

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

# **Mercury Use in the Goldmining Industry**

**A retrospective examination of elemental mercury use in the gold mining industry of the West Coast of New Zealand in the period 1984 - 1988.**

**A thesis submitted in partial fulfilment of the requirement for the degree of**

**Master of Philosophy  
(Science)**

**At  
Massey University  
Wellington  
New Zealand**

**By**

**Vernon Claude Newcombe**

**2008**

## **Acknowledgements.**

I would like to thank my Supervisors Associate Professor Philip Dickinson and Mr Stuart McLaren of Massey University for their support and advice.

My thanks also go to Dr. Cheryl Brunton, Medical Officer of Health, West Coast for her support.

I am indebted to my employer, Community & Public Health, a department of the Canterbury District Health Board for allowing me the time to research the thesis.

Massey University Human Ethics Committee:

This project has been evaluated by peer review and judged to be low risk. Consequently it has not been reviewed by one of the University's Human Ethics Committees. The researcher named above is responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher, please contact Professor Sylvia Rumball, Assistant to the Vice-chancellor (Ethics & Equity), telephone 06.3505249, e-mail [humanethics@massey.ac.nz](mailto:humanethics@massey.ac.nz).



**Contents:**

Contents.....page iii

Figures.....page viii

Tables..... page x

Glossary.....page xi

Properties of mercury.....page xviii

  

Executive summary.....page 2

  

Chapter 1. Introduction .....page 6

    1.1. Outline of thesis.....page 8

    1.2. Literature search.....page 9

    1.3. Methodology.....page 9

    1.4. Results.....page 9

    1.5. Discussion.....page 9

    1.6. Conclusion.....page 9

    1.7. Recommendation.....page 10

    1.8. Limitations.....page 10

    1.9. Future research.....page 10

Chapter 2. Introduction to the West Coast .....	page 11
2.1. West Coast land mass.....	page 12
2.2. Climate.....	page 13
2.3. Land coverage.....	page 14
2.4. Minerals .....	page 15
2.5. Mining .....	page 17
2.6. Economy .....	page 19
Chapter 3. Gold .....	page 20
3.1. The metal.....	page 20
3.2. Location of gold .....	page 21
3.3. Demand .....	page 22
3.4. Modern mining .....	page 22
3.5. Treatment of gold wash.....	page 28
3.6. Retort process .....	page 29
Chapter 4. Mercury .....	page 31
4.1. History of mercury.....	page 31
4.2. Alchemy .....	page 32
4.3. Historical use.....	page 33
4.4. Contamination.....	page 34
4.5. Mercury impact .....	page 39
4.6. Mercury uses.....	page 43
4.7. Mercury properties.....	page 46
4.7.1. The metal.....	page 46
4.7.2. Chemical properties .....	page 46
4.7.3. Occurrence .....	page 47
4.7.4. Chemical state.....	page 48
4.8. Production of mercury .....	page 49
4.8.1. Source.....	page 49
4.8.2. Process.....	page 49

Chapter 5. Toxicity .....	page 53
5.1. Hazard .....	page 53
5.2. Psychological effects .....	page 54
5.3. Dose.....	page 55
5.4. Body burden.....	page 56
5.5. Absorbtion.....	page 57
5.6. Carcinogenicity .....	page 59
5.7. Dermal .....	page 60
5.8. Excretion.....	page 61
5.9. Acute poisoning.....	page 62
5.9.1. Mercury poisoning cases.....	page 62
 Chapter 6. Environment .....	page 64
6.1. General.....	page 64
6.2. Airborne mercury.....	page 64
6.3. Pollutant .....	page 66
6.4. Mining.....	page 67
6.5. Artisanal .....	page 68
6.6. Food chain.....	page 69
6.7. Atmospheric mercury .....	page 71
6.7.1. Mercury cycle.....	page 71
6.7.2. Anthropogenic pollution.....	page 74
6.7.3. Speciation.....	page 75
 Chapter 7. Amalgamation.....	page 77
7.1. History.....	page 77
7.2. Theory of amalgamation .....	page 77
7.3. New Zealand mine & amalgamation.....	page 82
 Chapter 8. Objectives .....	page 83
8.1. General.....	page 83
8.2. Specific objectives.....	page 83

