EVALUATION OF A
LEAD EXPOSURE REDUCTION INTERVENTION FOR
SHUTDOWN MAINTENANCE CONTRACTORS
AT A PRIMARY LEAD SMELTER

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ABSTRACT

Inorganic lead is a hazardous substance, exposure to which has been linked to various adverse health effects including haematological, neurological, renal and reproductive health problems. These adverse health effects can be correlated with blood lead levels (BLL) and are potentially significant for lead workers, such as production and maintenance personnel at lead smelters. Such workers usually need to wear particle-filtering respirators in order to reduce uptake of airborne lead, and follow strict hygiene protocols. However, there is a paucity of literature on the effectiveness of lead exposure reduction programs for lead smelter workers, especially those engaged as contractors for short periods.

The aim of this study was to evaluate an intervention targeted at maintenance and refurbishment contractors engaged during a two-yearly plant shutdown of a primary lead smelter. This evaluation addressed a variety of factors that influence the uptake of lead and gathered information on a rarely-studied group of contractors so as to provide recommendations for improving future occupational health and safety (OHS) interventions in lead industries. Findings from the research may assist in refining conceptual models of OHS interventions addressing complex exposure scenarios.

The intervention for the contractors entailed training and the mandatory use of a single brand of half-face disposable particle respirator. Contractors were instructed by the smelter management to undergo a pre-employment blood lead test and attend a health and safety induction, where they were informed of lead hazards and trained in the correct usage of disposable respirators. A post-induction questionnaire was used to elicit information on personal characteristics, smoking status, lead-based hobbies (hobbies that expose contractors to inorganic lead), prior respirator experience and perceptions of the use of disposable respirators. Fixed-position air sampling was conducted to determine the levels of airborne lead-bearing dust generated during maintenance activities and to assess differences between areas, including rest areas. Compliance with respirator usage requirements was assessed by routine observation, and site inspection checklists were used for the assessment of lead contamination. After the two-week shutdown period and prior to departure from the site, contractors underwent a second blood lead test. Other information was gathered prior to, during and after the intervention, through repeated observation and discussions with key stakeholders, and formed the basis of a stakeholder analysis.

Full questionnaire and blood lead data were available for 62 male contractors, and of these 81% were previous contractors to the smelter, 87% had previous respirator experience, 78% believed disposable respirators were equal in protection to non-disposable rubber respirators, 87% were confident disposable respirators would keep blood lead down, and 35% reported non-occupational exposure to lead. The arithmetic mean entry BLL was 5.5 μg/dl (std dev=3.9) and the increase in BLL over the shutdown period was 14.4 (9.3). Smokers (n=18) had a mean increase of 17.4 μg/dl, compared to non-smokers (n=44) with 13.2 μg/dl, but this difference was not statistically significant. Similarly, potentially predictive factors such as age, job category, lead-based hobbies, respirator experience and confidence were not statistically significant. Crane operators and riggers (n=8) had the greatest increase in BLL (19.6), compared with welders (17.1, n=9) and general maintenance contractors (13.0, n=45). Although it was a non-smoking site, many contractors were observed to smoke. Observed compliance with respirator usage was

generally good (estimated at 95% via direct observation). However it appeared that compliance and airborne lead dust levels were variable between locations, indicating these may be task related. Hot work, e.g. welding in confined areas, was associated with lower respirator usage and sweat-related respirator deterioration. Air monitoring in an area ostensibly lead-free, i.e. the blast furnace crib room (rest area), demonstrated appreciable levels of airborne lead dust (GM = 55 $\mu g/m^3$, n=4).

A stakeholder analysis of the intervention identified a lack of consultation between contractors and management prior to implementation. It was evident that smokers had difficulty complying with the strict non-smoking rules and that some contractors wore contaminated clothing in crib rooms, a source of lead exposure and a breach of policy. In addition, contractors were often unshaven, which significantly reduces the effectiveness of the mandated respirators. Finally, some contracting companies exhausted their supply of respirators, suggesting logistical problems and limited consultation.

This study appears to be the first to report increases in blood lead for a cohort of shutdown maintenance contractors working in a lead smelter environment. It also demonstrates appreciable BLL increases in a relatively short space of time.

The findings relating to airborne lead and to BLL differences between contracting companies indicate that lead uptake is associated with task and that the use of a half-face disposable respirator with moderate protection performance may not be suitable for all tasks. The lack of personal inhalational exposure data limits the interpretation of the effectiveness of the respiratory protection program based on BLL alone. The stakeholder analysis highlighted disparate management and contractor perspectives on consultation.

Overall, however, the intervention was judged as successful by the lead smelting company on the basis of observed respirator compliance and by a crude comparison with BLL data observed in a previous shutdown period, two years earlier.

It is recommended that task-specific personal air sampling be undertaken, especially for hot work, in order to determine whether the half-face respirator is adequate for all tasks. The induction training should more explicitly address routes of lead exposure and the importance of factors determining respirator effectiveness. A greater degree of consultation between contracting companies and smelter management should be undertaken in order to address logistics issues, work practices and hygiene, especially for smokers. This study has highlighted the complexity of exposure pathways, often mediated by worker behaviour in response to company directives, and relatedly, the value of stakeholder analysis as a means of identifying areas for improvement. The change in BLL serves as an index of actual success for future interventions.

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STATEMENT

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.
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GLOSSARY AND ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists *A standard-setting group based in the USA*
APF	Assigned Protection Factor *This is the estimated (or nominal) ratio of the concentration of the airborne contaminant outside the respirator to the concentration inside the respirator*
ANOVA	Analysis of Variance
ASCC	Australian Safety and Compensation Council (now SafeWork Australia)
BLL	Blood Lead Level, typically measured as micrograms per decilitre (µg/dl)
Crib Rooms	*Designated areas for workers to take meal and rest breaks*
Donning	*The process of putting on a respirator*
EPA	Environmental Protection Agency
GM	Geometric Mean
GSD	Geometric Standard Deviation
HEPA	High Efficiency Particulate Arrestor
IARC	International Agency for Research on Cancer
ILO	International Labour Organization
IOM	Institute of Occupational Medicine (UK)
MMAD	Mass Median Aerodynamic Diameter
NIOSH	United States National Institute for Occupational Safety and Health *Part of the CDC (Centers for Disease Control and Prevention) NIOSH is responsible for conducting research and making recommendations for the prevention of work-related illnesses and injuries.*
OHSI	Occupational Health and Safety Intervention *Interventions designed to improve occupational health and safety outcomes through identification and control of hazards in the workplace that are potentially harmful to health.*
OSHA	United States Occupational Safety and Health Administration *US health and safety regulatory agency*
PbA	Airborne Lead
PAPR	Powered Air Purifying Respirator
PEL	Permissible Exposure Limit *Exposure limits set and enforced by OSHA*
PPE	Personal Protective Equipment *Equipment designed for individuals to use to minimise exposure to hazards.*
SME	Small and Medium Enterprises
TWA	Time Weighted Average
WPF	Workplace Protection Factor *The ratio of the concentration of the air contaminant outside of the respirator to the concentration inside the respirator, worn during actual work activity.*

CHAPTER 1: LEAD HAZARDS AND MODES OF EXPOSURE IN LEAD SMELTERS

Full-time employees in heavy industries such as lead smelters generally carry out their work under normal plant operating conditions where the hazards have already been characterised, and appropriate engineering, administrative and PPE controls implemented. In contrast, maintenance contractors employed during plant shutdowns work in conditions in which the hazards from exposure to toxic substances are often poorly characterised.

In this thesis, an evaluation of a primary lead smelter's respiratory protection intervention targeting contractor personnel during a major maintenance shutdown is presented. This intervention incorporated training in disposable respirator usage and hygiene measures, coupled with enforcement of compliance protocols to reduce maintenance contractor uptake of lead, as measured by Blood Lead Level (BLL). The contractors were welders, metal fabricators, transport personnel, cleaners, ceramic kiln service contractors, electricians, plumbers and other relevant workers employed during a biannual maintenance shutdown to replace and upgrade equipment in the primary lead smelter plant. The success, or otherwise, of this intervention was primarily judged on the basis of contractor BBL at the conclusion of employment, compared with BLL values recorded in a previous maintenance shutdown. Another criterion was respirator compliance.

1.1 DESCRIPTION OF THE HEALTH HAZARD

Lead is a naturally occurring soft bluish-grey metal; with the predominant use (80%) being in batteries (EPA, 1995). To a lesser extent, lead is used in construction materials, fuel tanks, TV glass, radiation shielding, ammunition, protective coatings, ballasts, weights, ceramics, wire and lead-based chemicals (EPA, 1995; Sharp Program 1999). It is also combined with other metals to form alloys. Lead-based industries may be a source of lead exposure to the surrounding population, and to lead workers, including their families (Aguilar-Garduno et al., 2003). The major mechanisms for distribution of lead include crushing and dry grinding operations and lead smelting (ILO, 1997).

Lead exposure can result in a wide range of acute and chronic health problems including neurological changes, damage to blood-forming tissue and increased blood pressure SHARP Programme (1999). To mitigate the adverse health effects of lead it is crucial to minimise exposure. Accordingly, lead industries have for many years been required to comply with prescriptive OHS and environmental regulations. For the purposes of this thesis, the emphasis will be on occupational exposure to inorganic lead arising from primary lead smelting.

1.2 ROUTES OF EXPOSURE

The important routes of human exposure to lead are through inhalation of lead dust or fume, ingestion primarily through handling food with lead-contaminated hands, and to a lesser extent - ingestion of contaminated soil and water. Percutaneous absorption of lead is also a possibility under certain circumstances (Stauber et al., 1994). Inorganic or elemental lead is not metabolised, instead it is absorbed and distributed through the body via the blood targeting the kidneys, bone marrow, bones, liver, brain and teeth before eventually being excreted. The traditional and most widely accepted measure of lead uptake is the blood lead level (Barbosa et al., 2005).

The body absorbs practically all inhaled lead, whereas 20 to 70 percent of ingested lead in adults is absorbed (ATSDR, 2007). The absorption of lead depends on several factors including chemical and physical form such as particle size. Individual factors are also important - these include sex, age and possibly, genetic background (ATSDR 2007). Absorption rates/levels per individual are also dependent on factors such as levels of fat, calcium, iron and proteins in the digestive system. A fatty diet increases the absorption of lead, while a healthy diet reduces absorption of ingested lead (ATSDR, 2007). It is also important to note that in adults, 90 percent of absorbed inorganic lead is stored in bones, which can be a significant source of endogenous lead, particularly for women during pregnancy (Gerr et al., 2002), and the period just after menopause when bone-resorbtion rates increase (ATSDR, 2007). Lead can also be ‘leached’ out of the bones by strenuous physical exercise. Accordingly, workers involved in heavy physical activity could be at risk from increased uptake of lead due to environmental exposure and leaching of lead from the bone into the blood, increasing BLL (ATSDR, 2007). Finally, heavy physical work increases respiration, which can increase uptake of lead by increased breathing rate, which increases the volume of air taken in by the lungs and the accordingly amount of lead taken into the body.

1.3 HEALTH IMPACTS OF LEAD EXPOSURE

The 1 table and figure summarise the various health effects corresponding to differing BLL concentrations.

Table 1: Health problems associated with blood lead[1]

NOTE:
This table is included on page 3
of the print copy of the thesis held in
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[1] Source: Adapted from SHARP Programme (1999) www.lni.wa.gov/Safety/Research/files/lead_work.pdf

NOTE:
This figure is included on page 4
of the print copy of the thesis held in
the University of Adelaide Library.

Figure 1: Dose-effect relationships for lead[2]

Blood Pressure

Sharps et al (1990), Moller and Kristenson (1992) and Tepper et al (2001) found a positive relationship between blood pressure and BLL. More recently, Gerr et al (2002) found

[2] Source: Tong et al (2000)

significant blood pressure differences for groups of young adults who, as children, inhabited towns surrounding lead smelters and groups of young adults who had not lived near lead smelters. There was also a positive correlation with bone lead concentrations even though the current blood lead levels of participants were low. This study implies that a strong and persistent effect of childhood lead exposure is increased blood pressure in later life.

Lead and Cancer

Epidemiological evidence of possible cancer hazards from exposure to lead and lead compounds was investigated by the International Agency for Research on Cancer (IARC). An IARC Working Group considered six occupational cohort studies of highly-exposed workers, including smelter workers in Italy, Sweden and the USA (two studies). It concluded that inorganic lead compounds are probably carcinogenic to humans, particularly with respect to renal and stomach related cancers (Group 2A). Further, lead can interact with proteins, including those involved in DNA repair. This latter mechanism may be responsible for the enhancement of genetic toxicity caused by other agents. These properties could result in mutation, cell proliferation and changes in gene expression, all of which would contribute to a carcinogenic response under conditions of sustained exposure to lead (IARC 2004).

Neurotoxicity

Even at relatively low BLLs significant differences have been found in executive function, as measured by the Wisconsin test (which measures prefrontal dysfunction and is used to evaluate schizophrenia), visual recognition tests, and visual spatial abilities and block design testing. Barth et al (2002) compared a group with relatively high BLL (mean = 30.8 μg/dl , which is similar to the Australian occupational guideline of 30 for male workers), and a reference group with low BLL (mean = 4.34 μg/dl). They found a significant dose response relationship with respect to cognitive deficits. Wu et al (2000) found a significant correlation between high, long-term lead exposure, measured by duration of employment and ambient lead concentrations and diminished hearing ability. Further, they found through different mechanisms, lead exposure can cause severe and permanent hearing damage.

Renal Damage

The body primarily excretes absorbed lead through the kidneys. Renal damage has been observed in the kidney proximal tubules where two thirds of lead is reabsorbed (Zenz 1994;

DeRoos 1997; Loghman-Adham 1997; Rodriguez 1997 cited by Wang et al., 2002). Furthermore, the toxic effect of chronic lead exposure can cause interstitial fibrosis (fibre formation between tubules in kidneys), glomerular sclerosis (degeneration association with renal arteriosclerosis), and both hyperplasia (abnormal increase in the number of cells in kidneys) and atrophy (deterioration) of tubules. Overall, these toxic effects can lead to irreversible renal damage (Nolan and Shaikh 1992; Loghman-Adhan 1997 cited by Wang 2002). Further, several studies (Payton et al., 1994; Staessen et al., 1992 and Wang 2002) have identified a dose response relationship between lead exposure and renal dysfunction. Wang and coworkers (2002) also found that male workers in a lead battery plant study were at a higher risk of renal dysfunction than female workers - this does not appear to be due to higher exposure, as workers were performing similar work. The study by Wang and coworkers (2002) also identified that the renal function indices of Blood Urea and Nitrogen and Uric Acid were best at identifying lead-induced renal dysfunction at exposures at a level of 60 μg/dl or above. Finally, Lin et al (2002) found that chronic exposure to lead increases the incidence of gout in lead workers.

Reproductive Health Effects

Lead can cross the placental barrier causing neurological impairment in the developing nervous systems (Zi-quiang et al., 1985). Moreover, even relatively low maternal exposure of 10 μg/dl produces behavioural and intellectual impairments in children (Goyer 1990; Mushak et al., 1989). Accordingly, pregnant women should avoid even low levels of lead exposure. Lead exposure can cause reproductive harm to males. BLLs of 60 μg/dl have been associated with male infertility (Fisher-Fischbein et al., 1987) and 40 μg/dl may cause decreased sperm count and abnormal sperm morphology (Alexander et al., 1996). Finally, several studies have found decreased sperm quality and hormonal changes in male workers exposed to lead with BLLs of 30 to 40 μg/dl (Ng et al., 1991).

