor was employed. All of the hospitals stated that they would still have mercury-containing items on site but it was difficult to quantify the amount. Due to the fact that the majority of the mercury-containing items have already been phased out, and appropriate disposal will take place for the remaining items, mercury releases from the medical arena are unlikely to be significant.

There are many research laboratories around New Zealand that utilise mercury in either their processes or in their equipment. Several of the laboratories contacted hold and use small volumes of mercuric compounds each year. For example, Hill Laboratories use mercuric iodide (< 20 g/yr), mercuric thiocyanate (< 20 g/yr) and mercuric sulphate (500 g/yr) and NIWA in Christchurch hold 1000 g of mercuric chloride, 100 g of mercuric iodide and 80 g of mercuric oxide. Many of the laboratories obtain the required chemicals directly from suppliers and therefore do not hold any on site. Suppliers of such chemicals in New Zealand include Biolab, Merck Ltd, Global Science, and Ajax Fine Chemicals. These suppliers, combined, held less than 3 kg of mercury in all of their mercury-containing products. These forms of mercury also tend to be held in containers or used for specific chemical reactions, and not emitted. This is therefore considered an insignificant source of emissions for this inventory.

The seven New Zealand Universities were contacted for this report to ascertain the quantity of mercury held and used on each campus, and also to determine how mercury is disposed of from each university. Massey University holds 90 kg for use in the Institute of Fundamental Sciences, Auckland University holds 1 kg of mercury salts, and 30 clinical thermometers. Auckland University stated that they would have a mercury removal rate of approximately 5 kg/year to an appropriate hazardous waste service provider. Lincoln University holds approximately 430 laboratory thermometers, and has a small amount of mercury (5 mL) in a gauge on a freeze dryer. The representative from Lincoln University stated that a majority of the mercury held on site historically would have been disposed of several years ago. This was a similar response to that obtained from Waikato University.

Otago University stated that they hold approximately 8.6 kg of pure elemental mercury which is in addition to mercury-containing equipment. Mercury-containing equipment includes thermometers, hydrometers, manometers and barometers. It was estimated by the representative that the mercury contained in these devices would amount to approximately 7.5 kg. Canterbury University have about 135 kg of mercury in one of their chemical labs. Victoria University did not respond to the information request.

After speaking to one of the universities, it became apparent that much of the mercury disposed of by some universities was being held by a solvent refining company, which currently has about 800 kg of mercury. It is understood that this mercury will be processed and sold on.

Based on the informal survey of institutional laboratories and hospitals, the amount of mercury-containing equipment and chemicals disposed of inappropriately would be relatively minor. Therefore the risk to the environment from such equipment and chemicals that are still circulating is considered to be low and therefore not worth attempting to quantify further (presupposing such quantification was even possible).

A range of other miscellaneous items can incorporate mercury. These include bougie and cantor tubes, vacuum pumps, lighthouses, tanning and pigments, explosives and fireworks. It has not been possible to quantify the use of these items in the New Zealand setting, apart from lighthouses and tanning and pigments.

Maritime New Zealand reported that the use of mercury in lighthouses in New Zealand was phased out a number of years ago. Mercury in the turning mechanisms in the lighthouses was phased out during the 1960's and mercury contained in the brush gear of a number of smaller beacons was phased out during the 1990's (Maritime New Zealand, pers.com. July 2009).

The New Zealand Defence Force has been contacted to determine any mercury content in explosives but have yet to provide any information. It can be confirmed however, that tanning and pigments do not involve mercury in New Zealand (New Zealand Institute of Chemistry, 1998).

There are two mains types of dental fillings used in New Zealand: metal amalgams and composites (New Zealand Dental Association, pers.com, February 2009). Mercury content in metal amalgams can be up to 46-50% (New Zealand Dental Association, pers.com, February 2009). Mercury emissions from these amalgams occur both during the fitting of the filling and during wear within the mouth. Use of mercury amalgam in fillings is currently considered safe by the Ministry of Health[5]. Recently, the United States Federal Drug Administration confirmed they regarded the use of mercury amalgams as safe, although advised people with allergies to avoid mercury amalgams[6]. Some dentists in New Zealand have discontinued use of mercury amalgam for dental restorations.

Information on the average number of amalgam fillings in the New Zealand population could not be located. The World Health Organization (1991) estimates that an average person with eight to 10 amalgam fillings might be expected to absorb into the body between 3 and 17 µg of

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[5] http://www.moh.govt.nz/moh.nsf/indexmh/moh-position-on-use-of-amalgam-for-dental-fillings-not-changed

[6] http://www.fda.gov/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/ucm073311.htm

mercury each day as a result of loss of mercury from the amalgams. It is not known whether this incidence of filling is representative of the current New Zealand population. Given the generally improved dental health with the use of fluoride in many water supplies, it may be a high estimate. However, using the assumption of 8 to 10 fillings in the absence of better information and taking the higher emission rate of 17 µg/day as conservative, a high end value of 24 kg/yr is arrived at for New Zealand. This assumes pre-school age children will have no fillings, leaving an exposed population of approximately 3,900,000 inhabitants between the age of 5 and 95 years (2006 data, Statistics New Zealand, 2006). This value represents the amount absorbed into the body, which is approximately 80% of total mercury emissions. Therefore total emissions from this source would equate to approximately 30 kg/yr.

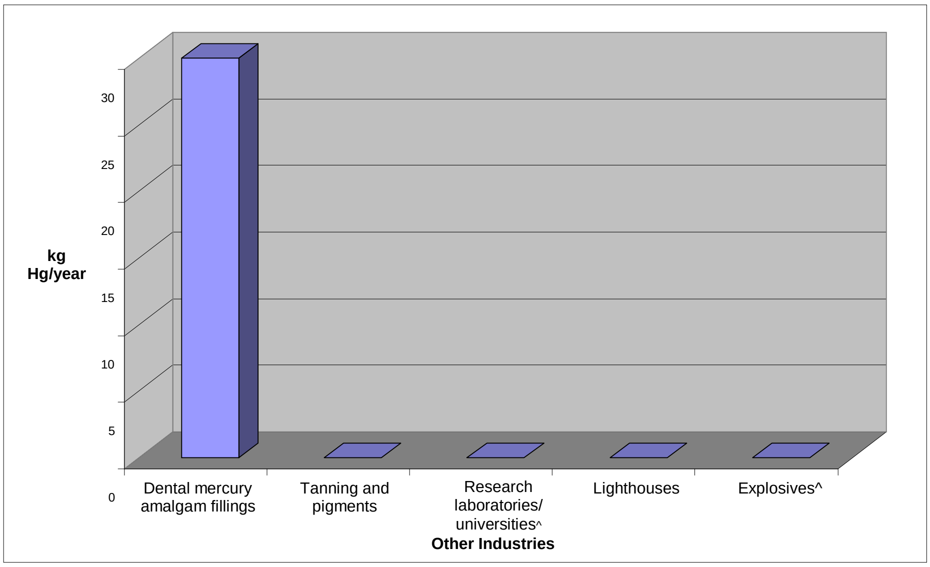
Much of the mercury absorbed into the body will be excreted and end up in the wastewater systems in towns and cities, with much of that, in turn, being adsorbed on sewage sludge or biosolids. Mercury in sewage sludge/biosolids is quantified in Section II-3.2.9. There is an unquantifiable double-counting of mercury emissions from dental amalgams accounted for here and within sewage sludge/biosolids, with an upper-bound of 24 kg/yr.

Estimates regarding the release of mercury from dental amalgam during burial and cremation are covered in Section II-3.2.10.

The mercury contribution within other intentional products and processes is summarised in Table 11-7 and shown in Figure II-6.

Table II-7: Contribution from other intentional products/process uses

Other intentional products/process uses	Mercury Emissions (kg Hg/year)
Dental amalgam	30
Tanning and pigments	0
Use in research laboratories/universities	Data not available
Lighthouses	0
Explosives	Data not available



^ Data unavailable in New Zealand, and therefore emissions have not been measured.

Figure II-6: Contribution from other intentional products/process uses

3.2.7 Production of Recycled Metals ("Secondary" Metal Production) (5.7)

Iron and steel are produced from scrap metal, using various high temperature processes. Mercury may be present in recycled metals/materials as a result of the presence of natural mercury impurities in the original materials, as well as presence of mercury contamination originating from anthropogenic use of mercury (e.g. mercury switches in cars going to iron/steel recycling) (UNEP, 2005). Much scrap steel is shipped overseas for recycling. However, production of recycled ferrous metals (iron and steel) is carried out at Pacific Steel in Auckland, which has a scrap metal recycling foundry. Monitoring of mercury in Pacific Steel's emissions is not carried out.

No attempt was made to define default factors for production of recycled iron and steel in UNEP (2005). Inputs are extremely dependent on the national or regional history of mercury-containing components, especially in scrapped cars and home appliances. In the absence of information with which to make a calculation, no estimate of mercury emissions from recycling iron and steel has been made.

Other, non-ferrous, metals are recycled in New Zealand, particularly by foundries. Recycled metals may contain mercury. No information could be located on likely emissions in New Zealand. UNEP (2005) does not provide default emission factors of non-ferrous metal recycling. In the absence of information with which to make a calculation, no estimate of emissions from non-ferrous foundries could be made.

3.2.8 Waste Incineration (5.8)

High-temperature hazardous waste incineration is prohibited in New Zealand under Clause 12 of the Resource Management (National Environmental Standards Relating to Certain Air Pollutants, Dioxins, and Other Toxics) Regulations 2004 except for three locations in Auckland, Christchurch and New Plymouth. Crematoriums are exempt from this prohibition. Emissions from crematoriums are discussed in Section 3.2.10.

The hazardous waste incinerators in both Auckland and Christchurch referred to in this regulation have been decommissioned, however the incinerator in New Plymouth is still operational. After discussion with Taranaki Regional Council, it was confirmed that no measurable mercury was emitted from the incineration processes occurring from the New Plymouth site.

School and hospital incinerators were also banned in New Zealand from October 2006 unless they obtain resource consent (Minister for the Environment, 2004). Hospitals in New Zealand should no longer incinerate waste and while low temperature incinerators of waste may occur at a limited number of schools within New Zealand the total amount of mercury released from such facilities is likely to be negligible.

3.2.9 Waste Deposition/Landfilling and Waste Water Treatment (5.9)

Waste deposition, landfills and waste water treatment represent significant pathways for mercury to enter the environment. Controlled landfills still receive an unknown but possibly large quantity of mercury-containing products, particularly from domestic (household and institutional) waste. In addition, there may be unregulated waste disposal (i.e. illegal dumping) occurring throughout the country. Quantifying mercury-containing products in either controlled or uncontrolled landfills is particularly difficult. Leachate is monitored from most large landfill facilities and therefore data on mercury concentrations in landfill leachate may exist, however this obviously is not the case for unregulated or unmonitored landfills.

Hazardous waste is also accepted at landfills after the waste has passed Toxic Characteristic Leaching Procedure (TCLP) tests. Mercury may be contained in some of these wastes, but at trace concentrations which are difficult to quantify.

Mercury cycling in landfills is a complex and not very well understood process. Landfills tend to be an anaerobic high sulphur environment which favours the production of methylmercury and mercury sulphide compounds as well as mercury-organic matter complexes. Overseas studies have found that mercury is emitted via both leachate (Christensen *et al*, 2001) and landfill gas (Lindberg *et al*, 2005). However, estimating the amount of mercury within a landfill is very difficult and emissions concentration are very low. The amount of mercury emitted from landfills as a percentage of the total amount of mercury deposited into a landfill is not reported in any of the papers reviewed.

Of the landfills contacted, only a few measured mercury in their leachate. In the landfills that do monitor mercury in leachate it was generally below the analytical detection limits). No landfills measured mercury in their landfill gas emissions to air. Currently there is insufficient information to undertake a mass balance of mercury within New Zealand landfills, or calculate emissions.

From discussions with various councils in New Zealand, wastewater biosolids (sewage sludge) in some regions are sampled for mercury, amongst other components. Mercury concentrations have been measured at 1-2 mg/L (Auckland) and 3 mg/kg dry weight biosolids (Whangarei). Other councils state that the level of mercury in their wastewater (as opposed to the solid residue) is below the level of detection (Napier City). Sources of mercury in biosolids include mercury excreted by humans (mostly from dietary sources with a contribution from dental amalgams) and any additional mercury contributed to a city's wastewater treatment plant from trade waste sources within the city boundary. The human contribution tends to be relatively constant, but the trade waste contribution can vary widely.

Most of the metal load (including mercury) in municipal wastewater ends up in the solid product of wastewater treatment (variously referred to as sewage sludge or biosolids), with very little being discharged to water after treatment. Disposal of biosolids then becomes the main issue. Some biosolids are spread on land (usually under resource consent), but most are still landfilled.

Watercare Services Limited in Auckland was contacted to obtain further information on mercury concentrations in its biosolids. The response showed that the mercury concentrations ranged from 0.15 to 6.62 mg Hg/kg, with an average of 0.9 mg Hg/kg. Watercare Services Limited produces around 118 dry tonnes/day of biosolids (300 wet tonnes), which equates to about 39 kg Hg/year.

In 2007, approximately 240,000 tonnes of dry biosolids were produced in New Zealand. This was a significant increase in the amount of dry biosolids produced in New Zealand in 2003 (Wang *et al*, 2008). The large increase in biosolids production in New Zealand between 2003 and 2007 is thought to be due to the upgrade of a number of municipal wastewater treatment plants (MfE, 2007). Based on the data in Table II-8, the average concentration of mercury in biosolids is 0.78 mg/kg. This results in an estimated 182 kg of mercury being released into the environment each year via biosolids disposal or use. At present, land filling or land reclamation are the most common methods for disposal of biosolids in New Zealand, with approximately 82% of the total biosolids used in either land reclamation or being landfilled (MfE, 2007).

As noted in Section II-3.2.6, some of the mercury in biosolids will be from emissions from dental amalgam fillings, absorbed into the body and subsequently excreted. This has been accounted for in Section II-3.2.6, but there is an unquantifiable double-counting of part of this emission within the biosolids, with an upper bound of 24 kg Hg/yr.

Table II-8: Mercury concentrations in wastewater treatment plants in New Zealand

Wastewater treatment plant	Mercury Concentration in Biosolids (mg/kg)
Bells Island	1.12
Christchurch	1.09
Foxton Beach	0.24
Green Island	0.56
Mangere	0.9
Moa Point	0.62
Rotorua	0.92
New Zealand Mean Value	0.78
New Zealand Guideline Limit [a]	7.5

Note: (a) Grade B biosolid limit for land application in New Zealand Guidelines (NZWWA, 2003).

Mercury was used as a hydrostatic seal in older (pre-1960s) trickling filters at the major wastewater treatment plants (ASCE, 1959). Although mercury is no longer used in modern trickling filters a number of the older filters are still used at several wastewater treatment plants in New Zealand, although the mercury-containing trickling filters have now been decommissioned at North Shore and Mangere wastewater treatment plants. The amount of mercury that might be escaping cannot be quantified.

3.2.10 Crematoria and Cemeteries (5.10)

As discussed previously, mercury is used as a major component of dental amalgam. Amalgam fillings constitute the main concentration of mercury in the human body, although mercury is also present in body tissues (UNEP, 2005). Mercury emissions will occur to the atmosphere during cremations and mercury can be released to the soil at the cemetery.

Based upon the official deaths registered in New Zealand for 2008 (NZ Statistics, 2009) and estimated ratio of cremations to burial of 60/40 obtained from Waitakere City Council water and sanitary services assessment (WCC, 2009) it is estimated approximately 17,500 corpses were cremated in New Zealand in 2008. Assuming an emission rate of 4 g Hg/corpse (which is based on the WHO (1991) estimate of the average number of fillings in an average person) provides a mercury emission rate of 70 kg Hg/year from crematoriums.

A further 11,700 people died in 2008, and are assumed to have been buried. Assuming the same incidence of fillings, this equates to 50 kg Hg/year being added to the soil in cemeteries around the country. It should be noted that during burial of corpse the mercury within the corpse will ultimately be released into the environment, this process may take hundreds or thousands of years (especially in the case of remobilisation of mercury in dental amalgams), whereas during cremation the mercury is released into the environment in a matter of hours.

The contribution of mercury from crematoria and burials is shown in Table II-9 and Figure 11-7.

Table II-9: Contribution from crematoria and cemeteries

Crematoria and Cemeteries	Mercury Emissions (kg Hg/year)
Crematoria	70
Cemeteries	50
Total	130

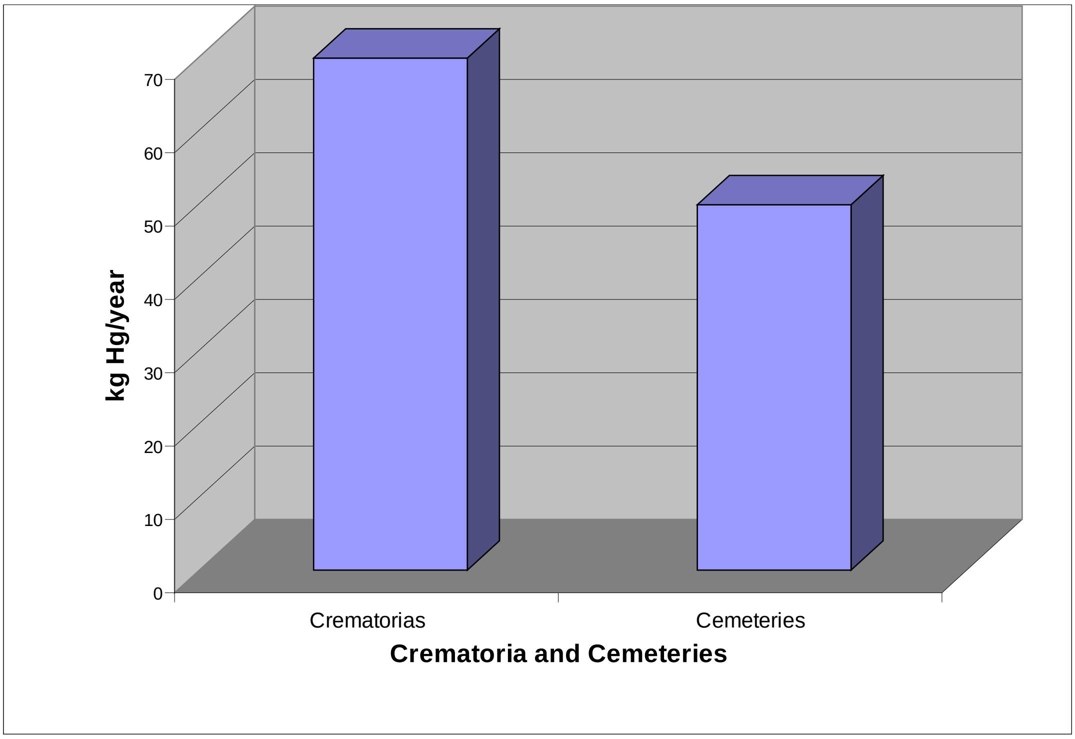


Figure II-7: Contribution from crematoria and cemeteries

3.2.11 Summary of Anthropogenic Sources of Mercury in New Zealand

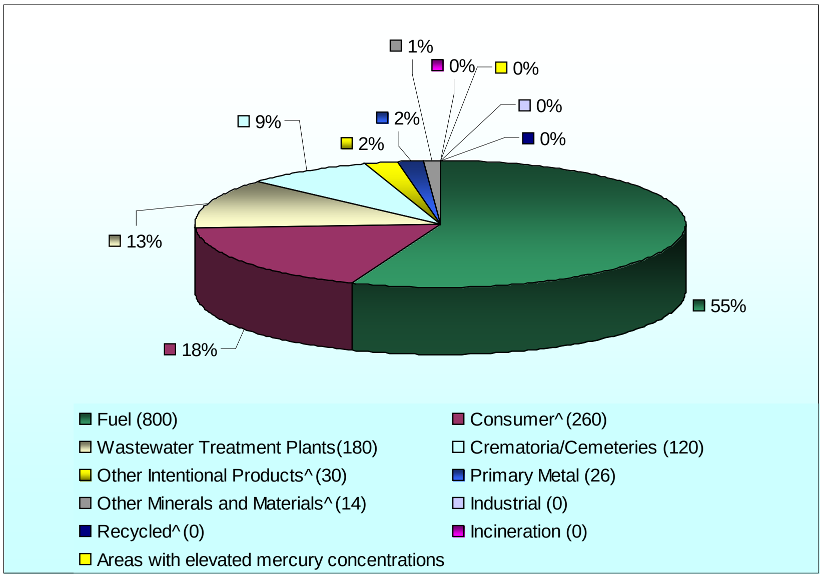
The data provided in Table II-10 and the graph provided in Figure II-8 summarise the relative contributions to mercury emitted to the environment from the different anthropogenic sources of mercury in New Zealand. Fuel (Section II-3.2.1) makes up the majority of the emissions, with landfills/wastewater, consumer products, and cemeteries/crematoria, providing the remaining sources.

Table II-10: Contribution from anthropogenic sources of mercury

Anthropogenic Source	**Mercury Emissions (kg Hg/year)**
Fuel Use	800
Consumer products^	260
Landfills/Wastewater^	180
Crematoria/Cemeteries	120
Other intentional products^	30
Primary metals	26
Other minerals and materials^	14
Use of mercury in industrial processes	Not quantifiable
Incineration	Not quantifiable
Production of recycled metals	Not quantifiable
Areas with potentially elevated mercury concentrations^	Not quantifiable
Total	1,400

Note: ^ Some sub-sources not accounted for due to lack of reliable data, as described in the individual sections.

Results have been rounded to two significant figures.



^ Some data currently unavailable in New Zealand

Figure II-8: Anthropogenic sources of mercury emissions

3.2.12 Identification of Potential Areas with Elevated Mercury Concentrations (5.11)

Areas which have elevated mercury concentrations in New Zealand are comprised mostly from historical land uses; however some areas with elevated mercury concentrations are natural, for example geothermal areas where there are large amounts of mercury-containing minerals (e.g. cinnabar) or soils having naturally elevated mercury concentrations.

A generic list follows of potential areas where mercury concentrations may be elevated in the New Zealand environment. This has generally been compiled without specific reference to any particular site for confidentiality reasons.

- Historical gold mining areas when mercury amalgamation processes were used or where high mercury concentrations are present in either the waste rock or ore. This source can not be quantified as either no monitoring is being undertaken at these sites or mercury concentrations are below analytical detection limits;
- Old and closed landfills, particularly unlined landfills;
- Mercury mining areas in Northland; e.g. Kaeo and Puhipuhi in Northland and for a short time in Thames and the Karangahake Gorge;
- Car scrap yards;
- Pesticide storage, formulation and repacking areas (the former Fruitgrowers Chemical Company Site at Mapua has been shown not to have significant mercury contamination – SKM, 2008);
- Historical market gardens, vineyards and orchards;
- Tanneries;
- Historical dental training schools (un-remediated) and other old laboratories; e.g. Mt Eden Science Centre (although this has been remediated and is being redeveloped for residential apartments);
- Defence areas, in particular dumping sites for old unexploded ordnance;
- Old slipways and dry docks where vessels painted with mercury-containing antifouling paints have been refurbished;
- Historical chlor-alkali plants within pulp and paper plants, e.g. Kinleith and Matarua;
- Areas of illegal dumping, e.g. dry-cell batteries;
- Geothermal sites;
- Electronic industry sites, e.g. batteries;
- Other identified sources, e.g. mercury arc valves operated by Transpower at the Haywards terminus of the Cook Strait power cable.

Mercury contaminated sites tend to be a relatively local issues which are unlikely to contribute the mercury exposures to the average person and are unlikely to contribute significantly to the New Zealand mercury fluxes on an annual basis. In general, PDP's experience in contaminated site work throughout the country that mercury contamination is generally not a significant issue.

