

# LITERATURE REVIEW AND REPORT ON BIOMONITORING OF EXPOSURE TO ANTIMONY AND POTENTIAL HEALTH EFFECTS ARISING

Report prepared by

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# **Executive Summary**

This report has been prepared to provide independent, evidence-based advice to assist the Victorian Department of Health in responding to concerns of residents in the Costerfield region of Victoria regarding potential short-term and long-term health effects associated with environmental sources of antimony in this area, including current mining activity. Antimony is mainly present in this environment in the form of dust that may be breathable by nearby residents or that may contaminate water storage tanks used as a potable water supply.

This report does not purport to be a comprehensive review of the literature on the toxicology of antimony. Rather, it is focussed on some specific issues relating to antimony toxicokinetics and the potential for urinary biomonitoring to assist with assessing potential community exposures to environmental sources of antimony.

The key features of the toxicokinetics of antimony are its slow and incomplete absorption after ingestion or inhalation of dusts, with negligible dermal absorption. It is distributed to most tissues, with the highest accumulation in erythrocytes (red blood cells), liver, kidney, thyroid and bone. It can also accumulate in the lungs after inhalation of insoluble Sb-containing dusts. Clearance of antimony from the body occurs slowly via urine and faeces, with the faecal component comprising antimony that is unabsorbed after oral ingestion and antimony associated with some biliary clearance. The slow urinary clearance makes spot urine sampling a useful biomonitoring tool for assessing current and past antimony exposures from all exposure sources and routes of absorption.

There is a substantive literature reporting urinary concentrations of antimony in the general population, exposed primarily through food, water and ambient air, as well as studies of urine and blood concentrations in occupationally-exposed cohorts. These studies have been summarised, with emphasis on those that might provide guidance to establish a suitable biomonitoring reference range in adults and children.

This information should be useful in interpreting urine concentrations already measured in some Costerfield residents and in communications with community groups. The urine values so far reported (1 to >35 nmole Sb/mmole cr – data provided up to 18 June 2014 seem to be much higher than those reported in the general population in the US and Germany (generally <1 nmole Sb/mmole cr). Even in some individuals from other regions of Victoria that do not have naturally occurring environmental sources the values (<1 to 25 nmole Sb/mmole cr – data provided up to 18 June 2014) are apparently higher than in workers exposed through occupational sources. Therefore, some care needs to be taken in interpreting the reported Victorian urine values, because of an inability to exclude collection/storage contamination of both the Costerfield and other Victorian urine samples. The analysing laboratory has noted that urine samples sourced elsewhere and analysed in that laboratory have been uniformly low or negative for antimony.

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### Report scope and literature review methodology

This report has been prepared by Professors Brian Priestly and Malcolm Sim, Monash University (see Appendix A with brief bios) to assist the Victorian Department of Health to respond to concerns of residents in the Costerfield region of Victoria regarding environmental sources of antimony in this area, including current mining activity. These releases have mainly been in the form of dust that may be breathable by nearby residents or that may contaminate water storage tanks used as a potable water supply.

This report does not purport to be a comprehensive review of the literature on antimony toxicity. It is focussed on some specific issues relating to the potential for urinary biomonitoring to assist with assessing exposures to environmental sources of antimony exposures and to assist with the interpretation of biomonitoring data already collected from residents, along with other exposure estimates. The terms of reference for this review are at Appendix B.

The intent is to provide independent, evidence-based advice to officials of the Victorian Department of Health to assist them to address issues raised by residents of the Costerfield region with concerns about short-term and long-term effects on their health associated with antimony exposures.

The format of this report is to first present a brief summary of the literature (Part A) addressing issues such as:

- antimony toxicokinetics,
- approaches to biomonitoring (particularly information on urine concentrations in occupationally exposed and general communities), and
- potential sources of exposure for the Costerfield community

This is followed by some specific comments on the questions raised in the brief (Part B), with cross-references to the relevant sections of the literature review.

This review complements information already provided to the Victorian Department of Health in a report from Golder Associates dated 16 June 2014, summarising potential pathways for antimony exposure and commenting on the potential for adverse effects on health for the local community.

The methodology of the review was to identify some key reviews undertaken by international authorities (U.S. Environmental Protection Agency (EPA), Health Canada, U.S. Agency for Toxic Substances and Disease Registry (ATSDR), European Union), International Agency for Research on Cancer (IARC) and to track back relevant references cited in those reviews. This was supplemented by a PubMed search, using key terms 'antimony toxicity', 'antimony biomonitoring' and antimony 'human exposures'

# Part A: Literature review of antimony (Sb) toxicokinetics and biomonitoring

# 1. Exposure routes and absorption

(a) Oral: Absorption after oral ingestion is slow and incomplete (Tylenda & Fowler, 2007, ATSDR 1992). The amount and rate of systemic absorption from the gut is highly dependent on the chemical form and solubility, the valence state (see speciation below) and the matrix in which the antimony is ingested.

Soluble antimony salts (e.g SbCl<sub>3</sub> and antimony tartrate) are absorbed more completely than insoluble salts. The extent of absorption after oral administration has been reported to range up to 20%, but there is some species variability. For example, estimates of oral absorption for soluble antimony salts have been reported as 5% in humans, but higher uptakes have been reported in cattle (18%) and rodents (7-15%). One estimate of the bioaccessible amount of antimony (amount extracted into simulated gastric juice) was only 10% for randomly sampled urban dusts (Falta *et al*, 2008).

Unlike some other metals considered to be essential nutrients, antimony absorption does not appear to be regulated by a specific carrier transport mechanism (Yokel *et al*, 2006).

**(b) Dermal:** Systemic absorption of antimony across the skin is considered to be negligible (US EPA 2012) although there are few, if any, studies with supporting data (Belzile *et al* 2011, ATSDR 1992).

(c) Inhalation: Antimony in dusts can be absorbed systemically after inhalation, but the amount absorbed is dependent on particle size and solubility, as well as the extent to which the particles penetrate deeply into the lower reaches of the respiratory tract (Belzile *et al* 2011). One estimate of the amount of systemically absorbed Sb after inhalation exposure is 15% (Belzile *et al* 2011, Patriarca *et al* 2009). It is likely that systemic absorption of antimony after dust inhalation will be greatest from the smallest particle sizes – i.e. those reaching the alveolar region, which are called respirable particles. More soluble particles are absorbed more quickly, while insoluble particles that remain lodged in the lower reaches of the respiratory tree may be absorbed slowly over several weeks.