Chapter 9. Health & safety .....	page 84
9.1. General.....	page 84
9.2. Occupational safety.....	page 84
9.2.1. Legislation.....	page 84
9.2.2. Administration.....	page 85
9.2.3. Compliance.....	page 87
9.2.4. Current legislation.....	page 88
Chapter 10. Methodology .....	page 92
10.1. General.....	page 92
10.2. Cohort.....	page 94
10.3. Control.....	page 95
10.4. Observation .....	page 95
10.5. Biological sampling .....	page 96
10.6. Urinalysis.....	page 97
10.7. Literature search.....	page 98
10.8. Questionnaire .....	page 98
10.9. Employee discussion .....	page 99
10.10. Environmental monitoring .....	page 99
10.11. Mercury meter.....	page 100
10.12. Personal dose badges.....	page 102
10.13. Dräger & smoke tubes.....	page 104
10.14. Air flow.....	page 105
10.14.1. Anemometers.....	page 105
10.14.2. Smoke tubes.....	page 106
Chapter 11. Results .....	page 108
11.1. General.....	page 108
11.2. Personal protective equipment.....	page 108
11.2.1. Masks.....	page 109
11.2.2. Clothing.....	page 110
11.3. Change/wash rooms.....	page 114
11.4. Work rooms.....	page 114

11.5. Ventilation.....	page 116
11.6. Mercury in air measurement.....	page 119
11.6.1. Work room air measurement.....	page 120
11.6.2. Non-retort air measurement.....	page 122
11.6.3. Retort air measurement.....	page 124
11.6.4. Breathing zone monitoring.....	page 127
11.7. Off site contamination.....	page 128
11.8. Mercury in urine levels.....	page 130
11.8.1 Biological exposure indices. BEI.....	page 130
11.8.2 Non retort urine results.....	page 132
11.8.3. Retort operator urine results.....	page 142
11.8.4. Controls urine results.....	page 154
11.8.5. Questionnaire.....	page 155
 Chapter 12. Discussion .....	page 160
12.1. General.....	page 160
12.2. Mercury in air & mercury urine relationship.....	page 169
12.3. Microenvironment.....	page 172
12.4. Questionnaire .....	page 175
12.5. Environmental pollution.....	page 178
 Chapter 13. Conclusions .....	page 182
13.1. General.....	page 182
13.2. Specific.....	page 183
 Chapter 14. Recommendations .....	page 187
14.1. General.....	page 187
14.2. Specific.....	page 191
 Chapter 15. Limitations and bias .....	page 193
15.1. Limitations.....	page 193
15.2. Bias.....	page 195



Chapter 16. Areas for additional research .....	page 197
16.1. Gaps.....	page 197
References.....	page 199
Appendices .....	page 214
Appendix 1. Mercury questionnaire.....	page 214
Appendix 2. Mercury vapour analyzer.....	page 215
Appendix 3. Mercury material safety data sheet.....	page 216

## Figures.

Fig.1. Map of New Zealand.....	page 1
Fig.2. Map of the gold mining area of the Westcoast covered by this study.....	page 11
Fig.3. West Coast land cover.....	page 14
Fig. 4. Value of minerals to New Zealand economy 1860-2004.....	page 16
Fig.5. Total gold production in New Zealand 1855 to 1995. ....	page18
Fig. 6. Small gold nuggets.....	page 21
Fig.7. Floating gold screen.....	page 26
Fig.8. Gold mining process.....	page 27
Fig.9. Retorting process .....	page 28
Fig.10. Retort diagram.....	page 29
Fig.11. Retort in use.....	page 30
Fig.12. Alchemy sign.....	page 32
Fig.13. Map of mercury sources in New Zealand.....	page 42
Fig.14. Mercury production diagram.....	page 52
Fig 15. Total global mercury emissions.....	page 65

