Impact of closure of a large lead-zinc smelter on elevated blood lead levels of children in adjacent suburbs, Boolaroo, Australia

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Abstract

The lead-zinc smelter at Boolaroo, near Newcastle New South Wales, Australia, was in operation from 1897 to September 2003. A study in 1991 found that 84% of children under 5 years of age in proximity to the smelter had blood lead levels ≥10 μg/dl. Blood lead levels were elevated in children resident within several kilometres of the smelter, with presumed contributions from historic emissions and ongoing fugitive emissions from the smelter. An Environmental Health Centre was established locally to provide free blood lead testing, advice on case management of children, assistance with cleaning, HEPA vacuum cleaner loans and health promotion activities. In 1997, the houses and yards of children with elevated blood lead levels were targeted for extensive environmental lead abatement. In 1998 a zonal household abatement program began which included carpet and ceiling vacuuming, removal of visible slag and top dressing of soil of residences closest to the smelter. Twenty-six houses were included and 640 zonal abatement episodes were completed before the program was terminated in 2001 because 1) the program appeared to be of little value due to rapid recontamination from ongoing smelter emissions, 2) it was expensive, and 3) it was viewed as inequitable by the community. Marked reductions in air lead levels have occurred since 1991 through emission controls. Blood lead levels in children declined rapidly in the first six years of the program but from 1997 to 2003 the mean blood lead levels plateaued with approximately 30% of locally tested children having a blood lead ≥ 10 μg/dl. The smelter ceased operation on September 12th, 2003. Blood lead testing of children < 13 years completed at 9 and 22 months post-closure demonstrated a decline in the annual percentage of blood lead levels ≥ 10μg/dl to 18% and 9%, respectively. Closure of the smelter, without significant local remediation, has made a significant impact on children's blood lead levels, especially among children under three years of age.
Keywords: blood lead, smelter, lead, lead poisoning, children.

1 Introduction

The lead-zinc smelter at Boolaroo, near Newcastle in New South Wales, Australia, was in operation from 1897 to 1922 and then from 1961 to September 2003 when it was permanently closed. A study in 1991 found 84% of children aged one to four years old from the neighbouring suburbs of Boolaroo and Argenton had blood lead levels ≥10 μg/dl, a level at which cognitive, developmental and other adverse health effects may occur [1,2]. Blood lead levels in children and soil lead levels were elevated for several kilometres around the smelter, with potential contributions from historic and ongoing smelter emissions. Details of blood lead and environmental investigations from the early nineties and maps of the area have been published previously [1]. From the 1960s the plant had focused on zinc and lead smelting and in the 1990's employed approximately 400 workers. Following the closure of the smelter in September 2003 it became important to assess whether local children's blood leads remained elevated requiring remediation of long-term environmental contamination. We analysed the July 2004 to June 2005 blood lead monitoring data and provide the results against the programmatic and environmental background relevant to assessing the impact of the closure.

1.1 The environment

The smelter is located on 191 hectares of land with the three residential suburbs, collectively referred to as North Lake Macquarie, of Boolaroo (4.1 sq kms, population 1190 2001 census), Argenton (1.6 sq kms, population 1295, 2001 census), and Speers Point (2.7 sq kms, population 3044 2001 census) extending predominantly north and south from the smelter with the closest residential properties located on the border of the smelter property. The area in which children's blood lead levels are found to be elevated extends from the border with Lake Macquarie, Australia's largest estuary, 2 kms. south of the smelter boundary, to the northern limits of Argenton 2 kms. to the north of the smelter boundary. The adjacent residential suburbs are of mid to low socioeconomic status with the lowest socioeconomic groups living closest to the smelter. A childcare center, three schools for children from 5 to 13 years of age, sporting fields, picnic areas, and dirt-bike recreational facilities are all found within 2kms. of the smelter.

Suburbs to the east of the smelter are protected from emissions by a prominent ridge line, rising 164 metres above sea level, providing an open space buffer 4 kms. long. The climate is temperate with 1139 mm of rain per year, and no significant restriction on irrigation for gardening purposes. Most residential property owners are able to maintain adequate ground cover with irrigation two to three times per week during summer months.