A diagram describing the size-dependent distribution of retained particulates in different regions of the respiratory tract can be found in enHealth publications (2012a,b), with specific discussion of factors that determine particulate lodgement and clearance in Section 5.5 of the Australian Exposure Factor (AEF) guidance.



Table 5.5.1 from the AEF document shows estimates of the respirability of particulates of varying size. This shows that respirability drops off markedly as the aerodynamic diameter increases and is negligible once the diameters reaches  $7\mu m$ .

Table 5.5.1: Proportion of respirability of dust by particle size  $(\mu m)^a$ 

Particle equivalent aerodynamic diameter (µm)	Respirability (percent)
0	100
1	98
2	92
3	82
4	68
5	50
6	28
7	0

<sup>a</sup> Adapted from Standards Australia AS 2985–2004 Table 1

# 2. Tissue distribution

Studies in animals suggest that the liver, kidneys, bone and thyroid are the main tissue sites where antimony accumulates after systemic absorption. Tissue storage at most other sites is not prolonged. Release of antimony from the thyroid of rats may be much slower than in other species.

Animal studies indicate that there may be some slight differences in the rate of tissue uptake of different valence states, with  $Sb(III)CI_3$  being taken up more rapidly than Sb(V) into the liver, with the opposite occurring for distribution into bone. Sb(III) has a strong affinity for erythrocytes and it can remain stored there for some time. Conversely, Sb(V) does not accumulate in erythrocytes and is found mainly in the plasma compartment.

Inhaled dusts containing antimony may remain lodged in the different parts of the respiratory tract for some time, and their clearance will depend on rates of upward ciliary movement. Intermediate particle sizes (1.6µm) may be cleared within hours, while smaller particles lodged deeper in the respiratory tree may take weeks to clear.

A useful source of information on tissue burdens in general populations, including newborns, infants and children, is in a review by Patriaca *et al* (2000). The authors noted the ethical difficulties in obtaining autopsy data from children and the scarcity of such data. Unfortunately, the only Sb data actually reported in the paper relate to breast milk and liver tissue Sb (ng/g wet wt) for UK infants and children up to 2 years age.

# 3. Excretion

(a) **Principal routes:** Antimony is mainly cleared from the body by excretion in urine after systemic absorption. There may be some excretion of antimony in bile, in a form conjugated with glutathione, and part of this may undergo enterohepatic recirculation.

The relative importance of urinary and faecal excretion (at least in rodents) can be determined by findings that, after an IV dose of SbCl<sub>3</sub> (800 µg/kg, with complete bioavailability), 51 µg of the dose was recovered in faeces, while 46 µg was recovered in urine over 96h (representing approx. 45% of the administered dose). In the first 24 hours after dosing, slightly more was recovered in urine (40 µg) than in faeces (34 µg). The fact that Sb appeared in faeces after IV dosing indicates that biliary excretion (at least in the rat) is a significant component of clearance from the body. In the same study, with bile-cannulated rats, 6-15% was recovered in bile in the first 7 hours after dosing. The significance of conjugation with glutathione (GSH) for biliary excretion was shown where treatments reducing the available GSH in liver markedly reduced faecal excretion and promoted urinary excretion. After oral administration, a significant amount of antimony excreted in faeces would be unabsorbed material passing through the gut.

(b) Clearance rates: Urinary excretion is relatively slow (Gebel 1997). The excretion half-life has been estimated from studies in exposed workers to be of the order of 90 hours (Bailly *et al*, 1991, Kentner *et al*, 1995) This means that, in the absence of any further intake, it would take about 19 days (4-5 half-lives) to clear >95% of an absorbed dose of antimony from a single exposure. With continued exposure, it would be expected that urinary excretion would approach steady-state, with urinary output matching systemic absorption.

The significance of solubility and chemical form on human urinary clearance is indicated in a report by Rees *et al* (1980). When administered by intravenous injection, as the sodium stibogluconate Sb(V) salt, around 80% of the dose was recovered in urine within 6-8 h, and more than 90% within 24 hours. The longer half-life reported in workers exposed primarily by the inhalation route probably reflects slow release of antimony stored in the lungs and bronchi.

As noted above, clearance of material deposited in the lung can be quite slow. Leffler *et al* (1984) demonstrated biphasic clearance from rat lung after intratracheal installation of antimony, with initial half-lives of 30h for dust and 40h for pure  $Sb_2O_{3,}$  and secondary half-lives of 20-40 days for both forms, reflecting the slow release of antimony stored in the lung tissue.

# 4. Speciation

(a) Valence states: Antimony has two valence states – III and V. The predominant valence state in nature is (III), but conversion to valence state (V) can occur in oxidising conditions. In water, under conditions of adequate oxygen and near neutral pH, antimony is expected to be in the (V) valence state (Canada, 2010). Two-way conversion of valence state can occur in vivo, but it is estimated that the amounts are relatively minor (less than 10%). Some differences in toxicokinetics of Sb(III) and Sb(V) compounds have been noted above, but whether differences are due specifically to the valence state or to differing water solubility is difficult to determine. Antimony speciation, solubility and occurrence in geogenic soils is discussed in more detail in Arai (2010).

Sb(V) is the dominant species in drinking water (Belzile *et al* 2011, Fillella *et al* 2009), including in waters contaminated by run-off from mining/smelting areas (Liu *et al* 2010).

**(b)** Toxicological differences: There is also relatively sparse information on the comparative toxicity of antimony (III) and (V) compounds (Krachler *et al*, 2001). Some reports suggest that compounds with valence state (III) are up to ten times more toxic than valence state (V), but this could be more influenced by the chemical form (oxides, chloride or tartrate salts etc) and solubility than the valence state. The chemical form is probably more critical than the valence state. For example: stibine (SbH<sub>3</sub>) is a gaseous form of antimony that is quite toxic (in

the same way that arsine gas,  $AsH_3$  is a more toxic form of arsenic) because it is readily absorbed after inhalation; the trichloride form of antimony (SbCl<sub>3</sub>) is more toxic than its oxides (Sb<sub>2</sub>O<sub>3</sub>) and sulphides because of its greater water solubility, and hence greater bioavailability after oral ingestion. The establishment of water quality standards for antimony are based on rat studies where the water soluble potassium tartrate salt was administered in drinking water.