Fig.16. Food chain biomagnifications.....	page 70
Fig.17. Mercury cycle.....	page 73
Fig 18. Mercury global emissions .....	page 75
Fig. 19a. Diagram of gold saving process.....	page 79
Fig.19b. Use of mercury plates.....	page 80
Fig. 20. Mercury lapel badge.....	page 102
Fig. 21. Dräger tubes.....	page 104
Fig. 22. Smoke tube kit.....	page 107
Figs. 23-25. Graphs of workplace equipment use.....	page 113
Figs. 26-29. Graphs of standard of workplaces.....	page 115-116
Fig. 30. Ventilation graph.....	page 117
Fig. 31. Graph of non-retort mercury handlers urine analysis levels 1988-1988 .....	page 133
Figs. 32-39. Graphs of individual non-retort mercury handlers results 1984-1988 .....	page 134-141
Fig. 40. Graph of retort mercury handlers urinary levels 1984-1988 .....	page 143
Figs. 41-48. Graphs of individual retort mercury handlers results 1984-1988.....	page 144-151
Fig. 49. Graph of normal/action/suspension levels of workers 1984-1988 & totals.....	page 152
Fig. 50. Graph of % of total urinary mercury samples .....	page 153
Fig. 51. Graph of number of study participants from total workforce.....	page 154
Fig. 52. Graph of control mean/min/max urinary mercury levels.....	page 155
Fig 53. Graph of control and worker subjective response to questionnaire 1986-88.....	page 159

## Tables.

Table 1.	Vapour pressure saturation concentration of mercury .....page 47
Table 2.	Absorption of mercury by route of contact.....page 58
Table 3.	Estimated average daily intake of mercury .. .....page 61
Table 4.	Grab sample results for non-retort mercury in air measurements.....page 123
Table 5.	Grab sample results for retort mercury in air measurements.....page 125
Table 6.	Range and mean of individual mercury In air measurements.....page 126
Table 7.	Dosimeter results for mercury in air .....page 127
Table 8.	Non workroom mercury in air measurement.....page 129
Table 9.	Questionnaire results for action level.....page 157
Table 10.	Questionnaire results for suspension level.....page 157
Table 11.	Questionnaire results for controls .....page 158
Table 12.	Total subjective responses to questionnaire by all participants.....page 158

## Glossary.

The terms, acronyms and abbreviations below appear in this document.

< - Less than;

> - Greater than;

°C - Degree Celsius [centigrade];

µg – microgram [ $10^{-6}$  gram];

**µg/kg body weight per day** – Micrograms per kilogram body weight per day; units used for describing intakes (or doses) of mercury such as intakes that are considered safe for humans.

µmol - micromole is 1 millionth of a mole;

**ADI** - Acceptable daily intake;

**AMAP** - The Arctic Monitoring and Assessment Programme;

**ATSDR** – USA Agency for Toxic Substances and Disease Registry;

**Balance** - Totality of quantitative estimates of input and output substance fluxes for a given geophysical reservoir or societal entity;

**bw** - Body weight;

**Dry deposition** – The transport of trace gases and particles to the earth's surface which is an important loss process for many reactive and soluble trace gases. It is of a continuous character independent of the occurrence or absence of atmospheric precipitation;

**EC** – European Community. Now called European Union with 27 member states.

**EMEP** – Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (under the LRTAP Convention);

**ESP** – Electrostatic precipitator; equipment used to reduce emissions of certain pollutants from combustion flue gases;

**FAO** – Food and Agriculture Organization;

**FF** - Fabric filter; filter type used to capture particulate matter (here: from combustion flue gases);

**FGD** – Flue gas desulphurization; process of/equipment for primarily minimizing emissions of sulphur from combustion flue gases;