4 Currently Unquantifiable Sources

The data presented above is compilation of available information. Unfortunately there were several items within the UNEP standard categories for which data could not be obtained. The information gaps are as follows:

- Biogenic emissions could not be quantified. Although these types of emissions are not explicitly required as part of the UN Toolkit they may be an important natural source of mercury emissions.
- Mercury emissions from coal washing, as it is not measured (Section II-3.2.1).
- Mercury emissions from pulp and paper industries and from other industries that produce other minerals, as mercuric emissions are not measured and/or default emission factors are not available. In general, where an industry operates under regional council resource consents, the absence of any given monitoring requirement tends to reflect the fact that risks were not identified as more than minor in the Assessment of Environmental Effects (Section II-3.2.3).
- Quantitative information on electrical switches and thermometers used in New Zealand. Import and disposal data is inadequate (Section II-3.2.5).
- Complete and accurate inventories of mercury-containing medical and laboratory equipment does not exist in New Zealand (Section II-3.2.6).
- Information from the New Zealand Defence Force regarding any old Defence landfills, and mercury-containing equipment and explosives. This information is unlikely to be obtained due to confidentially concerns of the Defence Force (Sections II-3.2.6 and II-3.2.9).
- No data is available in New Zealand for mercury emissions from the production of recycled metals (Section II-3.2.7).
- Information on landfill composition in New Zealand to the level of detail required to identify mercury-containing material and information on mercury emissions from landfills within leachate or landfill gas (Section II-3.2.9).
- The number of areas with elevated mercury concentrations around New Zealand, and the severity of the contamination is unquantifiable – the information is incomplete or inaccessible (Section II-3.2.12).

For the most part emissions from these sources are likely to be small and probably do not contribute greatly to total emissions of mercury in New Zealand.

5 Summary of Natural and Anthropogenic Mercury Sources in New Zealand

Table II-11 and Figure II-9 show the estimated breakdown of natural and anthropogenic sources of mercury in New Zealand. The results have found that there is a 52:48 split, with a slightly greater proportion of emissions being generated from natural sources.

Table II-11: Mercury contributions from natural and anthropogenic sources

Natural Sources	**kg/yr**	**% of Natural**	**% of Total Emissions**
Volcanoes	800	54	28
Volatilisation of Mercury from Soils	500	33	17
Geothermal Areas	190	13	7
Total	**1,500**	**100**	**52**

Anthropogenic Sources	**kg/yr**	**% of Anthropogenic**	**% of Total Emissions**
Extraction and use of fuels/energy sources	800	54.5	26
Primary (virgin) metal production	30	1.9	1.0
Production of other minerals and materials with mercury impurities	14	1	0.5
Intentional use of mercury in industrial processes	0	0	0
Consumer products with intentional use of mercury	260	18.5	8.9
Other intentional products/process uses	30	2.3	1.1
Production of recycled metals ("secondary" metal production)	0	0	0
Waste incineration	0	0	0
Waste deposition/landfilling and waste water treatment	180	13	6
Crematoria and cemeteries	120	8.7	4.2
Identification of potential hot-spots	Not quantifiable	Not quantifiable	Not quantifiable
Total	**1,400**	**100**	**48**
Total Natural and Anthropogenic Sources	**2,900**		

Note: Emission quantities have been rounded to two significant figures.

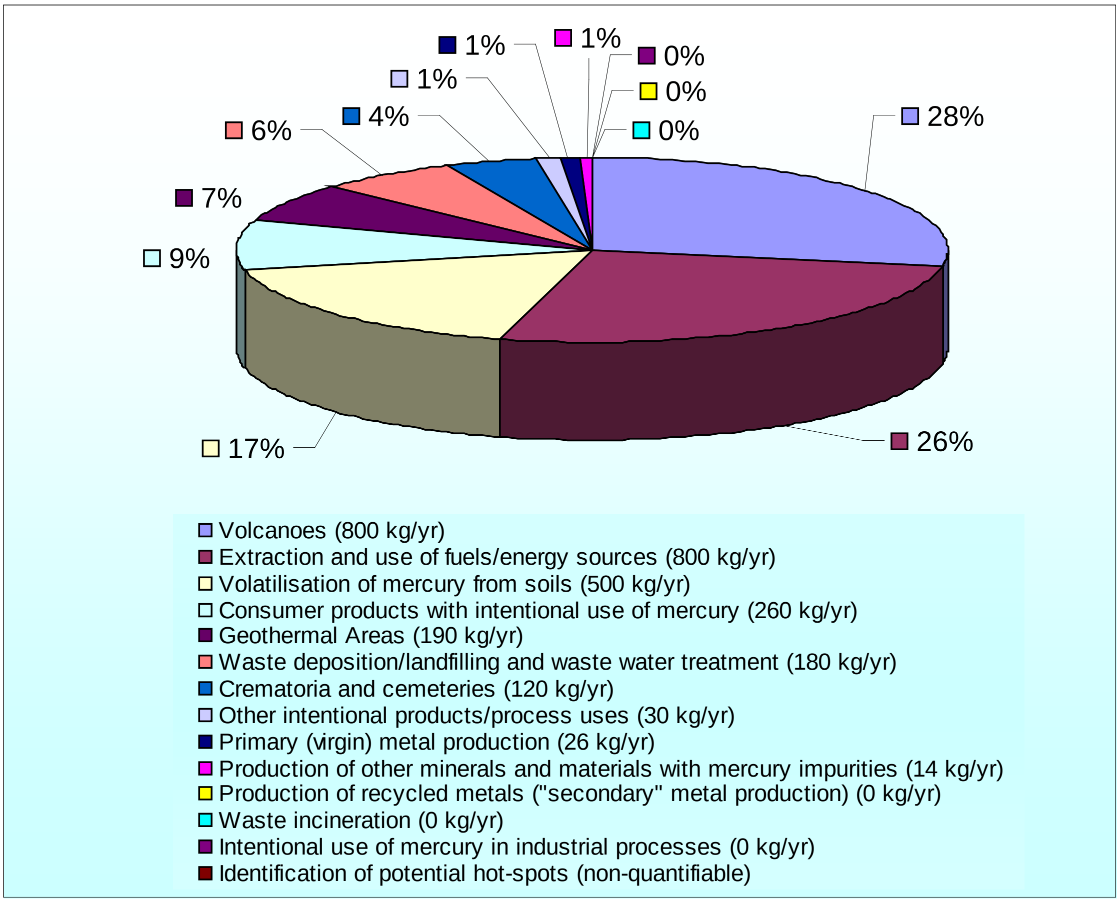


Figure II-9: Natural versus anthropogenic sources of mercury in New Zealand

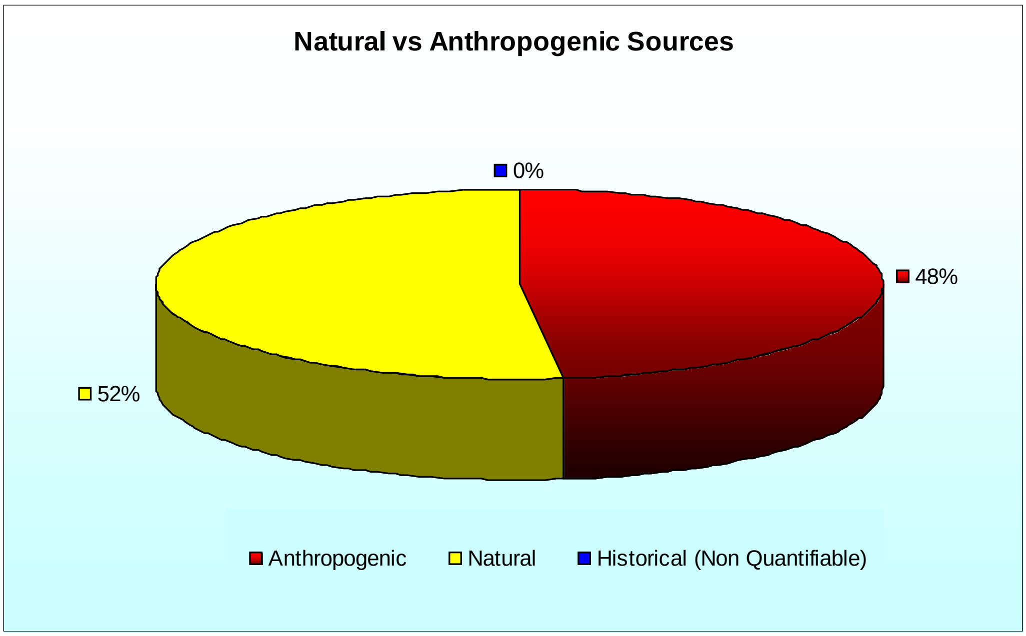


Figure II-10: Summary of natural versus anthropogenic mercury emission sources

6 Comparison of Emission with Other Countries

A comparison of anthropogenic mercury emissions reported from New Zealand, Ireland, Denmark, Canada, Australia, the United States and the United Kingdom is provided in Table II-12. The year of the inventories represents the most current information acquired as part of this study, ranging from 1994-1995 (United States), 2001 (Denmark), 2006-2007 (Ireland, Canada, Australia and United Kingdom) and 2008 (New Zealand). No natural emissions are included in the UN toolkit methodology and data on natural mercury emissions are not included in any of the above studies.

Only New Zealand and Denmark followed the protocols described in UNEP (2005) for identification and quantification of mercury releases. Mercury data reported from Ireland, Canada, Australia, the United States and the United Kingdom were originally compiled into source categories based on each individual country's environmental governing agencies individual assessment. As part of this study, the source categories were reclassified to fit in with the source categories specified in UNEP (2005) as shown in Table II-12.

A direct comparison between countries cannot be made as different countries included different items. Mercury data reported from Ireland, Canada, Australia, the United States and the United Kingdom is based predominantly on industrial mercury emissions, whereas, those from New Zealand and Denmark also report mercury within consumer products and measuring devices.

Australia also included mercury released from emissions off paved and unpaved roads, which accounted for 47% of their reported mercury (reported as a "potential area with elevated mercury concentrations" in Table II-12). Australia is the only country to report mercury emissions from this source and no data exists in New Zealand to calculate emissions off roads. Also the UN Toolkit methodology used in this assessment does not include emissions from roads as one of the potential mercury emissions sources.

In estimating the atmospheric emissions of mercury from petroleum products combusted in the Untied States, the US EPA estimated that crude oil contained 1.5 mg/kg (1.5 ppm) of mercury (US EPA, 1997; Wilhelm, 2001). However, recent work undertaken by the US EPA to determine the mean concentration of mercury in crude oil in the United States has found that the average (arithmetic mean) concentration of mercury in crude oil is close to 0.01 mg/kg (10 ppb) (Wilhelm, 2001; Wilhelm *et al*, 2004). Therefore, the US EPA estimate for mercury released by Fuel/Energy source is likely to be significantly in error on the high side (Wilhelm, 2001).

Because of such differences, including methodological differences, differences in population, land areas, climate, resources, industrial activities, emission controls and technological advancement, it is difficult to justify making direct comparisons of mercury releases and uses from each of the countries evaluated during this study. On a per capita basis (Table II-12), the total mercury inventories compiled for New Zealand, Ireland, Canada, the United States and the United Kingdom are comparable (of the order of 10^{-4} kg/person/year), whereas that of Denmark and Australia are an order of magnitude greater (10^{-3} kg/person/year). Excluding mercury releases from paved and unpaved roads, a total of 6×10^{-4} kg of mercury/person/year was reportedly released into the environment in Australia.

Given the differences in compilation methodology, no significance can be given to the United Kingdom per capita value being apparently lower than New Zealand and Ireland, which have similar per capita values. New Zealand and Ireland's per capita values are generally lower than all the other countries except the United Kingdom.

Consideration was given to making a comparison normalised by gross domestic product (GDP) in an attempt to measure mercury emissions in terms of economic activity, but given the different basis of the inventories for each country this was abandoned.

Table II-12: Comparison of mercury emissions and sources with other countries

Chapter	Main Source Category	New Zealand 2008 (kg/year)	Ireland 2007 (kg/year)	Denmark 2001 (kg/year)	Canada 2006 (kg/year)	Australia 2006-2007 (kg/year)	United States 1994-1995 (kg/year)	United Kingdom 2006 (kg/year)
5.1	Fuels/energy sources	800	800	800	2,200	2,200	78,000	3,500
5.2	Primary (virgin) metal production	26	5.5	0	1,300	11,000	100	1,200
5.3	Production of other minerals and materials with mercury impurities	14	0.96	230	1,100	440	6,500	
5.4	Intentional use of mercury in industrial processes	0	17	0	85	49	6,500	1,500
5.5	Consumer products with intentional use of mercury	260	0	2,700	18		2,200	20
5.6	Other intentional products/process uses	30	0	2,400		2.4	1,600	
5.7	Production of recycled metals (“secondary” metal production)	0	0	0			400	
5.8	Waste incineration	0	8.3	3,109	570	0.41	49,000	910
5.9	Waste deposition/landfilling and waste water treatment	180	22	4,500	140	300	70	370
5.10	Crematoria and cemeteries	120	0	0	190	0.12	<100	
5.11	Identification of potential areas with elevated mercury concentrations	Non quantifiable	0	0		12,000		
Total (kg/year)		**1,400**	**860**	**14,000**	**5,600**	**25,000**	**140,000**	**7,500**
Total (tonnes/year)		**1.4**	**0.86**	**14**	**5.6**	**25**	**140**	**7.5**
Population at Time of Inventory (millions of people)		**4.2**	**4.3**	**5.4**	**33**	**21**	**260**	**61**
Total Annual per Person (kg/person/year)		**3.3 x 10^{-04}**	**2.0 x 10^{-04}**	**2.5 x 10^{-03}**	**1.7 x 10^{-04}**	**1.2 x 10^{-03}**	**5.5 x 10^{-04}**	**1.2 x 10^{-04}**

Sources:

1) New Zealand: Mercury Inventory for New Zealand 2008 (this report).

2) Ireland: Spreadsheet developed by the Ireland EPA provided by Michael McGettigan, Office of Climate Licensing and Resource Use, EPA Monaghan Regional Inspectorate, Ireland.

3) Denmark: T*oolkit for identifications and quantification of mercury releases*, United Nations Environment Programme, Pilot Draft, November 2005.

4) Canada: Spreadsheet entitled *2006 Air Pollutant Emissions for Canada*, Version 2, 8 April 2008, obtained from www.ec.gc.ca/inrp-npri/default.asp?lang=en&n=F2B66EB1-1

5) Australia: National Pollutant Inventory: Summary Emission Report for Mercury & Compounds, obtained from www.npi.gov.au/cgi-bin/npireport.pl?proc=substance;substance=53

6) United States: Mercury Study Report to Congress Volume II:An Inventory of Anthropogenic Mercury Emissions in the United States, U.S. EPA Office of Air Quality Planning and Standards and Office of Research and Development, EPA-452/R-97-004, December 1997.

7) United Kingdom: National Atmospheric Emissions Inventory, from http://www.naei.org.uk/emissions/emissions_2006/summary_tables.php?action=unece&page_name=Hg06.html

8) Population data for New Zealand, Ireland, Canada, Australia and the United States obtained from various sources and is representative of the year of the inventories. The population estimate for Denmark is for 2005. The population estimate for the United Kingdom is based on mid 2007 estimates obtained from http://www.statistics.gov.uk/cci/nugget.asp?ID=6

7 Conclusion

The total annual mercury emissions for New Zealand in 2008 have been estimated using the UNEP (2005) Toolkit to be 3,000 kg, with roughly equal contributions from natural and anthropogenic sources.

The most significant natural sources of mercury were volcanic emissions (comprising 54% of natural emissions and 27% of total emissions).

The most significant anthropogenic sources were combustion of fossil fuels (440 kg Hg/yr) and geothermal power generation (350 kg Hg/yr), representing 29% and 23% of the anthropogenic emissions, respectively. Fossil fuel combustion may be broken down into power plant emissions of 240 kg Hg/yr (16%), liquid fuels (80 kg Hg/yr – 5%), other coal emissions and natural gas (each 60 kg Hg/yr – 4%). Other significant anthropogenic mercury sources included wastewater biosolids (180 kg Hg/yr) and consumer products (e.g. batteries (170 kg Hg/yr), and lamps, and cemeteries and crematoria.

Mercury-containing lamps contribute approximately 50 kg/yr which is only 3% of total anthropogenic emissions and less than 2% of overall mercury emissions from New Zealand. Compact fluorescent lamps make up only a minor part of the emissions. CFLs are about one third of the mercury load from all lamps, or about 1% of the anthropogenic total and about 0.5 % of the total from all sources.

A lack of data means that some of the UNEP categories could not be estimated. For the most part, emissions from these sources are likely to be small and probably do not contribute greatly to total emissions of mercury in New Zealand.

On a per capita basis the total anthropogenic mercury inventories compiled for New Zealand, Ireland, Canada, the United States and the United Kingdom are comparable (of the order of 10^{-4} kg/person/year), whereas that of Denmark and Australia are an order of magnitude greater (10^{-3} kg/person/year). Excluding mercury releases from paved and unpaved roads, Australia’s reported emissions are about twice those of New Zealand, the major difference being primary metal production. Given the different methods of compiling the inventories, no particular significance can be given to the relative ranking of the various countries without further study.

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Section III – Risk Assessment

1 Introduction

This section of the report presents scenarios for exposure to the significant environmental sources of mercury, both anthropogenic and non-anthropogenic, and assesses the absolute and comparative environmental risks arising from these sources.

Assessing risk is about identifying sources, receptors, and exposure pathways and then quantifying exposure and comparing the exposure level with what is acceptable. Section II of this report has identified six major emission sources of mercury into the New Zealand environment. The major emissions sources identified in this study which are examined in this section are emissions from natural sources, emissions from industry, emissions from landfills, emissions from agricultural sources, emissions from crematoria and emissions from the mining industry.

There are four main steps in any risk assessment process. These include hazard identification, hazard characterisation, exposure assessment and risk characterisation (WHO, 2008).

Hazard identification involves a review of relevant toxicological, biological and chemical information. This is covered in Section III-2.

Hazard characterisation defines the relationship between the degree of exposure (or amount of dose) observed in animal or human studies and the magnitude of the observed adverse health effects. This step has not been carried out in this document; instead a description of health-based standards which are used in New Zealand to assess risks is presented (Section III-2.5).

The third part of any risk assessment is an exposure assessment, where exposure pathways, and the extent, duration, frequency and magnitude of exposure are analysed. In Section III-3, the fate of mercury released from the significant environmental sources of mercury, and the potential risks they pose to ecological and human receptors are examined. Section III-4 studies the human exposure pathways (ingestion, inhalation and dermal exposure) for the general population and also identifies particular sub-populations which might be either more sensitive to the effects of mercury or which could potentially have a greater exposure to mercury.

Finally, the health risk from mercury-containing lamps, particularly compact fluorescent lamps is calculated and compared with other sources of mercury.

2 Health Effects Associated with Mercury Exposure

As outlined above, one of the first steps in a risk assessment is to identify and characterise the risks associated with exposure to a particular chemical or compound. The health effects associated with mercury are dependant on how a person is exposed to mercury (either via inhalation, ingestion or dermal absorption) and the chemical form of mercury when exposure occurs. The toxicity of mercury is highly dependant on its chemical form, the exposure pathway, and the vulnerability of specific body organs. This section details the health effects associated with the three main forms of mercury (elemental, inorganic and organic mercury compounds), the main target organ or organs that mercury can impact and the health effects associated with exposure to the different chemical forms of mercury (both acute and chronic exposures).

2.1 Elemental Mercury

Elemental mercury is the most volatile form of mercury. The major human exposure pathway for elemental mercury is via inhalation (WHO, 2003; Clarkson and Magaos, 2006). Inhaled elemental mercury vapour easily crosses from the lung into the blood stream (Tchounwou, 2003). Approximately 80% of inhaled mercury is absorbed into the blood stream, while only 0.01% of elemental mercury is absorbed though the gastrointestinal tract (WHO, 2003). Once in the blood stream, elemental mercury readily crosses the placental barrier and developing foetus can be exposed to mercury (WHO, 2003).

Some dermal adsorption may occur from skin contact with elemental mercury but it is thought to be only a minor exposure route (WHO, 2003).

The symptoms of acute metallic vapour toxicity include dyspnea (difficulty in breathing) which may be followed by coughing, chest pains, nausea and vomiting, however, exposure at this level is usually only seen in an occupational setting.

The main effects of chronic toxicity of mercury inhalation are tremors and psychological disturbances. The principal psychological symptoms include excessive timidity, diffidence, increasing shyness, loss of self confidence, anxiety, and a desire to remain unobserved and unobtrusive (Clarkson and Magos, 2006).

Although the actual fatal level of mercury vapour is not known, exposure of more than 1 to 2 mg/m^3 of elemental mercury vapour for a few hours can cause acute chemical bronchiolitis (bronchial infections) and pneumonities (inflammation of lung tissue) (Asano *et al*, 2000). If the amount of mercury inhaled is large enough, renal failure will develop (Satoh, 2000). Moderate and repeated exposures (lower than a few mg/m^3, but higher than 0.05 mg/m^3) causes tremors in hands, gingivitis (bleeding from the gums), excessive salivation and mercurial erethism (Satoh, 2000). Mercurial erethism is a term to describe the classic neurological symptoms associated with mercury poisoning, these include behavioural and personality changes such as extreme shyness, excitability, loss of memory, and insomnia (Satoh, 2000).

Lower and long-term exposure to mercury vapours can result in micromercurialism, which includes such symptoms as weakness, fatigue, anorexia, loss of weight and disturbances in the gastrointestinal tract (Satoh, 2000).

2.2 Inorganic Mercury

Some of the most important salts of mercury (inorganic mercury) are mercurous chloride ($Hg_2Cl_{2,}$ or calomel), occasionally used in medicines, mercuric fulminate ($Hg(CNO)_2$, which is used as a detonator in explosives; and mercuric sulphide (HgS, or vermillion), which is used as a paint pigment (Tchounwou *et al*, 2003).

Generally, the adsorption of inorganic mercury compounds is low, including via the lungs (WHO, 2003). The extent of adsorption of inorganic mercury though the gastrointestinal tract may depend on the solubility of the mercury compound and/or how easily the compound dissociates in the intestine to become available for absorption (WHO, 2003). There is indirect evidence that some inorganic mercury compounds may be absorbed through the skin.

Acute inorganic mercury exposure may give rise to lung damage. Chronic poisoning is characterized by neurological and psychological symptoms, such as tremor, changes in personality, restlessness, anxiety, sleep disturbance and depression. Ingestion of inorganic mercury compounds may cause kidney damage. The symptoms described above are reversible after cessation of exposure. Ingestion of very high concentrations of inorganic mercury, however, can be fatal (Asano *et al*, 2000).

2.3 Organic Mercury

Methylmercury is the most toxic of the organic forms of mercury and is taken up by terrestrial and aquatic organisms. Bacteria in lakes, streams and ocean sediment can convert elemental mercury into organic mercury compounds (Tchounwou *et al*, 2003).

Organic mercury, particularly methylmercury, is a cumulative toxin that can cause disruption of the developing central nervous system. Part of the reason why organic mercury, in particular methylmercury, is so toxic to humans is that the gastrointestinal absorption efficiency of methylmercury is in the order of 90 to 95% (Castro-Gonzalez and Mendez-Armenta, 2008). Organic mercury compounds (especially methylmercury) can be readily transformed into other chemical forms which allows them to pass through the blood-brain and placental barriers. Once the organic mercury compound has passed though the brain it can be oxidised into inorganic mercury, inhibiting its removal from the brain. The ability of organic mercury compounds to pass though the placental barrier means that developing foetus are particularly vulnerable to the effects of organic mercury (WHO, 2008). Infants and new born babies are also susceptible to the impacts of organic mercury compounds as they can be transferred from the mother during breast feeding.

Infants born to mothers exposed to methylmercury during pregnancy display a wide range of neurological effects including delayed onset of walking and talking, birth defects, cerebral palsy, lower IQ and reduced neurological test scores (Diez, 2008; Counter and Buchanan, 2004; Harada, 1995).

Exposure to high concentrations of organic mercury can result in a range of symptoms including tingling and numbness in the fingers and toes, loss of coordination, difficulty in walking, generalised weakness, impairment of hearing and vision, tremors and finally loss of consciousness leading to death (Diez, 2008).

Human exposure to methylmercury is almost exclusively due to the consumption of fish and marine mammals (Diez, 2008). The biological half-life of methylmercury in humans is approximately 65 days. Because the biological half-life of methylmercury is so long, it may take up to two years before the methylmercury accumulated in the body from one exposure is excreted. Given that consumption of fish is the predominant pathway of exposure to methylmercury for most people, and that most people will consume a fish meal more than once every two years, methylmercury is likely to accumulate in people.