Since potassium antimony tartrate has been used therapeutically in humans (Tylenda & Fowler 2007), it is useful to note that the doses used (2.8 mg diaphoretic; 30-60 mg emetic) are orders of magnitude greater than ingestion exposures expected from environmental exposures to antimony-containing dusts.

(c) **Bioavailabilty from contaminated soils and dusts:** Flynn *et al* (2003) studied five former British mining/smelter sites and found that bioavailability of Sb from soils containing up to 700 mg/kg was poor, with the Sb species quite immobile in the surface layers. However, their studies were confined to water leachates and ecotoxicological sensors, not humans or mammalian species. Similarly, Gal et al (2007) found that Sb was poorly bioavailable from soils containing 10-1200 mg/kg around a former Scottish mining/smelting site. They did however, report some Sb uptake into earthworms and grass. Perez-Sirvent *et al* (2012) also reported uptake of Sb into plants growing in mining-affected soils in southern Spain,

Significant soil contamination with several metals has been reported (Wang *et al* 2010) around China's largest antimony mine, with antimony levels as high as 2178 mg/kg. No studies were done on bioavailability.

# 5 Contamination sources

(a) general comments: Potential exposure pathways for Costerfield residents would generally fall into four categories:

- ingestion of contaminated food and water this is a pathway that generally accounts for most of the exposure in non-occupationally exposed groups; estimates of background exposures of this type are of the order of 5-6 µg/day (ATSDR 1992, Arnich et al, 2012, Belzile et al, 2011, Cooper & Harrison 2009).
- Direct ingestion of soil this is not normally a significant source for adults, although there can be some hand-to-mouth and food preparation transfer from household dusts. However, direct ingestion of soil and dusts by hand-to-mouth transfer can be a more significant exposure source in children (enHealth 2012 a, b)
- Inhalation of dusts, including those of local geochemical origin from soils in the region and possibly from dusts drifting across from mine operations
- Contamination of drinking water, sourced mainly from rainwater tanks collecting water from contaminated surfaces on individual properties

Estimates of total daily intake of antimony from diet, water and other sources are highly variable, with summarised values for various populations and non-occupationally exposed groups ranging from 0.01 to 80 µg/day (Belzile *et al* 2011).

(b) water contamination from PET bottles: It is understood that concerned residents have been urged to use bottled water as a substitute for tank water during resolution of the issues relating to the potential for antimony exposure from mine dusts. The issue of possible leaching of antimony into water stored in PET water bottles received significant media attention and scientific follow-up following initial reports in 2006 (Shotyk et al, 2006, Bach et al, 2013 a). The concentrations of Sb initially reported were up to 626 ng/L. although subsequent reports indicated that this could be increased towards 2000 ng/L the longer the bottles were stored (Shotyk et al 2007), or up to 2000-8000 ng/L from bottles stored at high temperatures (up to  $60^{\circ}$ C, and dependent on the type of fluid stored). (Bach et al 2013 b). Exposure to bottled water to sunlight (especially when carbonated) could increase Sb leaching towards concentrations of 500-2000 ng/L with only modest increases in temperature (mean around  $27^{\circ}$ C, and maximum up to 46<sup>o</sup>C) (Bach *et al* 2014). Similar results were reported by Westerhoff et al (2008) for commercially available bottled water from southwestern USA, including increased leaching with storage at elevated temperatures.

While these results suggest that some types of water stored in PET bottles may leach antimony over time, the concentrations in the water are generally lower than drinking water guidelines set by government authorities (e.g. the ADWG guideline value of 3000 ng/L), unless stored at very high temperatures. However, it must be recognised that the incremental exposure associated with antimony leached from PET bottles would be of greater significance for those whose background exposure from other sources is higher (e.g. in Costerfield residents).

# 6 Biomonitoring

# (a) groups studied

Literature reports include antimony blood and urinary data derived from occupationally exposed cohorts and populations that have been exposed primarily through food, water and ambient air. The most comprehensive summary of blood levels for biomonitoring purposes is in the review by Filella et al (2013). These values are generally in the range 1-2 ng/mL, but they are quite variable. Whole blood levels tend to be higher than serum or plasma because of the tendency for Sb to accumulate in erythrocytes. They include data for infants and patients treated therapeutically with organo-antimonials.

Most reported urinary Sb concentrations in 'unexposed' populations have not been corrected for creatinine output, and generally fall in a range up to 1  $\mu$ g/L. The values reported for different populations and sub-groups are summarised below.

(i) **General population reference values** (i.e groups exposed only via food, water and ambient air in non-antimony contaminated areas)

- NHANES (2013), reporting urinary data from the six survey periods of the US NHANES project, segregated into three age groups (6-11, 12-19 and >20 years), both genders and three ethnic groupings, with data reported in both µg/L and corrected for creatinine content in µg Sb/g cr (Tables reproduced in Appendix C). The creatinine-corrected geometric mean values ranged from 0.06 to 0.19 µg/g.
- Christensen (2013), reporting data from the 2007-08 cohort from the NHANES study and seeking correlations between urinary metals and thyroid function; reported Sb values: median 0.05 μg/L (range <0.04 to 0.08 μg/L).</li>
- Agarwal *et al* (2011), reporting data from the 1999-2006 cohort from the NHANES study and seeking correlations between urinary metals and cardiovascular/cerebrovascular disease; most of the report focussed on the association between urinary/blood cadmium levels and disease, and while a positive association was also reported for urinary Sb, the actual urine values were not reported. However, they may presumably be found in consolidated NHANES reports (see above).
- Navas-Ancien *et al* (2005) reporting data from the 1999-2000 cohort of the NHANES study and seeking correlations between urinary metals and peripheral artery disease; reported Sb values: geometric mean 0.11 μg/L (range <0.04 to 5.7μg /L).
- Gebel *et al* (1998a, 1998b), reporting data from the northern Palatine region of Germany (a region with relatively high ore-sourced Sb and As soil levels), compared to residents from lower Saxony; median Sb levels (and range) were males 1.23 (<0.04 to 4.74) and females 0.68 (<0.05 to 5.35); as µg Sb/24h. When segregated by region, values in the Saxony region were actually higher that the Palatine region; median (range) 1.1 (<0.05 to 5.86) vs 0.46 (<0.05 to 4.73) in µg Sb/24h.</li>
- Schramel *et al* (1997), reporting urine levels from 7 non-exposed people of each gender from a German population; mean (range) values reported were 0.08 μg/L (0.01 to 0.17).