1.2 Environmental monitoring

The smelter had a total mass emission of 92,000 kilograms of lead in 1985. During the 1990s various strategies were introduced to reduce stack and fugitive emissions. The National Pollution Inventory records annual lead to air emissions from the smelter decreasing annually from 14,000kg in 2000, 20,000kg in 2001, 11,000kg in 2002, 11,000kg in 2003, to 2,300kg in 2004. The smelter ceased operation in September 2003, explaining the reduction in output to June 2004. Lead concentrate was brought into the smelter via a railway link to the north of the smelter, the train vessels have been covered since mid-1990's. Lead dust could move offsite from slag stockpiles, stack emissions, and fugitive emissions from the process areas. Investigation of lead emissions from the smelter throughout the nineties identified significant fugitive emission sources.

Although it is difficult to attribute different sources of lead from blood and tooth lead, Gulson's isotopic lead studies strongly suggested that the major source of lead for children in his sample was lead from the smelter [3]. There was evidence that the slag used for landfill in the area is bioaccessible [4].

Environmental monitoring of lead has been conducted through a range of methods including systematic soil lead testing using a grid pattern across the three suburbs, monitoring of selected soil plots, dust deposition monitoring, high volume lead-in-air sampling and testing within residences to identify exposures of individual children with elevated blood lead levels.

For the 1991 soil survey two hundred and two samples were collected at the intersection points of grid lines mapped at 200m intervals, and superimposed on an area extending 2 kms. to the north and south of the smelter site [1]. A 20cm by 20 cm area of soil was collected to a depth of 5cm.

The mean lead in soil level was 1430ppm, with a range of 20–21,460ppm. Sixty-six (33%) of the 202 samples were 1000 ppm of lead in soil or greater, and 75 or 37% fell between 300 and 999 ppm. Most of the samples above 2000 ppm were within 400 metres of the smelter boundary that included residential areas. The mean lead in soil values by suburb were 2,866 ppm for Boolaroo, 1,296 ppm for Speers Point, and 766 ppm for Argenton.

When the Environmental Health Centre (EHC) commenced abatement activities in the Boolaroo and Argenton homes and public areas in 1997, there was concern that the remediated areas would rapidly become recontaminated. To determine the rate of surface soil lead recontamination, five soil plots were established at varying distances, up to 1km north, south and west of the smelter. Each plot was 16m^2, 300mm deep and was filled with the same coarse sandy loam used in the lead abatement program before being covered with grass turf. Annual testing prior to closure of the smelter found an average increase in lead of approximately 2ppm per month at 0–25mm and 1.5 ppm per month at 0–50mm. The mean total lead in the soil plots at 25mm on establishment was 5.5ppm.

Carpet dust lead concentrations ranged from 631 ppm to 2328 ppm with a mean of 1669 ppm in 13 houses situated from 225 metres to 1.1 kms. from the smelter that were prioritised for the Individual Household Abatement program in 1996.

High volume air sampling has been conducted at a monitor approximately 500 metres from the southern boundary of the smelter. Annual lead-in-air levels have gradually decreased over time, figure 1. The average daily lead-in-air level dropped below 0.1 μg/m^3 within 15 days of the closure of the smelter in September 2003 and has remained below this level.

1.3 Policy and regulatory environment

Lead in paint was reduced to 1% in Australia in 1973 then further reduced to a maximum lead content of < 0.1% in 1997. However, the township of Boolaroo was established in 1896 with homes built to accommodate workers at the local smelter and most of the housing stock within two kilometres of the smelter was built prior to 1970. Unleaded petrol was introduced to Australia in 1985 and by late 1995 unleaded petrol sales accounted for almost 63% of petrol sales with the sale of lead petrol ceasing in NSW in 2002.

