

Contamination of houses by workers occupationally exposed in a lead-zinc-copper mine and impact on blood lead concentrations in the families

Massimo Chiaradia, Brian L Gulson, Kerrie MacDonald

Abstract

Objective—To evaluate the pathway of leaded dust from a lead-zinc-copper mine to houses of employees, and the impact on blood lead concentrations (PbB) of children.

Methods—High precision lead isotope and lead concentration data were obtained on venous blood and environmental samples (vacuum cleaner dust, interior dustfall accumulation, water, paint) for eight children of six employees (and the employees) from a lead-zinc-copper mine. These data were compared with results for 11 children from occupationally unexposed control families living in the same city.

Results—The median (range) concentrations of lead in vacuum cleaner dust was 470 (21–1300) ppm. In the houses of the mine employees, vacuum cleaner dust contained varying higher proportions of mine lead than did airborne particulate matter measured as dustfall accumulated over a three month period. The median (range) concentrations of lead in soil were 30 (5–407) ppm and these showed no evidence of any mine lead. Lead in blood of the mine employees varied from 7 to 25 µg/dl and was generally dominated by mine lead (> 60%). The mean (SD) PbB in the children of the mine employees was 5.7 (1.7) µg/dl compared with 4.1 (1.4) µg/dl for the control children ($P = 0.02$). The PbB of all children was always < 10 µg/dl, the Australian National Health and Medical Research Council goal for all Australians. Some of the control children had higher PbB than the children of mine employees, probably from exposure to leaded paint as six of the eight houses of the control children were > 50 years old. In five of the eight children of mine employees > 20% of PbB was from the lead mine. However, in the other three cases of children of mine employees, their PbB was from sources other than mine lead (paint, petrol, background sources).

Conclusions—Houses of employees from a lead mine can be contaminated by mine lead even if they are not situated in the same place as the mine. Delineation of the mine to house pathway indicates that lead is probably transported into the houses on the clothes, shoes, hair, skin, and in some cases, motor vehicles of the workers. In one case, dust shaken from clothes of a mine employee contained 3000 ppm lead which was 100% mine lead. The variable

contamination of the houses was not expected given the precautions taken by mine employees to minimise transportation of lead into their houses. Although five out of the eight children of mine employees had > 20% mine lead in their blood, in no case did the PbB of a child exceed the Australian National Health and Medical Research Council goal of 10 µg/dl. In fact, some children in the control families had higher PbB than children of mine employees. In two cases, this was attributed to a pica habit for paint. The PbB in the children of mine employees and controls was independent of the source of lead. The low PbB in the children of mine employees may reflect the relatively low solubility (bioavailability) of the mine dust in 0.1 M hydrochloric acid (< 40%), behaviour—for example, limited mouthing activity—or diet.

(*Occup Environ Med* 1997;54:117–124)

Keywords: lead; mine; blood; adults; children

Toxic materials, such as lead, taken home from a parent's place of work is a primary pathway which can result in contamination of the household and possibly increased blood lead concentration (PbB) in children.¹⁻¹⁰ In the current study, mine employees lived in a rural town of 23 000 inhabitants located about 40 km from the (Woodlawn) mine.

The Woodlawn mine was discovered in the late 1960s and its main ore minerals are pyrite (FeS₂), sphalerite (ZnS), galena (PbS), and chalcopyrite (CuFeS₂). In the year ending June 1995, 0.59 million tonnes of ore were mined that contained on average 1.5% Cu, 3.7% Pb, and 10.9% Zn.¹¹ The ore was originally dug from an open pit but is now mined underground. Dust containing lead is generated during all the operations of ore extraction both in the open pit and underground. The ore is pre-treated in situ (grinding and concentration) and this generates additional amounts of fine grained dust containing lead as well as the fine material in the tailings dam, the residue after removal of the bulk of the sulphides.

Previous attempts to establish sources and pathways of lead in blood used indirect means of correlations between PbB and environmental variables. A more direct evaluation can be made with high precision lead isotope measurements such as those carried out in the Broken Hill lead mining community^{12 13} where the main

CSIRO/dEM, PO Box
136, North Ryde, NSW
2113, Australia
M Chiaradia
B L Gulson

Graduate School of
Environment,
Macquarie University,
Sydney 2109, Australia
B L Gulson

Goulburn Base
Hospital, Goulburn,
2580 NSW, Australia
K MacDonald

Correspondence to:
Professor B L Gulson,
Graduate School of
Environment, Macquarie
University, Sydney 2109,
Australia.