### (ii) Occupationally-exposed groups (some with referent groups)

In occupationally exposed groups, various urinary concentration ranges have been reported. These are summarised below:

- Bailly *et al* (1991) reporting data from 20 male workers from a non-ferrous smelter producing antimony pentoxide and sodium antimoniate; exposure duration 0.5 to 17 years; mean urinary Sb concentrations (in µg Sb/g cr) were 8.2 and 58.4 at beginning of shift for a wet and dry process, and 12.3 and 110 at the end-of shift for those two processes. Airborne Sb levels in the breathing zone (86 and 927 µg/m<sup>3</sup>) were relatively consistent with the measured urine levels.
- Shelly *et al* (2012) reporting data from a cohort of 712 Korean current and former workers in lead smelters and plants producing lead batteries, lead oxide, lead, crystal or radiators; the median and mean (SD) urinary Sb (µg Sb/g cr) reported were 0.77 and 3.6 (9.0) in current workers (n=450) and 0.1 and 0.25 (0.48) in former workers (n=234).
- Kentner *et al* 1995) reporting data from a cohort of 21 men in a starter battery production plant in Germany; the median (range) urinary Sb concentrations (µg Sb/g cr) reported were 3.9 (2.8 to 5.6) at end-of-shift in 7 men from the casting area, and 15.2 (3.5 to 23.4) in 14 men from the formation area. Airborne Sb levels in the breathing zone (4.5 and 12.4 µg/m<sup>3</sup>) were relatively consistent with the measured urine levels. Note: this study was one of those used to estimate the clearance t<sub>1/2</sub> (time to eliminate half the body burden) for antimony (see Section 3b above).
- dePerio *et al* (2010) reporting data from 24 employees (mainly fire fighters) from stations in North Carolina (group A), compared data with 42 Fire Dept employees (group B) who had worn clothing impregnated with an antimony-containing fire retardant. The range of urinary Sb concentrations (µg Sb/g cr) in both groups were within a claimed national normal range of 0.12 to 0.364, and there were no differences attributable to wearing the Sb-impregnated clothing.

The above papers were the only ones reporting creatinine-adjusted Sb concentrations. The remainder reported urinary Sb in terms of  $\mu$ g/L.

- Liao *et al* (2004) reporting data from 103 workers in Taiwanese plants manufacturing optoelectronic equipment; median duration of employment was 23.3 months; spot morning urine samples were taken at normal health checks and analysed by coupled ICP-MS; mean (SD), and median urinary Sb (µg /L) were reported as 0.80 (0.68) and 0.74; 0.71 (0.76) and 0.4; 0.70 (0.71) and 0.44 across three types of processes. These values were comparable to 0.64 (0.64) and 0.41 in 67 referent non-workers.
- Ludersdorf et al (1987) reporting data from 109 male workers in two glass-producing factories in Germany; the workers were exposed to airborne Sb<sub>2</sub>O<sub>3</sub> (<50 to 840 μg/m<sup>3</sup>); urinary Sb concentrations in spot samples ranged from 0.2 to 15.7 μg /L; the highest levels were in the batch-mixing

area; the worker levels were higher than values obtained from 8 unexposed controls (0.2 to 0.7  $\mu$ g /L).

- Arai *et al* (1994) reporting data from 70 Japanese cloisonné workers (and 62 non-exposed controls); spot urine samples taken during working hours were analysed by flameless AAS; mean (range) urine levels of Sb (μg /L) were reported as: 2.93 (2.56 to 10.26; n=49); 2.72 (2.56 to 5.13; n=16); across two different production areas; which were comparable to 2.56 (5 plant office workers) and 2.71 (2.56 to 5.13) in 62 controls.
- lavacoli *et al* (2002) reporting data from 39 male workers in an Italian textile factory using Sb<sub>2</sub>O<sub>3</sub> as a flame-retardant; the mean (range) Sb levels (μg /L) in spot urine samples were 0.31 (0.1 to 3.7) at beginning-of-shift and 0.36 (0.13 to 1.77) at end-of-shift; these were only slightly higher than 0.1 (<0.3 to 0.24) reported in 15 unexposed controls.</li>

# (iii) Urinary Sb in children

In addition to the NHANES data that included age-specific cohorts, three more papers were identified that specifically addressed biomonitoring of urinary Sb in children:

- Heitland & Koster (2006) reporting on 72 children and 87 adults (non-occupationally exposed) from western and northern Germany; mean (range) of urinary Sb (μg /L) in the children were 0.063 (LOQ to 0.72). When corrected for creatinine (μg Sb/g cr), the geometric mean values (range) were 0.048 (LOQ to 0.103); 0.032 (LOQ to 0.082); and 0.026 (LOQ to 0.39) in three age groups (2-6, 7-11, 12-17), suggesting corrected urinary Sb levels decrease slightly with age. For comparison, the mean (range) of adult values reported in this study were a little higher at 0.063 (LOQ to 0.57) μg /L. 21% of samples were <LOQ for both adults and children.</li>
- Cullen *et al* (1998) reporting on 100 infants in five age groups across the first year of life drawn from hospitals in Dublin and surrounding districts; The mean (SD) urinary Sb concentrations (µg /L) were reported for the five age groups as follows: 0.16 (0.03) 2-6 weeks; 0.16 (0.03) 8-16 weeks; 0.18 (0.04) 20-28 weeks; 0.17 (0.05) 22-41 weeks; 0.18 (0.04) 48-56 weeks, indicating little variability by age in the first year of life. When corrected for creatinine, the mean concentration across the cohort was 0.42 µg Sb/g cr, with an interquartile range of 0.64 and >95% of samples <2.6 µg Sb/g cr.</li>
- Dezatreux *et al* (1997) reporting on urinary levels of antimony and cotinine in 148 infants, as part of a study on infant exposure to tobacco smoke constituents; the mean (range) urinary Sb concentrations (µg /L) were reported for four clinical categories (healthy pre-term n=26; healthy younger-term n=74; healthy older-term n=58; prior wheezing n=43) as follows: 0.28 (0.19 to 0.41); 0.05 (0.04 to

0.07); 0.08 (0.05 to 0.14) and 0.12 (0.06 to 0.24). When corrected for creatinine ( $\mu$ g Sb/g cr), these values became: 2.25 (1.49 to 3.39); 0.48 (0.36 to 0.65); 0.40 (0.25 to 0.65) and 0.68 (0.37 to 1.25). The only remarkably high result in this study was from the healthy pre-term infants. These samples were collected within the first 24 h after birth, as opposed to 8-52 weeks after birth for the other groups, so they may reflect maternal transfer associated with smoking beahviours.