Other potential exposure to organic mercury is thimerosal (also known as thiomersal) in vaccines. Thimerosal was used as a preservative in vaccines to prevent fungi growth (Clarkson *et al*, 2003). Thimerosal has the same general toxicity characteristics as ethyl mercury, however early toxicological studies found no adverse effects of using it in a vaccine. However, this has been re-evaluated based on new toxicity data and thimerosal has now been removed from vaccines in the United States but the World Health Organisation (WHO) advisory committee has recently concluded that it is safe to continue using thimerosal in vaccines (Clarkson *et al*, 2003).

2.4 Mercury Toxicity Incidents

Toxic effects from a substance may arise from both short and long-term exposure. Acute mercury poisoning is that which occurs via exposure to a high concentration of mercury over a relatively short time period. In its mercury toxicological profile, the Agency for Toxic Substance and Disease Registry (ATSDR) (1999) defines acute exposure as being a period of 14 days or less. Acute toxicity usually occurs as a result of accidental exposure (e.g. a broken thermometer).

By contrast, chronic poisoning occurs as a result of exposure to a low concentration of mercury over an extended time period, until the tissue concentration is sufficient to induce a toxic reaction of one sort or another. The ATSDR defines chronic exposure as being a period greater than 365 days. Long-term occupational or food exposure could cause chronic effects.

Table III-2 outlines the major causes of mercury poisoning and the cause and type of exposure.

Table III-2: Major causes of mercury poisoning

Form of mercury	Type of exposure	Cause of exposure
Elemental	acute-chronic	Spills (including broken thermometers, barometers, CFLs)
Elemental	chronic	Industrial/occupational
Elemental	acute-chronic	Gold mining
Elemental	acute-chronic	Medicinal applications (including ethnic/folk remedies)
Inorganic	acute-chronic	Use in medications (e.g., merthiolate)
Inorganic	acute-chronic	Use in cosmetic products (e.g., skin-lightening creams)
Inorganic	acute-chronic	Primarily occupational
Inorganic	acute	Inks and dyes (including use in tattooing)
Organic Mercury	Chronic	Fish consumption

Note: Adapted from Risher *et al* (2003).

Several instances of large scale mercury poisoning incidents have occurred overseas, resulting in serious illness and multiple deaths. Incidents have included in Minnamata Bay in Japan in the 1950s and 60s, where industrial discharges cause contamination of sea food (Hazarda, 1995) and in Iraq in the 1970s and 80s, due to contamination of the food supply (Diez, 2008). Such large scale poisoning incidents have not occurred in New Zealand, where mercury poisoning incidents have been either as a result of occupational exposure or exposure as a result of accidental spills.

2.4.1 Occupational Poisoning

Felt hat manufacturing

Historically, mercuric salts were used to make felt hats. As the felt had to be heated to make the hats, the workers were exposed to mercury vapours (Satoh, 2000). Early symptoms amongst hatters included insomnia, forgetfulness, loss of appetite, and mild tremors. Continual exposures led to increased tremors, excitability, memory loss, timidity and sometimes delirium (Tchounwou *et al*, 2003). The term "as mad as a hatter" is thought to have arisen as a result of mercury exposure amongst hatters.

Police fingerprinting officers

The historic use of grey powder (a mixture of chalk and metallic mercury) resulted in several cases of chronic mercury poisoning occurring among fingerprint officers. In accord with the symptoms of erethism, some detectives became progressively more shy and bashful, weeping in corners and refusing to arrest people (N. Kim, 1995).

Dental professionals

Dental professionals are among the largest group of workers who are occupationally exposed to mercury. During the 1970s, air concentrations in some dental surgeries reached 20 mg/m^3, but since then levels have generally fallen to about one-tenth of those concentrations (Lars Järup, 2003).

A study of 43 former New Zealand School Dental Nurses, who were chronically exposed to high levels of mercury vapour and direct skin contact with elemental mercury, found that the nurses do not appear to display any neurological symptoms of mercury exposure. However, the study did find that unfavourable reproductive outcomes (conception difficulties, miscarriages, still births, low weight babies, children with birth defects) were twice as high as the control group. There was also a statistically higher incidence of hysterectomy (Jones *et al*, 2007). Research conducted by Olfert (2006) found limited evidence linking exposure to elemental mercury and spontaneous abortion, congenital abnormalities and reduced fertility.

In a review of the literature examining the effects of mercury exposure on dental professionals, Clarkson and Magos (2006) noted that some studies have found evidence of decreased hand steadiness and suffering from moods of tension, fatigue, confusion and hostility in dental professionals, with elevated mercury urinary levels compared to control groups. However, Clarkson and Magos (2006) concluded it was uncertain whether the apparent symptoms were the results of mercury exposure or whether dental professionals with those personality traits might spill mercury which resulted in higher mercury exposure.

2.5 Mercury Health Standards

In order to assess the risk to individuals from mercury exposure, it is necessary to establish what exposure is acceptable. This is typically expressed as a mass (in micrograms or milligrams) per kilogram body weight (kg bw) per day, or in some cases per week or month. Average exposure above the standard indicates a potential for effects whereas exposure below the standard suggests no effects. With respect to inhalation exposure, a health standard is often expressed as an allowable concentration in air (mg/m^3).

As noted previously, different forms of mercury have different toxicity, with organic forms (methylmercury) being much more toxic than inorganic forms. In addition, the route of exposure has an effect on toxicity; with metallic mercury having lower toxicity by the oral route (i.e. if swallowed) than via inhalation.

A variety of authorities around the world have considered the toxicity of the various forms of mercury (ASTDR, 1999; US EPA, 1997; WHO, 1972; and WHO, 2008). In New Zealand, the Ministry of Health (MoH), in setting the drinking-water standard for mercury, used a provisional tolerable weekly intake (PTWI) for methylmercury of 3.3 µg/kg bw/week from the report of the 1972 WHO/FAO Joint Expert Committee on Food Additives (JECFA). This is the equivalent of 0.47 µg/kg bw/day or 0.00047 mg/kg bw/day. This value has been used by MoH (2005) to conservatively calculate the drinking-water standard for inorganic mercury.

In 2003, the JECFA revised the PTWI for methylmercury downward to 1.6 µg/kg bw/week (WHO, 2008). Vannoort and Thomson (2005) adopted this value when considering food residue measurements for the 2003/04 New Zealand Total Diet Survey (NZTDS) conducted for the New Zealand Food Safety Authority (NZFSA). Thus, 1.6 µg/kg bw/week can be considered the most recent PTWI for organic mercury officially recognised in New Zealand. This is the equivalent of 0.23 µg/kg bw/day. This value is considered protective of developing foetuses, the most sensitive sub-group in the population.

For inorganic mercury, Vannoort and Thomson (2005) adopted the PTWI for total mercury of 5 µg/kg bw/week set by JEFCA in 1972. This is the equivalent of 0.71 µg/kg bw/day. More recently, a study carried out for MfE to support the derivation of contaminated land soil guidelines (Cavanagh, in prep), which has been reviewed by toxicologists from MoH, ERMA New Zealand and NZFSA, has recommended an oral intake for inorganic mercury of 2 µg/kg bw/day.

Chronic inhalation exposure has been assessed by the US EPA. The US EPA's recommended inhalation reference concentration (RfC), based on occupational studies, is 0.3 µg/m^3 (US EPA, 1995). The US ATSDR has developed a chronic minimum risk level (MRL) for inhalation of elemental mercury of 0.2 µg/m^3. The WHO ambient air quality air quality guideline for mercury is 1 µg/m^3 (annual average) (WHO, 2000).

3 Potential Impacts of Mercury Released into the Environment from Natural and Anthropogenic Sources

3.1 Introduction

Section II of this report (Mercury Contributors) has identified various mercury emission sources in New Zealand. This section will further assess the risk from six major emission sources of mercury into the New Zealand environment that are considered to be of potential concern (UNEP, 2005; UNEP, 2008). These are natural emissions (i.e. geothermal and volcanic emissions and soil mineralisation), industrial discharges, landfills, agriculture, mining and crematoria emissions. Once mercury is emitted from any one of those sources into the environment (either from natural or anthropogenic sources) it becomes part of the natural global biogeochemical cycle where it can change its chemical form and be distributed between the atmosphere, biosphere, hydrosphere and lithosphere.

A quantitative risk assessment has not been undertaken in this study as there is a lack of sufficient information in a number of critical areas and also because of the complex biological and chemical interactions that mercury undergoes once it has been released into the environment. Instead, a qualitative measure of impact of mercury emissions from each source (using the methodology outlined in HB203:2006 (Standards Australia, 2008)) has been used to rank the potential environmental impact of each significant source (Table III-3). A rank of 1 indicates low potential impact, a rank of 3 represents a more significant potential impact and a rank of 5 indicates large scale severe impacts including either direct or indirect toxicity to humans and ecological receptors.

A more detailed discussion of the pathways through which mercury is released to the environment, chemical forms in which the majority of the mercury is likely to be released, and the environmental receptors which could potentially be impacted by these emissions, is outlined in Sections III-3.2 to III-3.7 for each of the six sources.

Table III-3: Potential impact of natural and anthropogenic mercury emissions[7]

Receptor	Natural Emissions	Industrial	Landfills	Agricultural	Crematoria	Mining
General environmental and social Impacts	2 – Large scale emissions, potential to impact on mercury concentration in fish species used for human consumption. Major source of mercury in New Zealand.	2 – Most important anthropogenic source of mercury into the environment.	1– Small number of localised emissions via air discharges or discharges of leachate. Potential for transfer station operators to be exposed to mercury.	1 – Large numbers of localised low-level emissions.	1 – Small number of localised emissions.	1 – Small number of localised emissions concentrated around Northland and Coromandel. Current mining practices have an insignificant impact on the environment with respect to mercury discharges.
Human health	2 – Potential to impact on localised populations, and communities. Elevates mercury content in fish receiving geothermal discharges and is a significant contributor to the concentrations of mercury in the marine fisheries.	1 – Potential to cause a small increase in mercury burden of localised population.	1 – Potential to cause a small increase in mercury burden of localised population due to eating fish from leachate impacted waterways. Possible occupational exposure of mercury vapours for staff working at transfer stations and landfills.	1 – Potential to cause a small increase in mercury burden of localised population due to fish consumption.	1 – Potential to cause a small increase in mercury burden of localised population.	1 – Potential to cause a small increase in mercury burden of localised population due to fish consumption from waterways impacted by historical mining practices. Current mining practices are unlikely to have any significant impact on human health due to environmental releases.
Land-based ecosystem	1 – May be highly localised impacts on sensitive land-based ecosystem.	1 – May be highly localised impacts on sensitive land-based ecosystem.	1 – May be highly localised impacts on sensitive land-based ecosystem due to deposition of airborne discharges onto land surfaces.	1– May be highly localised impacts on sensitive land-based ecosystem.	1 – May be highly localised impacts on sensitive land-based ecosystem.	2 – Potential for localised contamination which may exceed soil guidelines for ecological receptors. Possible low level impacts on sensitive land based ecosystems. 1 - Potential to cause a small increase in mercury burden of localised population due to fish consumption from historical mining practices. Current mining practices have no measurable contribution of mercury into the environment.

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[7] Note this table assesses impacts on a scale of 0 to 5, with 0 = no effect and 5 = Severe large scale environment and social impacts.

Receptor	Natural Emissions	Industrial	Landfills	Agricultural	Crematoria	Mining
Aquatic ecosystem	3 – Direct discharges into aquatic waterways, potential for direct and indirect poisoning for sensitive organisms. Major source of mercury in aquatic organisms.	1 – Minor amounts of mercury being deposited within stream catchments or by direct discharges. Concentrations likely to be significantly below ANZECC (2000) water quality guidelines.	1 – Low levels of mercury directly discharged into aquatic waterways, potential for direct and indirect poisoning for sensitive organisms. In older landfills without liners and leachate recycling there is the potential for concentrations within the leachate to exceed ANZECC (2000) water quality guidelines for 99% ecosystem protection.	1 – Minor amounts of mercury being deposited within stream catchments or by direct discharges. Concentrations likely to be significantly below ANZECC water and sediment quality guidelines.	1 – Minor amounts of mercury being deposited within stream catchments or by direct discharges. Concentrations likely to be significantly below ANZECC water quality guidelines.	2 – Direct discharges of leachate and acid mine drainage may exceed sediment and water quality guidelines in the immediate area of the mine. The overall flux of discharges is likely to be very low and therefore impact area likely to be limited in size. Current mining practices have no measurable contribution of mercury into the environment.

3.2 Natural Emissions

Naturally occurring mercury emissions from volcanoes and geothermal areas are thought to be the largest contributor of mercury in New Zealand. However, mercury emissions from these types of sources, and the effects, are difficult to estimate due to spatial and temporal variability in activity (Gustin *et al*, 2008). Both volcanic and geothermal emissions can result in direct discharges of mercury into air and/or waterways and they also elevate the concentration of mercury in soils either by depositing mercury bound to particulate material (especially volcanic eruptions) or by mineralisation of the underlying rocks and soil.

Volcanoes, geothermal areas and mercury emissions from mineralised soils are the major sources of natural emissions of mercury.

Volcanoes are an important source of reactive and particulate mercury in the atmosphere. Deposition can occur over very large areas (Section III-3.2.1).

Geothermal fluids from geothermal systems are directly discharged into waterways (Section III-3.2.2) and epithermal mineralisation can result in elevated concentration of mercury in soil which then can be up-taken by plants or can be released via weathering processes into waterways and the coastal marine environment (Section III-3.2.3). Geothermal and volcanic emissions may also result in elevation of mercury in soils at a regional level through airborne deposition of reactive and particulate mercury species.

3.2.1 Volcanic Emissions

Volcanoes are thought to be an important source of particulate and reactive gaseous mercury into the atmosphere. Volcanic emissions may result in elevated mercury concentrations in soils at a regional level through wet and dry deposition of reactive and particulate mercury. It is estimated that continuous degassing of mercury from volcanoes accounts for approximately 10% of the volcanic mercury emissions, while small sporadic eruptions may account for 75% of the global volcanic mercury releases (Pyle and Mather, 2003). Rare large eruptions could release over 1000 tonnes of mercury, which would overwhelm the mercury emissions from all other natural and anthropogenic sources in New Zealand (Pyle and Mather, 2003).

The eruption frequency of volcanoes is sporadic and dependant on the type of volcano (Table III-4). In New Zealand, small volcanic eruptions tend to occur approximately once every one to five years from White Island, potentially depositing mercury-containing ash over parts of the Bay of Plenty, while the active volcanoes in the Tongariro Volcanic Centre are likely to have small eruptions approximately every 20 years. Large eruptions are only likely to occur once every 1,000 to 10,000 years in New Zealand (Neild *et al*, 1999).

The potential health and environmental risk of mercury emissions from volcanic eruptions in New Zealand is unknown. However, volcanic eruptions can disperse tephra (volcanic ash) containing elevated levels of mercury (and other elements) hundreds of kilometres from the vent. Mercury could potentially leach from the tephra into the surrounding environment and affect water supplies, soil and food sources (Cook and Weinstein, 2005).

Table III-4: Eruption frequencies of New Zealand volcanoes

Volcano		Last known eruption	Eruption size (lava and ejecta km^3)	Estimated frequency of occurrence
Auckland		~600 years B.P.	small – medium (0.1–2.0)	1000–2000 years
Mayor Island		6340 years B.P.	small – medium (0.1–1) large (>1.0)	?1000 years ?10 000 years
White Island		1998 AD	small (<0.01) medium (0.01–0.1) large (> 0.1)	1–5 years ?100 years ?10 000 years
Tongariro Volcanic Centre	Ruapehu	1996 AD	small (0.01–0.1) medium (0.1-1.0) large (>1)	20 years 100–500 years 10 000 years
	Ngauruhoe	1975 AD	small (< 0.01) medium (0.01–0.1)	10–20 years 100–200 years
	Tongariro	1896 AD	small (<0.01) medium (0.01–0.1) large (0.1-1)	100 years 1000 years 10 000 years
Taranaki		1755 AD	small (<0.01) medium (0.01–0.1) large (<.1)	90–500 years 1300–1600 years 10 000 years
Taupo		181 AD	small (0.1–0.9) medium (1–10) large (10–100)	1300–1600 years 2500–5000 years 5000–10 000 years
Okataina		1886 AD	medium (1–10) large (10–20)	1500–2000 years 2000–5000 years

Source: Neild *et al* (1999).

Soils in volcanic areas tend to be slightly more elevated in mercury that those in non-volcanic areas. Regional soil sampling undertaken by the Auckland Regional Council (ARC), Environment Waikato (EW) and Environment Canterbury (ECan) indicate that the average soil concentration of mercury in Auckland and Waikato soils is elevated (at a P=0.05 level of significance) compared to Canterbury soils. It is thought that the elevated concentration of mercury in Waikato and Auckland soils is due in part to volcanic nature of the soil parent materials (volcanic ash soils). The mean concentration of mercury in Auckland Volcanic Soils is <0.03-0.45 mg/kg (ARC, 2002), while the mean concentration of mercury in Waikato soils from background sites is 0.19 mg/kg (with a median of 0.10 mg/kg) (N. Kim, Environment Waikato, pers. com. 2009).

Currently, there are no New Zealand risk based soil guidelines for mercury; however US EPA regional screening levels[8] for human health protection in a residential setting range from

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[8] Available: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/index.htm

6.7 mg/kg for elemental mercury to 23 mg/kg for inorganic mercury compounds. Although people living in volcanic areas may have a slightly higher exposure to mercury from consumption of locally grown produce and contact with the soil, mercury concentrations in New Zealand soils are generally between 40 and 100 times lower than soil concentrations recommended by the US EPA as potentially posing a risk. The mercury concentration in New Zealand soils is therefore thought to pose little risk to human health.

3.2.2 Geothermal Emissions

Geothermal discharges release mercury into the air, water and into the soil. The airborne emissions from natural geothermal discharges do result in a slight elevation in the ambient air concentration of mercury as is shown by Fellow and Bates (1998), with ambient air concentrations near Kuirau Park (a public park in Rotorua with geothermal activity) approximately five to six times higher than ambient concentration measured in industrial areas in Wellington (Bibby *et al*, 1998). However, exposure to mercury via inhalation is generally regarded as an insignificant exposure route for the general population. Recent work undertaken by Durand *et al*, (2004) found that short term exposure to volcanic gases did not significantly increase the mercury urine concentration, which indicates that there is a very low risk to people visiting geothermal attractions. Overall, airborne emissions of mercury from geothermal discharges are thought to pose little risks to either the environment or human health.

Geothermal discharges (both from natural sources and from geothermal power stations) into waterways do have the potential to adversely affect human health. Mercury concentrations in the water separated from the steam recorded at some New Zealand geothermal power station wells ranged from 0.02 to 0.12 µg Hg/kg (Weissberg and Rohde, 1978). The total mercury added to the Waikato River from the Wairakei geothermal scheme is about 55 kg Hg/yr, being discharged at a mean concentration of approximately 120 µg/kg (Timperley and Hill, 1997).

Both the Waikato River and the Tarawera River receive significant quantities of geothermal fluids discharged from geothermal power stations (Webster-Brown and Craw, 2005). These can be viewed as technological enhanced natural discharges as the geothermal power stations have tapped into already existing natural discharges. The geothermal power stations have increased the level of the geothermal discharges at the locations. Although these discharges may have a localised impact on the fauna near the discharge points due to direct toxicological effects, the concentration of mercury is rapidly diluted in waterways, and the concentration of mercury after mixing is generally below analytical detection limits. However, of particular concern to the aquatic environment and human consumers of fish, is the ability of inorganic mercury (which has a relatively low toxicity and limited ability to bioaccumulate) to be transformed into organomercury complexes (particularly methylmercury) by bacteria. Organomercury forms are more toxic than inorganic mercury compounds and have very high bio-concentration factors (ANZECC, 2000).

Fish caught from the Rotoroa Lakes and along the Waikato River have elevated tissue concentrations of mercury (and methylmercury) (Table III-5). Environment Waikato has undertaken a risk assessment on fish consumption based on the average mercury content of short fin eels from the Waikato River (0.18 mg/kg) based upon the tolerable intake specified for mercury in Australian women[9] (Environment Waikato, 2005). Environment Waikato determined that the PTWI would be exceeded after ingesting 2.5 kg of fish per month

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[9] 1.6 ug/kg body weight/week at 65 kg body weight, equivalent to 460 ug/month

(approximately 17 servings of fish). While consuming this amount of fish from only the Waikato River would be theoretically possible, it is unlikely that anyone would eat this much fish from a single source.

The MoH has issued warnings for pregnant women to limit their intake of foods which could have a high mercury content, such as predatory species of ocean fish (shark, tuna, etc) and freshwater fish from geothermal rivers and lakes (MoH, 2000).

The lack of information on mercury in the New Zealand environment makes it difficult to determine the significance of mercury concentrations in rural lakes.

Table III-5: Methylmercury in trout from some New Zealand lakes receiving geothermal discharges

Lake	Trout mercury level (mg/kg)	
	mercury	methylmercury
Tarawera	0.18	0.13
Okareka	0.22	0.10
Rotorua	0.53	0.42
Okaro	0.65	0.16
Rotomahana	1.84	0.99

Source: Kim, JP (1995).

3.2.3 Mineralised Soils

Mercury occurs in a variety of minerals in epithermal deposits, principally as cinnabar (HgS), but it can also occur in excess of 0.5% wt as an impurity in phosphate minerals and iron sulphides (Craw *et al*, 2000). Mercury also occurs as a trace element naturally in soils at levels. Typical background concentration of mercury in soils tend to be around 45 to 160 mg/kg (Siegel, 2002) but mercury soil concentrations may be much higher in geothermal areas. A major source of mercury in soils is the weathering of the parent rocks and minerals that occurs during soil formation. As a result, the natural composition of soils mirrors to a large degree the chemistry of the rock from which they originated. In other words, soils which originated from rocks which contain high mercury (such as shales) tend to have high mercury concentrations (Siegel, 2002). Deposition of mercury from the atmosphere is a second natural source of mercury to soils.

In a study of children living around the Broadlands geothermal area, Bierre *et al* (1977) found children living in the area to have an elevated concentration of mercury in their urine. The study speculated that the children were exposed by long-term leaching of mercury into water supplies and possibly from locally produced meat or vegetables. Although the urine concentrations were elevated, the children showed no signs of peripheral neuropathy that could be attributed to mercury toxicity.

Erosion and weathering of mineralised soils and rock in some areas (e.g. the Coromandel and Bay of Plenty regions) may result in enhanced loadings of mercury into the local streams and marine coastal area. The concentration of mercury in sediments collected from the lower Firth of Thames (EW, 2007) is approximately six to 12 times higher (arithmetic mean 0.26 mg/kg) than mercury concentrations found in either the Tauranga Harbour (arithmetic mean = 0.06 mg/kg; (Environment Bay of Plenty, 2003) and Raglan Harbour (0.04 mg/kg) (Rumsby, 2009).

On average, the concentration of mercury in the Firth of Thames sediments is approximately 1.73 times higher than the ANZECC (2000) ISQG-low guideline values but lower than the ANZECC (2000) ISQG-high guidelines values. Concentrations between the ISQG-low and ISQG-high are thought to pose a moderate level of risk to aquatic organisms. Although some of the mercury present within Firth of Thames sediments is thought to be due to either soil erosion or historical mining activity, especially around Kuranui Bay and Thames areas, there is some tentative evidence that some of the mercury found in the Firth of Thames may originate from drainage of the wetlands and peatlands of the Hauraki Plains (Environment Waikato, 2007).

3.2.4 Overall Impact of Natural Emissions of Mercury

Natural emissions of mercury from volcanic and geothermal discharges, as well as volatilisation of mercury from soils, amounts to approximately 1,500 kg Hg/year or 52% of the mercury emission from New Zealand, and are the most important source of mercury to the New Zealand environment. The concentration of mercury in fluids discharged from geothermal sources may have a toxic effect on some biota near the discharge point. The effect of indirect exposure (consumption of food such as fish) remains the primary environmental exposure route for humans from natural emissions of mercury. Chronic mercury toxicity is unlikely to occur for people consuming fish unless they consume a great deal of fish from certain geothermal lakes (e.g. Lake Rotomahana). Natural emissions of mercury are undoubtedly increasing the amount of mercury the New Zealand public is exposed to, particularly in regions with geothermal activity (e.g. Waikato and Bay of Plenty).

Overall, natural emissions of mercury into the environment are thought to have a low to moderate risk to ecological and human receptors. The risk will tend to be localised or regional in nature. The main environmental and ecological risks are a result of mercury's ability to bioaccumulate up the food chain.