Accepted 11 September 1996

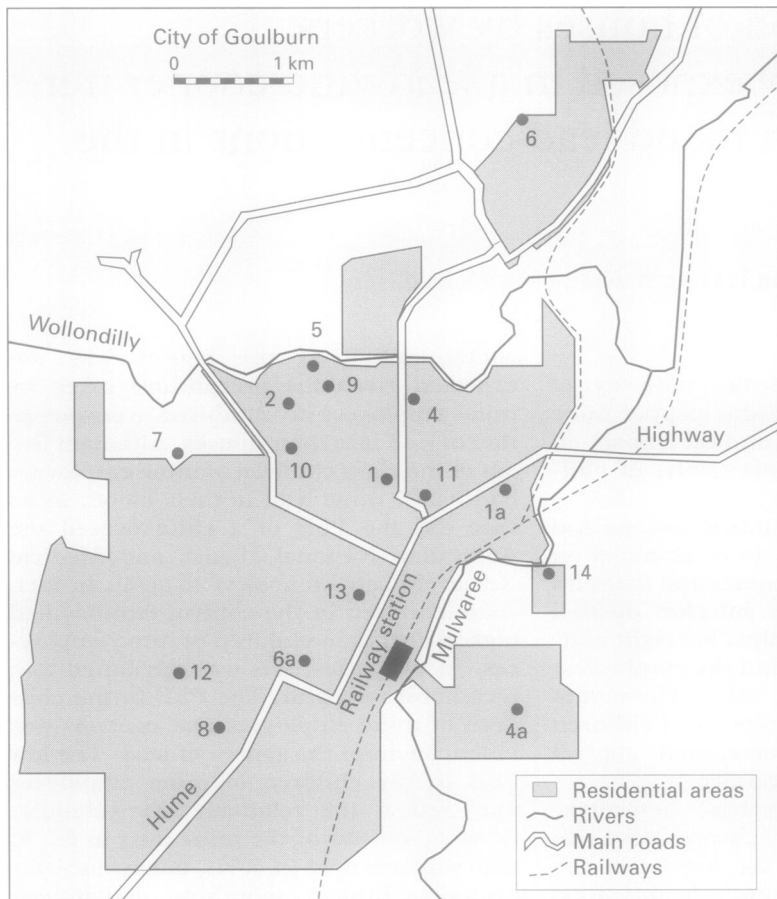


Figure 1 Map of study area (Goulburn, New South Wales, Australia) and the investigated houses. House 3 is located in a rural area about 10 km from the centre of town.

potential source of lead, the ore body, is more obvious.

All the workers in this study insisted that they took every precaution to limit the amount of lead brought home—such as showering at the mine, wearing street clothes before and after work, taking work clothes to a commercial laundry or to their home in a sealed plastic bag, and in some cases, going to work by company bus. The aims of this study were to find whether contamination of the houses was still possible under these apparently stringent condi-

tions, and if present, whether the contamination influenced the blood lead concentrations of the individual family members, especially children.

Methods

SUBJECTS AND EXPOSURE

The study was conducted on two main groups. The first was the mine group, which comprised six employees from the mine and their families. The employees were from the mill and workshop areas and also underground workers. Their houses were built after 1970, the approximate time at which lead was removed from domestic paint in Australia. One of the mine families (family 1) moved soon after the beginning of our study from a newer to an older house with lead paint.

The second group comprised eight families who had no contact with the mine or its employees. This group was the control or background group, even though six families lived in old houses with lead paint. One child from family 4 was monitored because of the concern over her pica habit (putting fingers and objects in the mouth) for paint. The family moved three months before the beginning of our study, from one old house with lead paint to another old house with lead paint.

SAMPLING

Figure 1 shows the location of the sampled houses and table 1 shows personal details. For the mine families, venous blood samples from all family members, when possible, and environmental samples were collected and analysed. For four control families, vacuum cleaner dusts and blood samples from the children were collected and analysed. Only blood samples were analysed from the other four control families.

In the cases in which families changed houses during the course of this study, environmental samples were collected from both dwellings (families 1, 4, and 6).

Sampling was carried out with previously established protocols.^{12,13}

Table 1 Summary of environmental and personal information about the investigated houses and families

Family	House age and condition	Family members n	Father's occupation	Children analysed			
				Child 1		Child 2	
				sex	age (y)	sex	age (y)
Mine group:							
1	Old: exterior Pb paint	5	Mill	M	5	Fe deficient	
1a	25 y						
2	New	5	Underground miner	F	4	Goitre	
3	< 2 y	4	Maintenance	F	4	M	2
5	20 y	4	Mill	M	5	F	Asthmatic
6	15 y	3	Fitter	F	2		
6a	20 y	3					
7	< 3 y	4	Electrician	F	4		
Control group:							
8	Old: interior Pb paint	5	Manager	M	4	M	2-5
9	New	4	Baker	M	5-5	M	2
10	New	4	Electrician	M	0-8	M	1-8
11	Old: interior Pb paint	3	Teacher	M	4		
12	Old	4a	Minister	M	3		
13	> 100 y	5a	Manual labourer				
14	Old	5	Educator	M	5	M	3
Paint eater:							
4	90 y: interior Pb paint	6	—	F	2		
4a	100 y: interior Pb paint	6	—				

1a, 4a, 6a denote current residence; 1, 4, 6 denote previous residence.

Soils

Soils were sampled with a hand corer and samples were placed into separate clean plastic tubes. Random sampling of the topmost 3 cm was performed from different parts of the house yards, with special emphasis on where children spent most of their time.

Vacuum cleaner dusts

Vacuum cleaner dusts were initially collected from the owners' vacuum cleaner into a clean plastic bag. Because of concern about contamination due to previous vacuuming especially as some owners vacuumed their vehicles which had occasionally, or frequently, been driven to the mine, samples were also collected with a different vacuum cleaner with new disposable bags. Bags were changed after every sampling and the vacuum cleaner was cleaned after each use.

Petri dishes

To obtain additional information on interior dust, the dust fall accumulation or lead loading was measured with the petri dish approach.¹⁴ Two precleaned polycarbonate petri dishes (85 mm diameter) were placed in separate rooms in each house. The location and the height of the petri dishes were registered. The dishes were left in place for periods ranging from three to 7.5 months.

Paint

Paint flakes were collected with a scraper and placed into clean plastic bags; the presence of lead was identified by a chemical spot test.

Water

Water was collected directly from the tap, after running it for 30 s, into a 125 ml precleaned polyethylene bottle. In the case of family 5, the water was collected from a bench top water filtering system.

Blood

Blood samples were collected by a trained paediatrician (KMacD) at the Goulburn Base Hospital in the presence of the parents. An anaesthetic cream (EMLA cream 5%) was applied to the child's arm one hour before taking the blood. Analysis of the cream showed it to have about 1 ppb Pb and a $^{206}\text{Pb}/^{204}\text{Pb}$ ratio of about 16.27. The cream was washed off the arm with soap and then the arm was washed with clean water. A 2–3 ml blood sample was placed into a precleaned, preweighed teflon vessel without anticoagulant. Random samples of needles and syringes had been previously tested and found to contain negligible amounts of lead.