More recent research by Canfield et al (2003) indicates that there is no safe threshold but rather a continuum of toxic effects, particularly in children.

1.4 SOURCES OF LEAD EXPOSURE

Areas near lead mines and smelters have high environmental concentrations of lead, which may lead to appreciable exposures to the adjacent human populations via ground level emissions, atmospheric fallout from stack emissions and historical poor practices. Industries and processes in which the highest potential exposure to lead exists include mining, primary and secondary lead smelting, production of lead-acid batteries, pigment production, construction and demolition (IARC 2004). Workers in these industries can unwittingly put their families and significant others at risk from secondary exposure due to bringing home lead dust in their clothing, shoes and on their bodies, such as hair (ATSDR 2007). Workers themselves are predominately exposed through fumes and dust. Maintenance contractors (especially those working during maintenance shut downs) may be at an elevated risk due to build up of leaded material over time, confined areas, non-routine activities and the need/desire to complete the job quickly.

The Effect of Heat on Lead Exposure

There is evidence that hot work may be a modifying factor for lead exposure, and uptake. Grauvogel (1986) examined a lead battery factory and found the highest ambient lead levels were in processes where moderate heat was involved. Paik and Park (2001) and Froines et al (1986) found proportionally more fine airborne lead particles (sub-micrometre size) in high temperature operations such as furnaces, soldering and dipping. The use of heat guns to remove old leaded paint can dramatically increase exposure to lead (Scholtz et al., 2001). In addition, metal cutting with either oxy acetylene and/or cutting with grinders also dramatically increases worker exposure to lead (Holness and Nethercott, 1988; Johnston et al., 2000; Waller et al., 1992; Scholtz et al., 2001). These situations suggest a greater health risk due to increased exposure, and probably more efficient uptake of lead from the finer particles. This is of concern for maintenance contractors in lead smelters as much of their activities may involve hot work, metal cutting and grinding.

1.5 DESCRIPTION OF A LEAD SMELTER OPERATION

The following figure is a schematic representation of a lead smelter operation.

NOTE:
This figure is included on page 8
of the print copy of the thesis held in
the University of Adelaide Library.

Figure 2: Schematic representation of a lead smelter operation concentrating and sintering[3]

Lead ores or lead concentrates are crushed, ground and concentrated on site. Then the concentrate is pelletised with coke in a sinter unit where fine particles are agglomerated, converting metal sulphides to metal oxides and sulphates. Sulphur is removed as sulphur dioxide (SO_2), which is fed to an acid plant to produce concentrated sulphuric acid. This sintered material is fed to a blast furnace together with coke and fluxes.

[3] *Source: Environment Australia (1999)*

1.5.1 BLAST FURNACE

Photograph 1: Top of blast furnace (note lead dust seen here as speckles)

Here, the lead is smeltered or reduced to molten material, which separates into four layers consisting of lead bullion, ‘speiss’ and ‘matte’ which are two layers containing copper, zinc, gold and silver. The other layer is ‘slag’, which is waste material. The speiss, matte and lead bullion are then ‘drossed’, meaning agitated and cooled in a drossing kettle. Here the lead and other metals are separated, copper is sent to a dross leaching plant to be converted to high purity copper while the lead bullion that contains lead, zinc, gold and silver is transferred to a desilderising kettle to separate the lead from the other metals (EPA 1995).

Photograph 2: Front of blast furnace illustrating the scale and size of the operation

CHAPTER 2: INTERVENTIONS FOR LEAD EXPOSED WORKERS

2.1 GENERAL MODEL FOR AN OHS INTERVENTION AND POTENTIAL POINTS OF EVALUATION

2.1.1 DEFINITIONS OF OHS INTERVENTIONS AND EVALUATIONS

OHS interventions may be broadly classified as efforts aimed at reducing workplace injuries and illness. OHS intervention research addresses the development, implementation and evaluation of such interventions, with the purpose being to convert fundamental research understanding into health and safety actions and benefits. This requires a multidisciplinary approach drawn from areas such as ergonomics, psychology and epidemiology (LaMontagne 2003). A range of ethical, practical and legal issues may need to be considered (Darragh et al., 2004; NIOSH, 2001).

Rarely do OHS interventions eliminate the risk, but evaluations provide an important means of cyclical improvement. As such, OHS intervention research is a form of action research (Runnals and Cowley, 2004).

In many cases, the evaluation of interventions relates to an assessment of effectiveness, expressed quantitatively, e.g. in terms of reduced workplace injuries and illness (Goldenhar et al 2001). However, evaluations may also refer to process (design and implementation) and diffusion (the spread of intervention once deemed to be successful and capable of transfer, e.g. to a similar industry or jurisdiction). Interventions may be conducted at the enterprise level (as in this research) or at the policy/government level.

2.1.2 CONCEPTUAL MODEL OF AN OCCUPATIONAL HEALTH AND SAFETY INTERVENTION AND EVALUATION

The current thinking in this field largely stems from research in the US and Canada (LaMontagne, 2003; LaMontagne, 2004; and Goldenhar et al., 2001). The following steps represent the basic approach as seen can be seen in Figure 3

Gather Background Information/Organisational Phase (Needs and Risk Assessment)

Consult with stakeholders and determine what the issues are. Establish or prioritise identified issues. Is the problem a chemical or process? (Rosenberg et al., 2001) Investigate in order of importance which health outcomes the intervention is trying to target and how outcomes will be measured (Marson, 2001). What are the foreseeable risks and evaluation history of this intervention/research? Have any evaluation studies been done before? (Goldenhar et al., 2001; LaMontagne, 2004). At this stage, it may be necessary to incorporate a mechanism to see if the risk is specific to human health such as exposure to chemicals, which can be quantified and/or other risk that may be more qualitative such as ergonomic risks. If the risk is quantifiable (such as exposure to ethyl oxide) then different measures, controls and immediate actions will be required (LaMontagne et al., 2003; LaMontagne et al., 2004). This may also require a disease registry - as was the case with an intervention to reduce occupational skin disease in hairdressers through the withdrawal of hair products using glyceryl monothioglycolate, a sensitizing agent (Dickel et al., 2002). The following information is research into OHS interventions incorporating, primarily Work Environment Impact Assessment (WEIS) (Rosenberg et al., 2001) and National Institute for Occupational Safety and Health (NIOSH), Intervention Effectiveness Team findings (1996), cited by La Montagne (2004a); La Montagne (2003a) and Goldenhar et al (2001). Establish and Cultivate Partnerships with Stakeholders

How will a commitment from the target (group) be established, if this can be done at all? How will their buy in be orchestrated? (LaMontagne and Shaw, 2002). What will the barriers be such as cultural, socio political, environmental? Is the organisation in the middle of downsizing? (Goldenhar et al., 2001; Frank et al., 2003).

Choose Study Designs, Research Methods

What OHS principles will be used? Is there previous research into the current issue? What baselines will be used? What study designs and subsequent statistical methods? (NIOSH 2001). It is usually not feasible to have control groups in intervention effectiveness studies however there are exceptions such as a study by Goldenberg et al (2000). If process or chemicals are substituted, what are the possible health effects? (Rosenberg et al., 2001).

Implement the Intervention/Research and Evaluate

What unanticipated barriers are there, such as target acceptance? Are there unanticipated or negative consequences such as under reporting of accidents? (Frank et al., 2003). Does it have other effects such as staffing requirements and skill levels? (Rosenberg et al., 2001). What is the feedback from targets? This could be customers as well as workers (Marson 2001). This feedback can be crucial for the effectiveness of an intervention. The intervention reported by Goldberg et al (2000) introduced control measure to reduce lead exposure at one site while another similar site was used as a reference site. At both sites the task was removal of old steel structures containing leaded paint. There was no significant difference between the two sites as measured by lead exposure. The researchers surmised that this was partly due to management problems in coordinating contractors, providing ongoing guidance to contractors and ongoing assessment of the new measures. If process evaluation was included as part of the intervention these problems may well have been addressed at an early stage, perhaps yielding the expected difference in exposures between sites. Some hazards such as chemicals require feedback to enable immediate corrective action, as was the case with ethylene oxide exposure in hospitals (LaMontagne et al., 2004). Finally, once the evaluation cycle has been completed, to what extent can diffusion research be employed? This can translate the intervention to other populations and worksites (Goldenhar et al., 2001).

Report and Dissemination of Findings or Feedback

Provide feedback to stakeholders on findings, share with others so that the knowledge is transferred. Findings must be fed back, where necessary redo the intervention, incorporating recommendations (Goldenhar et al., 2001; Marson, 2001).

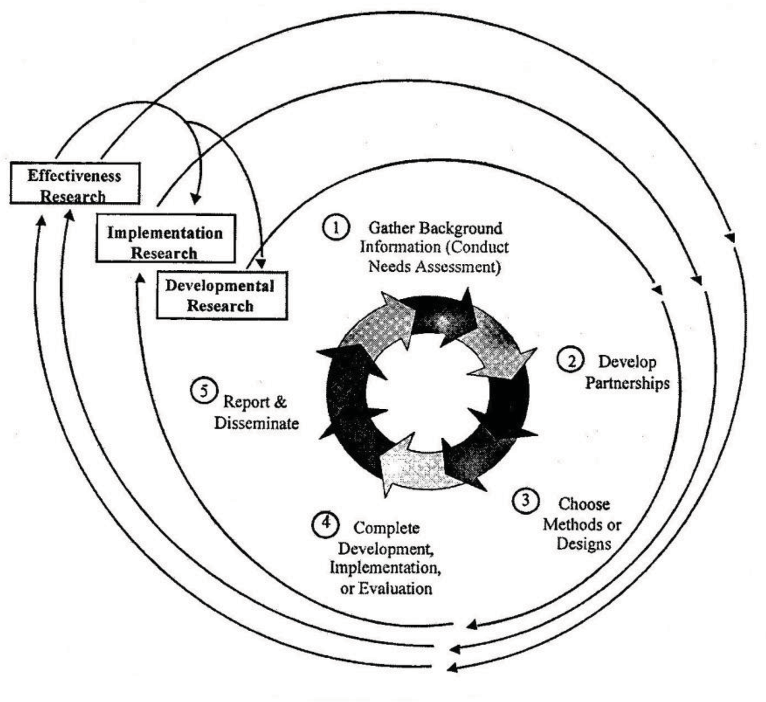


Figure 3: Occupational Health and Safety Intervention Model Conceptual Model (Goldenhar et al., 2001; NOHSC 2003). This is considered to be a classic theoretical representation of how to conduct an OHS intervention

2.1.3 PROCESS AND EFFECTIVENESS EVALUATION

There are two main areas of evaluation, each of which should be considered.

Process Evaluation

Process evaluation (also dubbed program monitoring) is more concerned with how well the intervention is executed and provides information aimed at improved implementation in subsequent iterations (LaMontagne 2004). This has particular relevance to policy level interventions.

The evaluation can be conducted during an intervention to provide corrective feedback; an example is a process evaluation of a program to reduce needle stick injuries. It may not be working properly because management do not understand the needs of employees (Goldenhar et al., 2001). That is, stakeholders have not been properly included (LaMontagne 2002). Another example in the literature is an evaluation of the ethylene oxide standard - ethylene oxide is a human carcinogen, neurotoxin and sensitiser, used for sterilising sensitive hospital instruments (LaMontagne et al., 2004). This revealed, that while most of the recommendations were implemented, workers were still being exposed to unforseen ‘accidental releases’. As a consequence, regulations were modified to mandate that all standards are reviewed every decade (LaMontagne 2004). Implementation evaluation encompasses details such as whether stakeholders were consulted throughout, appropriately involved in the intervention and most importantly given feedback. Key questions are: did the intervention actually reach the targeted groups and were there unforseen issues? For example a process intervention evaluation of near misses and fatalities in the fishing industry in Alaska found the need for improved immersion clothing and radio beacons (Smith 2001).

It is important not to use a process evaluation as merely a proxy measure for outcomes as it does not necessarily indicate cause and effect (Hulshof et al., 1999).

Effectiveness Evaluation Studies

An OHS intervention may be evaluated in terms of outcome. Key questions include:

Did the intervention decrease exposure to the hazard of interest? Did it lead to better health outcomes, or was it actually the intervention that ‘caused’ the observed changes, or desired effect (LaMontagne 2004). If a disease registry is established, is there is a decrease in prevalence? Other measures can be the impacts on social, political and economic outcomes from the intervention, such as how well or did the stakeholders attitudes or behaviours change (Goldenhar 2001). Conversely, did the intervention have negative effects such as management concealing injury data? (Frank et al 2003). In general, are the measures and data gathering activities established at the beginning of an intervention?

Finally, intervention effectiveness evaluations should incorporate, where possible, replication to ensure assessment of extraneous variables (Frank et al 2003). This is often, however, difficult in real world settings.

2.1.4 HIDDEN BENEFITS OF OHS INTERVENTIONS

There are a number of intangibles associated with effective interventions, e.g. reduced anxiety, which could be translated into job satisfaction and indirectly increased productivity (Miller et al., 2000). However, it appears that such benefits are rarely assessed.

Relatedly, it can be argued that much of the loss incurred or saved through an OHS intervention is not easily quantified. If it does not show on the "balance sheet", it may be considered a hidden cost or benefit. Heinrich (1959), cited by Rikardsson and Impgaard (2004), estimated that 75% of the cost from OHS injuries was hidden. Hidden costs include lost capacity, morale, hiring costs, adjustment costs (other employees needing to adjust to the impact of an OHS incident), retraining costs and workplace disruption (Corcoran 2004; Reville et al., 2001). Indeed, opportunity costs borne from poor OHS can include loss of competitive advantage. This alone is estimated to cost in the United States ten billion dollars per annum (Rikardsson and Impgaard 2004).

Several researchers have commented on the complexity of conducting such research, for example in the midst of workplace organisational changes, or when it is impractical to have suitable comparison groups (Estill and MacDonald 2002; Lazovich et al., 2002 and Darragh et al 2004). As one author commented 'Our experience shows the enormous complexity of undertaking intervention research in occupational settings' (Lazovich et al., 2002, p 1502,). In the Minnesota wood dust study, the goal of reducing wood dust exposure by 26% was not achieved but there were other benefits (Lazovich et al., 2002).

Researchers such as LaMontagne (2004) and Miller et al (2002), point out that organisations that formally evaluate OHS interventions are more likely to acknowledge benefits such as reduced medical/legal costs, and improved health and morale of employees translating into increased productivity through reduced absenteeism. Although the evidence may not be presented quantitatively or comprehensively, a strong business case for continuation and refinement of the intervention may emerge at the enterprise level. The evidence arising from evaluations may also lead to uptake of the intervention beyond the enterprise and into the general industry or community.

2.2 LITERATURE REVIEW OF OHS INTERVENTIONS FOR LEAD EXPOSED WORKERS

The following review of occupational lead intervention studies was assisted by a formal literature search using databases and search engines pertaining to the occupational health and safety literature: Medline, OSH-ROM, CIS-DOC, NIOSHTIC, HSE-line, Academic Search Elite and Google Scholar. Further articles were identified from the reference lists of the articles found. Key words used were: respirators, intervention, intervention research, OHS evaluation, contractors and OHS intervention(s). Selection criteria included work published after 1986 in English and from peer reviewed journals.

