The Science of the Total Environment 303 (2003) 1–13

the Science of the Total Environment
An International Journal for Scientific Research into the Environment and its Relationship with Man

www.elsevier.com/locate/scitotenv

Overview of lead remediation effectiveness☆

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Received 28 March 2002; received in revised form 14 August 2002; accepted 19 August 2002

Abstract

A Symposium on Lead Remediation Effectiveness, sponsored by the US Environmental Protection Agency, was held at Coeur d'Alene, Idaho, USA from 22–25 May, 2000. International participants from various levels of government, educational institutions, industry, and community representatives presented papers and posters on themes that ranged from engineering practices through community participation in the remediation processes. The papers in this volume represent a global distribution of sites, especially those outside the USA. In providing an overview of the symposium and the theme of Lead Remediation Effectiveness we have drawn on information from some presentations at the symposium, besides those described in this volume.

Keywords: Lead; Remediation; Mining; Smelting; Blood; Environmental samples

1. Introduction

Remediation is the process that is intended to reduce or nullify negative impacts of industrial hazards on residential areas, natural ecosystems, and in most cases, on the industrial site itself. Remediation implies the application of a remedy, and the ultimate objective of this remedy is hazard reduction. The remedy is expected to minimize the hazard to the extent that the environment is safe for human habitation and ecological habitability. In the sense of this symposium, the use of the term 'remediation' applies primarily to soil that has become contaminated during the mining, milling, transport, or smelting of lead ore, and to dust that is derived from that soil. The remedy differs from site to site according to the effort and expense that the community and the industrial group are willing to undertake, within their available resources. In terms of financial outlays, some remedies cost hundreds of millions of dollars, some cost almost nothing at all. In terms of community or ecological impact, the remedy, in some cases, results in or follows the shutdown of the industry and the loss of jobs; in others, the community recovers and prospers.

We do not pretend to be experts in this field, but offer some insight arising from the presenta-

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PII: S0048-9697(02)00361-3

Table 1
Summary of case studies

Country	Location	Smelter or mine active or closed	Topography	Remediation plan	Effectiveness (from PbB)
Australia	Port Pirie	S/A	Coastal plain	>20 years	Plateau
Australia	Broken Hill	M(S)/A[a]	Inland desert plain	>10 years	Plateau
Australia	Lake Macquarie	S/A	Rolling hills	>10 years	Plateau
Canada	Trail	S/A	Valley	>10 years	Decreasing to low levels
Romania	Zlatna	S/A	Valley	Limited	13 μg/dl decrease over 2 years
Russian Far East	Rudnaya River	S, M (?)	Valley/coastal plain	None	No survey
USA	Bunker Hill	S, M/C	Valley	>20 years	Plateau

[a] Active at the time of symposium.

tions and discussions of the symposium. Remediation of contaminated sites is a controversial issue as it usually involves industry (management, labor, and stockholders), the community (employees, other residents, schools, city planners), and governments (local, state and national officials). Large amounts of money can be involved, including the cost of removal and reclamation, the change in value of a company's stock, the change in property values, and the possible cost of relocation. Other costs, both social and emotional, cannot be measured in dollars.

There are many industrial sites that have been identified worldwide as requiring some type of remedial action to correct the environmental problems of lead contaminated soil. By participating in the symposium on Lead Remediation Effectiveness held at Coeur d'Alene, Idaho, risk assessment and risk management scientists sought to gain an international perspective on the issues involved with lead remediation. Some of the presentations from the symposium appear in this special volume. The symposium and these papers address only lead remediation associated with mining, milling, and smelting activities (Table 1). Lead-based paint in housing, and the impact of lead liberated during mining and smelting of other metals, such as copper and nickel, are not included, although they also have been the subject of intense scrutiny over several decades.

This paper, like several presentations in the symposium, considers both soil and dust to be key factors in the dispersion of lead throughout the community. The dust may have originated from the lead-contaminated soil and become mobilized by the normal processes that grind the soil into smaller and more mobile particles that can be carried on shoes or hands. The dust may also have been carried to the family's immediate environment as airborne emissions from the smelter stack or as fugitive dust from other parts of the mining and smelting process, including transport into homes on worker's clothing.

In this paper we briefly introduce some aspects of remediation plans. Then we summarize the goals, strategies and limitations of lead remediation and its effectiveness as described at the symposium. We offer a 'best practice' scenario for lead remediation effectiveness in Section 5, and in Section 6 point out some limitations and deficiencies even with 'best practice'. In Section 6, we also draw on other information besides that presented at the symposium.