Approval for blood sampling was obtained from the parents.

ANALYTICAL TECHNIQUES

Soils and vacuum cleaner dust

The whole sample was sieved through nylon sieves into three separate fractions: $> 250 \mu\text{m}$, $250 \geq 75 \mu\text{m}$, and $< 75 \mu\text{m}$. The $< 75 \mu\text{m}$ fraction was used for the analysis. In two cases, the $250 \geq 75 \mu\text{m}$ was analysed as a

control. Before the digestion of 30–60 mg sample in a 1:1 mixture of ultrapure 7 M HCl and 7 M HNO₃ for two hours, a 46% pure ^{202}Pb solution (spike) of known isotopic composition and lead concentration was added to the unknown sample to enable the lead concentration to be measured at the same time as the isotopic composition. Lead was separated by anion exchange chromatography in the form of a bromide and then further purified by anodic electrodeposition.¹⁵

Petri dish dust

Except for two families, the petri dish dusts from the two rooms were combined after acid extraction. The petri dish and lid were covered by a thin film of 7 M HNO₃ for about 15 minutes. The solution was transferred into a teflon beaker, ^{202}Pb spike was added and evaporated to dryness. Lead was separated by anion exchange chromatography in the form of a bromide.

Water

About 50 ml water with a ^{202}Pb spike was evaporated under a clean nitrogen flow and lead in the form of a bromide was separated by anion exchange chromatography.

Blood

About 2 g blood sample with a ^{202}Pb spike was digested in 16 M HNO₃ on a hot plate in a sealed teflon beaker. After digestion, the sample was evaporated under a clean nitrogen flow and lead in the form of a bromide was separated by anion exchange chromatography.

The purified lead was loaded onto a single rhenium-filament with the well established silica gel technique and analysed for lead isotopic compositions and lead concentrations on a solid source thermal ionisation mass spectrometer (VG ISOMASS 54E) run in fully automatic mode. Isotopic ratios measured were $^{208}\text{Pb}/^{206}\text{Pb}$, $^{207}\text{Pb}/^{206}\text{Pb}$, and $^{206}\text{Pb}/^{204}\text{Pb}$. Data have been normalised to the accepted values of the international standard National Bureau of Standards SRM 981, by applying a correction factor of +0.08% per unit mass. Precision estimates, based on over 1800 analyses of international standards and replicate analyses of natural samples are 0.1% (2σ) for the $^{206}\text{Pb}/^{204}\text{Pb}$ ratio and 0.05% for the $^{208}\text{Pb}/^{206}\text{Pb}$ and $^{207}\text{Pb}/^{206}\text{Pb}$ ratios.

Total blank contamination was around 100 pg for blood and water samples and 800 pg for soil and dust samples. As the blanks contributed a negligible amount to the lead in the sample, no blank corrections to the data have been made.

LEAD ISOTOPE METHOD

The lead isotope technique makes use of the four isotopes of lead. Three are the stable end products of radioactive decay of uranium and thorium: ^{238}U to ^{206}Pb , ^{235}U to ^{207}Pb , and ^{232}Th to ^{208}Pb . The fourth, ^{204}Pb , is not a product of radioactive decay and its abundance has been essentially constant since the earth formed. This isotope is commonly used as a reference isotope. Because three isotopes of lead are pro-

Table 2 Summary of the proportions of lead from different sources in the environmental samples

Family	Soil (back yard)		Soil (front yard)		Vacuum cleaner dust		Petri dish dust		Water Pb (ppb)
	Pb (ppm)	%	Pb (ppm)	%	Pb (ppm)	%	Pb load $\mu\text{g}/\text{m}^2/\text{dl}$	%	
Mine group:									
1	404		407	53 petrol	955		28	91 mine	1
1a	113	50 petrol			21	100 mine			1.15
2	56	46 petrol	61	46 petrol	36	62 mine			0.77
					474	43 mine			
3	5	100 bkg			630	83 mine	4	70 mine	0.3
	7	100 bkg			680	74 mine			
	7	100 bkg			940	91 mine			
					1300	87 mine			
5	18	18 petrol			1300	94 mine	7.3 (TV)	47 mine	1.6
								36 petrol	
								17 soil	
							1.5 (br)	78 mine	
								14 petrol	
								8 soil	
6	10	100 bkg			190	48 petrol	0.3	42 mine	0.63
	18	25 petrol							
6a			18	25	220	76 petrol			0.50
7			30	100 bkg	370	88 mine	1.3	88	0.82
Paint eater:									
4	31	45	170	45	82	70 petrol			1.2
					137	70 petrol			
4a					640	70 petrol			

bkg = Background; TV = TV room; br = bedroom; 1a, 4a, 6a denote current residence; 1, 4, 6 denote previous residence.

duced by radioactive decay, their amounts (abundances) have changed over geological time according to radioactive decay laws and this is reflected in the geological source (age) of the lead. The abundances are usually expressed as ratios so that lead from the geologically old (about 1700 million years old) lead-zinc-silver deposit of Broken Hill in New South Wales (Australia) has an abundance ratio of $^{206}\text{Pb}/^{204}\text{Pb}$ of 16.0 whereas the same ratio is 18.1–18.3 for geologically younger deposits (500–400 million years old) on the same continent.¹⁵ These isotopic differences are used to evaluate the source of lead in the environment, humans, and animals. Interpretations of lead isotopic data may not be straightforward because lead in the environment or animals may be a mixture of lead from different sources (mines). Hence, lead that is introduced to the body from soil, dust, air, food, or water is largely dependent on the source of lead present in the environment, which in turn is dependent on the age and isotopic composition of the rocks and ores from which the lead in the environment is derived.