**GEF** - Global Environment Facility;

**Hg** – Mercury;

**Hg<sup>0</sup>** - Elemental mercury;

**Hg<sup>2+</sup>** - Divalent mercury - the dominating mercury form in organic and inorganic mercury compounds. In the atmosphere, mercury species with divalent mercury are more easily washed out of the air with precipitation and deposited than elemental mercury;

**Hg<sub>p</sub>** - Particulate mercury - mercury bound in, or adsorbed on, particulate material. In the atmosphere, particulate mercury is deposited much faster than elemental mercury;

**IARC** - International Agency for Research on Cancer;

**ILO** - International Labor Organization;

**IPCS** – International Programme on Chemical Safety;

**kg** – kilogram;

**l or L** – Litre;

**LC<sub>50</sub>** - Lethal concentration, 50%; concentration of toxic substance in a medium (for example water) at which 50% of the individuals in the toxicity test sample die; a unit used to describe the level of toxicity of a substance to a specific species, for example fish;

**LD<sub>50</sub>** - Lethal dose, 50%; dose (intake) of a toxic substance at which 50% of the individuals in the toxicity test sample die; a unit used to describe the level of toxicity of a substance to a specific species, for example in laboratory tests on mice, birds or other animals;

**Life-time** - In atmospheric physio-chemistry: Time during which the first order processes (or totality of the first order processes) of scavenging results in mercury species mass reduction in  $e$  times in a geophysical reservoir; for a reservoir with homogeneous mercury species distribution the life-time is equal to the ratio of the mass contained in the reservoir to scavenging rate. Since the mass of mercury in the reservoir left to be reacted or removed decreases over time, the amount reacted or removed per unit of time decreases in a natural logarithmic fashion. For example, a lifetime of mercury of one year, does not mean that it would all be gone in one year if emissions were zero. It means that the rate of removal at the start of the time period in terms of mass per unit time would remove it all in one year, but since the rate of removal decreases as the mass of mercury left decreased, the amount of mercury left after one year would be  $(1/e)$  times the initial mass, where "e" is 2.71828183 defined to 8 decimals. In descriptions of life-cycles of products: The time span from when the product is put into use (usually time of purchase) until it is no longer used or discarded;

**LNB** – Low-NO<sub>x</sub> burner; utility boiler combustion technology designed specifically to generate relatively low levels of nitrogen oxides;

**Load** - The intensity of input of pollutants to a given ecosystem from the environment; atmospheric load - the intensity of input from the atmosphere;

**LOEL** - Lowest observed effect level (also called **LOAEL** – lowest observed adverse effect level); for toxic or other effects imposed on organisms or experienced by humans;

**LRTAP Convention** – Convention on Long-Range Transboundary Air Pollution;

**MBL** – Marine boundary layer; the air right over the ocean surface, where exchange of mercury between the two compartments takes place;

**MethylHg** or MeHg – Methyl mercury;

**Metric ton** or tonne – 1000 kg;

**mg** – milligram ( $10^{-3}$  gram);

**Mol** or mole - is the atomic weight of a molecule of the chemical in grams.  
E.g. 1 mole of mercury is 200.59g.

**MRL** – Minimum risk level; term used in evaluation of risk of toxic effects from various chemicals (such as methylmercury) on humans; the MRL is defined by US ATSDR as an estimate of the level of human exposure to a chemical that does not entail appreciable risk of adverse non-cancer health effects (see section 4.2);

**MSW** – Municipal solid waste;

**MW** – Megawatt a unit of electrical power;

**MWC** – Municipal waste combustor;

**MWh** – Megawatt-hour is a unit of energy most commonly used to express amounts of energy.

**Natural emission** - Input to the atmosphere, which is not connected with current or previous human activity;

**NEMA** – National Electrical Manufacturers Association (in the USA)

**ng** – nanogram ( $10^{-9}$  gram);

**NGO** - Non-governmental organization;

**NOEL** - No observed effect level (also called NOAEL – no observed adverse effect level); for toxic or other effects imposed on organisms or experienced by humans;