2. Remediation strategies—general aspects

2.1. Breadth of remediation plan

A remediation plan has to be country and site-specific, as does evaluating its effectiveness, because of variations arising from, for example:

1. Government policy—is there a mechanism for making a decision, and are there funds to support that decision?
2. Company policy/viability—can the company survive the economic impact of the cost of remediation?

3. Community relations—can the community participate in the decision-making, and will the community be better off after remediation? Will there be a change in the community's perception of fairness or benefits?
4. Topography—does the plan fit the topography? For example, a steep-walled canyon may have contained the dispersion of the smelter plume, but soil remediation is much more difficult on a steep slope than on level ground.
5. Climate—in a hot, dry climate, lead contaminated dust may travel much further than in a cold, wet climate.
6. Land use—some agricultural or recreational practices may be compatible with soil lead remediation, but other uses may need to be suspended if they will increase human exposure to lead in dust.
7. Population density—it is likely that not every resident will receive the benefits of remediation. If the landscape surrounding the mine or smelter is remediated to a distance of 2 km, based on the agreed upon remediation goal, then residents further away at 2.1 km may have higher lead exposure than those closer in at 1.9.
8. Metal species—although some forms of lead are less hazardous than others, the proceedings of the symposium do not provide sufficient information to clarify this issue.

2.2. Initiation of the remediation plan

Initiation of the remediation plan development begins with the recognition among all affected parties that a hazard exists and that it may be multi-faceted (that is, not just lead). In the past it has often been the community that has set in motion the initial remedial activities, often as a result of unusual incidents such as a high incidence of lead poisoned children (e.g. Bunker Hill Rosen, in press; Sheldrake and Stifelman, in press; von Lindern et al., in press a; von Lindern et al., in press b), or a high rate of dog mortality (e.g. Broken Hill). It is unfortunate that social instability can arise in a community during this early stage of remediation planning (Lunn and Rothery, symposium presentation; Morrison, in press), as rumors spread regarding the traumatic, irreversible effect of lead-poisoning, or of the possible loss of jobs.

Some questions must be resolved early in the development of the remediation plan. Who has the responsibility for developing it, approving it, and implementing it: the government at various levels? The company? Or the community? Must it be acceptable to all affected parties? Those who develop the plan must understand the full scope of the problem from the hazard itself, to health aspects, to community acceptance, to the actual remediation process and thence in evaluating its effectiveness. When all work is done, it is not likely that all parties will agree on the effectiveness of the remediation.

2.3. Funding of the remediation plan

Funds are required at various stages of the plan, beginning with the initiation phase and continuing thereafter for all of the engineering aspects of remediation and monitoring aspects of the effectiveness of the remediation program, including human aspects. Public relations are important from the outset to completion, and the cost for this effort must be factored into the initial plan. In the United States, the funding for Bunker Hill comes largely through the Superfund program through a charge to the mining industry. In Trail British Columbia, state and local governments and the company (Cominco) provide finance for remediation (Hilts, in press). In Australia, at Broken Hill, Lake Macquarie, and Port Pirie, funding is largely provided through the two state governments with some input from the company (Lively and Balding, symposium presentation; Lunn and Rothery, symposium presentation; Maynard et al., symposium presentation). In Russia and Romania, there is limited or no interest from government or the company to fund remediation.

2.4. Ecological approaches

Current emissions can include acid mine drainage, dust from mining and smelting operations, and stack emissions. Remediation of these sources largely involves the current owners, and its success depends on commitment and financial viability of the mining corporation, and influence of government agencies.

Restoration of the immediate environment largely revolves around 'engineering' practices associated with past contamination and current emissions, such as smelter stack emissions into the atmosphere, or waste rock and mill tailings into streams and their tributaries. Remediating past contamination involves minimizing the hazard to the community and environment by many different approaches. The aim of these approaches is to minimize the mobilization of metals from containment areas, especially those arising from 'acid mine drainage' and usually include soil capping and revegetation. The ecological approach should complement the community-based approach.

2.5. Community based approaches

Community involvement is probably the most complex area of remediation, as it can involve industry, government agencies, and the community. The role of the community in any remediation plan is crucial to its success. The direct involvement of the community, through committee representation, improves the interaction of families with their health care providers and can facilitate lifestyle modifications. Because employment opportunities are generally with mining and smelting companies and their peripheral industries, there is the dilemma of loyalty to the company vs. concern for health and social stability within the community. Acceptance of the remediation plan must be a joint effort in order to avoid factionalism in the community and a 'them-or-us' attitude, that can sometimes give rise to physical assaults and death threats. Distrust of governments, other outsiders and even internal conflict within community groups can possibly be averted with total involvement.