# (b) possible reference values<sup>1</sup> for urine biomonitoring

The largest dataset on urinary antimony concentrations for populations not occupationally exposed is from the NHANES project (NHANES 2013) – see above. This dataset includes age- gender- and ethnic-specific urinary data in both  $\mu$ g /L and creatinine-corrected  $\mu$ g Sb/g cr.

Most other datasets for 'background ' populations are reported in  $\mu$ g/L, although some have creatinine-corrected data as well. The upper levels for these populations generally fall in a range from the LOQ to <1  $\mu$ g /L. When corrected for creatinine contents, the upper limit of the 'normal range is generally <0.5 to 0.6  $\mu$ g Sb/g cr.

Urinary Sb values reported to the Victorian Department of Health from Costerfield and other parts of Victoria are shown in the following Figure and Table. These samples were collected during the period 1 January to 18 June 2014. Since these values have only been reported in nmole Sb/mmole cr, the factor applied to convert µg Sb/g cr to nmole Sb/mmole cr is to multiply them by 0.93.

It is clear that the creatinine-corrected values from Costerfield from 1 to >35 nmole Sb/mmole cr are substantially higher than most reference values in unexposed populations from the literature (generally <1 nmole Sb/mmole cr). They also appear to be comparable to or higher than many values reported for occupationally-exposed workers (see Section 6(a)(ii) of this report). The highest creatinine-corrected urinary values for occupationally-exposed workers were in foundry workers reported by Bailly *et al* 1991, (8 to 110 µg Sb/g cr; or 7.4 to 99 nmole Sb/mmole cr).

However, the urinary data, as reported for 'random' samples from other sites in Victoria are also suspiciously high (<1 to 25 nmole Sb/mmole cr), casting some doubt on the source and possible contamination of the samples. (The RPAH laboratory where the samples were analysed reports that other urine samples sourced elsewhere than the current batch of Victorian samples and analysed in

<sup>&</sup>lt;sup>1</sup> It is unfortunate that most of the literature values for urinary Sb concentrations have been reported in units µg/litre, and few have been corrected in terms of creatinine concentration. Where possible, figures from original sources have been converted to a common unit (nmole Sb/mmole creatinine) to facilitate comparison with urinary concentrations reported in the Costerfield cohort and the broader Victorian community

that laboratory have been uniformly low or negative for Sb). Details of the sites for collection of the samples from Victoria (Costerfield and related regions), as well as the methodology for sample collection and storage, are sketchy and the possibility of Sb contamination from collection/storage in PET bottles or tubes (see Section 6b of this report) needs to be ruled out before any credibility can be given to these apparently high urine concentrations.

#### De-identified Victorian random urinary antimony data, YTD 2014

A total of 137 random urinary antimony tests have been performed by Royal Prince Alfred laboratory, Sydney since 01 January 2014. Of these, 65% (n=89) are from residents living within the Costerfield postcode (3523).



#### Graph 1: Costerfield range, women of child bearing age

#### Table 1: Victoria data, by region for children <15 years, YTD 2014

Age (years)	Random urinary antimony (nmol/mmol cr)			
	Costerfield region	Other Victorian		
1.5 year old		2.6		
2 year old		19.7		
4 year old		8.0		
5 year old	9.7			
8 year old	5.6			
12 year old	3.7			

#### Note: Data collected only over the period 1 January to 18 June 2014

# 7 References

# (a) Source reviews from international agencies

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# Part B Comments on specific questions

i) Are urinary reference ranges health-based or derived from population surveys?

There are no reference ranges that appear to be health-based. Urinary reference ranges are generally derived from surveys on non-exposed or background exposed general populations, with some support from studies on occupationally-exposed workers.

ii) Identify any differences between the validity of test results for 24 hours urinary collection versus random spot urine collection.

Most of the studies reported in Section 6a have used spot urine collection to provide samples. The Gebel (1998a, b) studies were the only ones that reported Sb amounts ( $\mu$ g) in 24h urine collection. Since spot sampling studies were designed to biomonitor exposures, and the urinary clearance of antimony is relatively slow, spot samples are likely to be appropriate to indicate both current and historic exposure patterns. A few of the occupational exposure studies did report on multiple sampling times - e.g. pre- and post-shift, and the Kentner *et al* (1995) study extended sampling out to 100h after the last exposure. One study (Bailly *et al* 1991), in addition to reporting pre- and post-shift occupational exposures, reported multiple blood, urine, bile and gastric juice Sb concentrations out to 160h in a single woman after ingestion (attempted suicide) of an unknown amount of Sb<sub>2</sub>S<sub>3</sub>. The Bailly *et al* 1991 study also proposed a biological limit value of 35  $\mu$ g/g cr as an end-of-shift monitoring tool for occupational exposures.

ii) Is there evidence for an alternate urinary Sb level for sub populations living in areas that are naturally rich in antimony?

i el example	de ether rererende range		
Reference	Evidence supporting this	Study	Health end
range	range	population	points

For example – do other reference ranges exist?

There are certainly some urinary monitoring data from community groups where exposures have been associated with past or current mining/smelting operations (e.g. Gebel 1998a, b). Since the urinary data were reported as  $\mu g$  excreted in 24h, it is difficult to reconcile the figures with other urinary biomonitoring data (either  $\mu g/L$  or  $\mu g$  Sb/g cr). However, the Gebel studies suggested that there was little difference between urinary Sb levels in communities from a geologically-rich region of Germany, compared to another control region.

The soil bioavailability studies of Flynn *et al* (2003) and Gal *et al* (2007), although limited to studies of leaching and/or ecotoxicology, but not mammalian toxicity, suggested that Sb mobility and bioavailability from contaminated soils is extremely limited, so this is unlikely to be a major contributor to absorption in the Costerfield region.

iv) Is there any evidence of modelling or kinetic studies that have used intake to estimate a urinary antimony level? If not, can a urinary Sb threshold, be derived from intake (in the order of TDI) calculations?