3.3 Industrial Emissions

The major individual sources of industrial emissions in New Zealand are the Huntly Power Station, New Zealand Steel at Glenbrook, and cement manufacturing in Whangarei and Westport. Moderate individual discharges occur from geothermal power stations mainly located in the Waikato near and north of Taupo and near Kawerau in the Bay of Plenty.

Discharges from industrial sources are predominantly released into the atmosphere rather than being discharged into waterways, although the Wairakei Power Station discharges mercury (and other heavy metals) within geothermal fluid to the Waikato River.

Air discharges of mercury from most industrial sites are likely to be mainly gaseous inorganic mercury compounds (Hg^{2+}), elemental mercury (Hg(0)) or inorganic mercury compounds bound to particulate matter. Based on review of mercury emissions data presented for combustion sources in US EPA (1997a) and published literature (Peterson *et al*, 1995), approximately 80% to 100% of the total mercury emitted from industrial sources is emitted as mercury vapour (approximately 15 to 60% as inorganic mercury compounds and 20 to 100% as elemental mercury vapour (Hg(0)) (Table III-6). A vast majority (99%) of the mercury emitted as elemental mercury does not readily deposit and is subject to long-range transport, being spread throughout the Southern Hemisphere by the global atmospheric circulation patterns (Peterson *et al*, 1995). A significant proportion of the inorganic mercury compounds (roughly 70% of the total inorganic mercury compounds emitted) and 30 to 40% of the particulate bound mercury is deposited close (within 50 km) to the source.

On the basis of overseas work, it is expected that most (90%) of the mercury emitted from Huntly Power Station is in the elemental gaseous form (either elemental or inorganic mercury complexes), rather than particle-bound mercury (Laudal, *et al*, 2000). Environment Waikato estimates that only 10% of the mercury burnt in the power station ends up in the bottom ash (N. Kim, Environment Waikato pers. com.). In a recent soil survey of soils downwind from Huntly Power Station, Environment Waikato found no evidence of significant enrichment of mercury in the soils (N. Kim, Environment Waikato, pers. com.). However, this may be because Huntly Power Station only recently began burning coal in large quantities (instead of natural gas) and insufficient time has passed to detect any increase in the concentration of mercury downwind of the power station.

Models of the ground level concentrations of mercury adjacent to the Huntly Power Station indicate that peak one-hour average mercury concentrations could reach 0.008 $\mu g/m^3$ one kilometre downwind from the power station (ECNZ, 1992). Ground level mercury concentrations are expected to drop to typical ambient air concentrations (0.002 to 0.0004 $\mu g/m^3$) within two kilometres downwind of the power station (ECNZ, 1992).

Table III-6: Emission speciation percentages

Sector	Hg(0)	Hg(II)	Hg-bound to particulates
Combustion emissions from power stations	50	40	10
Combustion emissions from residential heating	50	40	10
Combustion emissions from industrial/commercial/residential boilers	50	40	10
Pig iron and steel production	80	15	5
Secondary iron and steel production	80	15	5
Non-ferrous (Cu, Zn, Pb) metal production	80	15	5
Cement Production	80	15	5
Waste and Other	80	15	5

Note: Adapted from WHO (2008).

3.3.1 Overall Impact of Industrial Emissions of Mercury

Industrial emissions are the second largest source of mercury into the New Zealand environment. Industrial emissions of mercury from power generation, including geothermal generation, steel, lime and cement production, and combustion of coal used in industrial boilers release approximately 800 kg of mercury per year. Most of the mercury emitted from industrial processes in New Zealand appears to be emitted directly to the atmosphere as either gaseous Hg(0) or mercuric compounds. The impact that this diffuse mercury pollution is having on ecological and human receptors is unknown. Direct toxicity as a result of mercury emissions is unlikely but mercury's ability to accumulate in certain environmental sinks (i.e. soil and sediments), where it can be taken up by organisms and bioaccumulated up the food chain means that it may result in indirect toxicity to consumers.

Studies undertaken by Fitzgerald *et al* (1994) have shown that small increases in atmospheric mercury loadings lead directly to a rise in the mercury content in fish. Therefore the atmospheric transport of anthropogenic mercury to aquatic and terrestrial ecosystems is a cause for concern as mercury released from industrial sources may bioaccumulate in organisms, to a greater or lesser extent depending on site-specific conditions (Jackson, 1997).

In general, New Zealand's low level of heavy industry, particularly coal-burning industries, will mean that impacts will be lower than that of more heavily industrialised countries. Unfortunately, a lack of atmospheric monitoring for mercury in New Zealand means that direct comparisons cannot be made.

3.4 Landfills

Mercury-containing waste enters landfills from a wide range of potential sources including batteries, electrical switches, fluorescent lights, thermometers and general wastes. However, the fate of mercury in landfills has not been widely studied in either New Zealand or overseas. Once mercury-containing waste is placed into the landfill it can be released in a number of different ways; as mercury vapour from the working face, as a result of passive emissions from the landfill surface cover or from active gas vents and landfill gas flares (Lindberg *et al*, 2005). Mercury may also be released as elemental mercury and/or as either inorganic or organic mercury compounds in the leachate.

There is no information on the amount of mercury currently within or being received by landfills in New Zealand, however, a calculation based on limited data regarding on the amount of electronic waste and batteries suggest there may be up to 100 to 150 kg of mercury being deposited into landfills in New Zealand annually. It should be noted that this calculation is only a first order approximation to provide an estimate of the order of magnitude of mercury entering landfills in New Zealand. This calculation will underestimate the amount of mercury entering landfills and there will be other (unquantified) waste streams which will also contain mercury (as all waste entering landfills will contain at least a very small amount of mercury). Approximately three millions tonnes of waste is deposited in municipal landfills each year (MfE, 2009).

Currently there is no data available on what percentage of the mercury deposited into landfills is released back into the environment. The anaerobic environment and high sulphur concentrations found within landfills would make the formation of mercury sulphide compounds thermodynamically favourable and the high concentration of organic matter could also act as a long-term sink for mercury in landfills. However, no published literature regarding the biochemical cycling of mercury within municipal landfills was found during a literature survey conducted as part of this study.

When monitored in New Zealand, the concentration of mercury leachate discharged from landfills is generally less than the analytical detection limit (0.05 µg/L). Currently there is insufficient information to undertake a mass balance of mercury within New Zealand landfills. Due to the high organic carbon content and reducing conditions found in landfills, a significant proportion of the mercury discharged from landfills as leachate may either be bound to organic compounds or be present as organic mercury compounds. Mercury discharged in these forms could potentially be transported over long distances and/or more easily up-taken by aquatic organisms.

In Florida, it has been estimated that between 10 to 50 kg of mercury per year is released into the atmosphere from municipal landfill operations with emissions from the active working face and landfill gas flaring (Lindberg *et al,* 2005). Most of the gaseous mercury emitted from landfill is elemental Hg(0) (Lindberg *et al*, 2005b). Lindberg *et al* found mercury emission rates from landfill cover of approximately 1–10 ng/m^2/hr, 8-20 mg/hr from landfill gas flares and 200 to 400 mg/hr from the working face of the landfill.

Work undertaken by Southworth *et al* (2005), shows that a large portion of the mercury in consumer products is lost before the material is deposited in the landfill. As much as 20-40% of the total amount of mercury emitted during the waste disposal cycle is emitted when the waste is stored in waste bins or when it is processed and compacted at transfer stations (Southworth *et al*, 2005).

3.4.1 Overall Impact of Mercury Emissions from Landfills

Mercury-containing materials enter municipal landfills from a wide array of sources. However, conditions within the landfill and modern landfill design limit the amount of mercury discharged into the environment.

Most landfills are not located near drinking-water supplies and modern landfills are equipped with liners and leachate recovery systems, which would limit the amount of mercury discharged into the aquatic environment. However, discharges of volatile mercury compounds within landfill gas or from the working face of landfills are uncontrolled. Workers operating near the working face of the landfill can potentially be exposed to elevated concentrations of mercury. Although the risk cannot currently be quantified, it is thought that the risks would be low.

Currently there is insufficient information to assess the impact of mercury emissions from landfills in New Zealand.

3.5 Fertilisers Usage

Inorganic mercury compounds are contained in fertilisers as an unintentional trace contaminant. Although the concentration of mercury in fertilisers varies depending on the type of fertiliser used and the source material where the fertiliser was obtained from, overseas research suggests the average concentration of mercury in phosphate fertiliser to be around 0.05 mg/kg (McBride and Spiders, 2001). Once the fertiliser is applied to land, mercury may enter waterways either as a dissolved species or in a particulate form either as a direct discharge soon after application (i.e. overland flow) or slowly leaching from the soils. However, it is thought that majority of most trace metals in fertiliser end up interacting with the soil and biota (Martin, 2005).

In a review of the effects of the impacts of metals associated with fertilisers, Martin (2005) concluded that due to the low concentration of mercury in fertilisers and in New Zealand soils, even at very high fertiliser application rates it would be difficult for mercury concentrations to exceed either soil or sediment guideline values.

Given that only approximately 40 kg of mercury is released into the environment each year from fertiliser, fertiliser use is a relatively insignificant source of mercury in the New Zealand environment, and therefore the environmental impacts of mercury from this source are limited.

3.6 Crematoria

Mercury is released from dental amalgams during the cremation process. Nieschmidt and Kim (1995) undertook a soil survey around three crematoria in New Zealand and found slightly elevated concentrations of mercury (up to 0.85 mg/kg dry weight) within 30 m of the crematoria. The higher than background concentrations may result in slightly elevated exposure for a small number of people who might be involved in garden maintenance around the facility, but the concentration is too small to be of significance[10].

Niescmidt and Kim (1995) estimated that about 23 kg of mercury is released from crematoria in New Zealand but most (99.95%) of the mercury either never reaches the ground or is deposited and then re-volatiles, so it does not accumulate in nearby soils. This finding is consistent with the expected chemistry of the mercury being discharged (elemental mercury vapour). A vast majority (99%) of the mercury emitted as elemental mercury does not readily deposit and is subject to long-range transport and therefore will not contribute significantly to increased local exposure.

Given the localised and minor nature of the direct exposure impacts and the relatively small volume of mercury being discharged to the air (between 20 to 30 kg per year), contributing only a small increase to air concentrations over a wide area, the overall environmental and human health impacts from crematoria emissions are likely to be negligible.

3.7 Mining

Historically, mercury was used in gold mining as part of the gold recovery process. As noted earlier, this may still occur on a small scale by gold fossickers, but commercial gold mining does not use mercury in New Zealand. New Zealand was the first country to use the cyanide process on a commercial scale for gold recovery in hard rock mining in late 1889 (MED, 2004). The cyanide process achieved much better recoveries and displaced the earlier mercury amalgam process used to recover fine gold. Commercial-scale mining of alluvial gold (from placer deposits) uses mechanical means (e.g. cyclones) to concentrate and recovery the fine gold.

Mercury can also be associated with gold within the ore. The conditions that resulted in gold accumulating can also result in some mercury accumulating. Discharges of mercury within Coromandel and Northland may be enhanced due to the release of metals into the environment from historical mining sites, mainly as a result of acidic mine drainage. Acid mine drainage (AMD) is the discharge of contaminated leachate which results in the deterioration of groundwater and local waterways. Although acidic conditions found as a result of sulphide

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[10] New Zealand does not currently have a soil guideline, but the Australian soil guideline for a residential setting for inorganic mercury is 15 mg/kg (NEPC, 1999) and, as noted earlier, the US EPA regional screening level is 23 mg/kg.

mineral oxidation, enhances the release of mercury into the environment, the solubility of mercury under low pH conditions is very low (Craw *et al*, 2000). In addition, in the Coromandel decomposition of sulphide minerals is very slow and mercury being released from mineralised areas and old mine workings is generally incorporated into low permeability iron oxy-hydroxide cements, ensures the concentration of mercury discharging into the environment is at very low levels (Craw and Chappell, 2000).

Generally New Zealand mines are small by international standards and consequently metal discharges and their environmental impacts are relatively localised and small. Mercury discharges from historical mine sites are generally rapidly diluted, and attenuated by adsorption onto iron oxides and therefore do not tend to impact on a significant area. Modern mine sites have significantly better controls on mercury discharges and therefore the concentration of mercury in their discharges is likely to be negligible.

Overall, the impact of mercury from mining practices in New Zealand is thought to be limited to only minor localised impacts at a relatively few historical mine sites. Although there is insufficient information to quantify the amount of mercury released from mining operations within New Zealand, the amount of mercury released is probably very low and it is unlikely to have a significant impact on ecological or human receptors.

4 Human Exposure Analysis

4.1 Introduction

To assess the potential human health risk from mercury to the ‘average’ New Zealander, an estimate of the total amount of mercury that an individual is exposed to via all the different exposure pathways (e.g. ingestion, inhalation) is required. In this assessment, dermal exposure (i.e. though skin contact) has been ignored as it is considered to be a relatively unimportant exposure pathway.

The second step in the exposure assessment is comparing the exposure estimate with a health standard for mercury (Section III-2.5) to establish if the exposure is acceptable.

Mercury exposure is idiosyncratic, as individual exposure may vary widely depending on individual circumstances, e.g. the amount and type of fish consumed and the number of amalgam dental fillings. In this human exposure assessment, average exposure estimates have been used to determine the concentrations of mercury that the ‘average’ person is exposed to. It is not possible to make individual estimates without a detailed study of the person to account for all intake routes.

The concept of the average person is somewhat of a convenient fiction. Although most people will fall in the middle zone, in reality there will be a distribution of mercury intake figures for individuals ranging from very low to very high, some of whom may exceed the recommended guideline values in Section III-2.5.

4.2 General Population

4.2.1 Dietary Exposure

The level of mercury in foods is variable and partly reflects the concentration of mercury in the soil and water in the area where the food was cultivated or captured. In the 2003/04 New Zealand Total Diet Survey (NZTDS) most of the food consumed in New Zealand did not have detectable concentrations of mercury (generally less than 2 µg/kg) with the exception of fish, which had elevated concentrations of mercury (Vannoort and Thomson, 2005).

The concentration of mercury in most oceanic fish is generally around or less than 0.15 mg/kg, however large and long-lived predatory fish species (shark, tuna, lemon fish) typically have mercury levels in the range of 0.20-1.5 mg/kg (Vannoort and Thompson, 2005). Battered fish measured in the 2003/04 NZTDS had concentrations of up to 0.85 mg/kg (Vannoort and Thompson, 2005). Organic mercury, particularly methylmercury, is the predominant form of mercury in fish, thought to comprise roughly 80% of mercury in fish (Tchounwou *et al*, 2003).

The WHO set a new PTWI of 1.6 µg/kg bw/week for methylmercury in 2003 (WHO, 2004), while the PTWI for total mercury is 5 µg/kg bw/week or 350 µg/person/week for a 70 kg adult (WHO, 1972). The NZFSA estimates average daily intake of mercury by adults from food sources ranges from approximately 0.60 to 0.74 µg/kg bw/week (Table III-7). It should be noted that dietary exposures in the 2003/04 NZTDS were based on average energy diets for each of the age-sex groups (Vannoort and Thompson, 2005). Some consumers have the potential to have significantly higher exposures, particularly high exposure groups (Section III-4.3).

Table III-7: Estimated weekly dietary exposures (µg/kg bw /week) for total mercury for the eight age-sex groups of the 2003/2004 NZTDS (from Vannoort and Thomson, 2005)

	Male 25+ yr	**Female 25+ yr**	**Young Male 19-24 yr**	**Boy 11-14 yr**	**Girl 11-14 yr**	**Child 5-6 yr**	**Toddler 1-3 yr**	**Infant 6-12 month**
Total Hg	0.74	0.60	0.74	0.74	0.46	1.1	1.3	1.3
% PTWI	15%	12%	15%	15%	9%	21%	25%	26%
%PTWI (MeHg)	46%	38%	46%	46%	29%	69%	81%	81%

Vannoort and Thompson (2005) estimate that the weekly dietary intake exposures for all age-sex groups was 26% or less than the PTWI for total mercury, and 86% or less if all of the mercury is assumed to be methylmercury. The NZFSA also states that the PTWI has safety factors built into it and the PTWI represent a level of no appreciable risk for a lifetime exposure. Overall, the NZFSA assessment is that the New Zealand population is highly unlikely to have any adverse health effects as a result of dietary exposure to mercury.

As noted earlier, there are likely to be regional differences in the concentration of methylmercury in some freshwater fish species. Fish caught anywhere on the North Island’s volcanic plateau (e.g. the Taupo area and in parts of the Waikato River) tend to have methylmercury levels up to ten times higher than their marine counterparts (Section III-3.2.2). This is a result of naturally high concentrations from discharges of geothermal waters. The NZFSA is currently investigating whether fish from certain marine fisheries may contain higher concentrations of methylmercury from geothermal discharges, e.g. Bay of Plenty due to geothermal inputs from White Island.

NZFSA notes that some high fish-eating consumers have the potential to have significantly higher exposures and that it may be advisable for toddlers, infants and women of child bearing age to limit the types of fish they eat and the frequency that it is eaten. However, while some fish are known to contain elevated concentrations of mercury, fish is also an important source of nutrition (Diez, 2008). Fish contain nutrients important for brain development, such as omega-3 fatty acids (WHO, 2008) as well as iodine and vitamins. Based on both the strength of the evidence and the potential magnitudes of effect, the benefits of fish intake exceed the potential risks from mercury (Tsuchiya *et al*, 2008). For women of childbearing age, benefits of modest fish intake, excepting a few selected species (Table III-9), outweigh risks from mercury (Mozaffarian and Rimm, 2006). NZFSA (2009) recommends eating fish during pregnancy as part of a well-balanced diet.

4.2.2 Drinking Water

Generally, mercury concentrations in drinking water supplies are below the analytical detection limit. Davies *et al*, (2001), in reporting on the chemical quality of community water supplies in New Zealand, detected total mercury (at a detection limit of 0.0005 mg/L) in only three drinking water zones (3% of those assessed) with a detection at greater than 50% of the then Maximum Acceptable Value (MAV) of 0.002 mg/L (now 0.007 mg/L) in only one zone, the latter representing an estimated 100 people.

As a conservative estimate of drinking water intake, Cavanagh (in prep) proposed using 10% of 0.002 mg/L, i.e. 0.0002 mg/L. For the normal assumption of an adult drinking two litres of water per day, this results in an intake of 0.4 µg/day, or 0.04 µg/kg bw/week (less than 1% of the PTWI). This is very conservative when compared to the actual concentration of mercury in the Waikato River at Lake Ohakuri, downstream of several major geothermal discharges, of less than 0.00008 mg/L (giving rise to an intake of less than 0.16 µg/day for a water consumption of two litres). The Waikato River is the source of several community water supplies, including Hamilton and a proportion of Auckland’s. However the concentrations of mercury in municipal drinking water supplies are generally lower than in their source waters because a substantial part of any mercury that is present is removed during the standard water treatment process.

Overall, drinking water is thought to be an insignificant exposure route for mercury exposure for most people in New Zealand.

4.2.3 Dental Amalgams

The amount of mercury absorbed into the body from amalgams is likely to be idiosyncratic, being higher in people with more amalgam fillings, particularly if the fillings are of poor quality. As noted in section II, WHO (1991) estimated that for an average person with 8-10 amalgam fillings, between 21 and 119 µg of mercury might be absorbed per week as a result of loss of mercury from the amalgams. For a 70 kg adult, this translates to 0.3 to 1.7 µg/kg bw/week, or 6 to 34% of the PTWI.

4.2.4 Inhalation of Air

A typical concentration of mercury in air in New Zealand has been estimated at between 0.42 ng/m^3 and 3.1 ng/m^3 (Bibby and Patterson, 1988, de Mora, *et al*, 1991, Fellows and Bates, 1998). If it is assumed that the average adult inhales approximately 22 m^3 of air per day (Fellows and Bates, 1998), an average adult will have an inhalation exposure to mercury of 0.07 µg/day or 0.48 µg/week. This translates to 0.007 µg/kg bw/week, or 0.1% of the WHO PTWI for total mercury.

Around Rotorua, mercury emission rates have been measured at up to 20 ng/m^3 (Fellows and Bates, 1998). Even at these concentrations, the total intake of mercury is only 3.08 µg /week or 0.044 µg/kg bw/week for a 70 kg adult, which is less than 1% of the PTWI. Therefore inhalation of mercury in air is unlikely to be a significant exposure route.

4.2.5 Smoking

A significant sub-group of the population is exposed to mercury through smoking. Fowler *et al* (2000) has estimated that smoking an average cigarette exposes a smoker to 5 mg of mercury per cigarette. Assuming a smoker smokes 10 to 20 cigarettes per day, the smoker could be exposed to between 0.35 to 0.7 µg of mercury per week. For a 70 kg adult this translates 0.005 to 0.012 µg/kg bw/week, a small fraction of the PTWI.

4.2.6 Summary of Estimated Exposure for General Population

Based upon the exposure scenarios above, it is estimated that the ‘average’ 70 kg adult New Zealander is exposed to between 76 and 174 µg Hg/week (1.1 – 2.5 µg/kg bw/week), or approximately 22 to 50% of the PTWI for total mercury (Table III-8). Assuming that the methylmercury concentration is approximately 80% of the total mercury measured in fish (Diez, 2008), the ‘average’ New Zealander is exposed to roughly 42 µg/week of methylmercury, or approximately 42% of the PTWI for methylmercury.

The consumption of fish is generally the most important exposure pathway in terms of human exposure to total mercury and methylmercury. However, for people with a large number of mercury amalgam fillings, exposure to mercury from these fillings may also be a significant source.

These calculations will underestimate a person’s exposure if they consume a large amount of seafood in their diet, particularly if they consume significant quantities of fish species which are high in mercury (Table III-9), or if they have a significant occupational exposure to mercury (Section III-4.3).

Table III-8: Summary of estimated adult exposure to mercury in New Zealand

Source of Exposure	**Elemental Mercury**	**Inorganic Mercury**	**Methylmercury**	**Total Mercury Exposure**
Air	0.48 µg/week			0.48 µg/week
Food - Fish	10 µg/week		42 µg/week	52 µg/week
Drinking water		2.8 µg/week		2.8 µg/week
Dental Amalgams	21-119 µg/week			21-119 µg/week
Total	31-130 µg/week	2.8 µg/week	42 µg/week	76-174 µg/week
PTWI[1]			112 µg/week	350 µg/week
% PTWI			37.5%	22%-50%

[1]Note: Exposure assumed for 70 kg adult.

4.2.7 Broken Compact Fluorescent Lamps

Exposure to mercury from broken compact fluorescent lamps (CFLs) results in a short term exposure. Studies undertaken by the New Jersey Department of Environmental Protection (Aucott *et al*, 2003) found about one third of the mercury in a broken lamp was released within the first eight hours. Assuming that a single CFL has approximately 5 mg of mercury and that the volume of air in a standard size room is approximately 33 m^3, a broken CFL could produce air mercury concentrations in the range of 8 to 20 $\mu g/m^3$ within eight hours after breakage if the room was not ventilated (Groth, 2008). These concentrations exceed the ATSDR (1999) MRL (0.2 $\mu g/m^3$) and WHO (2000) ambient air concentration (1.0 $\mu g/m^3$) guideline levels.

Mathematical modelling of mercury emissions from a broken CFL by the Florida Department of Environmental Protection (Chandrasekhar, 2007) found that by ventilating the room and using a fan to increase the air flow, the airborne mercury concentrations were reduced to below the ATSDR MRL within 12 minutes and were at background levels within 20-25 minutes (Chandrasekhar, 2007). Similarly, experiments by the Maine Department of Environmental Protection (DEP) (Maine DEP, 2008), measuring mercury concentration after breaking a hot CFL (when most of the mercury is likely to be in a gaseous phase), found that mercury concentrations generally dropped to below the US EPA inhalation reference concentration (RfC) of 0.3 µg/m^3 within minutes, although in some experiments concentrations remained above this value for more than an hour. Short term spikes in excess of 100 µg/m^3 were recorded for some experiments. Cleaning by vacuuming increased the concentrations, and re-vacuuming days later after an initial clean-up also remobilised the mercury to above the US EPA RfC.