2.2.1 STUDIES OF PERSONAL RESPIRATORY PROTECTION

In general, respiratory protection programs are effective in reducing BLL even though the respiratory route may not be the only route of exposure (Lee et al., 1993). On a unit basis, the cheapest form of respiratory protection from lead-bearing aerosols is the disposable half-face paper/fabric-type respirators. As lead is considered a toxic substance, the recommended filtration rating for the respirator is “P2”, as designated in the Australian Standard for personal respiratory protection (AS/NZS 1715:1994, Selection, use and maintenance or respiratory protective devices). This standard was used as a reference for this study it must be noted that is has been updated in 2009. The next cheapest is the non-disposable half face rubber respirator, which requires the use of an air purifying cartridge (again a P2 rating). This non-disposable respirator is traditionally regarded as the standard form of industrial respiratory protection for dusts. When fitted and worn properly, disposable half face fabric-type respirators have been shown to provide equivalent protection to the standard half-face non-disposable rubber respirators. Grauvogel (1986) compared the performance of conventional and Powered Air Purifying Respirators (PAPR) in a battery manufacturing plant. There was no significant difference in BLL which indicated that the disposable respirators were as effective as non-disposable types, including PAPR. Spear et al (2000) found no relationship between the concentration of airborne dust inside the disposable respirators worn by foundry workers and that in the ambient foundry environment, again suggesting that these respirators were effective. Hery et al (1991) found that total inward leakage of P2 masks actually decreased as the outside concentration of lead increased. A study by Myers et al (1996) found no difference between rubber and disposable half-face piece respirators in three foundries. They concluded that so long as they were conscientiously used and worn in conjunction with other existing controls in these foundries, disposable dust-fume-mist half-face respirators provided effective protection. A study by Lormphongs et al (2003) found using cotton masks did not reduce BLL. However, they also found no significant relationship between airborne lead level and BLLs.

These studies also indicate that disposable P2 masks are effective across a wide range of lead concentrations, with a nominal protection factor of 10. In other words, the imputed airborne lead concentration inside the respirator is one tenth of the concentration outside the respirator.

Scholtz et al (2001) recommended that any task involving exposure to lead be assessed and that appropriate respirators used. A protection factor higher than 10 may be necessary, in which case a powered air purifying or air supplied respirator might be selected (AS/NZS 1715:1994). Maintenance programs also need to be implemented such as regular changing of cartridges, or in the case of disposable respirators, regular changing of masks.

Training is also important to educate users on factors which may compromise the respirator's effectiveness. It has been found that as the concentration of lead dust increased, so too does breathing resistance which can lead to the failure of the respirator seal thus increasing exposure (Nelson and Colton 2000).

Frequent users of respirators have a more negative perception of the inconveniences associated with respirator usage such as visual impairment (Salazar et al., 2001). Once again training and education is important in addressing these perceptions. Another factor determining the effectiveness of disposable respirators is facial fit. Han (1999) found that the female shaped face does not have a good fit for current half face respirators. Further, manufacturers often use anthropometric data from the United Sates military and thus may not appropriate for other facial structures and profiles (Han 1999).

Another issue is compliance. Aiba et al (1995) used a questionnaire to evaluate the selection, use, maintenance, storage and training of respirators in lead workers. The study found 22 percent used unauthorized respirators and 73 percent used knit covers which interfered with the seal. Subsequent training of safety supervisors responsible for training employees led to a significant increase in use of correct respirators and a corresponding decreased use of knit covers. However, a follow up questionnaire found a significant number of employees were still using knit covers. This illustrates that despite training, employees may still not comply with safety directions hence compliance is a significant issue with respirator usage. Another study undertaken by Spear et al (2000) examined respirator usage in a lead factory. At the conclusion of this study, they surmised that observed increases in BLL were due to non-compliance.

Wu (2002) and Spear et al (2000) found significant variability in protection factors in respirator field studies, which they surmise were due to compliance. Spear et al (2000) commented that increased BLL may be attributable to a lack of compliance for various reasons, e.g. workers needing to communicate, not consistently wearing respirators and removing them well before entering canteens. Grauvogel (1986) also observed that workers regularly broke the seal of their respirator to communicate.

The issues of respirator selection, use and maintenance and training will be revisited later in the section 5 the Discussion section.

2.2.2 HYGIENE PRACTICES

Ingestion may be a key route of exposure for lead exposed workers (Grauvogel 1986; Holness and Nethercott 1988). Factors such as providing clean eating facilities, mandatory washing of hands before eating and removal of clothing before entering 'crib rooms'[4] (eating areas and rest rooms) can influence the intake of lead (Askin and Volkmann 1997; Choy 2004; Johnston et al., 2000). A study of lead refinery workers found a correlation between facial wipes lead levels and lead in fingernails with BLL, concluding that lead ingestion from contaminated face and fingers contributed to elevated BLL (Cherrie et al., 2006). Other hygiene factors relating to drinking or smoking on site can assist in reducing lead intake. In a study of lead battery factory workers Choy (2004) found that certain cultural practices, such as eating with hands, facilitated the intake of lead. This is supported by other studies (Far et al., 1993). Indeed, Askin and Volkmann (1997) and Ulenbelt et al (1990) found hygiene practices were statistically more important in controlling intake of lead than reducing airborne lead exposures. Chuang et al (1999) found hygiene behaviours, such as eating at work more than 3 days a week, had a 63% greater likelihood of a high BLL compared to those who never ate at work. A synergistic effect existed with workers eating and smoking at work more than 3 days a week such that they were 3 times more likely to exceed the Taiwanese maximum allowable exposure criteria of 40 μg/dl for males or 30 μg/dl for females, compared with those who did neither. Lai et al (1997) found that personal hygiene practices such as inappropriate usage of cotton gloves and masks was positively correlated with increased BLLs. This author found that education in appropriate hygiene practices is more important in reducing BLLs than reducing ambient exposure, particularly where engineering controls are difficult to implement. Overall most studies (Askin and Volkmann 1997; Chuang et al., 1999; Choy et al., 2004; Porru et al., 1993) found health promotion programs, such as worker education on the dangers of lead and education on good hygiene factors, significantly decreased BLLs. Chuang et al (1999) suggests health promotion may reduce average BLL concentrations by 10 μg/dl.

Education and training programs are essential. Indeed Paik and Park (2001) found a relationship between education and hygiene related messages and reduced BLLs. It is in most jurisdictions a legal obligation for management to ensure that training and education is provided on the health effects of lead coupled with enforcement of good hygiene practices. However, Lai et al (1997) found that while workers complied with the requirement to washing their hands with the recommended dilute nitric acid, management hadn't catered for the increased usage. Despite their best intentions workers still had significant levels of lead on their hands, which could be orally absorbed through handling of food.

2.2.3 SMOKING AND LEAD

A study by EL-Safety et al (2004) found that lead workers who smoked had a significantly higher excretion of urinary copper and zinc (a measure of renal functioning) than lead exposed non-smokers. It is however not entirely clear whether it is smoker's hand to mouth behaviour, the smoking or indeed a combination of both that increases their uptake of lead as was found Paik and Park (2001).

The contribution of smoking can be explained by contamination of the tobacco and cigarette paper by rolling cigarettes with dirty hands and by keeping the tobacco in the work clothes. This lead is inhaled as lead fume (Ulenbelt et al., 1990) or ingestion of larger lead particles. Expectoration is related to smoking but may actually be protective, e.g. spitting can reduce the potential for gastrointestinal uptake (Ulenbelt et al., 1990). A study by Hwang et al (2000), illustrated a high correlation between blood lead levels and the mass of lead detected on the lips of workers

2.2.4 ORGANISATIONAL CULTURE

OHS interventions such as respiratory protection programs may have many organisational facets, involving OHS professionals, regular workers, contractors and contracting companies and management. All stakeholders should be engaged and their knowledge, drivers and perceptions understood (Salazar et al., 2001). Workers can be ‘important allies for the industrial hygienist in developing interventions as the workers themselves will have intimate knowledge of how tasks will be sequenced and when operations will be performed’ (Goldberg et al., 1997 p 317). For this reason, stakeholder analysis is a useful adjunct to intervention evaluation and it is aimed at identifying how key stakeholders act, interact and determine implications for effectiveness of the intervention (Brugha and Varvasovszky, 2000; Varvasovszky and Brugha, 2000).

2.3 STUDIES OF MAINTENANCE CONTRACTORS

There is a large body of evidence indicating that maintenance personnel, including contractors, may have significant exposure to hazardous substances. However, there are few reports in the peer-reviewed literature pertaining to maintenance contractors potentially exposed to inorganic lead or other toxic substances. A recent exception was a study by Shih et al (2006) which found a significant increase in polychlorinated dibenzofurans (PCDD/Fs) in the blood of contractors after performing a month of annual maintenance inside municipal waste incinerators (MWIs). In this study the only method used to mitigate uptake of dust was dust masks.

In a study by Nosal and Wilhelm (1990) ship-breaking contractors were found to have excessively high levels BLL, with the majority of one group exceeding 50 μg/dl. [5] The exposure to lead was primarily through the use of oxy propane or acetylene torches to cut through metal which had layers of lead based paint. The company sought advice after some contractors experienced lead poisoning. An intervention was implemented. Likely routes of exposure were assessed, blood sampling was undertaken and control measures were

[5] The current Australian limit which should trigger immediate removal from lead exposure workplace is 50 μg/dl

introduced which included respirators appropriate for the exposure level. Specifically, contractors assessed to have the highest exposure to lead, such as those using oxy propane cutting torches, were issued with air purifying respirators. Hygiene controls were also implemented including wash up facilities and double lockers to minimise cross contamination. Two groups of contractors were also educated on the health effects of lead and trained in good hygiene practice. The results were impressive with a significant decrease in BLL for all groups of contractors after the intervention. Interestingly, those contractors displaying the largest decrease in the mean BLL were those who received training. This suggests that training and education can have a significant effect in reducing exposure to hazardous substances by changing behaviour to limit uptake of such substances. This is supported from the findings of a study by Buzzetti et al (2005), who reported on the success of a pilot “lead-safe” skills training program for home improvement contractors and their employees. Respondents showed statistically significant changes from before to after the training program, and the changes were maintained over time. Knowledge improved, and attitudes and behavioural intentions changed in a favourable direction.

In a similar scenario, Holness and Nethercott (1988) investigated contractors employed to dismantle an old water purification plant consisting of numerous pipes coated with multiple layers of leaded paint and lead joints. As with the Nosal and Wilhelm (1990) study contractors were required to cut through metal with layers of lead paint. Another similarity was that the researchers were notified after some contractors experienced lead poisoning. The researchers facilitated the introduction of hygiene measures such as enforcement of no drinking, eating or smoking in areas of lead exposure. All contractors were issued with respirators, however they were all disposable respirators unlike the Nosal and Wilhelm (1990) study where contractors with higher exposure were given more effective respirators (P2 respirators). There was also no training or education. Holness and Nethercott (1988) also introduced some engineering controls such as sand blasting layers of leaded paint away and improving ventilation. Following this intervention, there was a large decrease in airborne lead as measured by personal air monitoring as well as BLLs which were significantly lower at the end of the program, ($p = 0.001$). The researchers also found vigilance was required to ensure compliance with the use of respirators. Supervisors required extra training so they understood task related exposures, such as increased risk for cutters. They found the engineering control of sandblasting leaded paint was very effective in reducing exposure. Finally, the establishment of health and safety committees assisted in enhancing hazard communication including identifying possible sources of exposure.

Several papers have addressed exposure from work on bridges. An observational study by Sen et al (2002) focused on scaffold workers, erecting and dismantling large scaffold structures around a steel railway bridge so sand blasting could occur to remove old paint. The scaffolders were not directly involved with lead removal. The work practices included hygiene controls such as a prohibition in eating, drinking and smoking on site except for a designated area which was a “mess cabin”. The scaffolders were also issued with PPE consisting of gloves, hard hats, overalls and disposable respirators. The scaffolding company tested the BLL of workers just after they started work and found 93% (n = 27) had less than 10 μg/dl, but when they were retested 5 to 8 months later, there was an average of 183% (-10 to 448) increase in BLL (10 employees could not be followed up). The increase was thought to be due to the failure of hygiene measures to prevent lead exposure. The researchers also observed contaminated work clothes in areas that were supposedly free from contamination. Wipe testing found evidence of surface contamination, for example, on the clean side of the decontamination unit (up to 136 $\mu g/m^2$ on a bench), and on table tops where employees ate and drank (2.4 $\mu g/m^2$ of lead). Ingestion could have been a route of exposure in this group. The researchers also felt that overall hygiene controls needed to be enforced and enhanced, that scaffolders should be included in respirator fitting programs and scaffolding equipment be cleaned before removal from site. Finally, Sen et al (2002) recommended that training and supervision should be audited. They argued that hygiene programs should protect all workers equally.

Reynolds et al (1997) and Johnson et al (2000) examined lead exposure to contractors working on bridges that were thought to be de-leaded by sandblasting away old lead paint. After a few weeks work contractors complained of symptoms consistent with lead poisoning such as nausea, headaches, stomach pain, irritability and muscle aches. Some had subsequent diagnoses of lead poisoning. Reynolds et al (1997), reported on an intervention consisting of assessment of task related exposure, stopping tasks and practices which were deemed to be high risk, e.g. “rivet busting” by labourers where oxy acetylene torches are used to break open rivets and using compressed air to removed dust and debris. Pre-intervention BLL of the contractors seemed to be related to task: labourers 26.3 μg/dl, whose tasks included the “rivet busting”; iron workers 11.2 μg/dl, whose primary task was to cut through steel beams; carpenters 7.9 μg/dl, primary tasks were making form work for concrete pours, and operators/engineers, 4.4 μg/dl, who used air hammers to demolish old concrete[6]. A written hygiene based "Lead Compliance Program" was formulated and implemented. This consisted of respiratory protection, improved housekeeping, protective clothing and equipment, provision of hygiene facilities, improved practices, training and medical surveillance. The results were impressive, the mean BBL before the intervention was 27.2 μg/dl, and post 9.7 μg/dl, illustrating an intervention that analyses all aspect of exposure can reduce BLL. Another finding is not to assume surfaces have been de-leaded.

The study by Johnson et al (2000) reported on air sampling and wipe sampling data. Personal lead exposure was statistically higher ($p < 0.05$) with torch cutting and demolition work than carpentry or finishing work, which is consistent with what Reynolds et al (1997) found except they measured the exposure through BLL. Wipe samples of contractors found sub groups of contractors such as equipment operators had much higher lead contamination in their vehicles, (3140 $\mu g/m^2$) compared to iron workers 750 μg/ and labourers 1730 μg/, indicating that this subgroup may have significant indirect routes of exposure and that hygiene controls need to be thoroughly examined.

Several studies have examined exposure to lead from removing old leaded paint in building renovation work (Sussell et al., 1998). One study by Sussell et al (1999) assessed the exposure to lead through three different work practices to remove old leaded paint from large rooms in a university. The exposure was measured by air sampling and surface sampling of contractor's hands. They found dry scraping and sweeping led to highest exposures; wet scraping and wet vacuum with High Efficiency Particulate Arrestors (HEPA) had medium exposure while wet scraping, HEPA vacuuming and exhaust extraction had the least. Another finding was hand washing was very effective in reducing lead on hands. They also found airborne lead in the general area was still well above legislated limits and that exhaust extraction led to leaded dust being moved to other areas. Thus, when controls are implemented thought must be put into possible unintended exposures.