While some of the published papers have estimated intakes and compared them with putative health-based guidelines, no studies were identified that calculated a urinary excretion profile based on these intakes. In fact, some papers (Gebel 1998 a, b) noted a poor correlation between soil or airborne antimony concentrations and measured urinary outputs.

Droz (1993) suggested using pharmacokinetic models to predict urinary and blood biomonitoring concentrations for environmental contaminants, and provided the necessary equations. However, no specific example was given for biomonitoring for any metals.

v) What evidence exists to support the correlation of short and long-term health impacts with urinary antimony levels?

Urinary monitoring has been used to assess exposures, mainly in an occupational setting. There have been three attempts to correlate urinary Sb concentrations obtained in the NHANES survey with chronic diseases:

- With thyroid function (Christenesen 2013)
- With peripheral artery disease (Navas-Ancien *et a*l 2005)
- With cardiovascular disease (Agarwal *et a*l 2011)

While some metals suggested an association with altered thyroid function, there was no such association with antimony blood or urine levels. Neither was there a clear association with peripheral artery disease (PAD), although the PAD risk appeared to increase from low levels of urine antimony to peak at 0.1  $\mu$ g /L. (see Fig below from Navas-Ancien *et al* 2005).



Antimony was one of several metals found to have an adjusted odds ratio >1 for association between urine concentrations and cardiovascular/cerebrovascular disease (urinary cadmium had an even stronger association). Where associations with disease were noted, they were generally for multiple metals, and the possibility of confounding or a relationship with a common exposure source or lifestyle risk factor (e.g. smoking) could not be ruled out. Note that in all three studies, blood and/or urine Sb levels were within the expected range for a population exposed only through food, water and ambient air.

The occupational biomonitoring studies were not designed to assess health impacts, and no clear associations were reported, even at the highest levels of exposure.

vi) Assess the relationship of long term implications of low level exposure to antimony through oral and respiratory routes.

Most of the information in the literature on potential adverse health effects of antimony in humans is based on reports of industrial inhalation exposures, accidental/suicidal ingestion or therapeutic use of soluble Sb salts (e.g. tartar emetic – antimony potassium tartrate) as emetics or organoantimonials as anti-leishmanial drugs (Yan *et al* 2005). Ingestion of high doses generally produces gastric irritation and vomiting. Cardiac toxicity (arrhythmias) have been reported in association with poisonings with tartar emetic (Ming-Hsin *et al*, 1958). In a case of accidental poisoning with tarter emetic, a male subject presented with severe vomiting, intestinal cramps, diarrhoea, weakness and othostasis. His measured urinary Sb was 1200 µg /L (Tarabar *et al* 2004).

Adverse effects associated with occupational exposure are mainly in the lung and respiratory tract (inflammation, pneumonitis) and some reports of dermatitis (NTP 2005).

The toxicological database on animal studies is relatively limited. The ATSDR review (ATSDR 1992) of toxicity studies with  $Sb_2S_3$ ,  $Sb_2O_3$  and  $SbH_3$  indicate route-dependent effects on the respiratory passages (inflammation & interstitial fibrosis), heart (myocardial damage) and kidney (tubular dilation), with some evidence of impaired reproductive function. Most of these studies have limitations that restrict their utility for setting health-based exposure guideline values. The IARC monograph (IARC 1989) categorised antimony as 2B - possibly carcinogenic to humans, based mainly on *sufficient* evidence of lung tumours in rats after inhalation exposure to  $Sb_2O_3$  and *limited* evidence with inhaled  $Sb_2S_3$ . There was inadequate evidence for the carcinogenicity of antimony trioxide or antimony trisulfide in human studies.

There are conventional rat oral toxicity studies with various forms of antimony and these provide some insight into potential human toxicity. For example, sub-chronic/chronic toxicity studies with antimony potassium tartrate (including those conducted by the US NTP program) have been reviewed by Lynch et al (1999). The Poon et al (1998) 90-day study with potassium antimony tartrate in rats has been used by most authorities to set health-base drinking water guideline values, although the toxicity revealed was relatively mild (adaptive histological changes in thyroid, liver and pituitary glands of both sexes; spleen in males and thymus in females, along with mild changes in some serum electrolytes, glucose and liver enzymes). The NOAEL was set at 0.5 ppm in drinking water (500,000 ng/L or 60  $\mu$ g/kg/bw/d), with the LOAEL at 5 ppm.

However, since Sb toxicokinetics are different for soluble and insoluble forms and influenced by speciation (see sections 1 & 4), adverse health effects in these studies may have little significance for the exposure routes expected for Costerfield residents.

vii) Assess the literature for the health implications (short and long term) of elevated levels of antimony in the general community including children, pregnant women and foetuses and others to determine who is at the greatest risk from antimony exposure.

There are some references that specifically address antimony toxicokinetics and urinary excretion profiles for children - see Section 6(a)(iii). In the main, these show that children have urinary Sb levels comparable with those found in unexposed adults, but there may be some decline towards these adult levels during the first year of infancy.

Only one paper (Jain 2013) was found that specifically addresses Sb exposures in pregnant women. The paper used regression analyses to report that pregnancy appeared to increase urinary levels of some metals (but not antimony). The actual metal concentrations were not reported in the study, but they were presumably drawn from the larger NHANES database. The study did not address reproductive health implications.

# Appendix A: Brief author biographies

**Professor Brian Priestly** is a Professorial Fellow (now part-time) in the Department of Epidemiology & Preventive Medicine (DEPM) at Monash University and Director of the Australian Centre for Human Health Risk Assessment (ACHHRA). ACHHRA's core objective is to provide a national focus for human health risk assessment in the area of food and environment pollutants, and to contribute to workforce development by mounting training programs in health risk assessment. Brian's primary area of expertise is in toxicology. He was recently recognised as a Fellow (FACTRA) in the peer reviewed register of the Australasian College of Toxicology & Risk Assessment. He has been active on many government technical committees and scientific advisory panels over the past thirty years. He is currently a Science Fellow advising the food (FSANZ), AgVet chemical (APVMA) regulators, as well as being an advisor to the industrial chemical (NICNAS) regulator on toxicological issues, including those relating to the regulation of nanoscale materials.