The Air National Environmental Protection Measure standard for lead-in-air, established in 1998, is an annual average of 0.5 micrograms/cubic metre (μg/m^3), a reduction from the prior 90-day average goal of 1.5 μg/m^3. Monitoring data from peak sites in capital cities show a significant downward trend in ambient lead levels over the last two decades.

In June 1993, the National Health and Medical Research Council (NHMRC) abandoned the 1987 blood lead goal of 25 μg/dl and set new goals to be achieved by 1998 - a blood lead level of less than 15 μg/dl for all Australians and less than 10 μg/dl for 90% of 1 to 4 year old children. The National Survey of Lead in Children conducted early in 1995, found that 93% of Australian children aged 1–4 years had a blood lead level below 10 μg/dl [5]. The mean blood lead level was 5.8 μg/dl. The average blood lead among children 1 month to 7 years in an opportunistic survey in Sydney children's hospitals in 1999 revealed an average blood lead of 2.3 μg/dl [6]. These surveys provide useful benchmarks by which the relative contribution of smelter associated lead to blood lead levels in North Lake Macquarie children can be assessed. Children from North Lake Macquarie under 5 years had blood lead levels that were two to over fourfold higher (fig. 1) than the national and state levels respectively identified above.

1.4 Programs of the Environmental Health Centre

Since its establishment in 1996, the EHC has undertaken a range of lead abatement, case management and health promotion activities

1.4.1 Lead abatement programs

There has been limited direct abatement of lead in the 1600 residential blocks in North Lake Macquarie, largely because of concerns about the about the effectiveness of such programs in the presence of an operating smelter. In 1996–1997, 26 houses and yards of children with elevated blood lead levels were targeted for extensive individual environmental lead abatement. An initial inspection was made to identify all possible internal and external sources of lead. The abatement included structural repairs, external and internal painting, replacement of carpets, top dressing of grass lawns with one to two centimetres of uncontaminated soil, and removal of accessible black slag. The program was discontinued after a review which found a lack of local and international evidence for the effectiveness of abatement in the presence of continued and rapid recontamination; conflict in the community with regard to prioritisation, equity, and levels of abatement required; homes being sold or rental fees raised after abatement to realise the increased housing value associated with the improvement; and work specification disputes.

Between 1998 and 2001 a Zonal Abatement Program began which offered householders carpet and ceiling vacuuming, removal of visible slag and top dressing of soil. The program was aimed at reducing lead accessibility across the area and targeted 640 homes closest to the smelter, moving outward in a concentric pattern. In 2001 the NSW Government Environmental Protection Authority and Health Department jointly reviewed the program and increased the focus on further reduction of source emissions, targeted testing of children in the first 2 years of life, and case identification occurring as early as possible by working with pregnant women and families of young children. Targeted soil lead abatement for households with children with elevated blood lead levels and greening programs were continued but the removal of ceiling dust and one-off commercial vacuuming of houses was ceased. The only other programmatic community-wide soil lead abatement undertaken was in local school playgrounds, sporting fields, and parks where lead contaminated slag to a depth of 300mm was removed, soil was replaced, top dressing applied and improved irrigation established. Ground cover and topsoil was available free of charge to residents to encourage a natural protective barrier to existing lead within the soil and sand was provided for sandpits. From 2001, the ground cover supply has been restricted to families with children less than 5 years of age. Other interventions were restricted to children under case management for elevated blood lead levels.

1.4.2 Case management and health promotion

Children with blood lead levels of 10 μg/dl or more were offered case management which included environmental assessments, dietary counselling, long term loan of high efficiency particulate air (HEPA) filter vacuum cleaners, provision of door entry mats to decrease carriage of dust into the house and a one-off house cleaning. Where necessary, slag was removed and replaced with clean topsoil and turf, and lead based paint hazards were remediated.

Lead awareness packages including healthy cleaning, eating and hand washing programs were developed for teachers and cleaners in the local schools, and carers in preschools and family day care. A parent run playgroup for toddlers was established to provide a networking contact point for parents of young children to learn about lead issues.