Scholtz et al (2001) found contractors removing leaded paint had high levels of exposure to airborne lead dust with an arithmetic mean of up to 580 $\mu g/m^3$, well above the Australian occupational exposure limit of 150 $\mu g/m^3$, expressed as an 8-hr time weighted average

[6] Unfortunately no BLL data for each of these groups were reported by Reynolds et al (1997) post-intervention.

(NOHSC: 2015, 1994) or the US OSHA Permissible Exposure Limit of 50 μg/m^3. Johnson et al (2000) found contractors employed in bridge maintenance related activities had exposures to airborne lead dust with an arithmetic mean of up to 192 μg/m^3. Wipe sampling found appreciable surface contamination (up to 4766 μg/m^2). In all of these studies, workers wore respirators to assist in mitigating exposure to lead

2.4 DESCRIPTION OF INTERVENTION

This thesis refers to a respiratory protection intervention targeted at maintenance and refurbishment contractors engaged during a two-yearly plant shutdown of a primary lead smelter. The opportunity arose, via an invitation by the company to the University of Adelaide.

The intervention was determined by the company which incorporated initial offsite training in respirator usage and hygiene measures, mandatory usage of a specific disposable respirator, onsite enforcement of compliance protocols, and compulsory blood testing immediately before and after the two week contract period. The intervention was designed to reduce the uptake of lead as measured by BLL. Shutdown maintenance contractors comprised of welders, metal fabricators, transport personnel, crane operators, riggers, cleaners, ceramic kiln service contractors, electricians, plumbers and other relevant workers employed to replace and upgrade equipment. The success of this intervention would be judged on BLL and observed compliance with requirements.

A pilot study using disposable respirators was undertaken in the same lead smelter with a contracting group two years prior, in 2002. This study found that there was a slight reduction in BLLs (23.70 μg/dl versus 20.3 μg/dl). Further, the contracting lead smelter company reported a significant increase in compliance, compared to rubber non-disposable respirators. Users reported significantly greater satisfaction with the disposable respirators (Internal Lead Smelter Memo). Due to the success of this pilot study the company decided to implement an intervention mandating the use of a specific disposable respirator for contractors employed during a major plant shutdown. It was anticipated that the benefits obtained by using the disposable respirators during the pilot study would translate to contractors working during the lead smelter’s major blast furnace and sinter plant maintenance shutdown.

In order to take advantage of the scheduled intervention for research purposes, a variety of methods, including qualitative and quantitative approaches would be utilised. These are described in the next chapter and included questionnaires, inspection, air sampling and biological monitoring data.

Photograph 3 shoes the P2 particulate respirator (3M Brand model 9322) used for this intervention. It has an exhalation valve reducing effort and is suitable for both mechanically and thermally generated particles. It has a nominal (or assigned) protection factor of 10 in accordance with Australian Standard 1715: 1994, equivalent to N95 and EN 149: 2001, FFP2 respirator), as in Table 2.

Photograph 3: Disposable P2 respirator used in study

Table 2: Different respirator types and protection factors[7]

NOTE:
This table is included on page 25
of the print copy of the thesis held in
the University of Adelaide Library.

[7] Reference: 3M Australia Respirator Selection Handbook 2003

[8] AFP 10 are Assigned or Nominal Protection Factors, this is the estimated performance level of a respirator, assumes that the respirator will reduce the concentration of the contaminant by a factor of 10, this includes disposable and rubber half mask respirators

[9] PAPR are powered air purifying respirators, they have a significantly higher AFP than P2 respirators

2.5 AIM OF STUDY AND RESEARCH QUESTIONS

The aim of this study was to evaluate a respiratory protection intervention targeted at maintenance and refurbishment contractors engaged during a two-yearly plant shutdown of a primary lead smelter. This evaluation would address a variety of factors that influence the uptake of lead and gather information on a rarely-studied group of contractors so as to provide recommendations for improving future OHS interventions in lead industries and other heavy industries where air purifying respirators are commonly worn.

The shortage of literature relating to shutdown maintenance contractors and the opportunities afforded by the invitation to evaluate the intervention, provide justification for the following primary research question:

QUESTION 1: How effective was the intervention, based on quantitative measures (e.g. BLL) and qualitative indicators (e.g. stakeholder views) over the two week plant shutdown period?

The secondary research questions are:

QUESTION 2: What factors were associated with the initial blood lead levels and the changes in blood lead levels during the intervention period?

QUESTION 3: What were the airborne lead concentrations during the shut down period?

QUESTION 4: How well did the contractors comply with respirator usage and general hygiene requirements?

CHAPTER 3: METHODS

3.1 INTERVENTION EVALUATION APPROACH

OVERVIEW

Preliminary activities

The maintenance shutdown occurred from the 2nd to the 15th of August 2004. Prior to this, a range of activities occurred, providing several opportunities for stakeholder consultation.

A preliminary visit was arranged to the smelter in June 2004 in order to assess the work areas and facilities, discuss the proposed shutdown maintenance work, and understand the aspirations and perspectives of site safety officers, medical and nursing staff as well as senior management. In addition there was a number of follow up telephone conversations with smelter staff leading up to the intervention.

Off-site inductions for contractors prior to the shutdown maintenance

Prior to the shutdown, contracting company staff were required to undergo a 4-hour offsite induction, provided by the smelter company. The induction consisted of general lead smelter safety information followed by specific information on lead hazards, hygiene, respirator usage, and, finally, qualitative respirator fit testing. A series of induction sessions had to be scheduled prior to the shutdown in order to cater for the large number of contractors.

An information sheet, consent form, complaints form and a post-induction questionnaire (see Appendices 1-4) were hand-distributed to attendees immediately after each induction. Time for completion of questionnaires, and individual queries, was allowed for in the session. The completed questionnaires and consent forms were gathered by the author without being revealed to others.

During the various induction sessions there were opportunities for informal discussions between the researchers and contracting companies and individual contractors.

Finally, as part of the intervention protocol, pre-shutdown blood lead data for individual contract staff and a record of induction were to be provided before contractors were allowed to come on site.

On-site work during shutdown maintenance

During the shutdown maintenance period observations were made using a checklist and air monitoring was conducted. Respirator observation sheets (see Appendix 5) were used to check, *inter alia*, compliance with respirator usage in various areas, while a Crib Room Observation Checklist (see Appendix 6) was used to observe the general hygiene in these areas.

Perspectives on the intervention were gathered by attendance by the author at daily "toolbox meetings". Feedback was sought from contractors and supervisors about the implementation issues at various times.

At the end of the shutdown period, contractors provided an exit blood sample at the Smelter Health Centre. The feedback provided by contractors to the occupational health nurses was relayed informally.

After-hours contact with contractors during the shutdown period

The vast majority of contractors booked accommodation at nearby hotels/motels. The author intentionally spent time during the evening to speak to contractors during meal times at a local hotel to assess their impressions of the shut down and more specifically their thoughts on using disposable respirators.

A stakeholder analysis was subsequently conducted, using an iterative approach providing an appraisal of the different motivations, consultative arrangements, barriers, and unforeseen consequences affecting stakeholders as outlined by Brooks et al (2002), Brugha and Varvasovszky (2000) and Varvasovszky and Brugha, (2000). The stakeholder analysis was used to better understand the intervention and the reasons behind the results which cannot be explained purely from quantitative measures. This information elicited from this stakeholder analysis was also used to help ponder how to better formulate future interventions.

3.1.1 STUDY POPULATION

The study population comprised contractors from across Australia, although some specialists, such as welders, were recruited from overseas. Contractors worked 12 hour shifts, either day or night shifts (see Photograph 4) in four main areas of the lead smelter, namely the blast furnace, sinter plant, slag fumer and acid plant. Typical job types included boilermaker, rigger, trade assistant and crane operator.

Photograph 4: Contractors on night shift conducting maintenance work

3.1.2 TYPES OF ACTIVITY

Much of the work was routine preventive maintenance (Photograph 4 and Photograph 5). This typically consisted of dismantling equipment and reassembling with new parts. Much of the extensive pipe work was cut with welding equipment and/or grinders, with noticeable emissions. Another common activity was chipping and grinding away of solidified molten slag material from the smelting process that had built up over the previous two years. Contractors were also engaged with chipping off old tiles from the furnaces and re-tiling these furnaces. Overall, there was significant amount of ancillary activity such as crane operations, vehicle movement on site, shovelling and in some cases scrapping of old waste materials such as slag.

Photograph 5: Typical routine maintenance work contractors performed during day shift

3.2 QUESTIONNAIRES AND FORMAL DATA-GATHERING PROTOCOLS

No standardised (validated) questionnaires on lead exposure appeared to be available from the literature, and the questionnaire (see Appendix 4) was developed from first principles and piloted with a group of 20 contractors at the first induction session to assess the suitability of language and flow.

Contractor Post-Induction Questionnaire

At the end of the 4 hour offsite induction, contractors were provided with an Information Sheet, Consent Form and Independent Complaints Form (Appendices 1-3) and asked to complete the 'Post Induction Questionnaire' (see Appendix 4).

Data obtained from this questionnaire included demographic characteristics (age, smoking status), prior experience with respirators, non-occupational exposure to lead (hobbies such as lead soldering, car maintenance, lead lighting, house renovating), along with personal perceptions on the efficacy of disposable respirators. These questions were formulated to gather information on variables that might predict entry and exit BLL, as well as information relevant to the evaluation of a respiratory protection program such as attitudes to the use and effectiveness of respirators.

Crib Room Observations

Observations on (1) the general cleanliness of crib rooms and (2) personal hygiene practices whilst in crib rooms were carried out by the author and recorded a few hours after commencement of each shift and again towards the end of the shift (see Appendix 6 - Crib Room Observation Checklist). The observational checklist was formulated using recommendations from NOHSC: 2015 (1994) National Code of Practice for the Control of Inorganic Lead at Work.

This took into consideration dirty clothes or bags on dining tables, if door handles were dirty, if ledges and fixtures were clear of dust, if cigarette butts were present and how many, and finally if there was a ready supply of soap and towels. Care was taken to ensure it was not conducted after routine cleaning of crib rooms.

NOTE:
This photograph is included on page 31 of the print copy of the thesis held in the University of Adelaide Library.

Photograph 6: Crib Room with workers (Note: most wearing overalls, a source of lead contamination)

General Work Site Observations

A checklist, including a sheet addressing respiratory hazards and respiratory compliance (Appendix 6), was utilised to assess adherence to the general OHS requirements. Observations of work practices were made by the author and company site safety officers throughout the shutdown period. The observers walked in a regular route around the site several times a day, with special attention to the blast furnace and sinter plant, where there was considerable activity.

Blood Sampling

BLL values were determined by obtaining a venous blood sample both before first entry on site and at the completion of the shutdown period. The first blood sample was collected by the worker's doctor who then submitted the results to the lead smelter management. The site occupational nurse obtained the exit blood sample. Sampling was undertaken in accordance with national criteria NOHSC: 2015 (1994). Samples were sent to the smelters analytical laboratory for lead analysis by Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS) using an in-house method in accordance with AS4090: (1993) "Whole Blood – determination of lead content – graphite furnace atomic absorption spectrometric method".

Air Monitoring

Fixed position monitoring was carried out at various locations throughout the blast furnace, maintenance yard and crib room of the lead smelter during the blast furnace shutdown.

Inhalable dust and lead concentrations were measured using an Institute of Occupational Medicine (IOM) sampling head placed at a height of approximately 1.5 metres in accordance with Australian Standard AS 3640-(2004) "Workplace atmospheres – Method for sampling and gravimetric determination of inhalable dust". The sampling heads contained Gelman DM800 (25 mm, 0.8 micrometre nominal pore size) membrane filters. The sampling heads were connected to SKC Air Check personal air sampling pumps set at two litres/minute. The flow rate of the sampling pump was checked prior to and at the completion of the sampling period with a calibrated rotameter. Filter dust deposits were sent to the smelter's analytical laboratory for lead analysis by GFAAS using an in-house method in accordance with Australian standards.

Photograph 7: Air monitoring in the area adjacent to the blast furnace

3.3 ETHICS CONSIDERATIONS AND APPROVAL

This project represents an observational study of environmental factors, respirator usage and changes in biological indicators following normal work related patterns of lead exposure.

The only invasive procedure was that of drawing blood at specified times. Blood sampling is a lead smelter company requirement. The respirator fit testing (see below) was also a company requirement before commencing work and entailed no risk to participants. Further, this has only recently became compulsory in the recent edition of AS1715. Further, the study did not result in variations of work practices resulting in increased personal exposure to lead. All participants voluntarily completed questionnaires and gave informed consent (see Appendix 2) for use of the data for research purposes.

Finally, confidentiality issues were addressed via national occupational health surveillance criteria, published by the National Occupational Health and Safety Commission (NOHSC 7039 - 1995). This personal information was kept secure and confidential. Only members of the study team had access to the information and personal identifiers were stripped from the coded data file. Reporting was in anonymous group form.

Ethical approval for this research was granted by the University of Adelaide Human Research Ethics Committee.

3.4 TRAINING AND INDUCTION SESSIONS

As mentioned, it was a lead smelter company requirement that every contractor that worked during the shutdown undertook a four-hour induction and training session that was presented by lead smelter occupational health and safety staff. This provided information pertaining to OHS issues relating to working at a lead smelter environment, including the routes of exposure to lead, how the body absorbs lead, heath hazards from lead uptake and methods to control uptake of lead, specifically hygiene, such as washing hands.

Contractors were instructed that they were not permitted to eat or drink in work areas. Air-conditioned crib rooms were provided for this, which were strictly non smoking. Due to the smelter having a site-wide no smoking policy, contractors were not allowed to smoke whilst on site.

Contractors were instructed on the proper donning and use of a disposable P2 respirator, including a negative pressure fit check. This included qualitative fit testing using the validated 3M-sodium saccharin qualitative test procedure, Australian Standard AS 1715 - (1994).