It is important to avoid the stigma that is sometimes attached to residents living in a smelting/mining town that can affect property values and personal lives, as described by Lunn and Rothery (symposium presentation), Morrison (in press) in the Lake Macquarie area of New South Wales, Australia. Uprooting and relocating families after generations of residence in the community can rend the social fabric of the community and should be avoided.

3. Goals, strategies and limitations

3.1. Goals

The main goals of remediation can be summarized as follows:

- to protect human health, including both children and adults;
- to restore the environment;
- to retain the social fabric of the community; and
- to maintain viability of the industry.

Of these several goals that were espoused by participants at the symposium, the greatest emphasis was placed on the first, second and fourth, with less emphasis on retaining the social fabric of the community. It is our conclusion that this aspect was an 'unwritten' expectation among the participants. Likewise, the viability of the industry was not always applicable, especially in cases where the industry was no longer operational, as was the case for the smelter in Bunker Hill.

3.2. Strategies

From a theoretical standpoint, options available for contaminated sites can be discussed as follows:

1. shutdown with no clean-up, e.g. Russia Far East;
2. shutdown with clean-up (possible alternative to replace Industry—e.g. tourism);
3. shutdown with clean-up and continuous monitoring/intervention (Bunker Hill);
4. continue industry with monitoring (Romania); and
5. continue industry with 'controlled' emissions + clean-up + continuous monitoring (Lake Macquarie, Port Pirie, Broken Hill, Trail)

Shutdown can have global impacts and should be a last resort in order to prevent:

- loss of jobs;
- disruption/demise of community;

- loss of infrastructure; and
- relocation of the industry to a developing country with less stringent regulations.

If shutdown is the only option, there needs to be strategies to restore or retain the economic and social viability of the community by replacing the industry with alternative activities such as tourism; this has been adopted at both Bunker Hill and Broken Hill.

3.2.1. Strategies for remediation discussed at the symposium

In the case of the copper smelter around Zlatna, Romania (Niciu et al., symposium presentation), there was no remediation of soil or dust in residences or in the ambient environment. Soil and dust lead concentrations were measured at children's homes, kindergarten, day care facilities, and play areas. Blood lead surveys for children aged 1–11 years were undertaken in 1995 and 1997. The main lead reduction strategy entailed a family counseling program comprising a local general practitioner, pediatrician, nurses, local non-government organization members, supervised by experts from the US Environmental Protection Agency, who worked closely with local scientists and health professionals from the county and institutional level. It focused on interpreting the blood lead concentrations, and finding efficient methods to reduce lead exposure and absorption, including diet.

At the Pb–Zn smelter Port Pirie, South Australia, remediation strategies utilizing multidisciplinary teams have been in place for over 17 years (Maynard et al., in press). Current strategies include: (i) development of a buffer zone around the smelter; (ii) relocation of children; (iii) dust control; (iv) house decontamination; (v) family education and support; (vi) publicity and general community awareness; (vii) blood lead screening; and (viii) reduction in smelter emissions.

In western New South Wales, Australia, comprehensive remediation strategies for blood lead reduction in young children from the Broken Hill Pb–Zn mining community were implemented in 1994 (Lively and Balding, symposium presentation). The strategies involved a multidisciplinary team of nurses, educators, technicians, scientists and management and support personnel who developed and implemented an integrated strategy comprising: (i) blood lead monitoring and case management for all children under 5 years of age; (ii) public education and communication; (iii) home remediation; (iv) remediation of contaminated land (not on mining leases); (v) environmental monitoring and research; and (vi) project management and support.

In contrast to large clean-up programs in some other centers to permanently reduce lead exposures, the strategy for the Trail Community Lead Task Force, formed in 1990, was intended to help the smelter and the community to co-exist (Hilts, in press). The Task Force was composed of representatives from numerous community groups, local government, the province of British Columbia, and the smelter company (Cominco). As soil removal was considered too costly, inefficient and disruptive, the main strategies were: (i) community education; (ii) community greening and control of interior dust exposure by voluntary community service groups; (iii) case management; (iv) a better understanding of lead exposure pathways from environmental sampling; and (v) blood lead monitoring. In addition, the introduction of new smelter technology in 1997 resulted in major decreases in smelter emissions.

At North Lake Macquarie, a Community Consultation Committee was established in 1991 (to become the Environmental Health Centre (EHC) in 1996) after a study by Galvin et al. (1993) showed that approximately 88% of children aged 1–4 years had blood lead levels greater than 10 μg/dl (Lunn and Rothery, symposium presentation; Morrison, in press). The strategies undertaken by the EHC include: (i) information and education programs to parents, schools and community groups; (ii) case management for families where children have elevated blood lead levels; (iii) blood lead testing at monthly clinics at the EHC and annual testing at local schools; (iv) individual house and zonal remediation; and (v) greening programs.