It should be noted that in both the Maine and Florida studies, the selected health criteria are applicable to long-term continuous exposure. ATSDR (1999) emphasises that the chronic MRL is not intended to be used as an estimation of a threshold level, as exceeding the MRL does not necessarily mean that a health threat exists. ATSDR did not derive acute or intermediate MRLs – values that would be more applicable to exposure from a broken lamp – because of a lack of data. ATSDR (1999) notes that the chronic inhalation MRL is, by definition, a level that is considered to be without appreciable health risk over a lifetime of exposure at that level. It is further considered to be a "safe" level for all the exposed human population, when exposure exists for 24 hours a day, 7 days a week for an extended period of years. People may be able to "tolerate" metallic mercury levels above the MRL for intermittent periods.

The Maine DEP (2008) took a different view to the ATSDR MRL in their reporting of the lamp breaking experiments, regarding even short-term excursions over the MRL as a potential risk, particularly for a young child. This is a very conservative, precautionary approach.

Taking the ASDR (1999) view that each exposure case must be considered on its merits, it is possible to use the Maine DEP data to obtain an idea of an individual’s likely exposure to mercury in the event of CFLs being broken regularly.

It is appropriate, in the first instance, to use a conservative exposure scenario to assess the possible risk. Such an exposure is termed the reasonable maximum exposure estimate (RME). If it is assumed that an average house has 30 mercury-containing lamps, and the lamps have an average life of five years, then a lamp has to be replaced on average every two months. If it is further assumed that on every second replacement the lamp is broken (a conservative assumption) then an individual could be exposed to mercury on three occasions (being the actual event and the lingering effects) per year.

The Maine DEP studies showed that concentrations in air dropped to within the ATSDR MRL quickly – generally within minutes to a few hours. However, scenarios that had initial vacuum cleaning and subsequent regular vacuum resulted in extended period of several hours with average concentrations of around 1 µg/m^3. If a concentration of 1 µg/m^3 is assumed for the first 24 hours, the same average concentration occurs for 24 hours for two subsequent vacuuming cleanings one week apart and drops to half that concentration on a fourth vacuuming, after which concentrations stay within the ATSDR MRL regardless of vacuuming.

If the same adult is exposed for 24 hours within the room (an unlikely scenario), with the adult breathing at a rate of 15.2 m^3/day (US EPA, 1997b), then the average monthly rate of exposure is 13.3 µg. This is the equivalent of 0.19 µg/kg bw/month or 4% of the WHO PTWI.

The risk to a child would greater, given a lower body weight. A child remaining in the same room on each occasion would be unusual, but assuming a body weight of 15 kg for a toddler and an inhalation rate of 6.8 m^3/day (US EPA, 1997b) results in an average exposure of 0.4 µg/kg bw/month, or 8% of the PTWI.

It should be noted that the above estimates are conservative estimates and that an individual actual exposure to mercury as a result of breakages of CFLs is probably much lower, probably a fraction of 1% of the PTWI. This maximum likely extreme exposure assessment has been adopted to demonstrate that breakages of CFLs is unlikely to result in an unacceptable exposure to mercury. This exposure assessment supports the finding of a report prepared for the Ministry of Health (TERA, 2008), which also found that likely mercury exposure were also below risk-based acute exposure screening levels.

These studies confirm that there is only a very small risk from breakages of CFLs, a conclusion supported by Groth (2008). However, this risk can be reduce or eliminated if prompt and proper clean up is carried out. The Ministry for the Environment has recommendations on how to clean up mercury released from a broken CFL on its website[11].

When dealing a broken CFL it is advisable that children are removed from the room that the breakage has occurred in. This is because children are more sensitive than adults to mercury spills as:

- Mercury vapours are heavy and tend to settle, making mercury concentrations higher at floor level;
- The blood-brain barrier of children is not as effective at keeping mercury out of the brain;
- The respiration rate of children is higher than that of adults, so children inhale more mercury at a given concentration than adults do; and
- The nervous system of children is still developing and therefore more sensitive to the effects of mercury toxicity (Baughman, 2006.)

4.3 Populations with Potentially High Exposures

Some people are more susceptible to mercury toxicity. The WHO identifies two main susceptible sub-populations (WHO, 2008). These are:

1. people who are more sensitive to the effects of mercury exposure; and

2. those who potentially are exposed to higher concentrations or have a higher dietary intake of mercury (WHO, 2008).

4.3.1 Potentially Sensitive Populations

Foetuses, new born babies and infants are particularly sensitive to the effects of mercury as their blood-brain barrier is less developed than adults and is less effective at preventing mercury from reaching the brain. Excessive exposure can result in neurological effects (WHO, 2008). Besides being potentially exposed to mercury in the uterus, new born babies can be further exposed to mercury from drinking contaminated breast milk (WHO, 2008). It should be noted that the NZFSA does not consider breast milk as a significant source of mercury in New Zealand mothers and the benefits of breastfeeding far outweigh any risks posed by the small amount of mercury that may be present in breast milk (NZFSA, 2009).

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[11] http://www.mfe.govt.nz/publications/waste/disposal-household-lamps-mar07/disposal-household-lamps-mar07.html

Due to the risk that methylmercury poses to the developing foetus and infants, the WHO (2008) recommends that new mothers, pregnant women, and women who might become pregnant should be aware of the hazards associated with methylmercury. To minimise the potential effects on unborn children the NZFSA recommends that pregnant women should reduce their intake of some longer lived and larger fish (NZFSA, 2009). The NZFSA also recommends that consumption of fish from geothermal areas should be limited to no more than one serving per week or fortnight (NZFSA, 2009). A summary of the recommended intake of various fish species in New Zealand is outlined in Table III-9.

Table III-9: NZFSA recommended maximum fish intake of various fish species

No restriction necessary	**3 – 4 servings[12] per week acceptable**	**1 serving per 1 – 2 weeks acceptable**
Anchovy Arrow squid Barracouta Blue cod Brill/Turbot Brown trout from Lake Ellesmere Cockles Eel, long or short finned Elephant fish Flounders Gurnard Hoki John Dory Monkfish or stargazer Mussels (green and blue) Orange perch Oysters (Bluff* and Pacific) Parore Rainbow trout from non-geothermal regions Salmon (farmed) Scallops Skipjack tuna Sole (except Lemon sole) Southern blue whiting Surf clams (e.g. tuatua) Tarakihi Toothfish (Antarctic) Warehou (common, silver and white) Whitebait (Inanga)	Albacore tuna Alfonsino Bass Bluenose Gemfish Ghost sharks Hake Hapuka (Groper) Javelin Fish Kahawai Kingfish Lake Taupo trout Leatherjacket Lemon sole Ling Mackerel (blue and jack) Orange roughy Oreo dories Red cod Ribaldo Rig (Lemonfish, Spotted dogfish) Rock lobster Sea perch Silverside Skate Smooth oreo Snapper Sprats Trevally	Cardinal fish Dogfish (excluding rig) Lake Rotomahana trout Lake trout from geothermal regions School shark (Greyboy, Tope) Marlin (striped) Southern bluefin tuna Swordfish

Source: NZFSA (2009).

4.3.2 Populations with Greater Exposure to Mercury

In addition to people who are occupationally exposed to mercury (such as dental professionals), there are several groups within the general population with potentially high exposures (i.e. higher than background) to mercury (ASTDR, 1999). As eating fish and seafood is the major exposure pathway of mercury, individuals who eat a large amount of seafood have a greater exposure to mercury (especially methylmercury). Individuals who may have a higher

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[12] A serving is approximately 150 g of fish.

exposure to mercury include recreational anglers and subsistence fishers. Concentration of methylmercury in fish caught from geothermal lakes and the Waikato River hydro lakes are elevated (Section III-3.2.2). Methylmercury concentrations in sport fish (i.e. swordfish, marlin, sharks, etc) can be at least an order of magnitude higher than in commercial fish purchased from the supermarket (ATSDR, 1999).

People living near waste disposal sites (landfills) which operate landfill gas flares, and waste transfer stations, may be exposed to mercury through several exposure pathways, including inhalation, dermal contact and oral exposure (ATSDR, 1999). Currently there is insufficient information to determine the potential exposure risk for these populations.

People who use cosmetic products and medicinal products containing mercury are exposed to higher mercury levels than the general population (ATSDR, 1999). Mercury is not used in pharmaceuticals and cosmetic products sold in New Zealand, although some ethnic medicines (such as some Chinese traditional medicine, e.g. *Fufang Luhui Jiaonang*, which contains between 11-13% mercury)) and cosmetics (*i.e.* skin lighting creams and soaps) are imported into New Zealand and used by some individuals. Mercury-containing skin lightening soaps and creams are left on the skin overnight and the mercury contained within them can be absorbed through the skin (WHO, 1991). The evidence indicates that the total exposure to mercury is substantial from these sources (WHO, 1991).

4.4 Occupational Exposures

Worldwide, most occupational exposure to mercury involves exposure to inorganic or metallic mercury forms such as mercury from chemical processes (e.g. chlor-alkai production), electrical equipment, thermometers, metal processing and in medical and dental services (Hu, 2000). Mercury is still used in New Zealand in a number of occupational settings (such as dentistry, medical applications, commercial/research and school laboratories) and aryl mercury compounds are used in printing inks and resin manufacturing (Luckman and Slaney, 2005). There is no longer any chlor-alkali production in New Zealand.

In New Zealand between March 1992 and June 1998 there were four confirmed cases of work related mercury poisoning (Driscoll *et al*, 2004). However, no information on the type of exposure or the industrial setting that exposure occurred in was provided in the report.

It is likely that dentists and dental workers have the highest occupational exposure to mercury in New Zealand. A study conducted by Richardson (2003) found that the current single largest source of mercury exposure to a dentist is the removal of old amalgam fillings, which can increase the inhalation of mercury vapour within the dental surgery over the course of an entire week.

Potential occupational exposure may also exist for sanitation workers and employees involved in recycling fluorescent lamps (Aucott *et al*, 2003). Southworth *et al*, (2005) measured mercury emissions at transfer facilities and from waste bins in the field and found surprisingly high rates of mercury emissions (up to 100 mg/hr at some transfer stations). Up to 20-40% of mercury emissions from waste disposal processes may occur during the collection, transfer station activities and waste storage before landfilling (Southworth, *et al*, 2005). Aucott *et al*, (2003) suggested that airborne concentrations of mercury may exceed occupational exposure limits at some waste handling facilities under certain conditions.

5 Conclusion

Mercury is a naturally occurring, highly toxic metal, which is capable of producing a range of adverse physiological and neurological effects in humans depending on the concentration and chemical form that a person is exposed to. Mercury is particularly dangerous because it has the ability to cross the blood-brain and the placental barriers with the potential to cause significant adverse effects in the developing foetus. Mercury also has a strong tendency to accumulate in organisms. Organic forms of mercury (especially methylmercury) bioaccumulate in aquatic and terrestrial food chains and has the potential to cause toxic effects in humans if contaminated food is consumed.

Mercury emissions from natural sources (such as volcanoes, geothermal discharges and mineralised soil) are the single largest source of mercury released into the New Zealand environment. In New Zealand, natural emissions of mercury are unlikely to result in direct toxicity, however they do elevate the background concentration of mercury found in New Zealand biota, sediments, soils and waterways.

Mercury emitted from industrial sources, mainly from the combustion of coal and generation of geothermal power, is also a significant source of mercury in the New Zealand environment. Most of the mercury emitted from industries in New Zealand ends up being discharged via stack emissions resulting in a slight increase in atmospheric concentrations of mercury. Although these small increases in mercury are unlikely to pose any direct toxicity threats to humans, studies have shown that small increases in atmospheric loadings lead to a direct increase in the concentration of mercury in fish.

Other emission sources of mercury such as agricultural, crematoria and cemeteries, landfills and mining are thought to have a relatively minor contribution to mercury emissions.

Dietary exposure, through the consumption of fish, is the most important pathway for mercury exposure to the general population in New Zealand. Dietary exposure to mercury may account for up to 54% of a person’s total exposure to mercury and nearly all their exposure to methylmercury compounds. Mercury emissions from dental amalgams are thought to be the second most important exposure pathway for the majority of the population, accounting for between 20 to 34% of a person’s total mercury exposure. Although dietary exposure from fish consumption is believed to be the major route of exposure to mercury for the generally population, a number of studies have demonstrated that the benefits of eating a modest amount of fish outweigh the risks of exposure to methylmercury.

Exposure to mercury from broken CFLs will result in short-term exposure to mercury, which may exceed ATSDR MRL (0.2 $\mu g/m^3$) and WHO ambient air concentration (1.0 $\mu g/m^3$) guideline levels for long-term mercury exposure for a number of hours. However, exposure to broken lamps is of short duration and expected to be infrequent. It is thought that mercury exposure from broken CFLs poses minor or no direct threat to human health if prompt and proper clean up is carried out. Calculations using an extreme scenario of frequent breakages with improper clean-up techniques employed, suggests that an adult may be exposed to up to 4% of the WHO PTWI and an infant up to 8% of the WHO PTWI, but actual exposure is likely to be considerably less.

Overall, mercury does not currently present a significant health risk to the New Zealand public. However, there may be small sub-groups of the population which are exposed to significantly higher concentrations of mercury. This may, in some extreme cases, result in mercury toxicity. Potentially vulnerable sections of the population include: recreational or subsistence fishers who consume a large amount of fish particularly large long-lived predatory fish or fish from geothermal; people who are occupationally exposed to mercury (such as dental professionals); and people using skin lightening creams containing high concentrations of mercury.

Foetuses, new born babies and infants are particularly sensitive to the effects of mercury. People with certain medical conditions may also be more sensitive to the toxic effects of mercury. Therefore pregnant women and individuals with certain medical conditions may be wise to limit intake of fish and to consume fish species which contain lower amounts of mercury to reduce their risk from mercury exposure.

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Section IV – Ten-year Projections of Mercury Loadings

1 Introduction

In this section of the report predictions on how mercury contributions from the sources outlined in Section II (Mercury Contributors) might change over the next ten years are calculated. One of the purposes of this is to assess whether the relative contribution of mercury from mercury-containing lamps is expected to change significantly over the next ten years when compared to New Zealand's anthropogenic and overall mercury loads.

Making any predictions into the future is always difficult due to the large number of uncertainties that exist. Possible international conventions to combat mercury in the environment (e.g. the February 2009 agreement at the UNEP 25th Governing Council/Global Ministerial Environment forum to work towards an international convention to limit mercury use) may influence the amount of mercury in certain products (e.g. lamps and batteries) and hence mercury emissions in the next ten years and beyond. In addition, other worldwide policy changes related to minimising greenhouse emissions from combustion sources may also limit mercury discharges (i.e. coal use may be limited and renewable energy sources will be encouraged).

Due to the large number of uncertainties associated with the future, the predictions in this section are based on our current knowledge, existing information sources, and discussions with various industries. No attempt has been made to predict new technologies that might reduce mercury emissions in the future.

2 Methodology

A variety of methods have been used to calculate forecasts for anthropogenic emissions in ten year's time (2018 using 2008 as the baseline). In some instances industry estimates have been used, e.g. for CFLs sales into the future. However, a large part of the anthropogenic emissions calculated in Section II are for emissions associated with energy use in New Zealand. Prediction of New Zealand's energy use are therefore required to project mercury emissions into the future.

A number of official forecasts exist for energy use into the future. These include modelling by the Ministry of Economic Development to predict energy use through to 2030 (MED, 2006) and the Electricity Commission forecasting locations and types of electricity generation for planning electricity grid upgrades (EC, 2008, 2009). These reports have been used, together with supplementary information, to forecast future coal, natural gas and transport fuel use and to predict geothermal electricity generation. Later forecasts have been used in preference to earlier forecasts, where they contain similar information.

The MED Energy Outlook 2030 report (MED, 2006) considered energy use by sector (e.g. residential, commercial, heavy industrial, electricity generation) and fuel type (oil, gas, coal, geothermal) using 2005 as the baseline. Where GDP was used to forecast future growth in this document, New Zealand Treasury predictions were used for the five years between 2005 and 2010 followed by a linear decline in GDP growth from 2.6 to 2% from 2010 to 2020. It is necessary to examine these assumptions in the light of recent economic performance and the possibility of a prolonged economic downturn. These could affect the validity of the MED (2006) predictions.

Treasury has recently updated their quarterly economic forecast for the next five years (Treasury, 2009). These forecasts together with GDP statistics from Statistics New Zealand[13] were used to assess the validity of the MED (2006) GDP forecasts.

A comparison is set out in Table IV-1. The updated forecasts uses the actual GDP increases for the period 2005 – 2008, the treasury forecasts for 2009 – 2013 and the long-term average between 1988 and 2008 (2.7%) for the period 2014 – 2018. It can be seen that while the MED (2006) forecasts slightly over-predicted actual performance for the period 2005 – 2008, for the period 2009 – 2018 it is more pessimistic than the updated forecasts, mainly because the long-term increase MED has used is less than the long-term average to date. The overall increase from 2005 – 2018 is very similar and therefore it seems reasonable to use the MED (2006) forecasts to predict increases in energy use for the period from 2008 to 2018, in the absence of better information. However, where later information has been available, this has been used.

Table IV-1: MED and updated GDP forecasts

Period	MED (2006)		Updated forecast	
	Cumulative	Average	Cumulative	Average
2005 – 2008	9.2	3.0	8.2 (actual)	2.6
2009 – 2018	26.8	2.5	28.2	2.4
2005 – 2018	38.6	2.5	38.4	2.5

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[13] http://search.stats.govt.nz/search?w=economic%20indicators%20national%20accounts

In calculating the 10-year forecasts, it has been assumed that emission factors applicable to the current situation will be the same, that is, there will be no improvement in technology to improve the capture of mercury emissions following combustion. This assumption is conservative.

Some of the mercury emission projections in this section have been calculated based on expected population or household number increases to 2018. Statistics New Zealand provides such estimates. It is expected that New Zealand's population will increase around 9% from 2008 to 2018 (Statistics New Zealand, 2009)[14], and household numbers will increase around 14.3% (Statistics New Zealand, 2009)[15]. Population and household number increases have been used to project the emissions from some of the consumer products with intentional use of mercury (Section IV-5). Further information on the derivation of 10-year predictions is outlined in the individual sections.

A summary of the 10-year predictions is compiled at the end of the section, followed by an assessment on whether the relative contribution of mercury from mercury-containing lamps will change significantly over the next ten years when compared to New Zealand's anthropogenic load, and overall mercury load. In this study, the natural mercury emissions in ten year's time have been assumed to be the same as that assessed for 2008.

This may or may not be true depending on whether there are any volcanic eruptions over the next ten years. Volcanic eruptions have the potential to completely overshadow New Zealand's current mercury load. With the remaining natural sources, geothermal emissions are expected to remain constant over time, while volatilisation of mercury from soils may increase. The latter is due to a gradual increase in airborne concentrations of mercury over time, which when deposited, will lead to slight increases of average soil concentrations. This increase cannot be quantified and, given the slow increase in atmospheric concentrations, is not considered significant.

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[14] Projected Population Characteristics, 2006 (base) – 2061. Sourced from http://wdmzpub01.stats.govt.nz/wds/TableViewer/tableView.aspx?ReportName=Population%20Projections/Projected%20Population%20Characteristics,%202006%20(base)%20-%202061 5 (middle) predictions have been used.

[15] Projected households by household type, 2006 (base) – 2031. Series 5 (middle) predictions have been used. http://www.stats.govt.nz/browse_for_stats/population/estimates_and_projections/nationalfamilyandhouseholdprojections_hotp06-31projections.aspx

3 Extraction and Use of Fuels/Energy Sources

Primary energy includes the use of coal, natural gas, electricity and oil.

3.1.1 Coal

The MED's on-line energy data[16] records coal use amounted to 86 PJ/year, or 3.88 Mt in 2008. The biggest use was for the generation of electricity at 1.96 Mt (predominantly at Huntly Power Station, although coal is used in a small way to generate electricity as part of industrial co-generation).

MED (2006) assumed that Huntly Power Station would be using 18 PJ of coal for most of the period from 2005 to 2020. The actual recent use of coal at Huntly Power Station is currently considerably greater. If Huntly Power Station consumed 92% of the coal used for electricity in 2008, then its actual coal use would equate to 40.6 PJ (Section II-3.2.1).

The actual use of coal at Huntly Power Station over the next few years is difficult to predict as it depends on the availability and price of gas as an alternative fuel at Huntly and the price and availability of competing power generating capacity. The conservative position is to assume that Huntly Power Station continues using about 2 Mt /year and otherwise use the MED (2006) forecasts to increase the other coal uses. For non-electricity uses this amounted to about an 8% increase over ten years. Applying this to the mercury emission calculations from Section II-3.2.1 (of 237 kg Hg/year) would result in mercury emission of approximately 260 kg.

It should be noted, however, that the EC (2008) in its forecasts assumes that Huntly Power Station will generate less electricity in ten years time than now in four out of the five scenarios it modelled. In these four scenarios, Huntly was assumed to continue generating with coal at a high level for the next few years but reduce to about half by 2018. Both MED (2006) and EC (2008) assume there will be no new coal-fired generation within the next ten years.

Not accepting the EC (2008) assumption of reduced generation at Huntly is inconsistent with also accepting its scenarios of increased gas and geothermal generation (with associated increases in mercury from these forms of generation). Thus, the above estimate for Huntly is conservative by about 100% (the equivalent of about 1 million tonnes of coal) and a better estimate for Huntly in ten year's time is 130 kg of mercury. In 2008 Huntly made up 92% of coal-fired power generation, with the balance being industrial co-generation. Mercury emissions from other generation are estimated to have been 21 kg in 2008. If this amount is assumed to remain unchanged over the next ten years, the total mercury emissions for coal-fired power generation in 2018 would be 151 kg Hg/yr.

As noted earlier in this report, the main non-power station uses of coal are in steel manufacture, cement and lime manufacture, the dairy industry, the meat industry and other uses. The largest use of coal after Huntly is the Glenbrook steel plant. The future emissions from Glenbrook are considered under the primary metals production sector in Section IV-3.2. Future emissions from cement and lime manufacturing have also been specifically calculated in Section IV-3.3.

For the dairy sector, MED (2006) assumed that cow numbers would increase by 1% per year and therefore coal use would do the same, or about an 11% increase over ten years. However,

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[16] Available at: http://www.med.govt.nz/templates/ContentTopicSummary____21093.aspx

the Ministry of Agriculture and Forestry, in its 2008 outlook document (MAF, 2008), suggests dairy herd increases of 2 – 3% per year for the next few years. This may not be sustainable for the next ten years, but if the lower figure is taken and it is assumed milk production and coal use increases at the same rate, then the current dairy sector mercury emissions from coal will increase 22% from 39 kg Hg/yr to about 48 kg Hg/yr.

MAF (2008) is pessimistic about the meat industry growth, with sheep numbers declining and beef numbers stable. Based on this it is assumed the meat sector coal use stays static over the next ten years. In other words, the current 16 kg Hg/yr remains unchanged. This leaves other industrial users, with a current emission rate of 7 kg Hg/yr. If it is assumed coal use increases at the assumed rate of GDP increase, i.e. 28%, emissions will increase over ten years from 7 to 9 kg Hg/yr.

3.1.2 Oil

The MED's projected fuel oil (petrol and diesel) demand in New Zealand use amounted to 288.97 PJ/year in 2008 (MED, 2006). The MED forecasts that this figure will increase to 340.94 PJ in 2018. In 2008, approximately 70% of the fuel oil used in New Zealand was refined at the Marsden Point refinery and about 30% of the fuel oil was imported into New Zealand as refined product (NZRC, pers. com, 2009).

To estimate the amount of mercury generated from oil in 2018, the following assumptions have been made:

- That NZRC refinery is currently at 100% capacity and there will be no additional capacity in 2018. Therefore the volume of crude oil imported into New Zealand in 2018 for refining at Marsden Point will be the same as the 2008 figure. This means that in 2018 approximately only 59% of the fuel oils used in New Zealand will be imported into New Zealand as crude oil to be refined at Marsden Point.
- The current mercury content in imported crude oil will remain the same and will be emitted either at the refinery or in refined fuels.
- That approximately 55% of mercury in crude oil is lost during the refining process (Wilhelm, 2001) resulting in imported refined petroleum products having an average mercury concentration of 4.5 ppb if the average mercury concentration in the crude is 10 ppb.
- That the fuel used for international air and maritime transport from New Zealand does not contribute to New Zealand's total mercury emissions, as the majority is discharged outside New Zealand territorial boundaries.

The 10-year mercury forecast based on these assumptions is 83 kg Hg/yr from approximately 7,400 million litres of petroleum products.