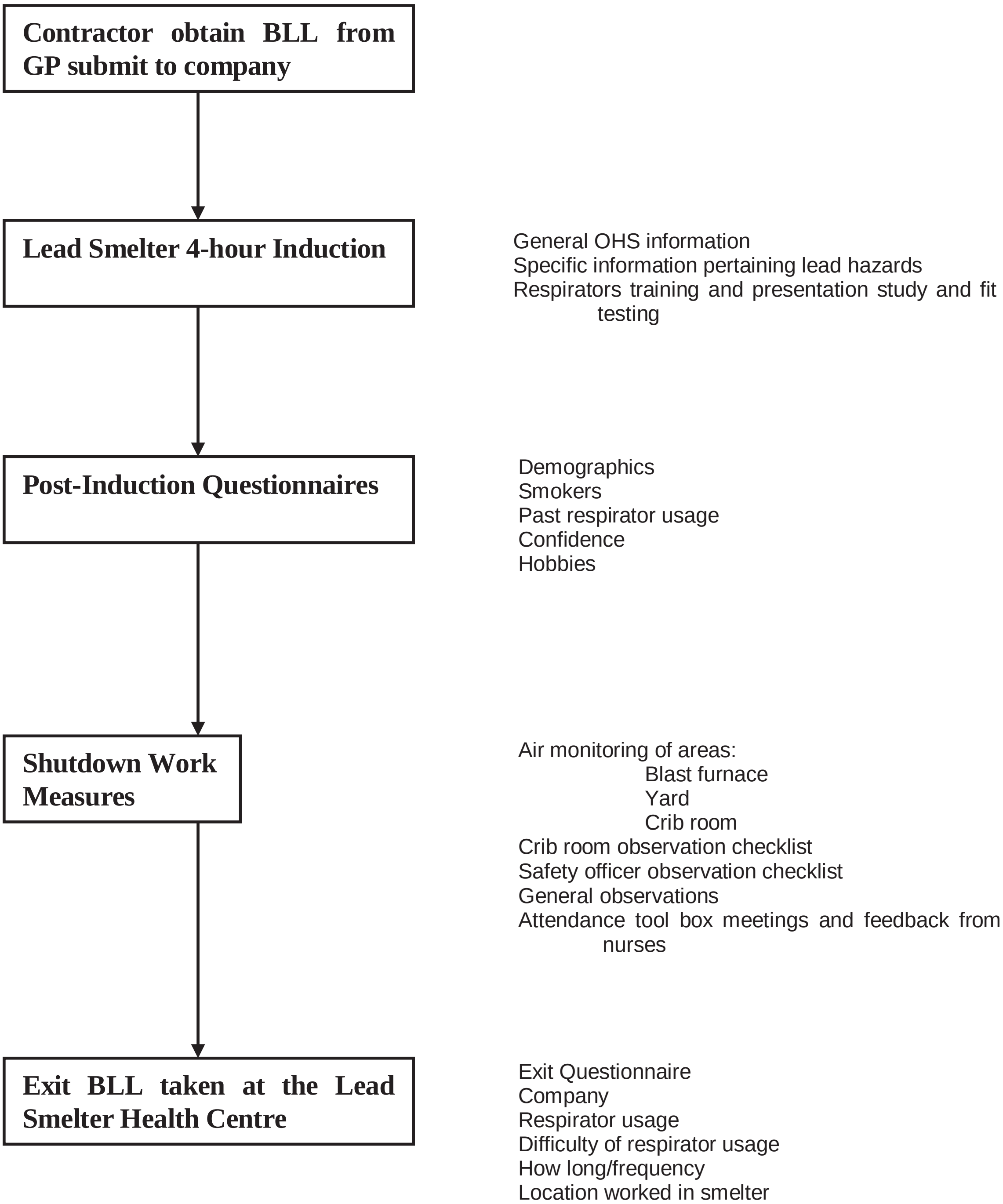
Photograph 8: Author holding air monitors was well as disposable respirator used in the study and other mandatory PPE

3.5 DATA ANALYSIS

The questionnaire data were coded and entered into an Excel spreadsheet.

Initial descriptive statistics were generated using Excel. Paired exit and entry lead levels were analysed using a paired t-test using SAS (Statistical Analysis Software) version 9 (SAS Institute, Cary, NC, USA). The continuous normally distributed outcome change (exit BLL – entry BLL) was analysed using Analysis of Variance (ANOVA). Post hoc testing was used to look at pair-wise comparisons between types of company with no adjustment made for multiple comparisons. For all analyses significance was assessed at the 5% level.

3.6 FLOW CHART REPRESENTATION OF RESEARCH CONDUCTED



CHAPTER 4: RESULTS

For the purpose of this thesis, the order of data presentation will be as follows - on site observations, environmental measurements, questionnaire data, blood lead data and finally information pertaining to stakeholder analysis.

4.1 ON SITE OBSERVATIONS

Weather

The shutdown occurred during winter (August 2004). It was wet and cold for most of the maintenance shutdown period (Photograph 9).

A weather station was located at this site, under the auspices of the Australian Bureau of Meteorology. The monthly rainfall for August 2004 was 42 millimetres (mm) compared with the long term August average of 35 mm, and a long term total annual rainfall average of 344 mm (monthly = 29 mm). The monthly daily maximum temperature for August 2004 was 18.4 degrees Celsius compared with the long term August average of 18.1 degrees Celsius, and a long term annual average maximum temperature of 24.4 degrees Celsius.

Despite breezy conditions at times, there appeared to be little visible airborne dust.

Photograph 9: Illustrates some of the blast furnace area and the wet terrain is evident

Tasks and Activity Patterns

The operation consisted of two 12-hour shifts over a 14 day period. Activity was constant over this period. The different tasks observed were grinding, welding, jackhammer operations (such as chipping away old slag material), dismantling old equipment, installing new equipment, removing old tiles from furnaces and replacing with new tiles.

The author observed that the welders often did not wear disposable respirators when they were welding. This might be due to the use of full face welding shields which would be impeded by respirator usage.

During the course of the observations it was noted by the author that there was limited power tool usage apart from grinders and jackhammers. This and the prevailing wet and windy conditions during the time the author was on site, may explain why overall the author did not observe much dust or fumes. It was also observed using the Respiratory Hazard Observation Sheet, (Appendix 6) that there were often between 50 to 74 employees present in the areas being observed. Usually the staff was scattered about in the areas performing individual tasks the exception was when plant and equipment was either being installed or replaced. In these case between nine to fifteen contractors would congregate in the same area.

Crib Room Observations

The author conducted observations of contractors to coincide with meal breaks. In all there were two meal breaks per 12 hour shift. In all eight crib room observations were conducted with between 12 to 20 contactors present in the crib room.

Overall, the crib room were observed to be relatively clean. Of the eight observations the author found the majority of contractors entered the crib room wearing overalls (see photograph 6), in contravention of company hygiene protocol. They also left bags on tables which is a potential source of lead exposure and another contravention of company hygiene protocol. There was however no alternative offered such as fresh clothing to change into.

Photograph 10: Crib room (note contractors with overalls and bags on tables)

Other Observations

It was noted that contractors brought their cars on site, this could lead to continual lead exposure due to lead contamination in contractor's cars (see Photograph 9).

Contractors were expected to shower after they had finished their shift. Shower facilities, soap, clean towels, laundered overalls to use before commencement of shifts and lockers for contractors to store their clothes while working were supplied. Wash troughs, soap and instructions on how to wash hands were also supplied at the entrance to the crib room.

Although it was a non-smoking site, some contractors were observed smoking in remote areas by the author. Due to the size of the site the author, when attempting to approach contractors observed smoking, found these contractors would extinguish their cigarette and quickly disperse into the surrounding area. Consequently the author could not identify who were the contractors breaking the no smoking policy. The author also noticed on several occasions the odour of tobacco combined with the observation of smoking in contractors led to the conclusion there was at least some non compliance with the no smoking policy. This is supported by comments from the occupational nurses that contractors cut holes in their respirators so they could smoke. The nurses also commented that contactors consumed lollies to alleviate cravings caused by not smoking. The author did not observe this behaviour.

Observed Compliance with use of respiratory protection

Table 3 illustrates the results of observations of respiratory compliance. Note that there is a 9% difference between the rotary kiln and both the blast furnace and sinter plant. This is not statistically significant ($p>0.05$, test of proportions, 2-tailed test). During several "toolbox"[10] meetings contactors reported that some of the companies ran out of respirators. Further, some contractors complained that due to the nature of their work (crawling through confined spaces etc), the foam nose bridge of their respirators "disintegrated". This implies that under certain extreme situation the disposable P2 respirator is not robust enough. It is plausible that problems with using respirators in extreme conditions explain why the compliance was less for contractors working in the rotary kiln. This was observed by the author to be very cramped, hot and humid. However, smelter safety staff reported that compared to the last major maintenance shutdown two years earlier, compliance had enormously improved.

Table 3: The results of observations of respiratory compliance

LOCATION	MEAN NUMBER OF WORKERS PRESENT	MEAN NUMBER OBSERVED WEARING RESPIRATORS	% COMPLIANT
BLAST FURNACE	136	133	98
ROTARY KILN	53	47	89
SINTER PLANT	180	177	98

[10] A meeting usually held daily, before commencement of a shift

4.2 AIR SAMPLING

Table 4 shows the inhalable lead concentrations obtained at various locations (see photograph 7 showing an air monitor) during the shutdown maintenance period. Geometric mean airborne lead concentrations ranged from 23 μg/m^3 on the bottom floor of the blast furnace where there was minimal contractor activity up to 515 μg/m^3 on the dross floor of the blast furnace where there was significantly higher contractor activity.

Given the nature of the work, particularly in confined spaces, it was not feasible to conduct personal air sampling.

Note the blast furnace crib room had appreciable airborne lead levels - higher than the blast furnace bottom floor and rotary furnace. Measurements in the “yard” were conducted in general thoroughfare areas (footpaths) and open areas. These concentrations were surprisingly high.

Table 4: Geometric mean airborne dust, lead and % lead in dust levels for fixed position air monitoring obtained at various locations during the maintenance shutdown

	Airborne dust %GM (milligrams/m^3)	Airborne lead % GM (micrograms/m^3)	% Lead in dust
Blast furnace dross floor (n=4)	1.47	515	35
CDF dross floor (n=4)	1.39	268	19
Blast furnace (n=2)	0.91	129	14
Blast furnace top floor (n=4)	0.27	81	30
Blast furnace crib room (n=4)	0.30	55	18
Blast furnace bottom floor (n=4)	0.20	23	12
Rotary furnace (n=2)	0.50	44	8
Yard (n=4)	0.50	71	14

4.3 QUESTIONNAIRE DATA

Basic Demographic Information

The basic demographic information is given in table 5. All were males. It is interesting that smokers account for almost half the workforce, a rate which is well above the Australian average[11].

Table 5: Basic demographic information for all contractors who completed the post induction questionnaire (n = 337, all male)

MEAN AGE (YRS) (RANGE)	38.4 (17- 67)
MEDIAN AGE (YRS)	43.0
PERCENT CURRENT SMOKERS (%)	48.0

From Table 6, it can be seen that almost half (46.7%) reported that they had a hobby or activity that potentially involves exposure to lead, while 86.7% reported that they had experience with respirators, and 81.1% indicated felt confident that a disposable mask would mitigate uptake of lead.

Table 6: Other background information from post-induction questionnaire

CONTRACTOR AT THE LAST BLAST FURNACE SHUTDOWN? (%)	11.9
CONTRACTORS WITH A LEAD-RELEVANT HOBBY OR ACTIVITY (%)	46.7
IN YOUR OPINION DOES A DISPOSABLE MASK (PAPER MASK) PROVIDE THE SAME AMOUNT OF PROTECTION AGAINST LEAD DUST AS A RUBBER MASK?(%)	78.3
CONTRACTORS' PREVIOUS RESPIRATOR EXPERIENCE (%)	86.7
HAVE YOU EVER HAD INSTRUCTIONS ON HOW TO CORRECTLY FIT A MASK BEFORE THIS INDUCTION? (%)	88.5
CONFIDENCE THAT A DISPOSABLE RESPIRATOR WOULD KEEP BLL DOWN (%)	81.1
WOULD YOU FEEL MORE CONFIDENT IN USING MASKS IF YOU HAD THE PROPER TRAINING? (%)	85.5
DO YOU THINK YOU HAVE A GOOD UNDERSTANDING OF THE HEALTH EFFECTS THAT MAY OCCUR FROM EXPOSURE TO LEAD DUST? (%)	96.5

[11] Australian Bureau of Statistics 2004 data

4.4 BLOOD LEAD MEASUREMENTS

Of the 337 contractors who underwent the induction, only 252 submitted an entry BLL. This is because some potential contractors decided not to take up the offer of work (or were not offered work).

Similarly, of those who worked on the site, only 138 submitted an exit BLL. This is probably due to the fact that many contactors decided to leave before fulfilling their contract (or were dismissed). Finally, full BLL data were only available for 113 contractors.

Table 7 presents the summary BLL data for all contractors who submitted blood samples.

Table 7: Mean entry, exit and BLL changes

	N	MEAN	MIN	MAX
ENTRY BLLS	252	5.7	1	31
EXIT BLLS	138	18.7	3	48
CHANGE IN BLL (EXIT – ENTRY BLLS)	113	12.6	-1	41

Interestingly, one contractor had a decrease in BLL of 1 μg/dl.

Full questionnaire and blood lead data were available for 62 male contractors (see Table 8).

Of these contractors 81% were previous contractors to the smelter, 87% had previous respirator experience, 78% believed disposable respirators were equal in protection of non-disposable rubber respirators, 87% were confident disposable respirators would keep blood lead level down, and 35% reported non-occupational exposure to lead.

Table 8: Summary table of blood lead and questionnaire data (n=62)

	Mean Change BLL (µg/dL)	Range Change BLL (µg/dL)	Mean Entry BLL (µg/dL)	Range Entry BLL Min Max (µg/dL)	Mean Exit BLL (µg/dL)	Range Exit BLL Min Max (µg/dL)	Range BLL (µg/dL)
Consolidated Data							
(n = 62)	14.4	2-37	5.5	1-18	20.0	4-41	1-41
Survey Questions[12]							
Smoking							
Smokers (n = 18)	17.4	4-35	5.2	2-18	22.4	6-41	2 - 41
Non-smokers (n = 44)	13.2	2-37	5.7	1-18	18.9	4 -38	1 - 38
Companies							
Welding (n = 9)	17.1	6-30	6.3	3-11	23.4	12-38	3-38
Crane and Rigger (n = 8)	19.6	7-30	5.4	2-11	25.0	17-33	1-33
General (n = 45)	13.0	2-37	5.4	1-18	18.4	6-41	1-41
Previous Contractor							
Yes	13.7	3-35	5.6	1-18	19.4	4-41	4-41
No	19.3	5-37	4.3	1-12	23.6	7-38	1-38
Respirator Experience							
No	16.5	15-17	5.5	5-6	21.5	21-22	5-22
Yes	14.5	2-37	5.5	1-18	20.0	4-38	1- 41
Previous Training							
Not	11.9	5-24	5.2	2-12	17.0	11-26	5-26
Previously	14.7	2-37	5.6	2-18	20.3	4-41	2-41
Equivalence Respirator							
No	9.4	3-33	4.6	1-18	14.2	4-36	1-36
Yes	15.3	2-33	5.2	2-12	20.5	6-38	2-38
Confidence Pb Down							
No	13.0	3-33	7.3	3-18	20.3	8-36	3-36
Yes	15.1	2-37	5.4	1-18	20.5	4-38	1-38

[12] Are you a current smoker?
Name of your company
Were you a contractor at the last blast furnace shut down?
Have you worn a rubber mask or "paper" dust mask before this induction?
Have you ever had instructions on how to correctly fit a mask before this induction?
In your opinion does a disposable mask (paper mask) provide the same amount of protection against lead dust as a rubber mask ?
Do you feel confident that the use of disposable "paper" masks will keep your 'lead in blood', level down?
Would you feel more confident in using masks if you had the proper training?
If you were required to wear a rubber mask, would you be less likely to take up a contract role?
Do you participate in any hobbies such as lead soldering, car maintenance, lead lighting, house renovating.