1.5 Surveillance for elevated blood lead

The earliest available study of children's blood lead levels in the North Lake Macquarie area in 1976 found that 176 (86%) of 204 children living in Boolaroo or Argenton and aged from 10 months to 14 years, had a blood lead level of 10μg/dl or greater [7]. Children in Boolaroo were found to have a mean blood lead level of 14.9μg/dl compared to 15.5μg/dl in Argenton. The percentage of children with blood lead levels greater than 20μg/dl and 35μg/dl were 17% and 2%, respectively but no blood lead level exceeded 40μg/dl. Based on the recommendations of the 1972 Amsterdam Conference on Environmental Lead it was concluded that no children had excessive blood lead levels.

The first recognition of the concerning community-wide elevation of blood lead levels came with the 1991 study by the local Public Health Unit [1]. In the 1991 risk assessment of Boolaroo and Argenton areas, 1,000 homes were surveyed by door knock survey and 138 children aged 1–4 years were identified. Subsequently 129 children (94% response rate) had a blood lead test either in their home or at the Baby Health Centre. Parents of children attending or eligible to attend a local primary school, were invited to have their children tested, with 195 of the 235 children participating, giving a response rate of 82%. This study found that 84% of children less than 5 years had blood lead levels of ≥10 μg/dl and 6% had levels ≥25μg/dl [1]. Among children aged 5–13 years 68% had levels above ≥10 μg/dl with 4% above 25μg/dl.

1.5.1 Recruitment for blood lead testing

Annual blood testing programs have been conducted at the schools since 1992 and since 2000, a monthly clinic has been run at the EHC. The monthly clinic offered a free accessible local service, convenient to the residents. Family doctors and paediatricians also conducted blood lead tests.

From 2001, the EHC narrowed its focus to children under 5 years of age as children in this age group are at increased risk of environmental lead absorption because of their hand-to-mouth activity and the greater impact of lead toxicity on development in this age group. Pregnant women were also encouraged to have a blood lead test either at the monthly clinic, through the antenatal department at their local hospital or to request a blood lead test from their family doctor when they were having their routine blood tests during pregnancy. EHC staff visited all new mothers in the area in the first 6 weeks after delivery to begin educating the family about lead hazards and encourage them to take their children to the monthly clinics to have their blood lead monitored from about 10 months of age.

Family doctors from 30 medical practices are regularly contacted and asked to encourage their families from North Lake Macquarie to participate in blood lead testing programs.

Promotion of blood lead testing of children has included home visits, written invitations, advertising in the both the smelter and EHC newsletters, posters in public places, and information sent home from the schools and preschool. Following the smelter closure, the EHC commenced offering a “thank you for participating” gift of $10 (approximately US $7) for 0–7 year olds in 2004 and $20 in 2005 and a double movie pass for older children. The gifts have been well received, and while it has not increased the number of children tested, it may be responsible for maintaining the number tested despite the declining interest in lead safety with the smelter closure. From 2001 to 2004 there were approximately 200 to 300 children tested each year.

2 Blood lead analysis methods for 2004 – 2005

Venous blood was collected and tested in the laboratory using the protocols established in the Reference Document 'Australian Standard 2636 - 1988', with blood lead concentration determined by Atomic Absorption Spectroscopy using Stabilised Temperature Platform Furnace and Zeeman Background Correction. Each blood sample was split into two tubes to ensure the reproducibility of blood lead results and all equipment used to collect and store samples was tested to ensure they were lead free. Internal quality control was maintained by the laboratory's participation in national and international quality assurance programs.

All means calculated were arithmetic means. Only the highest blood lead level for each child in each 12-month period was included in the analysis to better estimate the contribution to body lead burden. However, a reanalysis by using the mean results of all tests from children with multiple blood lead tests in a year, did not meaningfully differ from the mean blood lead levels calculated using the highest blood lead level.