3.1.3 Natural Gas

The EC has recently produced a new forecast for natural gas use (EC, 2009) as part of its forecasting for electricity generation. This has been used in preference to early forecasts by MED (2006).

The EC used Monte Carlo simulations to predict gas use for a number of different scenarios, based on current gas production and known reserves, with different assumptions for such things as future gas use, gas imports and new finds of gas in New Zealand. Gas use is very difficult to predict given the unknowns with respect to future prices, government policy on measures to limit greenhouse gas emissions (which affects price), price-sensitive competing uses for gas, and future production in New Zealand.

Taking EC's "Medium gas production forecast" 50th percentile prediction as a reasonable average, gas use is predicted to decrease from around 170 PJ in 2008 to about 125 PJ in 2018. This translates to a decrease in mercury emissions from 60 kg/year (Section II-3.2.1) to 48 kg/year.

3.1.4 Biomass Combustion

The MED (2006) forecasts predict an increase in biomass energy use between 2005 and 2020 of 10%. On a pro rata basis, the 10-year increase from 2008 would be about 7%.

The majority of biomass energy use is home heating. Increasing the mercury emissions from use of wood from home heating in Section II-3.2.1 by 7%, results in an increase of mercury emissions to 11 kg Hg/yr in 2018.

3.1.5 Geothermal Power Generation

Geothermal power generation has been forecast by the EC (2008). Using the "Medium Renewables Scenario" (as an "average" scenario, but all scenarios are similar for geothermal power), EC (2008) predicts about a 190% increase in geothermal generation. Taking the current mercury emissions estimate of 350 kg Hg/year (Section II-3.2.1) and multiplying by 2.9 results in 1020 kg Hg/year in 2018.

3.2 Primary (Virgin) Metal Production

The current contributors to mercury emissions in the primary metal sector are gold mining and steel production. The major contributor is steel production, the majority of which is expected to be from use of coal.

Glenbrook steel mill is currently running at close to capacity. There are no known plans to expand the current capacity and lead times for expansion are relatively long. On that basis it is assumed that mercury emissions will be the same in ten years, that is, 26 kg Hg/yr.

Emissions from gold production are relatively small; less than the error estimates from other sources. No information exists on what gold production may be in ten year's time. The mining at Waihi has known reserves that will take mining through to 2011, but active exploration is continuing and the mine's life may be extended[17].

New Zealand's other major gold mines are operated by Oceana Gold. The 2008 Oceana Annual Report (Oceana, 2008) states the mines have a further operational life of five years. However, exploration is on-going.

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[17] See http://www.newmont.com/asia-pacific/waihi-new-zealand

On the basis of current information, gold production will decrease and therefore mercury emissions will decrease. However, given the uncertainties, it is assumed gold production will remain static for the next ten years.

3.3 Production of Other Minerals and Materials with Mercury Impurities

Section II-3.2.3 provided estimates of current emissions from the cement and lime industries.

The primary source of emissions from the cement and lime industries is from the use of coal in the manufacturing process.

3.3.1 Cement

The current Holcim plant in Westport is running at capacity. Holcim is planning to build a new plant at Weston in North Otago to replace their Westport plant. This will have a larger capacity than the current plant and therefore use more coal. However, in information provided with the Weston resource consent application, Holcim predicts an annual increase in cement use of 1.5%, and presumably a coal use increase of similar magnitude. The consent application reported[18] that the plant was expected to emit around 0.0018 kg of mercury per hour, based on an annual usage of coal of 190,000 tonnes, the average mercury content of the coal to be used and assuming 40% of mercury being emitted. This translates to about 18 kg Hg/year for the plant running 24 hours per day. This compares with about 3 kg Hg/year for the current Westport plant.

The Weston plant will have a capacity of up to 790,000 tonnes of clinker per year, which equates to a mercury emission rate of 0.022 g/tonne, which is higher than the reported Westport emissions of 0.007 g/tonne, but similar to Holcim's international average (Section II-3.2.3). The UNEP (2005) default is 0.1 g/tonne. An annual increase of 1.5% is the equivalent of a 16% increase after ten years. Increasing Holcim’s current production by 16% and applying an emission factor of 0.022 g Hg/tonne translates to 11.7 kg Hg/yr. Similarly, taking the current emission estimate for Golden Bay Cement and increasing by 16% results in an emission rate of 11.6 kg Hg/yr. Combined, the projected total for 2018 from cement manufacturing is about 23 kg Hg/yr, compared with the current estimate of 13 kg Hg/yr.

3.3.2 Lime

There are no forecasts on the amount of burnt lime production in New Zealand, however, using the data in the MfE (2009) New Zealand Greenhouse Gas Inventory 1990-2007 it is possible to extrapolate the amount of lime that might be produced assuming that the increasing rate of lime production between 1990-2007 is continued to 2018 (Figure IV-1). Using this assumption, approximately 210,000 tonnes of lime is expected to be produced in 2018, which would equate

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[18] Reported in the resource consent application decision of independent hearings commissioners appointed by Otago Regional Council and Waitaki District Council , available at: http://www.orc.govt.nz/Documents/ContentDocuments/resource_consents/Feb_2008/Final%20Dec%20Feb%2008.pdf

to mercury emission rate of approximately 1.9 kg/yr or a 35% increase on the 2008 emission rate (Section II-3.2.3).

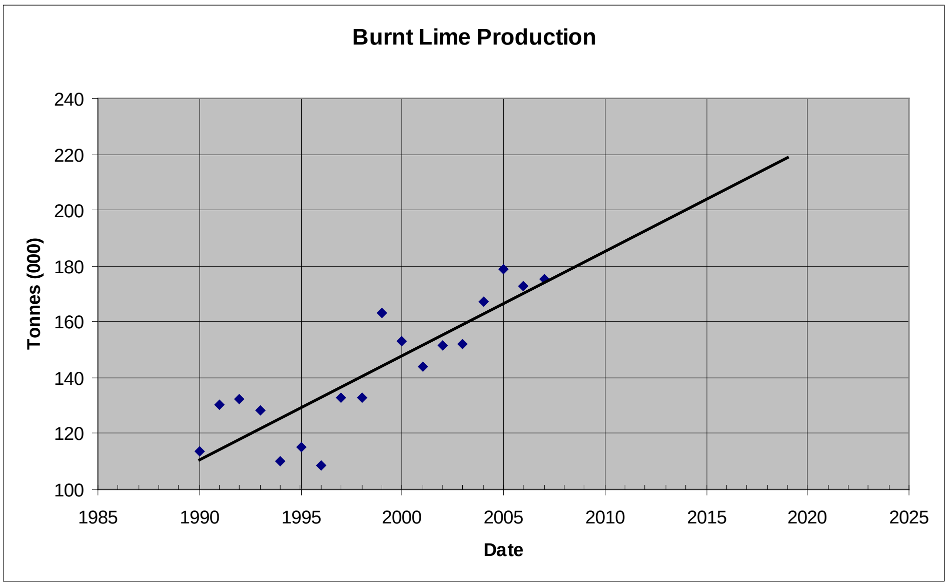

Figure IV-1 Projection for burnt lime production in New Zealand to 2018

4 Industrial Processes for which Projections Could Not be Calculated

No current mercury emissions have been reported from the intentional use of mercury in industrial processes. No additional industry in this sector is known to be planned; therefore no increase has been calculated.

Current mercury emissions from the pulp and paper industry have not been calculated, as data does not exist to allow this calculation, although emissions are believed to be small. Ten-year predictions have therefore not been calculated.

Information does not exist to calculate existing emissions for production of recycled metals ("secondary" metal production), therefore calculation of 10-year predictions of this category is not possible.

5 Consumer Products with Intentional Use of Mercury

As previously outlined in Section II-3.2.5, common examples of mercury-containing consumer products include batteries, antilock braking systems (ABS), thermometers, electrical switches and lamps. It was estimated that mercury emissions from these sources in New Zealand currently amount to approximately 260 kg Hg/year. This calculation only included emissions from batteries and lamps as insufficient data exist to quantify other products.

5.1 Mercury-Containing Lamps

Mercury-containing lamps include compact fluorescent lamps (CFLs), linear fluorescent lamps (LFLs) and high intensity discharge lamps (HIDs). The latter category includes high pressure sodium lamps, metal halide lamps and mercury vapour lamps.

Predicting future sales and subsequent disposal of mercury-containing lamps is extremely difficult. Several factors are relevant including government policy, subsidies on energy efficient lamps (i.e. CFLs and LFLs), overseas markets and control policies, consumer demands and health concerns, and technological advances.

In 2008, the government proposed to phase out inefficient lamps (also known as GLSs – General Lighting Service) under the minimum energy performance standards (MEPS). Such a phase out would have dramatically changed the lighting market, increasing the sale of CFLs. In a report carried out by KEMA (2007) for the EC it was stated that approximately 86% of households currently use incandescent lamps in New Zealand. Most of these lamps would have been expected to be replaced within the next ten years, with the majority being replaced by CFLs. With the change of government in late 2008, the proposal to phase out inefficient lamps was withdrawn. As a consequence the lighting industries projected increase in the sale of CFLs is not as high as originally estimated.

Under general market circumstances, CFLs are considerably more expensive than a GLS, costing the consumer $5 to $6 each. Incandescent lamps are approximately $1.20 each. Since 2005, the EC has subsidised the cost of many energy efficient lamps (CFLs and LFLs) in various subsidy programmes. Such subsidies have reduced the cost of CFLs down to as little as $2 per lamp. Since the first subsidy programme, the EC have subsidised 4.8 million lamps, with the majority being residential CFL lamps (Electricity Commission, pers. com, 2009).

As outlined in Section V (Mercury Pollution Controls), many countries have introduced controls on mercury-containing products. Such controls limit the amount of mercury that a particular product can contain. When the bigger markets, like the EU[19] and USA[20] impose such controls on lamps, manufacturers of the lamps change their processes to adhere to these controls and with economies of scale, it is cheaper for these manufacturers to make all lamps similar. As the

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[19] The EU RoHS directive and the United Kingdom RoHS regulations that limit the levels of mercury in lamps came into force on 1 July 2006.

[20] At the time of writing, there was no over-ruling control on mercury levels in lamps in the USA, however, The National Electrical Manufactures Association (NEMA) has implemented a voluntary reduction in mercury levels in lamps.

New Zealand market is small on the world scale, the lamps New Zealand receives are highly influenced by the international market.

It is difficult to determine if consumer concerns regarding mercury content in CFLs would be outweighed by the energy saving benefits of CFLs, or whether the cost of lamps is the major consideration when purchasing lamps. A consumer survey would be needed to obtain a snapshot of consumer's preferences of purchasing lamps, especially to determine the effects that price of an individual lamp has on consumer buying preference.

New technologies in lighting are developing all the time. The different types of CFLs now available on the market have increased dramatically. CFLs can now be bought in a variety of shapes, sizes and colours and CFLs can also be obtained that can be dimmed (EECA, 2008). In addition to CFLs, new lamps have been released on the market that do not have any mercury content. These are new generation halogen lamps, which are 30% more efficient than GLS, but not as efficient as CFLs (ECCA, 2008). The price of these lamps to consumers is somewhere between the price of GLSs and CFLs.

Light emitting diodes (LEDs) are another lighting technology that are becoming more popular for specialist applications, but which may move into the mainstream domestic market over the next several years. Like the new generation halogen lamps, LEDs do not contain mercury. At the moment the price of LEDs is high and models available currently are suitable for only limited applications such as down-lights and spotlights. Such circumstances are likely to change in the future (Consumer, 2007).

It is difficult to determine whether there will be a large uptake in the sale of these new generation lamps as consumers in the current market climate are mostly likely to be concerned about price.

Based on the above factors and combined with industry information, forecasts have been made for each subgroup of mercury-containing lamps:

Compact fluorescent lamps (CFLs)

Compact fluorescent lamps are mostly used residentially. The number of CFLs imported into New Zealand in the year up to November 2007 by LCNZ members was 2,522,190 (CFL/I and CFL/E) (LCNZ, 2009). The total number of CFL imports is about 4,700,000 lamps (Stewardship Solutions, 2008). This figure was strongly influenced by the Electricity Commission subsidies (LCNZ, pers. com. 2009). It has been suggested by the LCNZ that the sale of CFL lamps in the 2008/2009 period will return to 2004/2005 levels to reflect the removal of the EC subsidies.

Unfortunately, no data can be obtained on the 2004/2005 numbers of imported CFL lamps. The Stewardship Solutions (2008) report provides some data on imports of mercury-containing lamps, however the data has been categorized at a high level (a limitation of the New Zealand Customs Service Harmonised System Classification), and therefore the number of CFLs and LFLs cannot be distinguished. The report shows that approximately 5,000,000 fluorescent lamps combined were imported in 2004/2005 (Stewardship Solutions, 2008).

The LCNZ suggested that 2004/2005 levels would roughly equate to 67% of the numbers obtained in the 2007 survey, therefore it is expected that approximately 3,150,000 CFLs would be imported into New Zealand over the 2008/2009 period. It is possible that further subsidies will be brought in by the EC, which will serve to boost sales and imports while the subsidies are in place.

Projections of mercury contributions arising from CFLs over the period 2008-2018 can be carried out using three levels of assumptions:

1) A low estimate uses 2008/2009 lamp numbers, that is 67% of the 2007 subsidized import levels (3,150,000), and increasing the lamp numbers by the increase in household numbers for 2018 (14.3%) (Statistics New Zealand, 2009). In this estimate it has been assumed that the mercury content in the lamps has been reduced from 5mg/lamp to 1.4mg/lamp (USEPA Energy Star, 2008).

2) A middle estimate which uses 2008/2009 lamp numbers (3,150,000) and projects the lamp numbers by the increase in household numbers for 2018 (14.3%) (Statistics New Zealand, 2009). In this estimate, it has been assumed that the current mercury content in CFLs remains constant for the next ten years (i.e. 5 mg/lamp).

3) A high estimate increases the lamp numbers imported in 2007 while a subsidy scheme operated (i.e. 4,700,000) with the projected household number increase for 2018 (14.3%). This allows for the possibility that the EC could introduce new subsidy programmes in the coming years. In this estimate, it has also been assumed that the mercury content will remain at about 5 mg/lamp for the next ten years.

These estimates all assume the current recycling rate of 2% (Interwaste, pers.com, 2009). The estimates are presented in Table IV-2.

Table IV-2: 10-year projection of CFL lamps in New Zealand (2008-2018)

Scenario	Initial CFL use (No. of lamps) (2008)	Assumed Increase in CFLs (No. of lamps) (2018)	Assumed Mercury Content in CFLs (mg/lamp)	Projected Mercury content in lamps (kg)	Projected Mercury Disposal (kg/year)
1 – Low	3,150,000	3,600,450	1.4	5	5
2 – Middle	3,150,000	3,600,450	5	18	18
3 - High	4,700,000	5,372,100	5	27	26

Note. Results have been rounded to two significant figures.

Comparing the 2008 mercury emission value of 18 kg Hg/year (Section II-3.2.5) with the high estimate projection of CFLs above for 2018 (26 kg Hg/year), indicates that as a worst case scenario in terms of mercury levels, (i.e. Scenario 3. High usage of CFLs) the mercury contribution from CFLs may increase in ten years by roughly 9 kg Hg/year. However, the middle scenario suggests little increase and the low scenario suggests a substantial decrease of about 70%.

Linear fluorescent lamps

Linear fluorescent lamps (LFLs) are used mostly in commercial lighting. It is estimated that these lamps account for two thirds of lighting technology in the commercial sector (Stewardship Solutions, 2008). Typical LFL lamps include the T8, T12 and T5 tubes. As stated previously in Section II-3.2.5, T12 lamps contain around 12 mg Hg/lamp (Jang, 2004), T8 lamps contain around 4 mg Hg/lamp and T5 lamps contain 5 mg Hg/lamp.

T12 fluorescent lamps are an older style of lamp, which were originally produced in response to the energy crisis in the 1970s (The Applications Team, undated). These lamps are being replaced by T8 lamps and becoming less common.

T8 LFLs are the most common type of lamp used in New Zealand, with approximately 2.9 million tubes imported in 2007 by members of the LCNZ, compared to just over 6,000 T12 LFLs and approximately 320,000 T5 LFLs. T5 LFLs are generally the most energy efficient of the three types of LFLs, and it seems that there is a gradual shift from T8 to T5 lamps in many places, although slowly as T5 lamps do not fit into T8 fittings (Stewardship Solutions, 2008). T5 LFLs, however, have more mercury in them than T8 lamps (about 1 mg more).

It is likely that the use of LFLs over the next ten years will remain steady, perhaps with a 5% increase year on year (Lighting Council New Zealand, pers. com. May 2009). The shift from T8 to T5 lamps may increase, particularly in new office blocks, and therefore an annual 7.5% increase has been used for T5 lamps, and an annual 2.5% increase has been used for T8 lamps. A complete move away from using fluorescent lamps in the commercial sector is unlikely due to the cost of retrofitting. Ten-year projections for LFLs have been provided in Table IV-3.

Although many LFLs would still be disposed of in landfills in ten years, it is expected that there would be a higher rate of recycling of LFLs than CFLs. This is because many of the larger users of LFLs e.g. universities, hospitals, large office blocks, will have recycling systems in place.

Table IV-3: 10-year projection of LFL lamps in New Zealand (2008-2018)

LFL Type	Initial import of LFL (No. of lamps) (2007)	Assumed increase in use 2007-2018	Assumed Increase in LFLs (No. of lamps) (2018)	Assumed Mercury Content in LFLs (mg/lamp)	Projected Mercury content in lamps (kg)	Projected Mercury Contribution (kg/year)
T12	6,200	0%	0	12	0	0
T8	2,920,000	27.5%	3,723,000	4	15	15
T5	320,700	82.5%	585,280	5	3	3
Total						18

Note: As only 2007 data for LFLs is available, the predictions are for 11 years from 2007 to 2018.

Results have been rounded to two significant figures.

In Section II-3.2.5, the 2008 mercury emission value for LFL lamps was estimated to be 14 kg Hg/year. The above estimate suggests the mercury contribution from LFLs may increase to around 18 kg Hg/year by 2018.

High intensity discharge lamps (HID)

High intensity discharge lamps are a broad family of lamps which includes high pressure sodium lamps (used for street lights and security), metal halide lamps (used at industrial site or for specific purposes, e.g. indoor plant growing), and mercury vapour lamps.

It is very difficult to predict how the use and disposal of HID lamps will change over the next ten years. In their report, Stewardship Solutions (2008) suggested that there may be a shift away from HID lamps to high bay fluorescent systems. There may also be the replacement of mercury vapour street lights with metal halide lamps, and in shop fitouts low watt metal halides may replace halogen lamps. The result of the first two of these possible changes would lead to a decrease in total mercury waste, whilst the latter would lead to an increase mercury waste.

Although there may be a change in the type of lamp used over time, there will also be a change in the lamp technology itself. For example, the volume of mercury contained in metal halide lamps has reduced significantly over recent times. A 250W standard (old technology) metal halide lamp contains 35-45 mg Hg/lamp; a 250W quartz pulse start metal halide contains 14-17 mg Hg/lamp and a ceramic pulse start metal halide contains 5-8.5 mg Hg/lamp (Advanced Lighting Technologies, 2009). At this stage the ceramic metal lamps are generally available at lower wattages, but these are likely to extend to higher wattages at some stage (Advanced Lighting Technologies, pers. com. May 2009).

Discussions with the lighting manufacturing industry indicate that the use of LEDs in street lighting is already the best option available. LEDs can last for 25–30 years giving them a lower life cycle cost. Currently LED lamps have a relatively high unit cost, but it is expected that this will reduce in the not too distant future.

The following assumptions have been made in predicting future use of HID lamps:

- A general 5% increase year on year has been assumed for lamp usage (LCNZ, pers. com. May 2009).
- The use of high pressure sodium lamps will continue to increase over the next few years by 5% each year, but will mostly be taken over by LED technology within 5 years. An average mercury content of 50 mg Hg/lamp has been used.
- Metal halide lamps will increase by 5% year on year but the mercury content will reduce to 5 mg/lamp (Advanced Lighting Technologies, 2009)
- As a conservative estimate, mercury vapour lamps will continue to increase in use over the next ten years by 5% year on year. An average mercury content of 50 mg Hg/lamp has been used.

The predictions are set out in Table IV-4.

The 2008 mercury emission value from HID lamps was calculated to be 18 kg Hg/year. The 2018 prediction for HID lamps is 6.6 kg Hg/yr, with the main reduction being the reduction of mercury contained in metal halide lamps and the replacement of high pressure sodium lamps with LEDs.

Table IV-4: 10-year projection of HID lamps in New Zealand (2008-2018)

HID Type	**Initial HID use (# of lamps imported 2007)**	**Assumed increase in use 2008-2018**	**Assumed Increase in HIDs (# of lamps) (2018)**	**Assumed Mercury Content in HIDs (mg/lamp)**	**Projected Mercury content in lamps (kg)**	**Projected Mercury Contribution (kg/year)**
High Pressure Sodium	125,860	25%	157,300	50	7.87	3.9
Metal Halide	170,820	55%	264,800	5	1.3	0.7
Mercury Vapour	50,330	55%	78,000	50	3.9	2.0
Total						6.6

Note: As only 2007 data for LFLs is available, the predictions are for 11 years from 2007 to 2018.

<u>All mercury-containing lamps combined</u>

In 2018, it has been predicted that the mercury contribution from CFLs could increase from 18 kg Hg/year to 26 kg Hg/year (high use scenario); the mercury contribution of LFLs could increase from 14 kg Hg/year to 18 kg Hg/year, and mercury contribution from HID lamps could decrease from 18 kg Hg/year to as little as 6.6 kg Hg/year. Therefore the contribution from all lamps combined in 2018 appears to be very similar to the 2008 contribution, at about 51 kg Hg/yr.

5.2 Remaining Consumer Products

Remaining consumer mercury-containing products include thermometers, electrical switches, electrical equipment and batteries.

There is no data on the number of mercury-containing personal thermometers still in circulation in New Zealand. It is likely that the purchase of these thermometers will decline over the next ten years, as they will be replaced with alcohol or digital versions. The disposal of mercury-containing personal thermometers may be variable, as many households may not dispose of them for some time. It is not possible to quantify the change from 2008 to 2018.

As mentioned earlier in Section II-3.2.5, electrical switches can contain a range of different amounts of mercury (3,500 mg to 3.5 kg). Due to the large range of different switches that mercury can be present in, and the lack of data relating to the quantities of these switches in circulation in New Zealand, a mercury emission rate from electrical switches cannot be calculated. A 10-year prediction of the mercury contribution from electrical switches will largely depend on whether mercury will be continued to be used in switches throughout the world and the rate at which the unknown installed base is disposed of. The EU and USA are beginning to place restrictions on products that can contain mercury, and therefore this may have some impact on switches received in New Zealand. However, as most of our electrical equipment comes from Asia, it is difficult to assess how mercury content in such products will change over time.

Electrical equipment such as LCD TVs and computer monitors, thermostats, sensors, and relays may all contain mercury in them (Section II-3.2.5). LCD TVs can contain as much as 150 mg of mercury. Like electrical switches, the total mercury contribution from electrical equipment was not able to be quantified due to data limitations. As with the other consumer products containing mercury, it is likely that the quantity of mercury in each product will reduce over the next ten years due to influences of regulations adopted by the EU and USA.

There are various batteries that contain mercury. These include small button batteries of silver oxide, zinc air and mercury oxide composition, in addition to some alkaline, and zinc carbon batteries. In Section II-3.2.5, the mercury contribution from batteries was estimated to be 170 kg Hg/year using data obtained from New Zealand Customs. As previously described, some other nations are placing tight controls on the amount of mercury that can be used in a battery. These controls will be reducing the amount of mercury in batteries imported into New Zealand.

Battery use in New Zealand is likely to increase with population growth over the next ten years. In particular growth is expected for alkaline general use batteries, zinc carbon batteries which are used in smoke alarms and clocks, and silver oxide batteries which are used in watches and calculators. With an aging population in New Zealand, there is likely to be a greater demand on zinc air and mercury oxide batteries as they are used in hearing aids. A 10-year prediction for batteries is provided in Table IV-5. Assumptions for this prediction include:

- The mercury content in batteries will stay the same as in 2008 (a conservative assumption); and

- The demand for batteries will increase at the rate of population growth over the next ten years (around 9%, New Zealand Statistics, 2009).