At Bunker Hill, Idaho, the main strategies have focused on burial of smelter and mining waste, partial soil removal and capping at residences, dust monitoring, more recently dust removal from residences, blood lead survey of children aged 1–5 years (von Lindern et al., in press a). An aggressive intervention program provides follow-up services to children identified as 'at risk' in annual blood lead surveys.

There have been no remediation strategies in place for the Russian Far East although there have been over 30 years of sampling of media that included soil, agricultural products, precipitation, air, mollusks, and vegetation from the surrounding trees (Kachur et al., in press).

3.2.2. Strategies for monitoring

At the Pb–Zn smelter Port Pirie, South Australia (Maynard et al., in press), extensive environmental and biological monitoring has been undertaken that includes: soil and house dust measurements, air monitoring by the company, estimation of rates of smelter emissions, and annual blood lead screening of children aged 1–5 years old.

In the Broken Hill Pb–Zn mining community, blood lead monitoring and case management is undertaken on an ongoing basis for all children under 5 years of age; a soil survey of the Broken Hill city was undertaken by the local government; air and dust monitoring of the ambient environment is undertaken by the company in collaboration with the New South Wales Environmental Protection Authority (NSW EPA); soil, dust and paint in residences is monitored at the same time as blood sampling (Lively and Balding, symposium presentation). At Bunker Hill, monitoring for residences involves measurement of yard soil and house dust concentrations using vacuum cleaner bags and mats; for the ambient environment, ongoing measurements are made of air, soil and streams for leakage from the containment heaps. An effort is made to contact every family at least once a year to assess and refresh their awareness of potential lead hazards (von Lindern et al., in press a).

In the Russian Far East, the analyses over the earlier 30-year period were not focused on monitoring any remediation but only uncontrolled emissions. The later investigations by von Braun et al. (symposium presentation; 2002) provide an additional data base for soils, dusts, mine tailings, and river bank sediments. They recommend that future investigations should include evaluation of other potentially important pathways, such as air, surface and ground water, paint, interior dusts and garden produce as well as pediatric and occupational blood lead levels.

At Lake Macquarie, monitoring is mainly focused on air monitoring undertaken largely by the company and blood lead surveys using venipuncture performed by the local EHC. In addition, pre- and post-remediation analyses are performed on remediated houses but follow-up, in the manner of the Trail program, is rarely undertaken (Morrison, in press).

At Trail, blood lead sampling using the fingerstick method has been carried out generally in September of each year. Lead in air and dustfall were undertaken by the company. An excellent innovation at Trail to monitor changes in environmental conditions resulting from smelter emissions and other lead remediation efforts, has been the quarterly collection of soil and dust samples from a network of 32 'sentinel homes' (Hilts, in press).

4. Evaluation of remediation effectiveness

The collective experience of several remediation experts who presented their information and experiences emphasizes the patterns of findings and gaps in knowledge for the several projects that were discussed at the symposium. One conclusion might be that it is nearly impossible to evaluate the effectiveness of remediation, even in a semiquantitative manner. Even if all projects tried to meet the same remediation goal, success would still be measured by a different yardstick for each site. Other scientists might conclude that there is value in gathering experience from several different remediation programs.

Of the several projects from around the world that were discussed at the symposium, only one (Bunker Hill, Idaho) was from the US Environmental Protection Agency's Superfund program. At this site, remedial action goals were set and measurements were taken periodically to determine progress toward those goals. Other site-specific programs were likewise planned in great detail, and with a goal common to all remediation efforts: to reduce human exposure to lead.

Two authors focused specifically on remediation effectiveness. Mushak (in press) reviewed critical information essential for effective remediation and discussed some of the environmental, biological and biokinetic factors that influence estimates of exposure reduction. The paper identified who to evaluate for the highest risk among populations affected by remediation and post-remediation, how to evaluate Pb exposures at the outset and with changes in exposure, and the various dimensions biologically and biokinetically to the evaluation of exposure reduction. While reductions in blood lead are clearly expected as a result of remediation, increases may also occur if the remediation inadvertently increases exposure from another medium, such as dust from poor practices in paint removal. Rosen (in press) provided a critical review on the remediation that has taken place at the Bunker Hill Superfund site to date and whether the environmental and medical interventions have been effective in lowering blood lead concentrations in children. He drew attention to the problems of piecemeal or site specific remediation and inherent recontamination, an aspect that has been recognized only in the past decade in mining and smelting communities. Recontamination of houses and ongoing contamination from point sources and hence limitations of remediation effectiveness were described in a number of papers. He also stressed, as did Mushak (in press), the critical necessity for a rigorous scientific approach encompassing environmental sampling coupled with strict laboratory protocols.