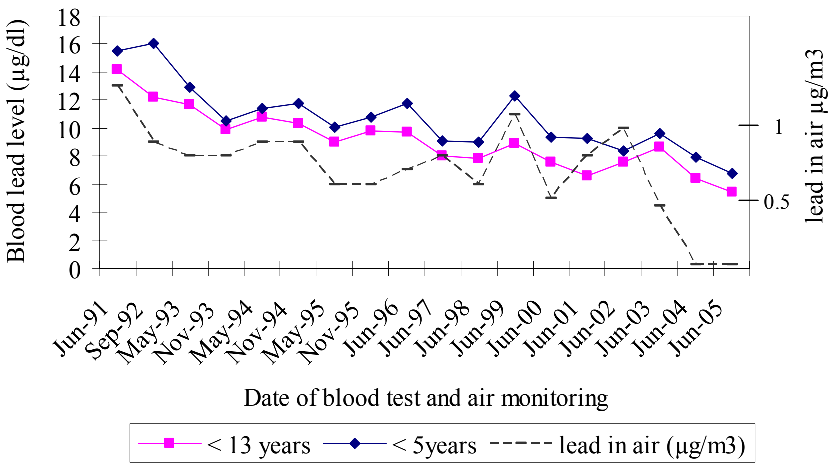

Figure 1: Mean blood lead levels of children < 5 years and < 13 years resident in North Lake Macquare, New South Wales Australia, June 1991–June 2005.

3 Blood lead screening results

One hundred and seventy one children in North Lake Macquarie had blood lead level testing from July 1 2004 to June 30 2005. Sixty-nine of the children were less than 5 years of age. Participation rates for children under 5 years of age based on 2001 census estimates were 33% for Argenton, 22% for Boolaroo, and 16% for Speers Point. The lowest blood lead level was 1 µg/dl and there were only two results over 20 µg/dl, at 21, and 38 µg/dl. The arithmetic mean blood lead level was 5.3 µg/dl among all children less than 13 years of age and 6.8 µg/dl among children less than 5 years of age Figure 1. This demonstrates a continued reduction in mean blood lead levels following closure of the smelter in September 2003.

Following an initial decline, the percentage of blood lead levels greater than 10µg/dl plateaued around 30% for all children and around 40% for children less than 5 years between 1997 and 2003 but then began to decline following closure of the smelter to a low of 9% and 17% for children less than 13 years and children less than 5 years respectively figure 2. The mean blood lead levels by suburb for children less than 5 years were: Boolaroo 8 µg/dl; Speers Point 6 µg/dl; and Argenton 6.5 µg/dl. There is a close association between the declines and peaks in the lead-in-air monitoring results and blood lead results in Figure 1.

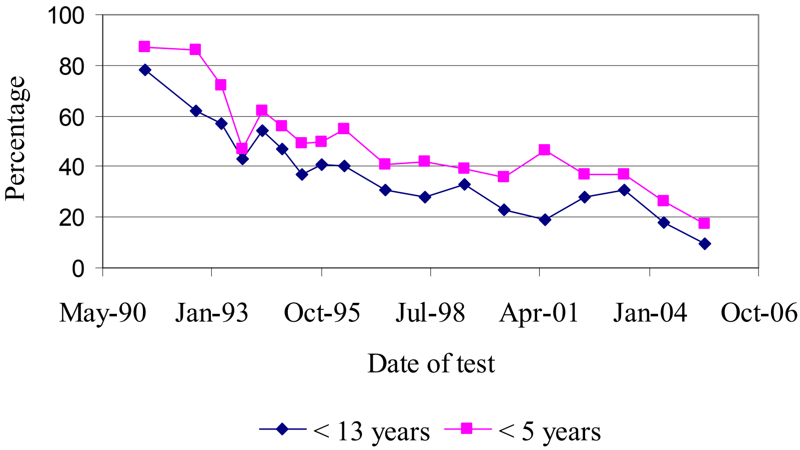

Figure 2: Percentage of blood lead levels greater than or equal to 10 µg/dl of children < 5 years and < 13 years resident in North Lake Macquarie, New South Wales Australia, June 1991–June 2005.

Figure 3 demonstrates a marked reduction in the mean blood lead level in each age group by year but particularly in children less than 3 years of age in the last years blood results, the only full year of monitoring during which the smelter was not in operation.