These assumptions can provide only tentative predictions. The demand for batteries will be more dependant on the number of portable items that a person has and the type of batteries they use (rechargeable batteries are becoming more common than disposal batteries). Further, electronic devices (e.g. hearing aids) are becoming more energy efficient over time. Finally, new technology may bring substitutes for currently used mercury-containing batteries.

Table IV-5: 10-year projection of batteries in New Zealand (2008-2018)

Battery	No. of batteries imported (2008)	Assumed Increase in battery No. (2018)	Assumed individual weight of batteries (2018) (kg)	Weight x Quantity of Batteries (2018) (kg)	Assumed Mercury Content in batteries (% weight of mercury)	Projected Mercury Contribution (2018) (kg/year)
Mercuric Oxide	59,240	64,572	0.001	65	33%	21
Silver Oxide (small)	994,984	1,084,533	0.001	1085	1%	10
Silver Oxide (large)	11	12	3.54	42	1%	0.5
Zinc Air (small)	5,761,039	6,279,533	0.001	6280	1%	64
Zinc Air (large)	97,651	106,440	0.001	106	1%	1
Alkaline (Mn-Dioxide) (small)	41,322,632	45,041,669	0.012	540,500	0.01%	62
Alkaline (Mn-Dioxide) (large)	638,766	696,255	0.129	89,817	0.01%	10
Total						**170**

The 2008 mercury emission value from batteries was calculated to be 170 kg Hg/year. The 2018 prediction for batteries is similar.

5.3 Other Intentional Products/Process Uses

Section II-3.2.6 outlined the contribution from other intentional products/process uses, these include dental amalgams, medical equipment, laboratory chemicals and equipment, other educational uses and miscellaneous (tanning, pigments, explosives, lighthouses etc.).

The mercury contribution from dental amalgam in 2008 was estimated to be approximately 30 kg Hg/year. The use of dental amalgam is generally decreasing in New Zealand because of concerns with respect to toxicity. Some countries, including Norway and Sweden, have already banned the use of mercury-containing dental amalgam. Anecdotal evidence suggests many dentists are no longer using amalgam and are replacing existing fillings when appropriate. However there is already a lot of amalgam in the general population. There is no information available to predict a decrease of the overall mercury burden and therefore emissions from dental amalgam. Due to the concerns with toxicity, it is expected that the contribution will decrease over the next ten years, however to be conservative, it has been assumed to be the same i.e. 30 kg Hg/year.

After contacting four of the main hospitals in New Zealand, it became evident that most of the mercury-containing devices used were either in the process of being phased out or had already been phased out. All of the hospitals contacted stated that they used appropriate hazardous waste contractors to disposal of the waste and therefore the mercury contribution in 2008 was already fairly minor. It is likely that in ten years time the mercury contribution from medical mercury-containing devices would be even less.

Mercury in research laboratories and universities is used for various processes and in various types of equipment. Many research laboratories and universities may be undertaking the same processes in ten years time, and possibly will be using the same equipment, resulting in no change to mercury emissions in ten years.

Mercury use in miscellaneous items such as tanning and pigments and in components of lighthouses is no longer carried out in New Zealand. Mercury use in explosives could not be measured in the inventory (Section II-3.2.6), therefore it is not possible to assess future contributions.

6 Waste

6.1 Incineration

Waste incineration, with minor exceptions, is not permitted in New Zealand. A 10-year prediction is therefore not relevant.

6.2 Waste Deposition/Landfilling and Waste Water Treatment

As previously mentioned in Section II-3.2.9, the quantity of mercury-containing products reaching landfills in New Zealand cannot be measured. This is because there is insufficient information on the volume and frequency of mercury-containing products entering individual landfills.

An overall trend on mercury content in landfills over the next ten years is difficult to predict as some products that historically contained mercury have had their mercury content reduced or eliminated. However, some other products have had their mercury content increased (e.g. LFLs). In addition, variable price and consumer demand will cause variations in the volumes of mercury-containing products sold and therefore disposed of in time.

It is also difficult to predict whether in the next ten years there will be an increase in the rate of recycling of certain mercury-containing products. Currently there are not many district or city councils in New Zealand that provide lamp recycling services (Stewardship Solutions, 2008), and therefore such recycling is left to businesses like Interwaste. Suppliers such as Panasonic and Sony also offer some level of recycling for larger battery users but, although working well, this recycling is not widespread.

With respect to disposal of mercury in wastewater and ending up in biosolids, improved control of mercury being discharged from dentists and medical facilities and the possible reduction in the use of dental mercury amalgams could reduce the amount of mercury entering the wastewater system. However, it is not possible to estimate the magnitude that these changes would have on the average concentration of mercury being discharged from the wastewater treatment plants and in biosolids produced by the wastewater treatment plants.

As noted in Section II-3.2.9, no information has been obtained on the amount of mercury in the treated waste water being discharged from the wastewater treatment plants. However, since mercury forms strong complexes with organic matter, most of the mercury being discharged from treatment plants will be associated with the biosolids. To estimate the amount of mercury being discharged in the biosolids from the wastewater treatment plants the following assumptions have been made:

- No major upgrades of any of the major wastewater treatment plants in New Zealand (most of the major treatment plant have recently been upgraded) between 2008 and 2018 which might change (increase) the amount of biosolids produced;
- The amount of biosolids per person remains that same as the 2007 levels (i.e. approximately 56.7 kg per person/year).
- The average concentration of mercury in biosolids remains the same as in 2007 (0.78 mg/kg) (Section II-3.2.9).

- There will be a 10.3% increase in population in New Zealand between 2007 and 2018, based on the mid-range projection for population changes from Statistics New Zealand.

The 10-year prediction for mercury emission rates from biosolids discharged from wastewater treatment plants is 210 kg Hg/yr in 2018, compared to 180 kg Hg/yr in 2008.

6.3 Crematoria and Cemeteries

Current mercury emissions from burial or cremating of bodies were based on the number of registered deaths for 2008 of approximately 29,200. Statistics New Zealand (2007) provides forecasts for population changes, including deaths, and recommends using its mid-range projection (referred to as Series 5). On-line tables associated with Statistic New Zealand (2007)[21] provide predictions of mortality in five-year intervals. The average mortality rate for 2016 – 2021 from the series 5 projections is 26,000 per year. This is a decrease to 89% of the 2008 rate.

The 10-year predictions for mercury emission rates for burials and cremations have therefore been calculated as 89% of the 2008 rates, being 46 kg and 69 kg, respectively.

The estimate was based on 1991 WHO estimates for the number of amalgam fillings an average person has. Given New Zealand’s general long-term improvement in dental health with the widespread use of fluoridated water, it is possible that the calculated rate is an over-estimate. In addition, anecdotal evidence suggests that the use of amalgam fillings is decreasing and some people are choosing to have amalgam fillings replaced with ceramic fillings.

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[21] Available at http://www.stats.govt.nz/methods_and_services/access-data/tablebuilder/population-projections-tables.aspx

7 Summary of 10-year Forecasts

Table IV-6: Summary of 10-year projections of mercury emissions (2008-2018)

Category	Trend	Mercury Emissions in 2008 (kg Hg/year)	Projected Mercury Emissions in 2018 (kg Hg/year)	% Change (2008-2018)
Natural sources				
Volcanoes	n/c	800	800	0
Volatilisation of Mercury from Soils	n/c	500	500	0
Geothermal Areas	n/c	190	190	0
TOTAL NATURAL		**1,500**	**1,500**	**0**
Extraction and use of fuels/energy sources				
Coal- fired power generation	↓	240	150	-40
Other coal combustion (but not cement or lime production)	↑	62	73	22
Oil	↑	80	83	4
Natural Gas	↓	60	48	-20
Biomass Combustion	↑	10	11	10
Geothermal power generation	↑	350	1020	190
Primary (virgin) metal production				
Steel	n/c	26	26	0
Gold	n/c	<1	<1	0
Production of other minerals and materials with mercury impurities				
Cement	↑	13	23	77
Burnt lime	↑	1.4	1.9	35
Pulp and Paper	UTM	UTM	UTM	UTM
Intentional use of mercury in industrial processes	n/a	n/a	n/a	n/a
Mercury-containing lamps				
CFLs (Scenario 3. High usage of CFLs)	↑	18	26	44
CFLs (Scenario 2. Medium usage of CFLs)	n/c	18	18	0
CFLs (Scenario 1.Low usage of CFLs)	↓	18	5	-72
LFLs	↑	14	18	29
HIDs	↓	18	7	-61
All lamps combined	n/c	50	51(a)	2
Consumer products with intentional use of mercury				
Batteries	n/c	170	170	0
Biocides, pesticides and fertilisers	n/c	38	38	n/c
Thermometers	↓	UTM	UTM	UTM
Electrical Switches	↓	UTM	UTM	UTM
Electrical Equipment	↓	UTM	UTM	UTM
Other intentional products/process uses				
Dental Amalgams	n/c	30	30	n/c
Medical Devices	↓	UTM	UTM	UTM
Mercury in Research Labs/Universities	n/c	UTM	UTM	UTM
Miscellaneous (explosives)	n/c	UTM	UTM	UTM

Category	Trend	Mercury Emissions in 2008 (kg Hg/year)	Projected Mercury Emissions in 2018 (kg Hg/year)	% Change (2008-2018)
Production of recycled metals ("secondary" metal production)	UTM	UTM	UTM	UTM
Waste incineration	n/a	n/a	n/a	n/a
Waste deposition/landfilling and waste water treatment	↑	180	200	11
Crematoria and cemeteries				
Crematoria	↓	70	52	-26
Cemeteries	↓	50	34	-32
TOTAL ANTHROPOGENIC	↑	**1,500**	**2,100**[(a)]	**40**
TOTAL EMISSIONS	↑	**3,000**	**3,600**	**20**

Notes: n/c - No Change; UTM - Unable to Measure; n/a - Not applicable in New Zealand; ↑ - increase; ↓ decrease

(a) Includes high usage of CFL scenario in total calculation.

Results have been rounded to two significant figures.

Table IV-6 provides a summary of the relative increases in the anthropogenic sources of mercury identified in this study. As can be seen in the table, and as detailed in the text previously, many of the sources have been assumed to remain unchanged in their emission levels in 2018.

The greatest predicted increase of mercury emissions in New Zealand in the next ten years is from geothermal power generation (190%), followed by cement (77%), CFLs (44%), lime (35%) and LFLs (29%). The predicted declines in mercury emissions in 2018 include HID lamps (-61%), coal-fired power generation (-38%), cemeteries (-32%), crematoria (-26%) and natural gas (-20%).

In 2018, geothermal power generation is likely to be the largest contributor to anthropogenic mercury loads (1,020 kg Hg/year), followed by coal-fired power generation and wastewater biosolids (200 kg Hg/year) and batteries (170 kg Hg/yr).

Overall, it is predicted that the total anthropogenic mercury load in New Zealand, may increase from 1,500 kg Hg/year to 2,100 kg Hg/year (40% increase), and the total overall mercury load may increase from around 3,000 kg Hg/year to 3,600 kg Hg/year (20% increase).

8 Comparison of Mercury Lamp Contributions with Other Sources

Section II of this report estimated mercury-containing lamps currently contribute 50 kg Hg/year, or about 3% of the total anthropogenic load and less than 2% of the load from all sources. Compact fluorescent lamps made up about a third of the mercury load from lamps, or about 1% of the anthropogenic total and about 0.5 % of the total from all sources.

Future use of mercury-containing lamps is uncertain, and will be affected by such things as future government policy and the price of lamps, including any further subsidy schemes that EECA might introduce. Ten-year predictions for mercury-containing lamps have therefore been estimated for high, medium and low use scenarios.

Using the high CFL use scenario as conservative (the scenario also assuming no change in the average mercury content of each lamp[22]), the total mercury load from mercury-containing lamps is expected to be a small increase (2%) over the present, to about 51 kg Hg/year, the increase in CFL use being off-set by a reduction in the use of certain types of HIDs. If the medium use scenario is used, a small decrease in mercury for all lamps is forecast over the next ten years.

For CFLs alone, the high-use scenario results in a 44% increase in mercury from these lamps from 18 to 26 kg Hg/year, but no change for the medium-use scenario. For LFLs alone, the 10-year prediction suggests an increase of 21%, from 14 to 18 kg Hg/year, while HIDs decrease 61 %, from 18 to 7 kg Hg/year.

In 2018, mercury-containing lamps are expected to contribute between 1.4 and 2.4% of the total anthropogenic mercury load, depending on which CFL use scenario is chosen, and about 1% of total mercury load. CFLs alone would contribute about 1.2% of the anthropogenic load using the worst-case CFL mercury content, and less than 1% for a more likely scenario.

Overall, the contribution from mercury-containing lamps is predicted to be small, with only a very modest change to the mercury load over the next ten years even for the worst case.

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[22] This is a worst case. It is perhaps more likely that mercury in each lamp will in fact reduce as technology improves.

9 Conclusion

Ten-year projections of the mercury contributions from the sources identified in Section II have been calculated in order to assess the change for each of these sources and overall. In addition the change in relative contribution of mercury from mercury-containing lamps has been assessed.

The total load for New Zealand’s natural mercury sources in ten years time was assumed to be the same as in 2008. It is possible that one or more of New Zealand’s volcanoes may have a small eruption in the next ten years. However, it is very difficult to predict such an occurrence and the amount of mercury that might be emitted, therefore no attempt has been made to include such a possibility. Geothermal emissions have been assumed to remain constant.

There are uncertainties associated with the predictions for future anthropogenic emissions, related to such things as economic performance, the price of competing sources of energy and changes in policies with respect to mercury both in New Zealand and overseas. The predictions made in this section utilised a variety of sources including MED, EC, Statistics New Zealand and Treasury forecasts, current knowledge and discussions with various industries. The calculations that have been carried out are based on a number of assumptions, which have uncertainties. In addition, the predictions are generally relative to the current emission calculations and therefore will have the same uncertainties as the current emission calculations.

The mercury contributions from geothermal power generation (1,020 kg Hg/year) is expected to be the largest contributor to anthropogenic mercury loads in 2018, followed by wastewater treatment (200 kg Hg/year) and batteries (170 kg Hg/yr). The geothermal power generation prediction is sensitive to the price and availability of competing sources of energy and relies on various power generators constructing power stations that they have indicated are or may be in the pipeline.

The greatest percentage change between 2008 and 2018 mercury emissions is expected to come from geothermal power generation (190% or 670 kg Hg/year), cement (77%), CFLs (44%, assuming the high use scenario), lime (35%) and LFLs (29%), with predicted decreases in HID lamps (-61%), coal-fired power generation (-38%), cemeteries (-32%), crematoria (-26%) and natural gas (-20%).

Overall the anthropogenic mercury loads in 2018 are predicted to be 2,100 kg Hg/year increasing from 1,500 kg Hg/year in 2008 (40% increase), and the total overall mercury load may increase from around 3,000 kg Hg/year to 3,600 kg Hg/year (20% increase).

The relative contribution from mercury-containing lamps is likely to reduce from 3% of total anthropogenic mercury emissions in 2008 to 2% of total anthropogenic mercury emissions in 2018. Similarly the contribution of mercury from mercury-containing lamps to the overall mercury load is expected to reduce in 2018 to less than 1%, from 2% in 2008. Compact fluorescent lamps contribute about half of the mercury from mercury-containing lamps.

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Section V – Mercury Pollution Controls

1 Introduction

This section sets out a summary of New Zealand's current controls on pollution from mercury and examples of controls in other countries which may have similar risk level to New Zealand's. The majority of controls in New Zealand are not specific to mercury, but are general controls that are in place for controlling hazardous substances and their effects. Overseas, some jurisdictions have imposed specific controls to limit the polluting effects of mercury.

This section looks at general legislative controls in New Zealand and then considers specific standards or guidelines for air and water. The section then outlines some controls in other countries, including controls in the European Union (EU) and the United States of America (USA). The section concludes with a comparison of New Zealand and international guideline values.

2 Mercury Pollution Controls in New Zealand

Mercury pollution in the environment can result from a number of activities. For example:

- Discharges as part of processes, e.g. discharges to air from certain processing plants;
- Discharges as a result of waste disposal, e.g. as residual concentrations of mercury in trade waste discharges or
- Misuse of hazardous substances containing mercury, i.e. spills or incorrect disposal; and
- Inappropriate disposal of mercury-containing products, e.g. lamps and batteries.

Discharges to land, water and air are controlled under the Resource Management Act (RMA) (1991) process, which allows regional councils to allow activities to occur under certain conditions (Section V-2.1). Such processes should limit the amount of mercury entering the environment from discharges where mercury is a residual component.

The use, storage, handling, transport and disposal of hazardous substances is controlled under both the RMA and the Hazardous Substances and New Organisms (HSNO) Act 1996. These two pieces of legislation aim to limit any pollution to the environment which may occur when using, handling and storing hazardous substances (Section V-2.2).

All mercury-containing products are made offshore and imported into New Zealand. The New Zealand Customs Service is responsible for enforcing the regulations around allowing certain products into the country. However the New Zealand Customs Service does not make decisions on which products are allowed over the border, rather it relies on other agencies such as the Environmental Risk Management Authority (ERMA), Ministry of Health (MoH), Ministry if Economic Development (MED), Ministry for the Environment (MfE), and the New Zealand Police to provide the regulations. Currently there are no controls on the quantity of mercury allowed in certain manufactured products that are imported into New Zealand.

2.1 RMA (1991)

The RMA 1991[23] (the Act) is New Zealand’s main environmental legislation, which sets out the framework for managing the effects of activities on the environment. The purpose of the act is to “promote the sustainable management of natural and physical resources”. A main principle of the Act is avoiding, remedying, or mitigating any adverse effects of activities on the environment.

Section 15 controls discharges of contaminants to the environment. Discharges of contaminants are not permitted unless allowed by a rule in a regional plan, by a resource consent or by a regulation.

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[23] http://www.legislation.govt.nz/act/public/1991/0069/latest/DLM230265.html

2.2 HSNO (1996)

The Hazardous Substances and New Organisms (HSNO) Act 1996[24] is an environmental and health and safety legislation, implemented and operated by ERMA and enforced by various agencies, that is designed to manage the risks of using hazardous substances in business and at home (MfE, 2001).

ERMA's roles include making decisions on applications to import or manufacture hazardous substances in New Zealand, and setting Tolerable Exposure Limits (TELs) that limit public exposure from the use of hazardous substances and Environmental Exposure Limits (EELs), which establish the maximum concentration of an ecotoxic substance legally allowable in a particular environmental medium (e.g. water, soil or sediment). To date ERMA has not set any TELs or EELs for any mercury-containing substance.

2.3 Local Government Act (1992)

The Local Government Act 1992[25] sets out the powers and responsibilities of regional and district councils in New Zealand. Section 145 provides general powers for territorial local authorities to make bylaws, with Section 146 providing specific powers for regulating, amongst other things, waste management, trade wastes and solid wastes. Many district and city councils have trade waste bylaws to control the concentrations of various hazardous substances, including mercury, entering sewers. The intent is to reduce the load on municipal wastewater treatment plants and to enable councils to meet the terms of discharge consents for their treated wastewater discharges.

2.4 Health and Safety in Employment Act (1992)

The Health and Safety in Employment Act 1992[26] controls health and safety in the work place, including the use of hazardous substances. Section 20 of the Act provides for issuing of approved codes of practice. One of these is the Approved Code of Practice for the Management of Substances Hazardous to Health in the Place of Work, issued by the Occupational Safety and Health Service (OSH) of the Department of Labour (OSH, 1997). This sets out good practice for the storage, use and monitoring of hazardous substances. OSH has also issued Workplace Exposure Standards (WES) for atmospheric contaminants, which includes a standard for mercury (OSH, 2002).

2.5 Health Act (1956)

The Health Act 1956[27] was amended by the Health (Drinking Water) Amendment Act in October 2007 and aims to protect public health by improving the quality of drinking-water provided to communities. The Health Act requires drinking-water suppliers to take all

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[24] http://www.legislation.govt.nz/act/public/1996/0030/latest/DLM381222.html

[25] http://www.legislation.govt.nz/act/public/2002/0084/latest/DLM170873.html

[26] http://www.legislation.govt.nz/act/public/1992/0096/latest/DLM278829.html

[27] http://www.legislation.govt.nz/act/public/1956/0065/latest/DLM305840.html

practicable steps to ensure they provide an adequate supply of drinking water that complies with the New Zealand Drinking-water Standards[28].

These standards set maximum acceptable values (MAV) for a range of contaminants, including mercury, and monitoring requirements. The MAV for mercury in New Zealand drinking water is 0.007 mg/L (Ministry of Health, 2008), which has been derived from World Health Organisation (WHO) information.

2.6 Food Act (1981)

In New Zealand, food is regulated under the Food Act 1981[29] and delegated legislation under that Act. Under Section 11C of the Food Act 1981, the Minister of Food Safety has the power to issue food standards that set minimum requirements for the quality and safety of food for sale.

One of the five New Zealand Food Standards made under the Food Act is the Australia New Zealand Food Standards Code. The New Zealand (Australia New Zealand Food Standards Code) Food Standards 2002 is the legal instrument that incorporates the Australia New Zealand Food Standards Code into New Zealand law. The New Zealand Food Standard (2002) sets a maximum level of mercury in fish of between 0.5 and 1 mg/kg.

2.7 Guidelines on Mercury in New Zealand

There are no mercury emissions standards in New Zealand. Instead, under the RMA 1991 the impact of a discharge on its receiving environment is evaluated and controls are then set on the discharge to avoid, remedy or mitigate any adverse effects that the discharge may have.

There are four main guideline documents which are commonly used in New Zealand to assess the impact of mercury on the environment. These are:

1. ANZECC (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality;
2. MfE (2002b) Ambient Air Quality Guidelines;
3. MfE (2004) Hazardous Waste Guidelines, Module 2: Landfill Waste Acceptance Criteria and Landfill Classification; and.
4. NZWWA (2003) Guidelines for the safe application of Biosolids to land in New Zealand.

The ANZECC (2000) guidelines provide water quality guideline trigger values for the protection of aquatic ecosystems (either fresh or marine) against toxicants. These guidelines have been derived using data from single species toxicity tests on a range of test species. High reliability trigger values were calculated from ‘chronic no observable effect concentrations’ (NOEC) data. A statistical distribution method has been used to calculate four different protection levels (99%, 95%, 90% and 80% ecosystem protection) for high reliability trigger

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[28] http://www.moh.govt.nz/water

[29] http://www.legislation.govt.nz/act/public/1981/0045/latest/DLM48687.html

values. The guidelines recommend that the 99% ecosystem guideline of mercury (0.06 µg/l for fresh water or 0.1 µg/l for marine water) be used to protect aquatic ecosystem due to mercury's ability to bioaccumulate.

The ANZECC (2000) guidelines also set interim guideline values for sediment quality (ISQGs) for the protection of sediment-dwelling organisms. For each trace element (including mercury), there are two ANZECC (2000) guidelines for sediment quality. The lower guideline value is the Interim Sediment Quality Guideline-low (ISQG-low) which represents a concentration below which adverse effects are unlikely. The ISQG-low guideline value for mercury is 0.15 mg/kg. Concentrations of contaminants below the ISQG-low pose a low level of risk to aquatic organisms.

The higher guideline value is the ISQG-high, which is a median level at which adverse effects are expected in half of the exposed organisms. The ISQG-high guideline value for mercury is 1 mg/kg. Contaminant concentrations above the ISQG-high are interpreted as being reasonably likely to cause significant adverse effects on aquatic organisms. Concentrations between the ISQG-low and ISQG-high are thought to pose a moderate level of risk to aquatic organisms. The ANZECC(2000) guideline values are designed to be trigger values which, when exceeded, trigger further investigations, although they are commonly used as compliance values in consents.

The MfE Ambient Air Quality Guidelines (MfE, 2002) are the minimum requirements that outdoor air quality should meet in order to protect human health and the environment. Where air pollution levels breach guideline values, emission reduction strategies should be implemented to improve air quality. Where levels do not breach the values, efforts should be made to maintain air quality and, if possible, reduce emissions (MfE, 2002).

The MfE (2002) Ambient Air Quality Guidelines set an annual average guideline concentration for inorganic mercury of 0.33 µg/m^3, and 0.13 µg/m^3 for organic mercury compounds. The value for inorganic mercury is derived from the occupational health standards for inorganic mercury and the US EPA reference concentration (RfC) and the Californian Air Resources Board's reference exposure level (REL) values (MfE, 2002). The value for organic mercury is derived from the value for inorganic mercury by scaling according to the occupational health standards (MfE, 2002).