Hence, as a measure of remediation success, the reduced risk to lead exposure can be assessed in two ways:

1. a reduction in blood lead concentrations of the most susceptible subpopulation of residents (usually children); or
2. a reduction in lead concentration of soil and dust, which were the major pathways of lead exposure.

Herein lies the difficulty. Neither of these measures adequately evaluates the long-term effectiveness of remediation. To illustrate this point, we describe in the following section several hypothetical remediation situations that, compared with the projects described at the symposium, are far more ideal than experience dictates. By describing the ideal or 'best practice' situation, it is then easier to explain the observations from the non-ideal circumstances that were reported at the symposium, for example, going on holidays away from the contaminated site and taking several days to get back into 'living with lead.' At the Woodlawn mine, in south-eastern New South Wales, Australia even though showers, a change room, and bus was provided, the majority drove their own cars the 40 km to the mine, for convenience, and the cars sat around with windows open. Hence the cars became contaminated and allowed a pathway for dust getting into the children (Chiaradia et al., 1997); the car problem also occurred at Broken Hill.

A summary of markers of remediation effectiveness as measured by specific monitoring activities is given in Table 2.

5. 'Best practice' remediation effectiveness

5.1. The concept of 'best practice'

In a general sense, all contaminated sites discussed at the symposium were similar in that the source of lead was mining residue or smelter emissions, and the routes of exposure were through the movement of 'dust' of varying particle sizes to residential areas. While these idealized hypothetical conditions or circumstances might serve as the basis for a study of remediation effectiveness, the important lesson learned at the symposium was that the ideal situation does not exist in the real world. For example, in designing the emissions control systems, the managers of the smelter normally use economic factors for decisions that ultimately determine the lead exposure to the residential community, and the amount of lead that escapes during the smelter process is not a major economic concern in terms of the overall effectiveness of the smelter. Reducing this loss through emissions to prevent human lead exposure is a negative economic factor.

We discuss here several hypothetical examples that collectively illustrate both the traditional thinking regarding remediation, as well as a few non-traditional thoughts that emerged from the symposium discussions. Our first hypothetical example is a residential site near a smelter that has operated for several years with emission controls typical for the era during which the smelter operated. The residential community is upwind and remote from the emissions stack. In other words, the managers of the smelter used reasonable technology and community planning to minimize lead exposure, based on current technical knowledge. In this case, exposure would be expected to be continuous over time, and would be a constant function of: (i) the amount of ore being processed through the smelter; (ii) the prevailing climate and meteorology; (iii) the presence or absence of other sources of lead exposure.

We can describe the type of study that would examine human exposure given the ideal circumstances (i–iii above). Let us consider several examples of a smelter community where the production is constant, the meteorology is predictable, there are no other sources of lead exposure such as lead-based paint, the population is stable and community-based needs are well-established.

Let's presume that there are 500 families in the community; 250 families have one or both caregivers as employees of the smelter, and 250 families derive their income indirectly from the community economic structure peripheral to the smelter. For simplicity, we describe two neighborhoods, each with its own grade school, parks, playing fields and other neighborhood facilities. At the community level, there is one middle school and one high school. Health care facilities and physicians are shared by all residents. In each neighborhood, families are not highly mobile, having lived in the community for several generations. Information about the possible health effects of lead exposure would come from within the community through the health providers, and all families would get the same information at about the same time. All play areas are maintained with the same quality of ground cover, and the homes are maintained at the same level of cleanliness.

With this design, there are two principal variables that would control lead exposure through the dust route: occupational dust brought into the home on the clothing of the smelter/mine worker; and airborne dust carried away from the stack by the prevailing winds then deposited on the residential properties in amounts proportional to the direction of the wind and the distance from the smelter. In case 1, the community is located at considerable distance from the mining or smelting operations, such as was the case at the Woodlawn lead–zinc–copper mine in south-eastern NSW. Here the employees lived approximately 40 km from the mine in a well-established community, the company provided change rooms (with showers), and a bus for transportation. This case provides the ideal design for evaluation of the effectiveness of the smelter or mine design. Were the requirements for onsite change rooms and bus transportation relaxed, the workers residences would become contaminated, as shown by Chiaradia et al. (1997). In a more realistic design, the two neighborhoods would be well-mixed, and some of the contamination of the smelter workers homes might be spread to adjacent residences.