In assessing the proportion of PbB from a lead source such as the Woodlawn mine with the lead isotope fingerprint method, knowledge of the background isotopic ratio in blood of the non-exposed population is required. Assuming that the background isotopic composition for exposed people would be the same as that for non-exposed people, any isotopic shift registered from this background value towards the isotopic composition of the suspected source can be used to measure the contribution of that source to the PbB of a person. Isotopic shifts in the opposite direction indicate the existence of a different source.

In estimating contributions to PbB from the lead in the mine, the dietary contribution is assumed to be negligible, being incorporated into the background control blood values.

Diagrammatic presentation of the isotopic data is usually as a plot of one isotope ratio versus another—for example, $^{208}\text{Pb}/^{206}\text{Pb}$ v $^{207}\text{Pb}/^{206}\text{Pb}$ —or as an isotope ratio versus 1/Pb concentration.

If only two sources are the contributors to the lead burden of a particular sample (two component mixing), the isotopic data will lie on a linear trend between the two end members on an isotopic plot of—for example, $^{208}\text{Pb}/^{206}\text{Pb}$ v $^{207}\text{Pb}/^{206}\text{Pb}$.¹⁶ For three contributing sources with different isotopic ratios, the isotopic data for the sample are constrained to lie within a triangle on the same type of plot. In the case of an isotope ratio versus 1/Pb plot, two component mixing shows well defined linear trends.¹⁶ Usually the number of sources is limited to two or three on the basis of environmental observations.

Results

Table 1 shows personal plus environmental information for the subjects. Table 2 shows a summary of the data obtained on the environmental samples of each family and the contributions from the different sources resulting from our calculations. Figures 2–6 show representative isotopic plots (detailed data on iso-

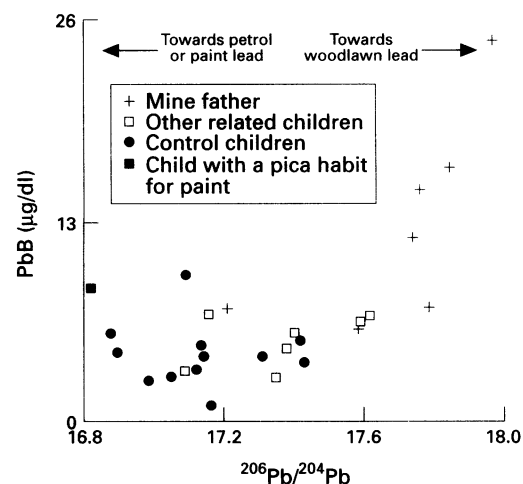


Figure 2 $^{206}\text{Pb}/^{204}\text{Pb}$ v PbB for all the blood samples analysed. The blood samples from background group lie at the lowest PbBs and at $^{206}\text{Pb}/^{204}\text{Pb}$ ratios in the range 16.8–17.4.

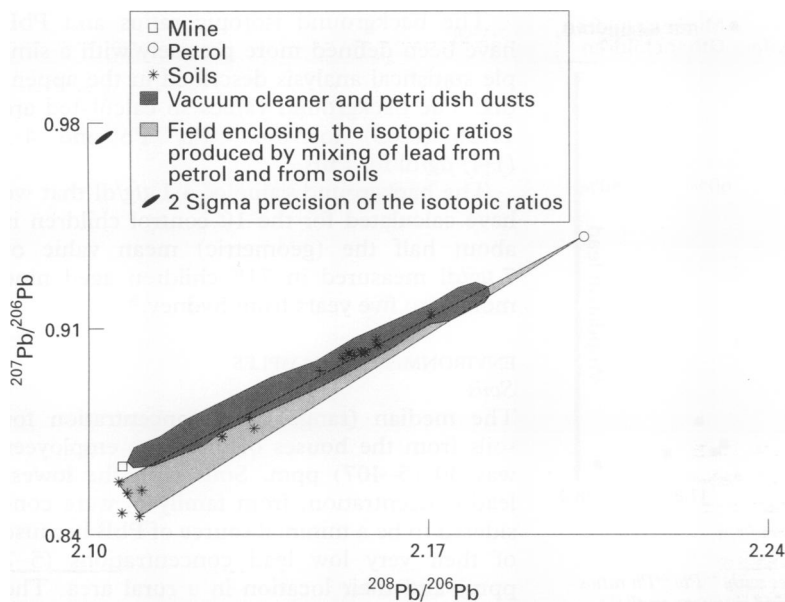


Figure 3 $^{208}\text{Pb}/^{206}\text{Pb}$ v $^{207}\text{Pb}/^{206}\text{Pb}$ for soils, vacuum cleaner dusts, and petri dish dusts showing that in both cases household dusts are aligned between petrol lead and mine lead. Lead in these soils is a mixture of natural lead and petrol lead.

topes and concentrations may be obtained from the corresponding author).

POTENTIAL SOURCES OF LEAD

As there is no lead industry in the town, the potential main sources of lead are from soils, petrol, and the mine possibly brought into the house by the mine employees, paint, and diet (including water).

Soils

Naturally occurring concentrations of lead in soils are a potential source in a rural town like that under consideration. Lead concentrations and isotopic compositions can be estimated from analyses in this study and from data on rocks published by Gulson.¹⁷ There is a fairly consistent cluster of isotopic data for soils sampled away from the centre of the town with a low ratio of $^{208}\text{Pb}/^{206}\text{Pb}$ (about 2.11) and variable $^{207}\text{Pb}/^{206}\text{Pb}$ ratios (0.8457–0.8583).