CONT.	MEAN CHANGE BLL (μG/DL)	RANGE CHANGE BLL (μG/DL)	MEAN ENTRY BLL (μG/DL)	RANGE ENTRY BLL MIN MAX (μG/DL)	MEAN EXIT BLL (μG/DL)	RANGE EXIT BLL MIN MAX (μG/DL)	RANGE BLL (μG/DL)
CONFIDENCE IN TRAINING							
No	17.6	2-30	4.3	2-8	22.1	6-38	2-38
Yes	13.9	3-37	5.7	2-18	19.6	4-38	2-38
LESS LIKELY TO WORK							
No	11.5	2-35	4.8	1-18	16.3	4-41	1-41
Yes	18.0	3-37	6.4	1-18	24.5	8-37	3-37
LEAD-RELATED HOBBY OR ACTIVITY							
No	15.5	4-35	5.3	2-18	20.9	6-38	2-38
Yes	14.6	4-38	5.9	1-15	18.4	4-38	1-38
AGE							
Age 21 - 30	11.8						
Age 31-40	5.4						
Age 41 - 50	17.9						
Age 51 - 60	14.5						
Age 61 – 70	9.7						

The overall increase in blood lead is significant (paired t-test, p<0.0001).

The arithmetic mean increase in BLL over the shutdown period was 14.4 μg/dl (std dev =9.3). Smokers (n=18) had a mean increase of 17.4 μg/dl (+/- 10), compared to non-smokers (n=44) with 13.2 μg/dl (+/- 8.8). Analysis of variance was used to investigate the relationship between change in blood lead concentration (outcome variable) and smoking status (predictor). There was no significant relationship (p=0.1114).

Crane operators and riggers (n=8) had the greatest increase in BLL (19.6), compared with welders (17.1, n=9) and general maintenance contractors (13.0, n=45).

Analysis of variance was performed to determine whether type of worker (‘WELD’, ‘CRANE’ and ‘GENERAL’) is related to the outcome variable of change in blood lead concentration. There was no significant relationship found between maintenance workers and change in blood lead concentrations (p=0.1139).

Similarly, potentially predictive factors such as age, lead-based hobbies, respirator experience and confidence were not statistically significant.

As the results of the aforementioned analyses were not statistically significant, no further statistical analysis (multivariate modelling) was undertaken.

4.5 STAKEHOLDER ANALYSIS

To better understand the intervention and glean some insights such as the perspectives of primary stakeholders not possible through quantitative methods the author conducted a stakeholder analysis. The actual different groups that were considered was based on Brooks et al (2002) and Brugha and Varvasovszky, (2000). The author gained the information from the key stakeholders through, informal open ended interviews and meetings with the various stakeholders as follows:

Lead Smelter Management: The author and colleagues met with management prior to the intervention. They made it clear they wanted to use disposable respirators primary due to cost of using rubber respirators. The cost in rubber was primarily due to laundry costs of cleaning after use, as well as replacement costs. It was apparent after the intervention that this meeting should have incorporated representatives from the other stakeholders.

Lead Smelter OSH Professional, Hygienist and Safety Officers: The author met with this group during preliminary meetings and regularly discussed how the intervention was progressing during the time the author was on site during the shutdown. This is how it was revealed that there was conflict with management, as the OSH Professionals insisted all personnel involved with the shutdown should use disposable respirators. However they were not supported by Senior Management who did not want permanent lead smelter staff to have to use disposable respirators.

Medical Staff : During frequent discussion with the author revealed the information in Table 9 below.

Contractors: Most of the issues such as fogging of respirators were revealed at tool box meetings. The positive feedback was contractors reported they would return due to disposable respirators as opposed to previously used rubber respirators. This was revealed at tool box meetings, during discussions with the author while conducting crib room observations as well as at meal times at the local hotel.

Contracting Companies: The information gained was from discussion prior to tool box meetings and at contractor induction, between the author and contracting company team leaders. It was at these tool box meetings that contracting companies reported they were running out of respirators and that they were concerned with expense. In hindsight, contracting companies should have been extensively consulted in a preliminary stakeholder analysis as they have the most influence on the contractors who are the key to the success of this intervention.

The following stakeholders with the summary findings of the stakeholder analysis are given in Table 9. The categories as set out on the top column are derived from Brooks et al (2002).

Table 9: Stakeholder Analysis

KEY STAKEHOLDERS	DRIVERS OF INTERVENTION	EXTENT OF CONSULTATION AND PARTICIPATION	PERSPECTIVE, CULTURE OF STAKEHOLDER	FORESEEABLE BARRIERS, CULTURAL AND ENVIRONMENTAL TO SUCCESS	UNFORESEEN OUTCOMES
LEAD SMELTER MANAGEMENT	Keep BLL to a minimum; Legislative changes potentially flowing from international developments; Cost of providing rubber respirators; Compliance	Extensive consultation and participation in whole process	Strategically important to lead smelter company, management culture is directive	Implementation (process of rolling out intervention)	Contractors wanting to return to next shut down (lowered contracting costs)
LEAD SMELTER OHS PROFESSIONALS, HYGIENIST AND SAFETY OFFICERS	Ensuring compliance; Keeping BLL to a minimum	Extensive consultation and participation in whole process	Motivated to keep BLL down; Compliance	Time and resources	Conflict with management over non consistent roll out to all lead smelter staff; Identified moustaches as issue and smoking
MEDICAL STAFF: OHS NURSES AND DOCTORS	Keep BLL down in contractors	Extensive	Keen to assist keeping BLL down	Time and resources	Yielded vital insights into possible reasons BLL increased; smokers; (lollies); mistrust discolouration
CONTRACTORS	Keen to use due to	None, except for	Due to itinerant	Perception of	Fogging issues

	comfort and ease of use	ad hoc feedback at toolbox meeting consultation and questionnaire	nature of workers no interest except to get job done	effectiveness; Compliance due to itinerant nature of employment; Come contractors commented that they were suspicious se lead smelter staff didn't use disposables	with glasses (training); Non-compliance with overalls in crib rooms; smoking; Using lollies
CONTRACTING COMPANIES	Directive from lead smelter management	None	Vital to participate for current and future contracts with lead smelter	Cost to provide multiple respirators	Increased cost per contractor due to cost of respirators; Missed opportunity to engage in intervention

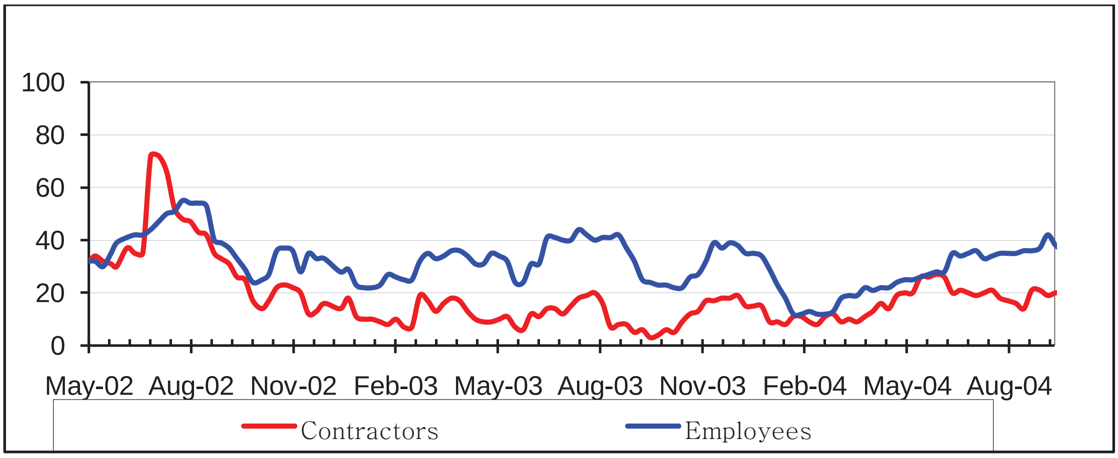
4.6 WAS THE INTERVENTION SUCCESSFUL?

There were no predetermined criteria for success, although the company pilot study in 2002 (See section 2.4) suggested that lower BLL, greater worker compliance and satisfaction were important measures.

Following the 2004 shutdown, smelter management judged the intervention to be a success. BLL were generally lower, and with fewer high values, than those measured at the previous maintenance shutdown. Evidence for this was in Figure 4, illustrating BLL for regular employees and contractors from May 2002 to August 2004.

During the previous maintenance shutdown in July of 2002, approximately 70 contractors possessed a BLL greater than or equal to 35 μg/dl [13]. In the 2004 August shutdown, few contractors had a blood lead in excess of this figure.

Figure 4: Blood lead levels for regular employees and contractors from May 2002 to August 2004. x axis is time in months while y axis is the number of contractors and employees with BLL in excess of 35 μg/dl



In addition, company-observed respirator compliance suggested success. Data from the author was not available to the company at that point.

13 A BLL of 35 μg/dl is the company performance indicator. That is, no worker should exceed this value if best work practice is adhered to.

CHAPTER 5: DISCUSSION

5.1 OVERVIEW

The overall aim of this study was to evaluate an intervention designed to improve respiratory protection for contractors working in a lead smelter. A secondary aim was to investigate what factors are associated with initial BLLs at the beginning of the intervention and subsequent changes in blood lead levels after the intervention. A final aim was to assess the airborne lead levels during the shutdown period. The success of this intervention is gauged by contractors' respirator wear compliance along with the change in BLL levels, and a stakeholder analysis.

5.2 STRENGTHS AND LIMITATIONS

5.2.1 STRENGTHS

It is a systematic study of respirator usage in the field, in which all participants were educated and trained on correct usage of respirators, entry and exit BLLs taken and compliance was both enforced and, in a limited manner, observations of compliance undertaken. Finally, it also encompassed both quantitative hygiene measures (through air monitoring), and qualitative measures (such as questionnaires). Combined, these provided information on blood lead changes during a relatively short period of time.

5.2.2 LIMITATIONS

This study is merely a snap shot in time - thus there will need to be a follow up study to verify the findings.

Due to the itinerant nature of contractor workers, any follow up study won’t necessarily be a sound comparison with this present study as the subjects may be different.

While safety officers reported compliance was high, the compliance observations were for only 3 days by the researcher.

Despite a relatively large number of respondents to post-induction questionnaires, there were only 62 contractors who provided both entry and exit BLL and post induction questionnaires. In future, there is a need to better capture contractor BLL information. A consideration could be to possibly link contractor remuneration with completion of the questionnaire and other requirements.

Demographically, the population was mainly Caucasian men. Accordingly, it is difficult to generalise any of these results to the general population, particularly considering the changing demographics of the Australian population.

No personal air sampling was undertaken, thus it is difficult to quantify to what extent specific contractors were exposed to what levels of airborne lead and accordingly the effectiveness of respirators. It is likely that some tasks, involving hot work in relatively confined space require more than a disposable respirator.

5.3 INTERPRETATION OF RESULTS

The following discussion addresses the research questions posed earlier.

5.3.1 OVERALL CHANGES IN BLL BEFORE AND AFTER SHUTDOWN AND COMPLIANCE

Question 1: How effective was the intervention, based on changes in blood lead levels over the two week plant shutdown period?

Inspection of data in Figure 4 might suggest the training and the use of the disposable respirators in this intervention led to a decrease in BLL compared to previous shutdowns. In Figure 4 the 2002 spike is not observed after the latest blast furnace shutdown for contractors (August 2004) when the disposable respirators were worn. It is assumed that the shutdown maintenance workforce and tasks/activities/environmental conditions were similar.

However, due to the lack of availability of "before and after" BLL data from the previous blast furnace shutdown (July 2002), where rubber respirators were used, a direct comparison of BLL data is not possible.

On face value, an average BLL increase of 14.4 μg/dl over two weeks suggests that the intervention was only partly successful, but, again, there appear to be no comparable data in the literature. This illustrates that lead-exposed contractors working in shutdowns or scheduled maintenance can absorb lead despite the introduction of a respirator program and other measures such as crib rooms. This is similar to what was found by Holness and Nethercott (1988); Johnson et al (2000); Nosal and Wilhelm (1990); Reynolds et al (1997) and Sussell et al (1998). Indeed, this suggests that interventions to reduce the uptake of hazardous substances require more than the introduction of PPE - a training program and enforcement of PPE usage etc is required. It should be noted that these control measure are at the bottom of the hierarchy of controls[14]. Ideally, these measures would be used after other measures such as engineering controls are introduced.

Question 2: What factors were associated with the initial blood lead levels and the changes in blood lead levels during the intervention?

Entry and Exit Blood Lead Levels

The average entry BLL was 5.7 μg/dl, while the exit was 18.7 μg/dl (see Table 7). The entry level BLL seems to be similar to general population values. Overall, the average change in BLL for 113 contractors who supplied both entry and exit BLLs was 12.6 μg/dl.

Interestingly, one contractor had a decrease of 1 μg/dl compared to an increase of 41 μg/dl for another. This indicates that some contractors are being exposed to very high levels of lead dust (overwhelming the protection factor of the disposable respirator) and/or are not complying with the requirements of the lead exposure reduction program. Future research could answer these findings by individual exposure monitoring.

Relationships between BLLs and Different Factors Associated with Contractors

Smoking

Comparison of smoking and non-smoking contractors showed that there was an observable correlation between smoking and lead uptake, smokers increasing 17.4 μg/dl, non-smokers 13.2 μg/dl, and change in lead in blood concentrations (Table 8). However, statistical analysis failed to find a significant difference. This could be due to the low sample size of 18 smokers, out of 62 contractors in total. Despite this, the trend is that smokers will have a greater increase in BLL. Further, although smoking is not permitted on site, smoking was observed in secluded areas of the plant and every time of the day cigarette smoke could

[14] The hierarchy of controls is a method used in OHS to reduce hazards. The top and most desirable is elimination of the hazard, followed by substitution, engineering controls, admininistrative and finally PPE contol of the hazard.

clearly be detected in the blast furnace crib room. There was no safe designated ‘clean’ area for contractors to smoke. As a result smoking occurred in various “hiding” spots across sites where smokers were less likely to have clean hands. This could contribute to the observed difference in BLL observed between smokers and non-smokers. Another observation was the fact that smokers were eating lollies to help alleviate their cigarette cravings, which may be associated with hand to mouth behaviours and further increase lead exposure through ingestion. This is indirectly supported by Paik and Park (2001) and Chuang (1999) that it is the combination of smoking and hand mouth behaviour due to smoking that significantly increase exposure to lead. Finally, via the OHS nurses, it was revealed that some of the contractors who smoked cut holes in their respirators to do so.

In addition, the stakeholder analysis identified that there was lack of any consultation with the key stakeholder, the contractors. Future interventions may benefit from using a stakeholder analysis to identify motivating factors, which could be emphasized to improve compliance with policies, such the non-smoking policy. It is highly likely smokers would have serious difficulties getting through a 12-hour shift without cigarettes and possible measures like smoking breaks. Smokers may well need more frequent breaks or even given the option of free nicotine patches during the course of shut down work. Further, there may be the need for smokers to have designated, “clean” smoking areas. It may also be necessary for the lead smelter company to assess how many contractors will be smokers, and then conduct an analysis to ascertain if it is worth supplying these extra resources.

Contractor Company Status and BLL

The average increase in BLL for all contractors in Table 7 (n = 113) was 12.6 μg/dl. Nine contractors had an increase in BLL of greater than or equal to 25 μg/dl. This could be due to these contractors undertaking tasks which exposed them to higher levels of lead, and/or could be due to these contractors not being compliant in wearing their respirator at all times. Unfortunately, due to the nature of the work it was not possible to ascertain in advance what contractor’s tasks were going to be. Consequently no measurement of task related exposure was possible. Analyses (Table 8) of contractors belonging to certain contracting companies, which performed specific tasks such as rigging and crane operations had observable increases in BLL with crane and rigging company employees with the highest, 19.6 μg/dl then welding employees 17.1 μg/dl compared to general companies employees, 13.0 μg/dl, however these differences were not statistically different, as with smokers it is possible this is due to low sample size.