The 500 families could be divided into study groups according to the presence or absence of secondary occupational exposure, then ranked according to their proximity to the smelter stack. Selecting one child from each family to participate in the study, all in the same age group, for a blood lead sample taken at the same time, an investigator would expect to observe a strong correlation with distance from the smelter for the two 'treatment' groups based on the occupation of the parent. Sampling the housedust from each home and inspecting the premises for potential hazards would be done each year. In an ideal situation, evaluation and monitoring require a multifaceted approach covering various aspects, such as shown in Table 2.

As an alternative to the use of 'sentinel houses' as pursued in Trail, another method to qualitatively evaluate remediation effectiveness is to undertake a survey of the householder's satisfaction with residential lead abatement. Such a survey was undertaken in the Lake Macquarie area by Warner-Smith and Hancock (1999). They surveyed 19 remediated households in which resided three to seven people and one to five children (16 years or under). The opinions of residents were polarized,

Table 2
Markers of remediation effectiveness as measured by specific monitoring activities

Monitoring activity	Marker of success
1. Monitoring current emission sources using air filtration, dust fall accumulation (Port Pirie, van Alphen, 1999), moss envelopes (Trail)	Decreasing emissions
2. Ambient soil to evaluate recontamination	No increase in Pb concentration/loading
3. Water systems to evaluate leakage from containments	No increase in Pb concentration
4. Monitor residential soils and house dust	No increase in Pb concentration/loading in individual residences
5. Blood Pb surveys, especially individual children	Decreasing PbB levels, especially in individuals
6. Predictive modeling of blood Pb	Decreasing PbB levels

with the majority being either greatly satisfied or greatly dissatisfied with the process. The level of satisfaction was clearly linked to the perceived quality of the remediation performed at each residence.

5.2. *Limitations that restrict remediation evaluation*

From the descriptions of the smelter and mining communities presented at the symposium, we observed the following departures from this ideal situation:

1. Blood lead studies are usually designed to monitor the health status of the children, not progress toward remediation effectiveness. It is unethical to involve children experimentally (i.e. treatment vs. controls), or quasi-experimentally for the purpose of evaluating the effectiveness of engineering projects. All children should receive the same treatment equally and fairly, so that the possibility of lead poisoning for some children is not overlooked. Therefore all children in a family would be sampled unless the parents felt otherwise. In the statistical treatment of a family unit, multiple children with varying ages would distort the distribution pattern that one would expect from sampling a single child of a specific age group. Furthermore, children with older siblings generally have exposure patterns more advanced in age than single children or cases where the child is the oldest sibling. Other bias arises from the degree of compliance in the blood testing. If the blood lead of a child is below the 'level of concern' of 10 μg/dl, the parents commonly withdraw from the monitoring program (Hilts, in press, Maynard et al., in press, Morrison, in press, Rosen, in press). This biases the community results towards higher blood lead concentrations.
2. The play area soil lead concentration is the parameter most closely related to childhood exposure. Although there is sometimes a clear correlation between distance and soil or dust lead concentration, this relationship can be distorted by local topography. Apart from the three Australian examples, most terrains are too complex to show a convincing correlation with distance from the smoke stack. All communities are not arranged in the same spatial pattern relative to the smelter, and the surrounding terrain differs substantially, especially if the smelter is in a valley between steep mountain slopes. This creates zones of high and low contamination that are not immediately obvious until the environmental measurements are made. Other factors, such as large asphalt surfaces at supermarkets and shopping malls, may have a concentrating effect in the runoff zones, such as creeks and drainage ditches, that can often be play areas for older children. In these situations, distance from the smelter is not the primary exposure factor.
3. Communities are of course more complex than this simplified example of 500 families. Families may have one or two working parents,

either part time or full time, and in some cases, both may work at the smelter or mine. Furthermore, the quality of the housing usually varies, with the older homes usually near the smelter or mine. These may or may not be the residences of smelter or mine workers. Some families may live in mobile homes or apartments, or multiple families in a single family home. Even in an ideal case where the employees are located at a considerable distance from the operations in a well-established community, and the company provided change rooms and bus transport, it is still possible for residences to become contaminated from 'take-home' lead because of independence of the employees in driving their own vehicles (Chiaradia et al., 1997).