Mine

Lead from the mine can be transported to the houses on clothes or vehicles or both. The isotopic compositions of the ores and rocks from the mine are well documented.¹⁸

Petrol

Petrol sold in the study area is supplied by Sydney refineries. The isotopic composition of petrol lead has been calculated from the average of 40 petrol samples collected from the Sydney metropolitan area at intervals covering the time of this study.

Paint

Lead paint was found in three houses and analysed for isotopic composition and lead concentration. The isotopic compositions of the paints analysed were similar and indicate that they were derived from a geologically old source such as from the Broken Hill mines ($^{206}\text{Pb}/^{204}\text{Pb}$ about 16.0). Paints from the con-

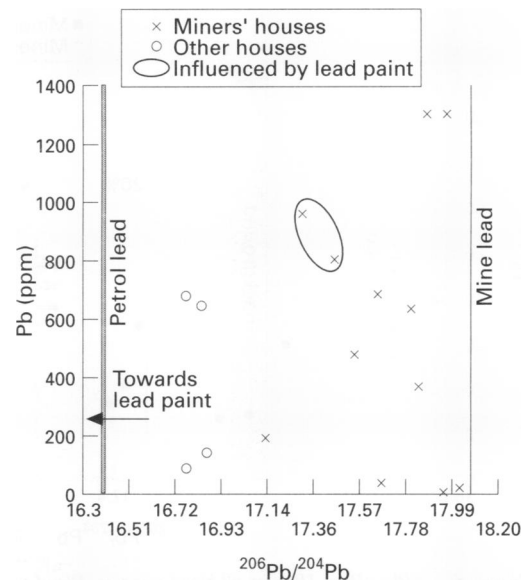


Figure 4 $^{206}\text{Pb}/^{204}\text{Pb}$ v Pb (ppm) for vacuum dusts showing a general increase of lead concentration with increasing isotopic ratio—that is, approaching the mine lead composition. Lead paint influenced field refers to the houses in which the children are either known or thought to have a pica habit for paint. The isotopic composition for petrol and paint are denoted by vertical bars representing the limited isotopic variations in these sources.

trol houses have not been analysed and may have more complex isotopic compositions than found in Sydney houses.¹⁹

Diet

No dietary analyses were undertaken in this study. However, previous studies with quarterly market basket surveys from three major Australian cities¹³ and ongoing quarterly six-day duplicate diet surveys in Sydney and Brisbane involving 54 samples (unpublished data) showed that the mean Pb concentration was 5.4 (2.5) $\mu\text{g}/\text{kg}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ was 17.4 (0.25) (range 16.9 to 18.0). Lead in water is usually a mixture of natural lead leached from the rocks and sediments with which it has been in contact and lead from the plumbing system. The plumbing contribution is usually overwhelmingly dominant compared with the natural contribution. The lead used in Australian plumbing systems is usually derived mainly from the Broken Hill mines with some lead from other geologically younger sources.

SOLUBILITY OF MINE DUST

To obtain an estimate of the solubility of the mine dust, if ingested for example by a child, two samples of particles sized 100 μm from the workshop area were subjected to leaching by 0.1 M HCl at 38°C for two hours.

ESTIMATION OF BACKGROUND VALUES OF CONTROL BLOOD

As mentioned earlier, with the lead isotope fingerprint method, assessing the proportion of PbB from a lead source such as the Woodlawn mine requires knowledge of the background isotopic ratio in blood of the non-exposed population. We have analysed blood from 10 children from control families, living in old and new houses. The blood samples of the

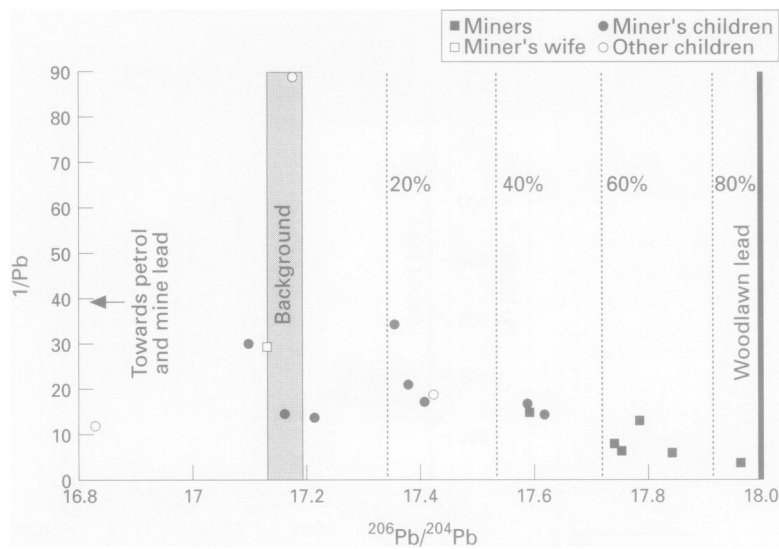
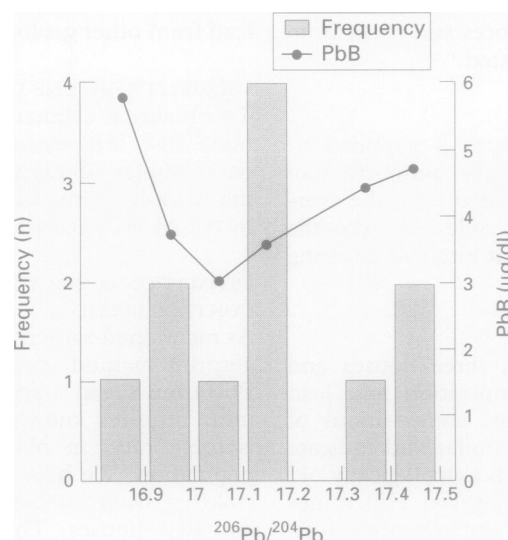