**Professor Malcolm Sim** is an Occupational and Public Health Physician and epidemiologist who leads a team of 25 research and teaching staff in the Monash Centre for Occupational and Environmental Health (MonCOEH). His main research interests chemical and physical occupational and environmental risk factors for chronic diseases, such as cancer and respiratory disease. He also has interests in exposure assessment, occupational disease surveillance, veteran health research and the health effects of environmental exposures to mobile phones, small particles, arsenic, pesticides and other environmental contaminants. He is a co-investigator on several NHMRC and ARC grants and other national and international collaborative studies. Malcolm is the Editor-in-Chief of Occupational and Environmental Medicine, a specialty journal of the BMJ.

# Appendix B: Terms of reference for the review

1. A description of the toxicokinetics of antimony in all its forms for children and adults.

- 2. A literature review with interpretation;
  - I. Review of the outcomes of bio monitoring studies in populations that were used to determine the current Australian urinary reference ranges.
    - a. Is this a population norm or a health based level?
    - b. Identify any differences between the validity of test results for 24 hours urinary collection versus random spot urine collection.
  - II. Determine whether there is evidence for an alternate urinary Sb level for sub populations living in areas that are naturally rich in antimony?

Tor example de other reference ranges exist.				
Reference	Evidence supporting this	Study	Health end	
range	range	population	points	

For example – do other reference ranges exist?

- a. Any evidence of modelling or kinetic studies that have used intake to estimate a urinary antimony level.
  - i. If not, can a urinary Sb threshold, be derived from intake (in the order of TDI) calculations and if plausible then please calculated for us.
- III. Determine what evidence exists to support the correlation of short and long-term health impacts with urinary antimony levels.
- IV. Assess the relationship of long term implications of low level exposure to antimony through oral and respiratory routes.
- V. Assess the literature for the health implications (short and long term) of elevated levels of antimony in the general community including children, pregnant women and foetuses and others to determine who is at the greatest risk from antimony exposure.

# Appendix C:

# Urinary antimony concentrations in U.S populations from the 2013 NHANES report

#### Urinary Antimony (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

		Geometric Selected percentiles					
	Survey	mean		(95% confide	ence interval)		Sample
	years	(95% conf. interval)	50th	75th	90th	95th	size
Total	99-00	.124 (.108143)	.119 (.102143)	.185 (.164214)	.276 (.233333)	.385 (.333430)	2276
	01-02	.126 (.119134)	.120 (.115126)	.173 (.162188)	.267 (.242300)	.364 (.320414)	2689
	03-04	*	.080 ( <lod086)< td=""><td>.135 (.119143)</td><td>.208 (.192230)</td><td>.277 (.250294)</td><td>2558</td></lod086)<>	.135 (.119143)	.208 (.192230)	.277 (.250294)	2558
	05-06	.072 (.068077)	.070 (.060070)	.100 (.100110)	.160 (.150190)	.230 (.190290)	2576
	07-08	.064 (.060068)	.060 (.060060)	.090 (.080100)	.140 (.140160)	.200 (.170230)	2627
	09-10	.060 (.056064)	.060 (.050060)	.090 (.080090)	.140 (.120160)	.200 (.180230)	2847
Age group							
6 11 years	00-00	101 ( 147, 248)	185 ( 158, 220)	250 ( 200- 417)	AA7 (271-741)	7/1 (333-130)	316
0-11 years	01-02	178 (159, 200)	173 (150-103)	228 ( 200- 272)	338 (285-480)	<b>A71</b> (313, 727)	368
	03-04	<b>116</b> (103-130)	118 (008-138)	167 ( 148- 187)	256 ( 194- 317)	333 (250, 500)	200
	05-04	092 (081-104)	090 (080-110)	130 (110-150)	180 (150-210)	220 (180-270)	255
	07-08	089 (079-100)	090 (070- 100)	120 (110-140)	200 (150-240)	300 (200-370)	304
	09-10	094 (084-106)	090 (080- 100)	140 (120-180)	200 (170-250)	280 ( 220- 320)	378
10.10	00 10	.004 (.001 .100)	.000 (005 .140)	.140 (.120 .100)	.200 (.110 .200)	.200 (.220 .020)	000
12-19 years	99-00	.121 (.104140)	.120 (.095146)	.1/6 (.148207)	.259 (.208310)	.310 (.228421)	663
	01-02	.121 (.112131)	.115 (.100127)	.160 (.138180)	.224 (.199245)	.266 (.244310)	762
	03-04	.075 (.068082)	.068 (.061077)	.100 (.092113)	.156 (.126173)	.193 (.1/2255)	725
	05-06	.070 (.065076)	.070 (.060080)	.100 (.090110)	.140 (.120150)	.1/0 (.150250)	/01
	07-08	.062 (.054070)	.060 (.050070)	.090 (.070100)	.120 (.100160)	.160 (.110240)	3/6
	09-10	.059 (.053066)	.060 (.050060)	.090 (.070100)	.130 (.110170)	.180 (.150220)	451
20 years and older	99-00	.118 (.104135)	.111 (.097135)	.175 (.149209)	.263 (.227320)	.352 (.320391)	1297
	01-02	.122 (.115129)	.115 (.108121)	.167 (.153181)	.265 (.241300)	.364 (.318405)	1559
	03-04	*	.079 ( <lod087)< td=""><td>.135 (.116145)</td><td>.209 (.195233)</td><td>.278 (.250294)</td><td>1543</td></lod087)<>	.135 (.116145)	.209 (.195233)	.278 (.250294)	1543
	05-06	.070 (.066075)	.060 (.060070)	.100 (.090110)	.170 (.150190)	.250 (.190300)	1520
	07-08	.062 (.058066)	.060 (.050060)	.090 (.080100)	.140 (.130160)	.200 (.160240)	1857
	09-10	.057 (.053061)	.050 (.050060)	.080 (.080090)	.130 (.120140)	.190 (.160220)	2018
Gender							
Males	99-00	.112 (.099127)	.109 (.095127)	.164 (.146181)	.226 (.204268)	.320 (.235391)	1132
maico	01-02	.114 (.107123)	.108 (.103115)	.153 (.138171)	.228 (.205250)	.333 (.281438)	1334
	03-04	.080 (.076084)	.075 (.069081)	.122 (.111132)	.192 (.173209)	.253 (.230278)	1281
	05-06	.070 (.064077)	.060 (.060070)	.100 (.090120)	.160 (.130220)	.250 (.170310)	1271
	07-08	.061 (.057066)	.060 (.050060)	.090 (.080100)	.140 (.130160)	.210 (.160260)	1327
	09-10	.055 (.050060)	.050 (.050060)	.080 (.070100)	.130 (.120150)	.190 (.160210)	1397
Females	00.00	137 ( 117, 181)	131 ( 108- 184)	213 (178-247)	320 ( 283, 417)	A20 (357-495)	1144
remales	01-02	130 (131, 149)	132 (124-140)	106 (178-211)	205 (287-317)	371 (333-444)	1355
	02.04	*	<10D	1/3 (125-181)	225 (188, 281)	300 ( 250, 222)	1333
	05-04	074 (070-079)	070 (070-070)	140 (100-110)	170 (150-190)	2200 (.200333)	12//
	07-08	067 (082,074)	060 (080-070)	100 ( 000- 100)	1/0 (130-180)	200 (180-220)	1200
	00.10	.001 (.0020/1)	060 (080, 070)	.100 (.080100)	150 (130-170)	200 (.100230)	1450
	09-10	.004 (.000009)	.000 (.000070)	.030 (.080100)	100 (.130170)	.220 (.100200)	1400