4. Other socio-economic factors determine the make-up of the neighborhoods, besides the occupation of the primary provider. The complex socioeconomic status (SES) of the family plays an important role in the location of the home relative to the source of the contamination and the response of the family to community education regarding lead exposure, including nutritional factors (e.g. calcium, vitamins) that affect blood lead concentrations.
5. Some families may mistrust community education programs, believing that they are: (i) inadequate; (ii) superfluous; or (iii) an improper imposition on their lives by a government agency.
6. There may be other industries (e.g. battery recycling plants) or non-industrial sources of lead contamination (e.g. lead-based paint) in the community. These would confound the effort to pinpoint specific requirements for limiting smelter or mining emissions, and to determine responsibilities for soil clean-up. In such cases, it may be necessary to undertake more sophisticated analytical methods such as lead isotope fingerprinting to evaluate the different sources.
7. Widespread contamination may arise not only from point sources but also from the use of smelter/mine waste as 'fill' for recreational areas and residences in earlier times (Morrison, in press).
8. Local, state, and federal policies determine the types of health care programs available to the residents, including the dissemination of information about potential hazards from exposure to lead. The impact of this information varies according to the value that the local community places on it, and the trust that they have in the information providers. Usually this trust is highest with the local health providers, and lowest with the federal officials who 'don't understand our community.'
9. Abrogation of the financial responsibility for the clean-up and monitoring.

6. Assessment of effectiveness from symposium examples

In almost every case study presented at the meeting, except for the Russia Far East, there was a clear remediation plan. Although the experiences at Trail and Broken Hill have come closest to ideal in lead remediation effectiveness, ongoing surveys at Broken Hill have shown a tapering off in PbB reduction since 1995, as stated by the authors '…our ability to reduce lead levels in Broken Hill children is reaching a plateau (Lively and Balding, symposium presentation).'

In Trail, the decrease in blood lead concentrations appears closely linked to recent reductions in smelter emissions and bioavailability of lead in the dust as much as to historical remediation activities (Hilts, in press).

At the Pb–Zn smelter Port Pirie, South Australia, Maynard et al. (symposium presentation) noted that the initial 10-year program failed to recognize the substantial ongoing contamination from the smelter, recontamination of houses, or pathways of childhood exposures. Furthermore, there will be difficulty in reaching the national goal of 10 μg/dl for blood lead concentrations in young children. Even reaching a goal of 15 μg/dl….'

A similar situation is present around the Cockle Creek smelter in the Lake Macquarie area. Since 1997, the blood leads in children aged 0–13 years have reached an equilibrium with approximately 30% of the children having blood leads above 10 μg/dl (Lunn and Rothery, symposium presentation; Morrison, in press).

In Romania, the 13 μg/dl in blood lead reduction over the 2-year period is highly encouraging but without smelter modifications, the community will never achieve overall levels of 10 μg/dl (Niciu et al., symposium presentation).

The established objectives are currently being met at Bunker Hill (Sheldrake and Stifelman, in press; von Lindern et al., in press a; von Lindern et al., in press b). The use of the homeowners vacuum cleaner bag could be replaced with methods that determine lead loading and lead load rate, such as the recently reported mat method.

von Braun et al. (symposium presentation) and von Braun et al. (2002) outlined the special challenges unique to the Russian Far East and pointed out that it is highly unlikely that conditions will improve unless stricter controls from the point sources of mining and smelting are implemented, concurrent with environmental clean-up and community intervention. None of these are likely to happen in the near future.

These investigations and others discussed at this workshop demonstrate how critical it is to remediate on a community wide basis (zonal remediation) rather than on an individual house basis (Lunn and Rothery, symposium presentation; Lively and Balding, symposium presentation). Given the clean-up recommendations and requirements for lead-based paint removal and clean-up and recent evidence for adverse health effects at lower blood lead concentrations in children, the issue of whether the current clean-up goals at any site will be protective of the children was debated to some degree at the symposium. This problem illustrates the dilemma common at remediation sites: should the risk management plan be based on a quick decision regarding the remediation goal that is based on current guidelines for protectiveness, or should the risk managers proceed slowly as the science of risk assessment becomes more precise through technological advances?

7. Discussion

Problems arise in implementing a remediation plan or evaluating its effectiveness in places where there is a legacy of previous mining/smelting activities and negligible commitment from the government or the company to undertake remediation. Sometimes this problem is just too large. A global standard for contamination prevention and remediation effectiveness would provide some advantages to all parties.

One approach that could be taken is similar to that in Australia where there is a Code of Environmental Management produced largely by, and with, the mining and energy industry (MCA, 1998). Australia has been very proactive in 'best practice' environmental management of mining sites (Mulligan, 1996). This practice has been generally applied to young mines because of the relatively short life of the mines (e.g. 20 years) but not to historical ones. Due to the remoteness of many of these mines, limited attention has been paid to human impacts. Most companies operating in Australia now produce an annual Environmental Management Report that includes areas of non-compliance. However, without a globally accepted policy, the concept of best practice environmental management in mining sites may not apply to other countries, as witnessed by the recent tailings dam rupture at the Baia Mare mine in Romania that was operated by an Australian company.