This is consistent with Johnson et al (2000), who found contractors performing metal cutting having the highest exposure of 188 μg/dl followed by dry paint removers 93.7 μg/dl, then demolition laborers 43.4 μg/dl. These studies and the results of the air monitoring (Table 4) study indicate tasks companies perform are related to increased exposure to lead as reflected by increased BLL; these areas require targeting to reduce exposure at future maintenance shutdowns. Future research should assess potential exposures companies are likely to have so to analyse relationship between job and/or task type, lead exposure and BLL increase as recommended by Goldberg et al (1997); Holness and Nethercott (1988); Sussell et al (1999), and implement more rigorous controls. Indeed, Spear (2000) and co-workers recommend that tasks should be evaluated for lead exposure levels and those with very high exposures may require better protection than the standard half mask respirators with the accepted AFP of 10. This is possible through controls using HEPA filters or even better protection through PAPR devices, enhanced training and administrative controls such as increased daily allocation of respirators. Administrative controls could also encompass methods to reduce exposure to lead by minimising activities that create lead dusts and/or fumes; this was successful in significantly reducing BLLs for construction contractors renovating a bridge (Reynolds et al., 1997).

Contractors at previous shutdown experience

Contractors who worked at the previous shutdown had an increase of 13.7 μg/dl compared to contractors that hadn't with a 19.3 μg/dl increase. While this was not statistically significant, there appears to be a relationship signifying that contactors with experience in the previous shutdown are more familiar with the environment; accordingly they were more cautious and diligent with respirator usage and hygiene. This suggestion is supported by a finding by Shih et al (2006), who found a significantly greater increase in PCDD/Fs for contractors who had never worked in municipal waste incinerators than those who had. Contractors with no previous experience may require additional training. It would also be prudent for their supervisors (or possibly a lead smelter safety person) to assess the competency of inexperienced contactors fitting their respirators before the commencement of work. There were also reports from contractors that their safety glasses fogged up when using the disposable respirators. This indicates that there is a need to assess on site the correct donning of respirators as this should not occur if the respirators where correctly used. A solution could be a green sticker on their hard hat denoting they are “green hats”[15], and accordingly require attention from lead smelter staff in enforcement of respirators and hygiene protocols.

Contractors Respirator Experience, and Change in BLL

Contractors with previous respirator experience had marginally smaller increases in blood lead compared to contractors who had no experience (14.5 versus 16.5). Again, this may indicate that contractors with no experience may require more training in usage of the respirators than those who have such experience. In this study the difference was not statistically significant, however this could be due to low sample size.

Contractors training in respirators

Contractors who had not been previously trained in using respirators had an increase of 11.9 μg/dl, while contractors who had had training showed an increase of 14.7 μg/dl. This cannot be explained easily. Once again, this was not statistically significant.

Contractor’s perceptions (confidence) of the effectiveness of disposable respirators compared to rubber respirators and changes in BLL

The average increase for BLL for contractors reporting they were confident disposable respirators would be equivalent to rubber respirators was 15.3 μg/dl, which is higher than the increase for those contractors who didn’t regard them as equivalent (9.4 μg/dl). It is possible that the latter workers, believing the disposable respirator to be an inferior product, were being more diligent. However, the result was statistically non-significant.

Contractor’s confidence in disposable respirators keeping BLL down

Contractors who were not confident disposable respirators would keep BLL down had an increase of 13.0 μg/dl. Contractors who were confident had an increase of 15.1 μg/dl. This difference is small and non significant.

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[15] A “green hat”, is a commonly used term in heavy industry as well as mining, oil and gas for a person who is new to the industry.

Contractor's confidence in training

Contractors who were not confident in training had an increase of 17.6 μg/dl compared to those who were had an increase of 13.9 μg/dl. Once again while this result was not statistically significant. However, it is interesting that about 15% of contractors (Table 6) felt that the training was not a key factor.

Lead-Based Hobbies

There was no relationship between BLL changes and non-occupational exposure to lead such as hobbies including lead soldering, car maintenance, lead lighting, and house renovating. This could be explained by the fact that most workers were away from home during the shutdown period. Future research needs to consider the characteristics of contractors before interventions. It was found in this intervention that the contractors had a small lead load with an average entry of BLL of 5.7 μg/dl, suggesting that lead exposure during these hobbies is not high.

Blood Lead Concentrations and Age of Contractors

As with lead based hobbies there was also no relationship between age of workers and changes in BLLs.

Question 3: What Were The Airborne Lead Levels During The Shut Down Period?

Air monitoring (Table 4) revealed contractors were potentially exposed to large quantities of lead dust, exceeding the Australian 8 hour time weighted average exposure standard of 150ug/m^3. Large variability in exposures was observed with the lowest levels found in the blast furnace bottom floor, GM 23 ug/m^3 compared to GM 515 ug/ m^3 in the blast furnace dross floor. Fixed position air monitoring in the yard area found a GM of 71 ug/ m^3, these "safe areas" requires evaluation through air monitoring. It appears this was a significant source of lead exposure - it would be sensible to educate contractors to use respirators in this area. Grauvogel (1986), found in a similar area airborne lead concentrations of GM 28 ug/ m^3 and corresponding non-compliance with respirator use. Accordingly these areas could be a source of lead exposure, which partially accounts for the increased BLL observed.

These results also signify there was highly variable exposures to lead dust and may be a reason for the variable difference in BLL for contractors. This indicates contractors are exposed to different lead dust exposure. It is more likely that the differences were due to exposure rather than compliance as observed compliance was very high. This is supported by fact that some groups of contractors, i.e. the riggers and crane operators had the highest observable increases in BLL. This finding is supported by Reynolds et al (1997), who found contractors deemed high risk from lead exposure indeed had higher BLL than employees at low risk. Indirectly this is supported by Johnson et al (2000) and Scholtz et al (2002), who both found certain tasks lead to much greater exposure to lead dust than others.

Overall the air monitoring results indicates that control measures may need to be reviewed considering such large exposures to lead dust and the corresponding sharp increase in BLL over a short time frame. Future maintenance shutdowns should also utilise personal air monitoring.

Question 4: How Well Did The Contractors Comply With Respirator Usage and General Hygiene Requirements?

General observation of contractor work practices suggests that overall compliance was excellent (Table 3), with overall compliance being 95 percent. Based on personal opinions of full time smelter staff involved in the previous blast furnace shutdown two years ago, there was a significant improvement. This is partially supported by Figure 4 illustrating an overall decrease in BLLs for contractors between the July 2002 shutdown and the August 2004 shutdown, with no observed spike. Coupled with no observed spike in BLL for staff, it indicates that disposable respirator usage leads to higher compliance, which led to reduced exposure to lead dust, which in turn leads to lower BLL for contractors. The implication here is that if companies make PPE and/or compliance with safety rules and regulations simple then compliance will be higher.

This is reinforced by overwhelming positive feedback the author received from contractors pertaining to disposable respirator usage when attending “tool box” meetings. These meetings however revealed logistical issues, with some contracting companies exhausting their supply of respirators (usually when employees were conducting particularly dirty work. This would have greatly affected the ability of contractors to comply with the respirator program.

During this study a number of issues were either verbally communicated to researchers or recorded on contractor exit questionnaires that may partly explain the observed non-compliances. A number of contractors complained of safety glasses fogging up while wearing the disposable masks. This suggested that the respirators were not being donned correctly to produce an effective seal. Through discussions with safety officers and researchers own observations, observations of non-compliance were due to experienced contractors lowering their masks below their chins out of habit to talk even though they could be clearly heard with their respirators on. This could be easily addressed at the next shutdown by focussing on the benefit that the disposables improve communication compared to standard rubber respirators. Spear et al (2000), comments in their discussion that this was due to a lack of compliance due to workers needing to communicate, not consistently wearing respirator (some not conscientious) and removing them before entering their crib rooms. Others studies have identified compliance as a key issue in ensuring the correct use of respirators. Both Wu (2002) and Spear et al (2000) in respirator (using both negative and positive pressure), field studies found significant range in outside (ambient) lead concentrations and contamination in-side respirator face pieces. They both surmise it was due to lack of compliance. This may be addressed by targeted training and strict enforcement of compliance with respirators. This could also be addressed by consistent stake holder analysis and better risk communications. If contractors were made aware of how important it is to have good seals and were consulted on any issues they were having then targeted training might be possible before and as needed (fine tuning) during the shutdown.

Another interesting observation was that almost all of the non-compliance observations recorded were of contractors with moustaches, indicating possessing moustaches is a contributory factor in non-compliance with respirator usage which could increase the exposure and subsequent uptake of lead. The lowering of respirators can significantly increase the amount of lead inhaled as contamination from the neck of the contractor can be breathed in once the respirator is placed back on correctly. At future shut downs, training should make mention that contractors with moustaches need to be diligent and even trim back their moustaches. It may even be necessary to mandate moustaches be trimmed. Further, future research should identify contractors with moustaches via the post induction questionnaire; the BLLs of contractors with moustaches should be compared with those without so to ascertain if indeed moustaches contribute to increase BLLs.

Some areas had different levels of compliance such as the rotary kiln, accordingly it would be prudent to identify what tasks these contractors were performing to ascertain if they are different from tasks in the blast furnace and sinter plant to ascertain if the non-compliance is work related. The workers in this area in future may need special attention in training as well as area monitoring to see if exposures are different. The rotary kiln was observed by the author to be cramped and hot, it would be prudent to identify if this non-compliance is work related and if their BLLs differed from the whole group. Overall future interventions require careful consideration of factors such as compliance, training and education. Previous research has identified the need for a comprehensive management program to ensure correct fit, worker hygiene factors, education, compliance and training of individuals (Aiba et al., 1995; Askin and Volkmann 1997; Chuang et al., 1999; Choy et al., 2004; Porru et al., 1993; Sun et al., 1995).

For future maintenance shutdowns and indeed future interventions, stakeholder analysis could be a useful tool for identifying the subsets of key stakeholder, such as workers with moustaches, and their characteristics and dynamics influencing implementation and effectiveness of OHS programs.

Hygiene Requirements

Observations were undertaken and recorded to assess the overall cleanliness of the crib rooms and other sources of lead exposure through contractor hygiene practices. The, 'Crib Room Observation Checklist' (Appendix 5) was routinely conducted at a few hours after commencement of each shift and near conclusion. Fixed position air monitoring carried out within the blast furnace crib room (Table 4) suggests that this area where the contractors are not required to wear respirators may have contributed to their lead exposure. The air monitoring found ambient airborne lead levels higher than both the blast furnace bottom floor and the rotary furnace. Although cleaned every twelve hours, they were for the most part visually very dirty. Contractors entered wearing contaminated clothing, dirty boots (even though booties were provided) and many were observed by the researchers not washing their hands before eating even though crib room hygiene protocols were addressed during the induction and training sessions. Further, it was observed that besides not changing out of overalls before entering the crib room as required by management, bags were left on tables, in contradiction of management requirements. These observations indicate contractor training and induction need to be rethought. While the actual implementation of hygiene, controls may need a reporting, reward and penalty component.

Seemingly, workers require more education of the oral route of exposure by lead and how they contribute by not complying. As mentioned by Grauvogel (1986); Holness and Nethercott (1986), the oral route of exposure must be considered in reducing lead exposure accordingly contractors require more education on the oral route of exposure by lead and how they contributed to this by not complying. Management may need to devote more resources to enforcement of hygiene practices such as crib room attendants. Discussions with management since this investigation indicate that these recommendations will be initiated at the next maintenance shutdown, including the requirement that wipe sampling of crib room facilities should be conducted to verify if hygiene protocols are effective.

Further, wipe sampling should be conducted of the crib rooms using the NIOSH method (9100) Lead in Surface Wipe Samples[16]. OSHA provides guidance on lead loading (surface lead dust) for non-lead work areas. Method 9100 would be useful in ascertaining where crib rooms are a source of lead.

Finally, the food supplied was inappropriate for a lead hazard environment. This food was mainly handled by the contractor's hands, such as pies, pasties and sausage rolls. The hand mouth behaviour through consuming food combined with the soiled overalls, boots and bags introducing lead dust into the environment no doubt contributed to ingestion of lead and consequently some of the observed increase in BLL. These factors were found by Askin and Volkmann (1997); Chuang et al (1999); Choy (2004); Johnston et al (2000); Fairfax (1996) as important influences in the uptake of lead. In future strict enforcement of hygiene such as no overalls or bags and supplying food to be consumed by utensils would be appropriate for the situation.

Stakeholder Analysis

To better understand the dynamics of this study a 'stakeholder' analysis was conducted (see Table 9). It identified that there was no consultation between the lead companies' management and safety personnel, and with contractors and contracting companies. If this had been conducted this may have identified smokers as a susceptible subgroup with difficulty attempting to work a 12 hour shift without a cigarette. If this had been the case, measures such as more frequent breaks for smokers could have been introduced. Such an

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[16] This uses a crayon to mark out a 10 x 10 cm square (100 cm of a surface Drier Sterna Traffic Accident Marking Crayon No. 199), then swabbing the surface inside the square, using refresher towelettes.

analysis could have identified other susceptible groups such as contractors subject to high level exposure such as the riggers and crane operators.

The stakeholder analysis also identified logistical issues in supplying respirators might have contributed to some of the observed increase in BLL of contractors. In future, a stakeholder analysis should consider contracting companies and include them in planning, particularly in large scale maintenance projects such as the shutdown. It is foreseeable that there might be difficulties coordinating the multitude of contracting companies to ensure they comply with the required safety standards. The lesson here for large companies such as the lead smelter company is they must scrutinise their contractors for possible inclusion thorough a stakeholder analysis. A recent spate of fatalities in the WA mining industries all occurred in sub contracting companies, and suggests that contracting companies are the weak link in OSH directly attributed to lack of consultation with contracting companies. Some companies, (predominately those performing dirty tasks, leading to accelerated deterioration of the respirators), were not informed of the numbers of respirators required.

In principle, a stakeholder analysis is a useful tool for planning OHS interventions, in particular determining the relevant demands placed on stakeholders, the proceeding ripple effects and interactions between groups during an intervention. One such ripple effect was that smokers were not compliant; they cut holes in their respirators to smoke, and consumed lollies to alleviate cravings. This illustrates how difficult it is to conduct interventions and that there needs to be consultation with stakeholders

The stakeholder analysis also identified safety officers as crucial stakeholders, who revealed that riggers and crane operators historically had the highest increase in BLL. By using this information the researchers were able to focus on this group which revealed they had high observable changes in BLL compared to general contractors (Table 8) however this was not statistically significant Nevertheless, future shut downs, should target this subgroup of contractors possibly using engineering controls such as HEPA air conditioners for crane operators and improved respiratory protection and /or programs for riggers.

When combining the observable differences in BLL changes for the different contacting groups and the large differences in airborne lead measured at different areas it may be prudent to assess tasks for potential lead exposures as recommended by Goldbery et al (1997); Holness and Nethercott (1988); Sussell et al (1999). Finally, any hot work must be monitored for its lead exposures to contractors Chuang (1999); Froines et al (1986); Gauvogel (1996); Paik and Park (2001) all found that hot work increased exposures to workers, particularly $\leq 1.0\ \mu g/m^3$ airborne lead, which is absorbed by the lungs at a much greater efficiency. Accordingly, control measures would be prudent such as enhance training and increased requirements for daily allocation and usage of respirators. In the future any hot work should be risk assessed and personal monitoring conducted to ascertain if the contractor is being exposed, then controls measures introduced. This could be simply modifying the task to lessen the creation of lead dusk. In cases where there is welding or other hot work extra protection such as fully faced air supplied respirators.