< LOD means less than the limit of detection for the urine levels not corrected for creatinine. \* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

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Biomonitoring Summary: http://www.cdc.gov/biomonitoring/Antimonv\_BiomonitoringSummary.html

#### Urinary Antimony (creatinine corrected)

Geometric mean and selected percentiles of urine concentrations (in µg/g of creatinine) for the U.S. population from the National Health and Nutrition Examination Survey.

		Geometric		Selected p	ercentiles		
	Survey mean		( 95% confidence interval)				Sample
	years	(95% conf. interval)	50th	75th	90th	95th	size
Race/ethnicity							
Mexican Americans	99-00	.120 (.107135)	.114 (.105129)	.167 (.148203)	.250 (.209315)	.333 (.280357)	787
	01-02	.138 (.128149)	.130 (.117143)	.182 (.159203)	.269 (.229308)	.338 (.308429)	682
	03-04	.086 (.076098)	.082 ( <lod092)< th=""><th>.129 (.107151)</th><th>.189 (.154238)</th><th>.238 (.185321)</th><th>618</th></lod092)<>	.129 (.107151)	.189 (.154238)	.238 (.185321)	618
	05-06	.087 (.076099)	.080 (.070080)	.120 (.110130)	.190 (.150310)	.370 (.200800)	652
	07-08	.069 (.059081)	.060 (.050080)	.100 (.080120)	.160 (.130180)	.200 (.160360)	515
	09-10	.066 (.063071)	.060 (.060060)	.100 (.080110)	.160 (.130190)	.240 (.190280)	613
Non-Hispanic blacks	99-00	.114 (.099133)	.112 (.098130)	.163 (.144183)	.236 (.195338)	.343 (.255425)	554
	01-02	.123 (.113134)	.115 (.108127)	.163 (.150181)	.233 (.208267)	.300 (.248373)	667
	03-04	.078 (.071085)	.074 (.069082)	.109 (.096124)	.170 (.148192)	.222 (.179257)	723
	05-06	.064 (.058071)	.060 (.050070)	.090 (.080090)	.130 (.120150)	.190 (.150220)	692
	07-08	.062 (.059066)	.060 (.050070)	.090 (.080090)	.140 (.120160)	.180 (.160220)	589
	09-10	.058 (.053063)	.060 (.050060)	.080 (.070090)	.130 (.110160)	.170 (.150190)	544
Non-Hispanic whites	99-00	.129 (.109152)	.125 (.102152)	.195 (.167225)	.298 (.239352)	.400 (.333444)	768
	01-02	.127 (.117138)	.120 (.113130)	.176 (.159198)	.280 (.241317)	.380 (.318471)	1132
	03-04	*	.081 ( <lod089)< th=""><th>.139 (.124147)</th><th>.217 (.200238)</th><th>.286 (.253333)</th><th>1074</th></lod089)<>	.139 (.124147)	.217 (.200238)	.286 (.253333)	1074
	05-06	.072 (.068077)	.070 (.060070)	.110 (.100110)	.170 (.150190)	.230 (.190280)	1041
	07-08	.064 (.060069)	.060 (.050070)	.090 (.080100)	.140 (.140160)	.210 (.170230)	1095
	09-10	.060 (.055065)	.060 (.050060)	.090 (.080100)	.140 (.120170)	.200 (.170250)	1225

< LOD means less than the limit of detection for the urine levels not corrected for creatinine. \* Not calculated: proportion of results below limit of detection was too high to provide a valid result.

Biomonitoring Summary: http://www.cdc.gov/biomonitoring/Antimony\_BiomonitoringSummary.html

# Glossary of acronyms

AEF APVMA ARC ATSDR BMJ cr EPA et al	Australian Exposure Factor Australian Pesticides & Veterinary Medicines Authority Australian Research Council Agency for Toxic substances and Disease Registry (US) British Medical Journal creatinine Environmental Protection Agency (US) indicator of multiple authors
FACTRA	Fellow, Australasian College of Toxicology & Risk Assessment
FSANZ GSH IARC	Food Standards Australia & New Zealand glutathione (a tripeptide involved in chemical detoxification) International Agency for Research on Cancer
ICP-MS	Inductively coupled plasma mass spectrometry
IRIS	Integrated Risk Information Service (US)
LOAEL	
mg/µg MonCOEH	Monash Centre for Occupational & Environmental Health
	National Health & Medical Research Council
NICNAS	National Industrial Chemicals Notification & Assessment Scheme
NOAEL	No Observable Adverse Effects Level
NTP	National Toxicology Program (US)
PAD	Peripheral Artery Disease
PET	Polyethylene Terephthalate
RPAH	Royal Prince Alfred Hospital (Sydney)
Sb (III & V)	Antimony (representing its 3 <sup>rd</sup> and 5 <sup>th</sup> valence states)
TDI	Tolerable Daily Intake
ISCA	Toxic Substance Control Act (US)
	United Kingdom
	World Health Organization
ULIN	