Figure 5 $^{206}\text{Pb}/^{204}\text{Pb}$ v $1/\text{Pb}$ for all blood samples. Blood samples with $^{206}\text{Pb}/^{204}\text{Pb}$ ratios higher than the background form a straight line with $R = 0.92$ and intercept on the isotopic ratio axis at 18.06, the same as the mine lead. This indicates that samples on this line are the result of two sources mixing—namely, mine lead and background lead.

three year old child from family 14 and child 1 from family 4 have been excluded from the following calculations due to their high PbB, which possibly arises from exposure to lead in paint, as they both had a pica habit for paint. The blood of the mother of family 6 was incorporated into the background group. The validity of the control subjects as having background isotopic compositions of PbB for the population is proposed because their mean (SD) PbB (4.1 (1.3) $\mu\text{g}/\text{dl}$) is lower than any single value of other samples belonging to non-background families, and their isotopic compositions fall between those of the two main potential lead sources of this community (petrol and paint as one source and Woodlawn mine as the other). However, the isotopic compositions of the background subjects still showed a wide range of values in $^{206}\text{Pb}/^{204}\text{Pb}$ (16.88 – 17.43). The variability in isotopic ratios is probably related to diet as this is a significant contributor to PbB at concentrations of $< 5 \mu\text{g}/\text{dl}$.

Figure 6 Histogram showing the frequency distribution of the isotopic compositions of blood samples of the background group into 0.1 intervals of the $^{206}\text{Pb}/^{204}\text{Pb}$ ratio. The distribution shows a peak corresponding to the 17.1–17.2 with frequency decreasing on both sides of it, approximating to a gaussian distribution. Mean PbB of the samples are also reported. The 17.1–17.2 ratio has the second lowest PbB and is the one that more closely approximates to the requirements of a background population.



The background isotopic ratios and PbB have been defined more precisely with a simple statistical analysis described in the appendix. The background values so calculated are 17.16 (0.03) for the $^{206}\text{Pb}/^{204}\text{Pb}$ and 4.1 (1.4) $\mu\text{g}/\text{dl}$ for PbB.

The background value of $4.1 \mu\text{g}/\text{dl}$ that we have calculated for the 10 control children is about half the (geometric) mean value of $7 \mu\text{g}/\text{dl}$ measured in 718 children aged nine months to five years from Sydney.²⁰

ENVIRONMENTAL SAMPLES

Soils

The median (range) lead concentration for soils from the houses of the mine employees was 30 (5 – 407) ppm. Soils with the lowest lead concentration, from family 3, were considered to be a minimal source of PbB because of their very low lead concentrations (5 – 7 ppm) and their location in a rural area. The data for soil samples were aligned between petrol lead and natural soil lead (fig 3) indicating a contribution from both sources. This hypothesis that two components were mixed is supported by the good correlation of $R = 0.92$ for the soil data on a plot of $^{206}\text{Pb}/^{204}\text{Pb}$ v $1/\text{Pb}$ plot (not shown).

However, in houses with exterior or interior lead paint (back yard soil of family 1 (second house) and front yard soil of family 4), the presence of particles of lead paint in the soils around the houses was suspected on the basis of isotopic ratios and lead concentrations. Rare paint flakes were confirmed by microscopical inspection of the samples.

There was no evidence in the isotopic composition of the town soils to indicate any long distance airborne transport of leaded dust from the mine, or leaded dust inadvertently deposited on to soils by employees from their clothes and vehicles.

Vacuum cleaner dusts

Figure 4 shows that the vacuum cleaner dusts from the houses of mine employees had a median (range) lead concentration of 470 (21 – 1300) ppm. Isotopic ratios of these vacuum cleaner dusts showed that from 40% to 100% are mine lead (table 2). The results for vacuum dusts collected with the homeowners' own cleaners showed higher contributions of mine lead, especially in the cases where the owners had vacuumed their vehicles, which were often driven to the mine (family 5).

The isotopic ratios of $^{208}\text{Pb}/^{206}\text{Pb}$ v $^{207}\text{Pb}/^{206}\text{Pb}$ for the vacuum cleaner dusts were aligned between petrol lead and mine lead (fig 3). There seems to be little or no lead from the soils to the vacuum cleaner dust. The relatively high lead concentrations and low $^{206}\text{Pb}/^{204}\text{Pb}$ ratios in the vacuum cleaner dust of family 1 (a mine family) could be related to fragments of lead paint; $^{206}\text{Pb}/^{204}\text{Pb}$ ratios in the analysed paints ranged from 16.02 to 16.49 .

Vacuum cleaner dust from the control families had similar isotopic compositions with the overwhelmingly dominant contribution from petrol or lead paint (fig 4).

Petri dish dusts

Only petri dish dusts from the houses of the mine employees were measured. Isotopic data for the petri dish dusts were also aligned between petrol lead and mine lead (fig 3). The lead loading (or lead flux) in the petri dish dusts was variable ranging from very low values of $9 \mu\text{g}/\text{m}^2/30$ days, up to $849 \mu\text{g}/\text{m}^2/30$ days. These values compare with mean values of $86 (56) \mu\text{g}/\text{m}^2/30$ days ($n = 164$) measured in urban environments such as Sydney and Brisbane (unpublished data).

Between 40% and 90% of lead in the petri dish dusts was from the mine (table 2). However, the petri dish dusts showed a preferential accumulation of petrol lead compared with the vacuum cleaner dusts from the same houses indicated by the higher $^{208}\text{Pb}/^{206}\text{Pb}$ ratios in the petri dish dusts. The larger petrol contribution in the petri dish dusts is possibly related to the finer grain size and lower density of the petrol lead compounds compared with galena from the mine.