4 Discussion

It is difficult to predict the impact of the closure of a lead smelter on children's blood lead levels as the relationship between these parameters is complex and there are few well documented examples in the scientific literature. Children are subject to multiple pathways including ingestion of lead in soil and dust that contaminate backyards and household floors and surfaces. Lead contamination may be accumulated in the soil by years of fallout or by direct contamination of household surfaces by fresh emissions from the smelter. Additionally there is a contribution from the inhalation of recent emissions from an operating smelter. The most important finding of the 2004–2005 blood lead analysis is the suppression of the typical peak in blood lead levels at 2 years of age. While this peak is seen in 2002–03 and 2003–04 (and in prior analyses of data back to the early nineties), it is absent in the 2004–05 results. Children' blood lead levels typically peak around 2 years of age as their hand to mouth behaviour, susceptibility to lead absorption, and mobility reach a peak [2]. This is the peak period for accumulation of body lead burden that could have a lifelong impact. These data strongly suggest that the closure of the smelter has led to a reduction in the blood lead in children less than three years of age. However, the mean blood lead level in this age group is above 5 μg/dl, which is approximately double the estimated mean blood level for children for children under 7 years of age in NSW in 1999.

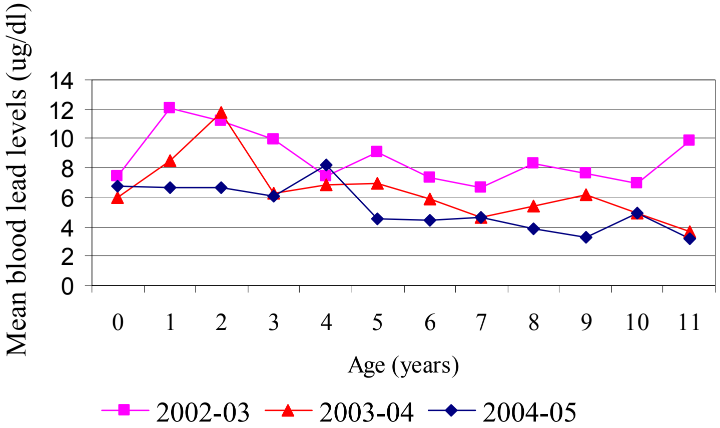

Figure 3: Mean blood lead levels by age group of children < 12 years from 2002–03 to 2004–05, resident in North Lake Macquarie, New South Wales Australia, June 1991–June 2005.

The shut down and replacement with a low emission smelting process in Trail, Canada dramatically reduced children's blood lead levels between 1991 and 2001 without significant community soil remediation [8]. Soil lead levels were essentially unchanged, however, there was a reduction in the environmental load of highly bioavailable lead in fine mobile dusts from active smelter emissions. Similarly, dustfall containers near the Port Pirie smelter in South Australia identified dust deposition as being more from current smelter emissions than recirculation of old lead emissions [9]. In 1991 an investigation of the relationship between blood lead levels and soil lead levels of 490 children under 6 years of age in Granite City, Illinois, exposed to lead contaminated soil in the vicinity of a battery recycling smelter that had closed 8 years earlier, found that contaminated soil was a lesser contributor to their blood lead than lead paint and general household condition [10]. In contrast the heavily contaminated Bunker Hill Superfund site was able to achieve important and continued reductions in children's blood lead levels over a 20 year period following the closure of the lead smelting and mining operation in 1981 [11].

While it appears that the closure has led to a decrease in blood lead levels, it is difficult to predict if the closure of the smelter alone will allow children's blood lead levels to decrease to NSW background levels.

Only a small proportion of eligible children are tested in the blood lead monitoring program and this group may not be representative of all children in North Lake Macquarie.

To confirm these reassuring findings, at least two additional annual community child surveys with blood lead monitoring should be conducted. To identify the major sources of lead exposure, detailed examination of the environment and behaviour of all children with elevated blood lead levels, particularly those under three years of age, should be conducted.

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