One of the main controversies in almost all the examples presented at the symposium was the contribution of emissions/contamination from current operators vs. historical contamination, i.e. it is strongly argued that present problems arose from resuspension or redistribution of contaminants from earlier operations when negligible controls were in place. Recent evidence indicates that current smelter emissions contribute significantly to ongoing contamination. For example, at Trail, introduction of new flash-smelting technology in 1997 resulted in air lead concentrations decreasing from 1.1 μg Pb/m^3 in 1996 to 0.28 μg Pb/m^3 in 1998 (Hilts, in press). These dramatic air lead reductions produced reductions of approximately 50% in lead loadings and concentrations in outdoor dustfall, street dust and indoor dustfall. Even more telling was the situation when the smelting and refining operations at Trail were shut down completely for 3 months during the summer of 2001. Then average air lead levels dropped to 0.03 μg/m^3 and the average blood lead level in pre-school children at the end of the shutdown was 4.7 μg/dl. Likewise, at Lake Macquarie, the smelter was closed for a period in 1993, during which time blood lead concentrations were significantly lower (Morrison, in press).

At Port Pirie, van Alphen (1999) measured heavy metal deposition rates and showed that indoor lead loadings could increase floor lead levels to 1000 $\mu g/m^2$ in less than 1 week in houses downwind from the smelter for prolonged periods and having open doors or windows. Modeling studies of air and dust lead deposition, by Maynard et al. (in press) have confirmed that the overwhelming source of household contamination is the smelter.

At Lake Macquarie, in spite of reductions in lead emissions from 92 tonnes per annum in 1988 to approximately 15 tonnes to September 2000, these emissions still commonly exceed the ambient air quality (operational) consent conditions of 1 $\mu g\ Pb/m^3$ with continued deposition of high lead dusts in residential areas (Morrison, 2000).

Another dispute concerns the issue of bioavailability of the lead. Because the dominant lead-bearing mineral is galena (lead sulfide), both at the mine site and the smelter feedstock, it is generally argued that the bioavailability of the lead is low. Experiments on ingestion of high-lead soils by swine and humans suggest that the bioavailability is of the order of 30% (Casteel et al., 1997; Graziano et al., 1996; Maddaloni et al., 1998). Furthermore, Healy et al. (1982) have shown that the bioavailability of fine-grained galena (say approx. 60 μm) is much higher than coarser material. Likewise, simple leaching experiments with dilute HCl have shown that the lead in dusts and soils that have been oxidized over time in mining communities, such as Broken Hill, is highly soluble (Gulson et al., 1994). A similar investigation of slag from the north Lake Macquarie area has shown high solubility of lead in the fine particle size fractions (Morrison, in press, personal communication). The experiments of Casteel et al. (1997) were also performed on various mining industry wastes in which galena was a significant component, but subject to minor modification in the environment.

From an international perspective, the most discouraging outcome from this symposium is the improbability that blood lead concentrations below 10 μg/dl will be achieved for all children in several mining and smelting communities, even with the most dramatic interventions. Despite early reductions in blood lead with implementation of remediation strategies, the inability to achieve further reduction is contingent on several factors that include: historical contamination, recontamination of houses, lack of funding, disinterest of government ('lead is no longer a problem'), and dietary and behavioral aspects of life styles.

However, the symposium reinforced certain essential remediation principles that include the importance of community nursing staff providing individual attention for the child and caregivers and how critical it is to remediate on a community-wide (zonal remediation) basis rather than on an individual house basis. Furthermore, it demonstrated that experts can differ in interpretations of blood lead surveys and also appropriateness of making a decision on the basis of a biokinetic model.

Is contamination always a significant problem? Here we suggest a tentative 'No' because in isolated communities where there is limited population, limited vegetation and water supplies because of a desert environment and hence less likelihood of widespread contamination, it may be less of a problem. Furthermore, if companies instigate 'best practice' which includes setting aside funds for restoration, there should be minimal impact.

Finally, it may be necessary to follow the theme of 'learning to live with lead' espoused by Dr Mark Jacobs, who undertook the 1991 blood lead surveys in Broken Hill (Jacobs, 1992). The intent of this concept is that communities with historical lead contamination unfortunately must be diligent in maintaining awareness within the community of potential lead hazards remaining after the completion of the remediation program. In many cases, this concept is built into the remediation plan. On the other hand, from the perspective of the home-makers in the community, 'learning to live with lead' can be seen as a form of social injustice if it is advocated as a substitute for environmental clean-up.

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