The dust shaken from the clothing of one workshop employee had an isotopic composition characteristic of the mine lead and a lead concentration of 3000 ppm.

Solubility of mine dust

Two samples of particles of dust sized $100 \mu\text{m}$ from the workshop contained 2.36% and 1.10% Pb. The lead soluble in 0.1 M HCl was about 40% and 30%, respectively, and was relatively low compared with that measured in dusts from Broken Hill and from urban areas.²¹

Waters

All the water samples had very low concentrations of lead, about 1 ppb and isotopic ratios which indicated an uptake of lead mainly from the householders plumbing systems. These lead concentrations would be a negligible contribution to PbB.

Discussion

BLOOD SAMPLES

Blood samples in children

The mean PbB for the 10 control children of $4.1 (1.3) \mu\text{g}/\text{dl}$ was significantly different from the mean PbB of $5.9 (1.8) \mu\text{g}/\text{dl}$ ($P = 0.02$) for the children of mine employees. None of the children in this study had concentrations of PbB $> 10 \mu\text{g}/\text{dl}$, the Australian National Health and Medical Research Council goal for all Australians.²²

For five of the eight children of mine employees, between 21% and 50% of PbB was

from mine lead (fig 5, table 3). In this group of five children, the highest proportion of mine lead (about 50%) and the highest PbB ($> 6.3 \mu\text{g}/\text{dl}$) were found in the two children of family 5. Dust from their vacuum cleaner had the highest proportion of mine lead (94%) and the highest concentrations of lead (1300 ppm).

The other three children of mine employees (families 1, 2, and 3, table 3) had a minimal proportion of mine lead in their blood and yet two of the three had the highest PbB of any children. Hence, there was no systematic relation between PbB and percentage of mine lead.

Three of the children in the control families had higher PbB concentrations than children of the mine employees. The PbB in the child from family 4 was $8.9 \mu\text{g}/\text{dl}$ and was attributed to a pica habit for paint.

Blood samples in the mine employees

The fathers employed at the Woodlawn mine all had high proportions of lead from the mine in their blood samples, ranging from 47% to 86% (fig 5). The employee with the smallest percentage of mine lead in the blood had the lowest PbB ($6.7 \mu\text{g}/\text{dl}$) among the mine employees. The largest proportion of 86% was for the man in family 5 whose family home showed the highest degree of contamination of mine lead and his children had the highest percentage of mine lead in their PbB.

Although based on limited data, a positive correlation ($R = 0.91$) was found between PbB and an increased ratio of $^{206}\text{Pb}/^{204}\text{Pb}$ in the blood samples of mine employees and their children (not shown). The line of best fit to the data for the blood samples of mine employees and their children intercepted the isotopic ratio axis at a value of 18.06, the same as the mine lead (fig 5). This is strong evidence that the source of increased PbB in these people is related to the mine lead introduced to their houses. However, for three children of mine employees the PbB came from other sources such as petrol and background lead and there was no contribution from mine lead. This finding reinforces the concern that generalisations in attributing lead sources to the PbB of community members can be misleading and that each case has to be assessed individually.

In summary, this study has shown that houses of employees from a lead mine can be variably contaminated by mine lead even if they are not situated in the same place as the mine. This indicates that lead is probably transported into the houses on the clothes,

Table 3 Summary of PbBs ($\mu\text{g}/\text{dl}$) and percentage of mine lead in blood samples of all people in the mine group

Family	Child 1				Child 2				Father		Mother	
	Sex	Age (y)	PbB	%	Sex	Age (y)	PbB	%	PbB	%	PbB	%
1	M	5	7.6	0	—	—	—	—	16.8	73	—	—
2	F	4	3.5	0	—	—	—	—	7.8	67	—	—
3	F	4	7.1	0	M	2 y	5.0	24	6.7	47	—	—
5	M	5	6.3	46	F	4 y	7.2	50	25.0	86	—	—
6	F	2.5	6.0	27	—	—	—	—	12.3	62	3.6	0
7	F	4.5	3.1	21	—	—	—	—	15.4	64	—	—

shoes, hair, skin, and in some cases, motor vehicles, of the workers. Other pathways—such as, through shoes, hair, skin, and motor vehicles—were not evaluated in this study but remain obvious routes to the houses. Contamination of the houses was not expected given the precautions taken by mine employees to minimise the lead transported into their homes. These precautions include showering at the mine site, wearing street clothes and shoes after work, carrying their work clothes in plastic bags which are usually left in the garage or in the laundry room (some take them directly to a commercial laundry). Moreover, most employees go to work on a bus provided by the mining company. Despite high concentrations of dust in some houses, none of the children had PbB which exceeded the Australian National Health and Medical Research Council national goal of 10 µg/dl. In fact, some children in the control families had higher PbB than children of mine employees, which in two cases, was attributed to a pica habit for paint.

We thank the General Manager of Woodlawn Mine, Tony McPaul, for discussions about the mine activities and the employees, Jeff Davis for microscopical examination of some of the vacuum cleaner dusts, Michael Korsch for software development and maintenance of the mass spectrometers, and all the families participating in this project for their ongoing collaboration.

Appendix: Statistical estimation of background values

We have defined more precisely the background isotopic ratios and PbB with a simple statistical analysis of the background subjects, in which the background population has been identified according to two requirements, the largest number of samples with similar isotopic ratios, and the lowest average PbB.