**NRC** – National Research Council of the United States of America is under the auspices of the National Academy of Sciences (NAS), the National Academy of Engineering (NAE), and the Institute of Medicine (IOM). The NAS, NAE, IOM, and NRC are part of a private, no-profit institution that provides science, technology and health policy advice under a congressional charter signed by President Abraham Lincoln that was originally granted to the NAS in 1863. Under this charter, the NRC was established in 1916, the NAE in 1964, and the IOM in 1970. The four organizations are collectively referred to as the National Academies

**OECD** - Organization for Economic Cooperation and Development;

**pg** – picogram ( $10^{-12}$  gram);

**POPs** - Persistent Organic Pollutants;

**ppb** – parts per billion;

**ppm** - parts per million;



**Pre-industrial state** - A conventional term implying the state of the natural [mercury] cycle before the beginning of human industrial activity; in Europe the beginning of a noticeable production and consumption of mercury is related to medieval centuries;

**PS** - Particle scrubber; equipment designed to reduce emissions of particles from combustion flue gases

**Re-emission** - Secondary input to the atmosphere from geochemical reservoirs (soil, sea water, fresh water bodies) where mercury has been accumulating as a result of previous and current human activity;

**RfD** – Reference dose; term used in evaluation of risk of toxic effects various chemicals [such as methylmercury] on humans; the RfD is defined by US EPA as an estimate [with uncertainty spanning perhaps an order of magnitude] of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime;

**SCR** - Selective catalytic reduction; equipment designed to reduce emissions of certain pollutants from combustion flue gases;

**SDA** - Spray dryer adsorber system; equipment designed to reduce emissions of certain pollutants from combustion flue gases;

**Slag** – A substance produced by mixing chemicals with metal that has been heated until it is liquid in order to remove unwanted substances from it.

**SNCR** - Selective non-catalytic reduction; equipment designed to reduce emissions of certain pollutants from combustion flue gases;

**TLV** - Threshold limit values are guidelines [not standards] prepared by the American Conference of Governmental industrial Hygienists, Inc [ACGIH] to assist industrial hygienists in making decisions regarding safe levels of exposure to various hazards found in the workplace. They reflect the level of exposure that the typical worker can experience without an unreasonable risk of disease or injury. TLVs are not quantitative estimates of risk at different exposure levels or by different routes of exposure;

**Torr** - Is a non-SI unit of pressure defined as 1/760 of an atmosphere;

**TWA** - Time weighted average. The average exposure to a contaminant that a worker may be exposed to without adverse effect over a period such of an 8 hour day or 40 hour week. E.g. mercury vapour TWA is  $0.05 \mu\text{mol}/\text{m}^3$ ;

**UN** - United Nations;

**UNCED** - United Nations Conference on Environment and Development;

**UNEP** - United Nations Environment Programme;

**US EPA** – Environmental Protection Agency of the United States of America;

**USA** – United States of America;

**Wet deposition** - Flux of substance from the atmosphere onto the underlying surface with atmospheric precipitation;

**WHO** - World Health Organization.

## Properties of mercury.

Atomic number: 80

Density: 13.5336 grams per cubic centimetre

Melting point:  $-38.83^{\circ}\text{C}$  [234.32K]  $-37.89^{\circ}\text{F}$

Description: Silvery, odourless, heavy liquid

Molecular formula: Hg

Molecular weight: 200.59 g / mol

Period number: 6

Group number 12

Boiling point:  $356.7^{\circ}\text{C}$  [ $629.88^{\circ}\text{K}$ ]  $674.11^{\circ}\text{F}$

Phase at room temperature: Liquid

Element classification: Metal

Vapour pressure: 0.002 torr @  $25^{\circ}\text{C}$

Vanderwaals radius: 0.157nm

Solubility: Soluble in concentrated nitric and hot sulphuric acid; dissolves to some extent in lipids

CAS number: 7439-97-6

Oxidation states: +2, +1

Inhalation reference exposure level:  $0.09\text{ mg} / \text{m}^3$

TWA :  $0.05\text{ mg} / \text{m}^3$