The MfE state that the Ambient Air Quality Guidelines for mercury should be viewed as applicable where exposure to mercury is mainly through inhalation. They need to be adjusted downwards where dietary intake of mercury is significant (MfE, 2002).

The Hazardous Waste Guidelines (MfE, 2004) published by MfE set out waste acceptance criteria for two classes of landfills, Class A and Class B, as well as recommending the use of the US EPA Toxicity Characteristic Leaching Procedure (TCLP) to assess the leachability of hazardous waste material. While the guidelines are recommended for use by landfill operators in setting out which wastes are prohibited and for setting limits on acceptance of hazardous waste, they have no regulatory force unless referenced by the consents for a particular landfill or within a district plan. Many landfills were consented prior to the publishing of the guidelines and therefore may have different limits set. The landfill operator may voluntarily choose to apply the waste acceptance criteria in MfE (2004) if the criteria are more stringent than the consented limits.

The guidelines state that waste containing more than a screening limit of 4 mg/kg of mercury or a leaching test concentration of greater than 0.2 g/m^3 should not be disposed of to a Class A landfill without treatment to reduce its leachability. The corresponding values for a Class B landfill are a tenth of the Class A values.

Individual items such as batteries, fluorescent lamps and thermometers will considerably exceed the screening limits for mercury set in MfE (2004). Whether such items exceed average concentrations will depend on how much other waste the items are landfilled with.

The NZWWA (2003) Guidelines for the Safe Application of Biosolids to Land in New Zealand are designed to provide a framework for biosolids management to minimises the risk of adverse effects on human health, the environment and the economy from long-term application of biosolids to land (NZWWA, 2003). The biosolids guidelines recommend that soil concentration should not exceed more than 60 mg/kg of mercury and the biosolids should not contain more than 4 mg/kg (NZWWA, 2003).

3 International Mercury Pollution Controls

There are various pollution controls adopted internationally that relate specifically to controlling mercury discharges (e.g. to air, land, and water), hazardous substances controls, and limits on mercury content in certain products.

Some examples of international controls from several countries and international bodies are as follows:

3.1 The United Nations (UN)

United Nations Environment Programme (UNEP) has created a Global Mercury Partnership which includes various partnership areas aimed at tackling certain industries that use mercury. Some examples of these partnership areas are mercury-containing products, coal combustion, and mercury waste management (UNEP, undated).

Agreement was reached to negotiate an international treaty to manage mercury at the 25th UNEP Governing Council in Nairobi, Kenya in February 2009 (Governing Council of the UNEP, 2009; Zero Mercury Global Campaign, 2009). It is proposed that the treaty will include actions to reduce mercury supply, reduce its use in products and processes, and reduce atmospheric mercury emissions, in order to ultimately reduce human exposure to mercury globally. It is expected that negotiations on the treaty will start in late 2009.

3.2 The European Union (EU)

The European Union (EU) manages mercury under the EU Mercury Strategy.

Since 1 July 2006 the EU has been controlling the use of mercury in certain products through legislation (Directive on the Restriction on use of certain Hazardous Substances in electrical and electronic equipment (RoHS)) which prohibits or severely restricts the use of mercury in electrical and electronic equipment such as batteries (EUROPA, 2008a; 2008b; Ireland Environmental Protection Agency, 2008). The RoHS directive has restricted the level of mercury to 5mg/lamp in CFLs (Stewardship Solutions, 2008).

Other EU legislation limits the amount of mercury in pesticides and biocides, cosmetics, wood preservatives, textile treatment agents, anti-fouling agents for boat hulls, and switches in vehicles.

The Waste from Electrical and Electronic Equipment (WEEE) directive is also written into EU legislation. The WEEE directive aims to “prevent the generation of electrical and electronic waste and to promote reuse, recycling and other forms of recovery in order to reduce the quantity of such waste to be eliminated through landfilling or incineration” (Ireland Environmental Protection Agency, 2008).

The EU controls the mercury emissions from major industrial sources under the EU Directive (96/61/EC) on Integrated Pollution Prevention and Control (IPPC) which was implemented in 1999 (EUROPA, 2008).

The EU bans the export of metallic mercury and certain mercury compounds and mixtures (Sweden Ministry of the Environment, 2009).

Some countries in the EU have restricted the use of mercury in dental amalgam, including Sweden (from 1 April 2008) and Norway (from 1 January 2008) (Williams, 2008).

The Water Framework Directive (WFD, 2000/60/EC), which has been adopted by the member states, provides for measures against chemical pollution of surface waters (EUROPA, 2009). Under Article 16 of the WFD, mercury is a priority substance and requires the member states to adopt specific measures against mercury pollution.

In 2007 the EU adopted a new European Community Regulation on chemicals and their safe use (EC 1907/2006). It deals with the registration, evaluation, authorisation and restriction of chemical substances (REACH), including mercury. The aim of the regulation is to improve the protection of human health and the environment through the better and earlier identification of the intrinsic properties of chemical substances. The regulation sets out certain information requirements that chemical manufactures or importers must provide before a chemical can be registered for use in Europe.

3.3 The United States of America

The United States of America has a number of federal controls on mercury, implemented by the US EPA. Individual states also have their own controls.

On March 15, 2005, the US EPA issued the Clean Air Mercury Rule, which creates performance standards and establishes permanent, declining caps on mercury emissions. The Clean Air Mercury Rule will be implemented in two distinct phases. The first phase cap is 38 tonnes per year. In the second phase, due in 2018, coal-fired power plants will be subject to a second cap, which will reduce emissions to 15 tonnes upon full implementation (US EPA, 2009a).

The US EPA has also recently announced it is proposing to introduce controls on Portland cement kilns (US EPA, 2009b). When the US EPA measures are fully implemented in 2013, the US EPA hopes to reduce mercury emissions by 81%.

The US EPA has also issued standards for areas with high emission sources in the iron and steel foundry industry in December 2007 (US EPA, 2009d). Existing facilities with greater than 20,000 tonnes/year capacity must comply with emissions limits and apply pollution prevention management practices. Facilities with less than 20,000 tonnes/year capacity are required to apply the pollution prevention management practices only. The US EPA hopes to reduce mercury emissions from foundries by requiring them to remove mercury switches from automotive bodies before being recycled and preventing certain material being used as foundry charge.

The USA intend to phase out mercury-containing batteries under the Mercury-Containing and Rechargeable Battery Management Act of 1996 (US EPA, 2009c).

The US EPA also requires that the EPA is notified 90 days prior to U.S. manufacture, import or processing of elemental mercury for use in automobile convenience-light switches, anti-lock brake-system switches and active ride control system switches in certain motor vehicles as part of its “significant new use” rule for elemental mercury of October, 2007 (US EPA, 2009d).

Many states in the USA have their own laws related to the use of mercury (US EPA, 2009f). Some states prohibit disposal of mercury-containing lamps in landfills (Stewardship Solutions, 2008).

Mercury-containing lamps were added to the federal list of hazardous wastes in 1999 (Stewardship Solutions, 2008) and the National Electrical Manufactures Association (NEMA) has implemented a voluntary reduction in mercury content in lamps, limiting the mercury content to 5 mg/lamp for lamps of less than 25 watts (Stewardship Solutions, 2008).

3.4 Other Countries

Countries with comparable risk from exposure from mercury emissions to New Zealand include Ireland, Australia and Canada. New Zealand is of a similar size to Ireland, and has similar urban/rural population distribution (Stewardship Solutions, 2008). Australia and Canada, conversely, are much larger nations. Australia has a large mining sector which influences the level of mercury emissions. New Zealand is also distinct from these three countries due to natural contribution of mercury from volcanoes and geothermal emissions.

Ireland's mercury controls are established under the EU directives.

Both Canada and Australia are federal states with individual provinces and states able to enact specific controls. These have not generally been considered here. At a federal level, both Canada and Australia have various specific controls on mercury.

- Canada has various regulations and plans for the management of mercury, including regulations to control the mercury released from chlor-alkali plants, a pollution prevention plan in respect of mercury releases from mercury switches in end-of-life vehicles processed by steel mills, and also some proposed risk management instruments for mercury-containing products (Environment Canada, 2004).
- The Environment Protection Heritage Council (EPHC) of Australia is currently investigating the end-of-life management of CFLs and other mercury-containing lamps and the issues associated with such waste (Department of the Environment, Water, Heritage and the Arts, 2009a). Australia has several standards outlining the allowable content of mercury in certain lamps. Under these standards, linear fluorescent tubes must contain less than 15 mg/lamp, and under a new standard set to be introduced in 2009, CFLs will be required to contain less than 5 mg/lamp (Department of the Environment, Water, Heritage and the Arts, 2009a).
- In some states of Australia, landfill disposal of large amounts of mercury-containing lamps is forbidden.
- From 1998, a National Pollutant Inventory (NPI) was implemented in Australia as a National Environment Protection Measure. The NPI provides information about substance emissions throughout Australia. A variation to the NPI took place in 2007, requiring a lowering of the reporting threshold for mercury and compounds to 5 kg (Department of the Environment, Water, Heritage and the Arts, 2009b).

4 Comparison of New Zealand and International Guidelines Values

The section sets out a number of comparisons for standards and guidelines for occupational settings and for air and water environments.

4.1 Occupational Exposure Limits

Occupational exposure limits for mercury in New Zealand and in most overseas countries tend to be based upon the guideline values recommended by the American Congress of Government and Industrial Hygienist (ACGIH). As shown in Table V-1 and Table V-2, the values for mercury and methylmercury for most jurisdictions are the same. No short term exposure limits (STEL) for either inorganic or organic mercury compounds have been set in any of the countries reviewed.

Table V-1: Occupational exposure limits for inorganic mercury (mg/m^3)

Country	**TWA (8 hour)**	**Ceiling**
Australia	0.025	
Canada		
- British Columbia	0.025	
- Quebec	0.025	
Denmark	0.025	
Ireland	0.025	
New Zealand	0.025	
UK	No guideline	
USA		
- ACGIH	0.025	
- NOISH	0.05	0.1
- OSHA	0.1	0.1

Note: TWA = time weighted average

Table V-2: Occupational exposure limits for akyl (organic) mercury (mg/m^3)

Country	**TWA (8 hour)**	**Ceiling**
Australia	0.1	
Canada		
- British Columbia	0.01	
- Quebec	0.01	
Denmark	0.01	
Ireland	No guideline	
New Zealand	0.1	
UK	No guideline	
USA		
- ACGIH	0.01	
- NOISH	0.01	0.1
- OSHA	0.01	0.1

4.2 Ambient Air Quality Criteria

Ambient air quality guidelines for various jurisdictions are presented in Table V-3. There is a considerable range of values. The values from Texas and Washington State are very conservative compared with the New Zealand ambient air quality guidelines (MfE, 2002b). However, the MfE criteria are lower than the WHO ambient air quality criteria for Europe (Table V-3).

Exposure to the MfE ambient air quality criteria of 0.33 µg/m^3 would result in the total intake of mercury of only 50.82 µg /week, or 0.726 µg/kg bw/week, for a 70 kg adult, which is less than 1% of the PTWI.

Table V-3: Air quality limits for mercury (µg/m^3)

	Compound	**24-hour**	**Annual**
US - Texas Commission for Environmental Quality ESL	mercury (inorganic)	0.25	0.025
	mercury (organic)	0.1	0.01
US - Washington State Department of Ecology ASIL	mercury (divalent)	1.03	9x10^{-3}
	mercury (ion)	0.95	8.95x10^{-3}
NZ- MFE-Ambient Air Quality Guidelines	mercury (inorganic)		0.33
	mercury (organic)		0.13
WHO- Air quality guidelines for Europe	mercury		1

4.3 Water Quality Criteria

In Australia and New Zealand the ANZECC (2000) guidelines provide water quality guideline trigger values for the protection of aquatic ecosystems (Section V-2.7). As can be seen in Table V-4, the Australian and New Zealand guideline values are slightly higher than the equivalent Canadian guideline value, but are significantly lower than the chronic continuous concentration (CCC) for long-term exposure to aquatic organisms and the chronic maximum concentration (CMC) for short term exposures set by the US EPA, and the Environment Quality Standards recommended by the EU. However, all four jurisdictions allow their guidelines to be adjusted upwards or downwards by the regulator authorities depending on site-specific conditions. Only Canada has set a water quality criterion for methylmercury.

Table V-4: Water quality criteria for mercury (µg/m^3)

Country	**Freshwater**	**Marine**
Australia/New Zealand (99% protection)	0.06	0.1
Canada – inorganic mercury	0.026	0.016
– methylmercury	0.004	
United States – CCC	0.77	0.94
– CMC	1.4	1.8
European Union	5	7

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Abbreviations/Glossary

Absorption – Incorporation into the body. For a person or an animal, absorption is the process of a substance getting into the body through the eyes, skin, stomach, intestines, or lungs.

Acrodynia – Paediatric disease possibly linked to mercury poisoning. Symptoms include generalised skin rash, pruritus, edema, painful extremities that appear pink, profuse sweating, clammy skin, scarlet-coloured cheeks and nose, photophobia, polyneuritis, digestive problems, irritable episodes that alternate with apathetic attitudes, and general failure to thrive. Also called erythredema polyneuropathy, Feer's disease, Pink disease, or Swift's disease.

Acute exposure – Contact with a substance that occurs once or for only a short time (up to 14 days).

Adsorption – Accumulation of a substance on the surface.

Adverse effect – A change in body function or cell structure that might lead to disease or health problems.

Aerobic – Occurring in the presence of oxygen.

Anaerobic – Occurring without oxygen.

ANZECC – Australia and New Zealand Environment and Conservation Council.

AMD – Acid mine drainage.

ARC – Auckland Regional Council.

Atmosphere – The mass of air and gases surrounding the earth.

ATSDR – Agency for Toxic Substance and Disease Registry (United States).

Bioaccumulation – When a chemical compound is absorbed by a species at a greater rate than the species can remove it.

Biogeochemical – The cycling of elements and compounds between the living (i.e. biosphere) and non-living parts of the earth (i.e. lithosphere, atmosphere, and hydrosphere).

Biological half-life (of a substance) – The time it takes for a substance to lose half of its pharmacologic and/or physiologic activity. In the case of most metals (including mercury) it can be thought as being the rate at which the metal ion is lost from the body (usually though excretion via urine or faeces but some may be lost via exhalation of air). It is generally taken that 10 times the half-life is needed to elapse before the compound is eliminated.

Biomagnification – The tendency of certain chemical compounds (e.g. methylmercury) to become concentrated as they move into and up the food chain, resulting in the larger predatory species having the greatest concentration.

Blood-Brain Barrier (BBB) – A specialised structure composed of physically merged endothelial cells and fine capillaries which restricts the passage of various chemical substances and microscopic objects (e.g. bacteria) between the bloodstream and the neural tissue itself, while still allowing the passage of substances essential to metabolic function (e.g. oxygen). For most substances, ease of passage across the BBB is determined by their lipid-solubility.

Methylmercury is able to cross the BBB so effectively because in the body it forms strong complexes with the amino acid cysteine, which is nearly structurally identical to an essential amino acid methionine.

Biosphere – The regions of the Earth's surface and atmosphere where living organisms exist.

Biota – Living species, including all plant and animal life.

CCC – Chronic continuous concentration.

CFL – Compact Fluorescent Lamp.

Chronic exposure – Exposure to a substance over a long period of time (more than a year). Chronic exposure can either be continuous or as a series of small repeated doses.

CMC – Chronic maximum concentration

Complexes – Any compound in which the bonding is by interaction of electrons of the donor with empty orbitals of the acceptor.

Dermal absorption – The transport of chemicals from the outer surface of the skin both into the skin and into the systemic circulation. Dermal absorption is most effective for those heavy metals which are capable of forming strong organic complexes (thus, for example, lead and mercury are more efficiently absorbed through the skin than cadmium and zinc). Dermal absorption can occur from occupational, environmental, or consumer skin exposure to chemicals, cosmetics, and pharmaceutical products.

Dry Deposition – The process of when mercury compounds are deposited to land or water as result of air movement and circulation.

Dyspena – Slurred speech.

EC – Electricity Commission.

ECan – Environment Canterbury.

EECA – Energy Efficiency and Conservation Authority.

Ecological Receptors – Any living organisms other than humans, and the habitat which supports such organisms, or natural resources which could be adversely affected by environmental contaminations.

EELS – Environmental exposure limits.

EPHC – Environmental Protection Heritage Council (Australia).

Epithermal Mineralisation – Pertaining to mineral veins and ore deposits formed from warm waters at shallow depth, at temperatures ranging from 50-200°C, and generally at some distance from the magmatic source.

Erethism – Abnormal irritability or sensitivity of an organ or body part to stimulation.

ERMA – Environmental Risk and Management Authority.

ERMANZ – Environmental Risk and Management Authority New Zealand.

EU – European Union.

Evasion – Release of mercury into the atmosphere from water bodies.

EW – Environment Waikato.

Exposure – Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term [acute exposure], of intermediate duration, or long-term [chronic exposure].

Exposure Pathway – The path from sources of pollutants via, soil, water, or food to man and other species or settings.

Exposure Standard – An airborne concentration of a particular substance in a worker's breathing zone, exposure to which should not cause adverse health effects nor cause undue discomfort to nearly all workers. The exposure standard can be of three forms; time-weighted average (TWA), peak, or short term exposure limit (STEL).

Exposure Standard – peak: A maximum or peak airborne concentration of a particular substance determined over the shortest analytically practicable period of time which does not exceed 15 minutes.

Exposure Standard – short term exposure limit (STEL): A 15 minute TWA exposure which should not be exceeded at any time during a working day even if the eight-hour TWA average is within the TWA exposure standard. Exposures at the STEL should not be longer than 15 minutes and should not be repeated more than four times per day. There should be at least 60 minutes between successive exposures at the STEL.

Exposure standard – time-weighted average (TWA): The average airborne concentration of a particular substance when calculated over a normal eight-hour working day, for a five-day working week.

FAO – Food and Agricultural Organisation.

GLS – General Lighting Service (incandescent lamps).

HID – High Intensity Discharge (lamps).

HSNO Act – Hazardous Substance and New Organisms Act.

Human Receptor – People who could come into contact with hazardous substances.

Hydrosphere – The water layer of the earth surface, including water vapour.

Ingestion – The act of swallowing something through eating, drinking, or mouthing objects. A hazardous substance can enter the body this way. Ingestion is usually the main route of heavy metal exposure for members of the general (non-occupationally-exposed) population.

Inhalation – The act of breathing. A hazardous substance can enter the body this way. In general, the lungs are more efficient at absorbing molecules than the gut, so the fraction of a given heavy metal which will be absorbed by the lungs may typically be 10 times the proportion absorbed by the gut. However, ambient concentrations of heavy metals in the air are usually far lower than those in food.

Inorganic Compounds – Compounds that do not comprise of a combination of carbon, hydrogen and oxygen atoms. Generally compounds other than those found in plants and animals.

IPPC – Integrated Pollution Prevention and Control.

ISQG – Interim Sediment Quality Guidelines.

JECFA – Joint Expert Committee on Food Additives.

LCNZ – Lighting Council New Zealand.

Leachate – Water escaping from a landfill site.

LFL – Linear Fluorescent Lamp.

Lipophilic – Fat or oil soluble compound.

Lithosphere – Solid portion of the Earth's surface.

MAV – Maximum Acceptable Value. A New Zealand Drinking Water Standard which is the concentration of a chemical below which the chemical compound does not result in any significant risk to a consumer over a lifetime of consumption.

MED – Ministry of Economic Development.

MEPS – Minimum Energy Performance Standards.

Methylation – The substitution of a methyl group (CH_3) for a hydrogen atom in an organic compound.

Methylmercury – An organic form of mercury with the chemical formula CH_3Hg. Methylmercury is lipophilic and can bio-magnify in living species.

Mercury Burden – T he amount of mercury present in the body of a human or animal.

Mercury Pathways – The processes and transformations that mercury and associated compounds make between the different environmental compartments i.e. land, water and atmosphere.

Mercury Sinks – Areas of the environment where there is a high concentration of mercury, usually in the sediments at the bottom of the ocean, where insoluble mercury compounds have been deposited.

Mercuric Compounds – Mercury compounds in the monovalent (Hg1+) state, denoting mercury (I) compounds.

Mercurial Erethism – The classic neurological symptoms associated with mercury poisoning, they include timidity, memory loss, insomnia, excitability, emotional instability, and in severe cases, delirium. Fits of anger and the inability to make decisions are common problems.

Mercurous – Mercury compounds in the divalent (Hg2+) state, denoting mercury (II) compounds.

MfE – Ministry for the Environment.

Micromercurialism – A form of mercury poisoning resulting from long-term exposure to low doses of mercury. The syndrome of micromercurialism involves complex symptoms of stress, fatigue, memory loss, fine tremors, muscular and reflex insufficiency and low blood pressure, caused by accumulation of mercury in the system.

MoH – Ministry of Health.

MRL – Minimum Risk Level.

NEMA – National Electrical Manufactures Association.

NIOSH – National Institute for Occupation Safety and Health (USA).

NOEC – No observable effect concentration.

NOSHC – National Occupational Health and Safety Commission (Australia).

NPI – National Pollution Inventory.

NZFSA – New Zealand Food Safety Authority.

NZTDS – New Zealand Total Diet Survey.

Omega-3 fatty acids – A family of unsaturated fatty acids that have in common a final carbon–carbon double bond in the n–3 position; that is, the third bond from the methyl end of the fatty acid.

Organic Compounds – Compounds that comprise of a combination of carbon/hydrogen/oxygen atoms, generally relate to living species, both plant and animal.

OSH – Occupational Safety and Health of the Department of Labour (NZ).

OSHA – Occupational Safety and Health Administration (USA).

Oxidation – The loss of electrons (an increase in the oxidation state of mercury).

Peripheral neuropathy – A functional disturbance or pathological change in the peripheral nervous system. Also referred to as being polyneuropathy.

Proteinuria – The presence in the urine of abnormally large quantities of protein, usually albumin. Healthy adults excrete less than 250 mg of protein per day. Persistent proteinuria is usually a sign of renal disease or renal complications of another disease, such as hypertension or heart failure.

PTWI – Provisional Tolerable Weekly Intake. PTWI are set for substances, such as metals, that are contaminants in food and are known to accumulate in animals and humans. The PTWI is defined as being the estimate of the intake of a substance over a lifetime that is considered to be without appreciable adverse health effects.

Reasonable Maximum Exposure (RME) – Represent a high end (but not worse case) estimate of an individual exposure. It provides a conservative estimate that falls within a realistic range. The RME is defined as reasonable as it is a product of several factors that are a mix of average and upper-bound estimates. RME estimates typically fall between 90th and 99.9th percentile of the exposure distribution (i.e. 90 to 99.9% of the population will have an exposure equal or less than the RME estimate).

Reduction – The gain of electrons (a reduction in the oxidation state of mercury).

Renal Failure – Partial or complete loss of kidney function resulting in the inability of the kidneys to excrete waste products.

Residence Time – The time that a compound or element will remain in a certain state or environmental compartment (e.g. atmosphere, water, land).

RfC – Reference concentrations. The concentration of a chemical in air that is very unlikely to have adverse effects if inhaled continuously over a lifetime which can be used to derive a guideline value for the protection of human health.

RMA – Resource Management Act (NZ)

RoHS – Restriction on use of Hazardous Substances (EU)

Sorbed – Attachment via either absorption or adsorption processes

Stomatitis – Inflammation of the mucous lining of any of the structures in the mouth, which may involve the cheeks, gums, tongue, lips, and roof or floor of the mouth.

TCLP – Toxic Characteristic Leaching Procedure.

TELS – Tolerable Exposure Limits.

Tephra – Solid matter that is ejected into the air by an erupting volcano. The material may range in size from so-called ‘bombs’, which are greater than 32 mm in diameter, to fine dust and ash. The coarser, heavier particles fall out close to the volcano vent, while, depending on wind conditions, the finer dust may be carried hundreds of kilometres.

UNEP – United Nations Environmental Programme.

US EPA – United States Environmental Protection Agency.

Volatilisation – The transfer of a chemical from the aqueous or liquid phase to the gas phase. Also known as evaporation.

WEEE – Waste electronic and electrical equipment

Wet Deposition – The process of when mercury is dissolved into water droplets (either by rain or other types of precipitation) and returned to land or water.

WFD – Water Framework Directive.

WHO – World Health Organization.