Figure 6 shows the frequency of blood sampling of the background children with $^{206}\text{Pb}/^{204}\text{Pb}$ ratios in a fixed range. The chosen interval was of 0.1 units. The frequency distribution displays a peak ($n = 4$) corresponding to the $^{206}\text{Pb}/^{204}\text{Pb}$ isotopic interval 17.1–17.2 and frequency values decreasing on both sides of this. The four samples in this range give an mean (SD) isotopic ratio of 17.16 (0.03). The PbB increases on both sides of the minimum value and corresponds to the isotopic composition 17.0–17.1. The highest frequency unit ($^{206}\text{Pb}/^{204}\text{Pb}$ ratios in the range 17.1–17.2) has the second lowest PbB (3.6 (1.5) µg/dl), which is reasonably close to the lowest PbB value of the adjacent unit (3.0 µg/dl based on only one sample). Hence, the 17.1–17.2 unit is the one which better satisfies simultaneously the two requirements of the background isotopic compositions and the background PbB. With the average isotopic ratio of this unit ($^{206}\text{Pb}/^{204}\text{Pb} = 17.16$) as a background value, we have calculated the background PbB of the samples with higher $^{206}\text{Pb}/^{204}\text{Pb}$ ratios assuming that their isotopic shifts are uniquely due to contamination with Woodlawn mine lead ($^{206}\text{Pb}/^{204}\text{Pb} = 18.1$). We have obtained a mean (SD) PbB of 3.8 (1.6) µg/dl which is in good agreement with the mean PbB of the four samples that define the background group (3.6 (1.5) µg/dl). This supports the

choice that we made of the background isotopic ratios and PbB. A similar recalculated background PbB was also obtained for samples with isotopic compositions shifted in the direction of the petrol lead, which was assumed to be a source of contamination.

- Barker EL, Folland DS, Taylor TA, Frank M, Peterson W, Lovejoy G, et al. Lead poisoning in children of lead workers. *N Engl J Med* 1977;296:260–1.
- Dolcourt JL, Hamrick HJ, O'Tuama LA, Wooten J, Barker EL. Increased lead burden in children of battery workers: asymptomatic exposure resulting from contaminated work clothing. *Pediatrics* 1978;62:563–6.
- Katagari Y, Toriumi H, Kawai M. Lead exposure among 3-year-old children and their mothers living in a pottery-producing area. *Int Arch Occup Environ Health* 1983;52:223–9.
- Kawai M, Toriumi H, Katagari Y, Maruyama Y. Home lead work as a potential source of lead exposure in children. *Int Arch Occup Environ Health* 1983;53:37–46.
- Piccinini R, Candela S, Messori M, Viappiani F. Blood and hair lead levels according to their parents' occupation. *G Ital Med Lav* 1986;8:65–8.
- Grandjean P, Bach E. Indirect exposures: the significance of bystanders at work and home. *Am Ind Hyg Assoc J* 1986;47:819–24.
- Knishkowsky B, Barker EL. Transmission of occupational diseases to family contacts. *Am J Ind Med* 1986;9:543–50.
- Kaye WE, Novotony TE, Tucker M. New ceramics-related industry implicated in elevated blood lead levels in children. *Arch Environ Health* 1987;42:161–4.
- Fischbein A, Wallace J, Sassa S, Kappas A, Butts G, Rohl A, Kaul B. Lead poisoning from art restoration and pottery work: unusual exposure source and household risk. *J Environ Pathol Toxicol Oncol* 1992;11:7–11.
- Gittleman JL, Engलगau MM, Shaw J, Wille KK, Seligman PJ. Lead poisoning among battery reclamation workers in Alabama. *J Occup Med* 1994;36:526–32.
- Denehurst Limited. *Annual Report* 1995.
- Gulson BL, Mizon KJ, Law AJ, Korsch MJ, Davis JJ. Source and pathways of lead in humans from Broken Hill mining community—an alternative use of exploration methods. *Economic Geology* 1994;89:889–908.
- Gulson BL, Mizon KJ, Korsch MJ, Howart D, Phillips A, Hall J. Impact on blood lead in children and adults following relocation from their source of exposure and contribution of skeletal tissue to blood lead. *Bull Environ Contam Toxicol* 1996;56:543–50.
- Gulson BL, Pisaniello D, McMichael AJ, Mahaffey KR, Luke C, Mizon KJ, et al. Stable lead isotope profiles in smelter and general urban communities. Comparison of biological and environmental measures. *Environmental Geochemistry and Health* 1996 (in press).
- Gulson BL, Davis JJ, Mizon KJ, Korsch MJ, Bawden-Smith J. Sources of lead in soil and dust and the use of dust fallout as a sampling medium. *Sci Total Environ* 1995;166:245–62.
- Gulson BL. *Lead isotopes in mineral exploration*. Amsterdam: Elsevier, 1986.
- Faure G. *Principles of isotope geology*. 1986. New York: John Wiley, 589.
- Gulson BL. Application of lead isotopes and trace elements to mapping black shales around a base metal sulphide deposit. *Journal of Geochemical Exploration* 1977;8:85–103.
- Carr GR, Dean JA, Suppel DW, Heithersay PS. Precise lead isotope fingerprinting of hydrothermal activity associated with Ordovician to Carboniferous metallogenic events in the Lachlan fold belt of New South Wales. *Economic Geology* 1996;90:1467–505.
- Gulson BL, Davis JJ, Bawden-Smith J. Paint as a source of recontamination of houses in urban environments and its role in maintaining elevated blood leads in children. *Sci Total Environ* 1995;164:221–35.
- Mira M, Bawden-Smith J, Causser J, Alperstein G, Karr M, Snitch M, et al. Blood lead concentrations of preschool children in central and southern Sydney. *Med J Aust* 1964;399–402.
- Gulson BL, Howarth D, Davis JJ, Mizon KJ, Korsch MJ, Law AJ. Lead bioavailability in the environment of children: blood lead levels in children can be elevated in a mining community. *Arch Environ Health* 1994;49:326–31.
- Australian National Health and Medical Research Council. Lead in Australians. Revision of the 1987 (103rd session) guidelines. Canberra: ANHMRC, 1993.