Another consideration with hot work is whether it contributes to poorer compliance possibly through increased fouling of the disposable respirator compared to other tasks. There is also the need to ascertain if hot work reduced compliance due to fogging up the goggles of welders and whether the task itself inherently might reduce compliance through welders lifting masks to communicate as was observed. It may well indicate welders will require a different type of respirator, which includes communication devices such as two way radios.

Besides welding, certain tasks also fouled respirators quicker than other tasks. It was observed that there were particularly "dirty" tasks which caused respirators to become dirty reducing their effectiveness. Once again risk assessing tasks and considering methods to reduce exposure or if this is not possible introducing extra controls such as HEPA exhaust systems may reduce exposure to lead dusk. Personal monitoring for such tasks is also a must so to assess which the controls worked. It must be noted some tasks such as confined space work make introducing extra controls difficult. Whatever controls are considered, they must be also risk assessed to ensure they will not contribute to heightened exposure. For example a HEPA exhaust system may cause leaded dust to be blown over the work site

Certain tasks that heighten the risk to exposure from lead dust may require risk assessment that includes an assessment to whether they will also decrease compliance to respiratory programs. It was found for instance contractors working in the rotary kiln had significantly lower compliance compared to other contractors. This area was observed as very cramped and hot. It may be necessary to rate certain tasks in their potential for non compliance and allocate resources to ensure better compliance to these tasks. This could include ensuring supervisors and lead smelter staff are alerted of certain tasks that are likely to have poor compliance so to increase vigilance for these tasks. It must be noted that in certain industries such as mining there is a zero tolerance approach to non compliance to PPE. In certain situations such as the rotary kiln it would be fruitful to investigate introducing other controls to reduce the exposure and possible in this situation even elimination of the need to use masks. Air monitoring may reveal there is low risk from exposure to lead dust, otherwise methods such as HEPA filters supplying clean air to this area could be considered as long so this does not introduce other hazards such the air movement causing dust to be blown elsewhere.

Overall, this study illustrates that a comprehensive management program is needed. Careful consideration of factors such as logistics, compliance, task related exposures, introduction of additional control methods, training and education is essential. Previous research has identified include the need for comprehensive management programs to ensure correct fit, worker hygiene factors, education, compliance and training of individuals (Aiba et al., 1995; Askin and Volkmann 1997; Chuang et al., 1999; Choy et al., 2004; Porru 1993; Sun et al., 1995). Through the stakeholder analysis model much of this can be achieved. The stakeholder analysis was useful in identifying unforseen outcomes such as contractors wanting to return to future shutdowns, conflict between lead smelter staff and OHS professionals, insights from nurses into non compliance such as smokers, lolly usage, mistrust, while contractors reported they themselves while positive about use of respirators were distrustful due to lead smelting company workers using rubber. It is however crucial that for this and other interventions that the stakeholder analysis is undertaken in the planning stage. By doing so threats as well as opportunities from the different stakeholders can be identified, even leading to identifying opportunities for collaboration (Varvasovzky and Brugha 2000). It is at this point a further comprehensive stakeholder analysis should be undertaken to ensure all of these measures are explained so to include stakeholders to work towards a collaborative approach to this and future interventions. By doing so attention can also be directed though analysing which stakeholders have influence and using this influence to target group so goals are met (Brugha and Varvasovzky 2000) such as in this intervention the goal is to minimise uptake of lead in contractors is achieved. To elaborate, the contracting companies have low influence overall however they do have the most influence on the contractors, if they were included in a preliminary stakeholder analysis they could become a vital partner and assist the organisation, here the lead smelter, achieve its overall objective (Brugha and Varvasovzky 2000) of reducing the uptake of lead in contractors. This could be from the beginning such as briefing them on the need to target smokers, contractors with moustaches and those who haven't worked in lead smelter environments before.

Process evaluation of interventions is also essential to provide "real time" feedback on how successful the intervention is. This could be through daily toolbox meeting attendance by researchers to elicit feedback, fix position monitoring and personal monitoring analysed daily to identify lead exposure "hot spots", compliance observations by researchers and staff collated daily to help target potential areas of low compliance. Daily hygiene measures such as wipe sampling could also be employed to ensure areas such as crib rooms are maintained lead free. It must also be noted appropriate food it required. Finally, better training including fit testing on site would no doubt assist, this needs to target new users and contractors with moustaches.

5.4 OPPORTUNITIES FOR IMPROVING THIS INTERVENTION

The following recommendations are made:

1. The relationship between physically demanding tasks contractors undertake, increased respiration rate and increased uptake of lead warrant exploration.
2. Greater observation by safety staff and researchers is needed to identify areas where there are non compliances, so to identify tasks that have poor compliance such as what was found in the rotary kiln and contractors with moustaches. It may well be that the above aforementioned strenuous tasks, lead to lowered compliance and associated increased BLL. This will further assist targeted training, as well as targeted compliance checks.
3. Certain contractor factors such as the relationship between smokers and non-smokers and uptake requires better understanding.

4. The following sub groups of contractors - smokers, contractors with moustaches and experienced respirator users - require targeting during the induction and training sessions. For smokers training and education on how it can increase uptake of lead; contractor with moustaches, need education on how this interferes with the seal; while experienced contractor need training on the communication benefits of disposables that is you don't need to lift to communicate.

5. Overall, all contractor need to be educated and trained on the importance of hygiene in crib rooms, that is not to take work clothes and/or bags into crib rooms and to consistently wash hands before consuming food and/or beverages. All crib rooms require more rigorous enforcement of lead smelter lead management protocols.

6. Crib rooms must be evaluated for the contractor's exposure to lead this can be achieved by wipe sampling of crib rooms.

7. Fixed position air monitoring needs to evaluate airborne lead levels and cross referencing measured exposures with BLL of contractors working in the vicinity, will facilitate understanding of tasks that generate lead dusts and the subsequent increased in BLL. This will be aided by analysis of mass median aerodynamic diameters, particle size distribution and geometric standard distribution from samples to identify what processes(s) are producing what types of lead particles so to better understand relationship between the respirable component lead dusts and increased BLL. If resources allow, personal monitoring of contractors performing specific tasks will greatly enhance this understanding.

8. Tasks should be risk assessed for lead dust generation, and appropriate control measures implemented such as engineering controls (HEPA filters on power tools), implemented. This needs to commence at the planning stage at the next shutdown, including consultation with key stakeholders such as contracting companies. A method could include obtaining job descriptions then use company occupational hygienist to assess the potential of lead dust generation then recommend appropriate control measure. Further, contractors BLL could be compared with job descriptions (this was intended at the last shutdown).

9. The BLL of lead smelter employees should be taken simultaneously as contractors, before and at conclusion of the next shut down as a comparison group or control group to contractors and a useful extra quantitative measure of effectiveness of

disposable respirators. Entry and exit BLL samples should be mandatory for any remuneration of contractors. Further these data need to identify how long contractor were employed on site so BLL increases can be compared to a timeframe.

10. A stakeholder analysis should be conducted at the next intervention. This should address groups most affected by interventions and associated policies such as the hygiene and non-smoking policies, in this study, contractors with moustaches and smokers. This stakeholder analysis could also benefit planning such as supply of respirators and elicit from contractor(s) and their companies what task may require better protection than that afforded by respirators.

11. All stakeholders should be briefed before the intervention, possibly a letter of introduction on why we are conducting such a study followed by a meeting which should serve as a preliminary stakeholder analysis. It would be at this point when briefing key stakeholders such as lead smelter management that the importance of consistency in the execution of an intervention is conveyed for instance in this study ensuring all employees working during the shutdown are using the same disposable respirators. By conducting a stakeholder analysis before the intervention opportunities and threats could also be identified and collaborative relationships (Varvasovzky and Brugha 2000). In this intervention the contracting companies themselves appears to have been totally excluded in any decision making and consultations despite having probably the most influence on the key to the success of the intervention, the contractors themselves.

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APPENDICES

APPENDIX 1: INFORMATION SHEET

The University of Adelaide

INFORMATION SHEET

Respiratory Protection Intervention for Contractors in a Lead Smelter

The University of Adelaide is collaborating in a study of the use of disposable respirators in a maintenance shutdown environment. This study will focus on the usage of disposable respirators to reduce dust exposure.

In this study we will be measuring concentrations of lead available to be breathed in, and looking at blood lead results, which will be, upon your consent, provided to us by management, at the conclusion of the maintenance shutdown. We ask you to participate in this study by completing a questionnaire survey after your induction and an exit questionnaire after your final blood test. The questionnaires will take around 5-10 minutes. Participation is voluntary - accordingly you are free to withdraw from this study at any time with out affecting your current or future employment.

In order to gain your permission to use these details we ask you to sign a consent form. When the final report is published no information will be released which will enable individuals to be identified.

The main purpose of this study is to assess how effective disposable respirators are at reducing lead uptake in the body through inhalation of lead dust. We are also interested in whether there is any relationship between, smoking, lead based hobbies, age, type of work and previous experience with respirators (both disposable and standard), and the uptake of lead as measured by blood lead testing. There is currently very limited information available.

The results of this research should assist in developing policies and procedures for using disposable respirators in the future, and to improve occupational health and safety interventions. If you would like further information or need assistance, please contact:

Dr Dino Pisaniello, Dept. of Public Health, University of Adelaide. Ph: 8303 3571

An independent complaints procedure form will also be given to you, if you would like to lodge a complaint about the conduct of the research.

APPENDIX 2: CONSENT FORM

Department of Public Health

CONSENT TO PARTICIPATE IN STUDY

1. I, ……………………………………………………………………… (please print name)

   consent to take part in the University of Adelaide research project called:

   Evaluation of a Respiratory Protection Intervention for Contractors in a Lead Smelter

2. I acknowledge that I have read and understood the Information Sheet called:
   Respiratory Protection Intervention for Contractors in a Lead Smelter
3. Even though this study aims to improve the occupational health and safety of workers, I have been informed that I may not gain any direct benefit.
4. I understand and have been informed of the need for an entry lead in blood test and exit lead in blood test as required by management to perform contract work at the lead smelter.
5. I understand that the results from blood tests will be used for research by the University team.
6. I understand that information obtained from me from questionnaires will also be used by this team.
7. I have been given the right to refuse any information I don't want to give.
8. I have the right to inform management through my contracting company that I want to withdraw from this study at any time and that any information obtained will be destroyed. This won't affect my current and future employment.
9. I understand and have been told that information from the questionnaires will not be used by anyone except members of the University study team.
10. I'm aware that a copy of this form will be stored by the Department of Public Health at the University of Adelaide.
11. I acknowledge that the above information was verbally presented to me during my induction - I understood it and had time to query anything I didn't understand.

……

(please sign here) (please print date)

……....

Witness Position Date

APPENDIX 3: INDEPENDENT COMPLAINTS FORM

INDEPENDENT COMPLAINTS FORM

HUMAN ETHICS COMMITTEE

Document for people who are subjects in a research project:

Evaluation of a Respiratory Protection Intervention for Contractors in a Lead Smelter

CONTACTS FOR INFORMATION ON PROJECT AND INDEPENDENT COMPLAINTS PROCEDURE

The Human Research Ethics Committee is obliged to monitor approved research projects. In conjunction with other forms of monitoring it is necessary to provide an independent and confidential reporting mechanism to assure quality assurance of the institutional ethics committee system. This is done by providing research subjects with an additional avenue for raising concerns regarding the conduct of any research in which they are involved.

The following study has been reviewed and approved by the University of Adelaide Human Research Ethics Committee:

Project title: Evaluation of a Respiratory Protection Intervention for Contractors in a Lead Smelter

1. If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the project coordinator:

   Name: **Dr Dino Pisaniello, Department of Public Health, University of Adelaide**

   Telephone: **8303 3571**

2. If you wish to discuss with an independent person matters related to

   - making a complaint, or raising concerns on the conduct of the project, or
   - the University policy on research involving human subjects, or
   - your rights as a participant

   contact the Human Research Ethics Committee's Secretary on phone (08) 8303 6028

APPENDIX 4: POST INDUCTION QUESTIONNAIRE

Today's Date _____ / ______ / ______

Your age: _____ yrs ____ months **or** **Date of Birth** _____ / _____ / 19____

Name: ____

Name of your company: ____

Are you a current smoker? YES ☐ NO ☐

Were you a contractor at the last Blast Furnace shutdown? YES ☐ NO ☐

Have you worn a rubber mask or "paper" dust mask before this induction?

Rubber Mask ☐ Paper Dust Mask ☐ Both ☐ Neither ☐

Have you ever had instructions on how to correctly fit a mask before this induction?

Rubber Mask ☐ Paper Dust Mask ☐ Both ☐ Neither ☐

In your opinion does a disposable mask (paper mask) provide the same amount of protection against lead dust as a rubber mask?

YES ☐ NO ☐

Do you feel confident that the use of disposable "paper" masks will keep your 'lead in blood', level down?

YES ☐ NO ☐

Would you feel more confident in using masks if you had the proper training?

YES ☐ NO ☐

Do you have the following hobbies or activities at home?

Lead Soldering ☐ Renovating ☐

Car maintenance ☐ Lead Lighting ☐

Do you think you have a good understanding of the health effects that may occur from exposure to lead dust?

YES ☐ NO ☐

Thank you for your cooperation.

APPENDIX 5: RESPIRATORY HAZARD OBSERVATION

Area of Observation:

Time: **Shift:** **Date:**

How many employees are present in this area:

50-74 □ 75-100 □ 100-125 □ 125-150 □ 150-175 □ 175-200 □ 200-225 □

225-250 □ 250-275 □ 275-300 □ 300-325 □ 325-350 □

How many of these employees are correctly wearing their disposable respirator at this particular time?

What is the level of power tool usage, creating dust, during this observation?

High □ Medium □ Low □ Non-Existent □

Is this usage causing any obvious dust? Yes □ No □

If so how many employees are in the vicinity?

25-50 □ 50-75 □

75-100 □ 100-125 □ 125-150 □ 150-175 □ 175-200 □

200-225 □ 225-250 □ 250-275 □ 275-300 □ 300-325 □ 325-350 □

APPENDIX 6: CRIB ROOM OBSERVATION CHECKLIST

Name of Inspector ____

Crib Room/Location ____

Date: _______ / ______/ **2004** **Time:** ___________ **Shift**_________________

Photo id. _____________

Have you collected two-wipe samples from tabletops, while adhering to collection guidelines?

Yes □ No □

Is there dirty clothing on table tops Yes □ No □

Is there dirty clothing on surrounding floors Yes □ No□

Loose visible dirt/dust on table tops Yes □ No □

Is there loose visible dirt/dust on tops of chairs Yes □ No □

Are the door handles dirty? Yes □ No □

Are the ledges and fixtures visibly clear of dust? Yes □ No □

Dirty cigarette butts visible anywhere? Yes □ No □

If so how many _________

Is used chewing gum visible anywhere? Yes □ No □

Has the crib-room been cleaned within the last 24 hours Yes □ No□

Is there a ready supply of soap and towels in the area? Yes □ No □