

Inadvertent ingestion exposure in the workplace

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Phase I Literature review

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Little is known about the relative importance of inadvertent ingestion of hazardous substances from work activities. In this report we review the available scientific literature to help understand whether inadvertent ingestion is an important route of exposure and for which agents. Proposals are made for a conceptual model of the processes involved with this type of exposure and for possible exposure metrics to be used for workplace measurement.

This is the first of three reports dealing with inadvertent ingestion exposure in the workplace.

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SUMMARY

Human exposure to hazardous substances in the workplace by inhalation and skin contact are well understood, but there has been little systematic research into ingestion of hazardous substances used at work. This report attempts to identify from published information whether inadvertent ingestion is an important route of exposure in the workplace and examines possible methods that could be used to quantify ingestion exposure.

A number of papers highlight jobs and substances where inadvertent ingestion may be important, typically through case reports or from a theoretical analysis. These scenarios involve exposure to some metals or metal compounds, pharmaceuticals, pesticides, some infectious agents, unsealed radioactive sources and some high molecular weight allergens.

A conceptual analysis of inadvertent ingestion exposure highlights the role of hand-to-mouth and object-to-mouth events as the primary exposure processes. Two exposure “compartments” are defined: the *peri*-oral area (i.e. the area of skin around the outside of the mouth) and the oral cavity. Several options are highlighted for exposure-related measurements, including *peri*-oral wipes, saliva samples, mouth-rinse samples, hand-wipes and under-nail scrapings.

Human behaviour has a key role in determining inadvertent ingestion exposure. For example, some people are habitual nail biters or repeatedly touch their mouth, both of which will increase the chance of ingesting contaminants on their hands. The frequency that people touch their face is dependant on the circumstances of their work and probably the degree of psychological stress they are under. A proper understanding of the importance of these factors will help in designing interventions to reduce the risks from ingesting hazardous substances at work. When making inhalation or dermal exposure measurements we recommend that details of personal behaviours should be recorded so that some estimate of ingestion risks can be inferred.

This is the first volume of three reports that describes the results of a programme of research to investigate inadvertent ingestion.

1 INTRODUCTION

For chemicals to have a toxic effect on the body they must first pass across a functional barrier separating the environment from the internal organs. Most textbooks that deal with human exposure contain a description of the routes of entry for chemicals into the body, commonly: inhalation with the barrier being the lining of the lung; dermal absorption with the *stratum corneum* as the barrier and ingestion with the wall of the gastrointestinal tract as the barrier (Dinman and Dinman, 2000). Inhalation exposure is invariably singled out as the most important route in terms of potential to cause toxicity, followed by dermal contact with chemicals and then ingestion.

The assessment of exposure to chemicals in the workplace has tended to focus primarily on inhaled material. Mines, smelters, cotton mills and many other manufacturing processes traditionally produced large quantities of airborne dusts, gases and vapours that were generally poorly controlled and often damaged workers lungs or induced other target organ toxicity from absorption through the lungs into the blood. During the last decade occupational exposure research has focused more on the potential for chemicals to pass through the unbroken skin and the need for greater understanding and control of dermal exposure has been highlighted (Dost, 1995) The importance of the ingestion route of exposure has tended to be considered unimportant. This is likely to be due to a number of reasons:

1. the common belief that ingestion of chemicals can only occur by intentional means or acts of gross negligence, and hence can be avoided;
2. the recognition that many materials are only very poorly absorbed from the gut (i.e. they have low bioavailability) and as such are unlikely to produce toxic effects when swallowed in small quantities;
3. the presumption that where a worker is exposed by inhalation, dermal contact and ingestion, the mass of material taken into the body by ingestion may be small in comparison with the other routes.

There are some obvious examples of all three of the above assumptions being used in occupational hygiene. For example, people handling hazardous chemicals will not knowingly eat or ingest the material unless there is some intent to self-harm. Exposure to some transition metal elements, such as zinc, nickel and chromium, while having toxic effects by inhalation, are poorly absorbed by the gut and are therefore not considered to be a serious risk by ingestion. Indeed, there is evidence that ingestion of some metal compounds may have prophylactic properties.

Despite the pragmatic approaches to ingestion risks from chemicals at work there has been little systematic research on this topic and so there is no real understanding of the relative importance of this route of exposure. The Technical Guidance Document on chemical risk assessment from the European Chemical Bureau (ECB) states: "There are no accepted methods for assessing exposure by ingestion. It is usually controlled by straightforward good hygiene practices such as segregating working and eating facilities and adequate washing prior to eating." (ECB, 2003). However, the effectiveness of this approach has never been properly investigated.

Work-related ingestion of chemicals may occur in one of four ways: (1) clearance of inhaled aerosols deposited within the ciliated airways of the lung; (2) ingestion of contaminated food or beverages; (3) transfer of contamination by hand-to-mouth or object-to-mouth contact; and (4) by the more passive but more direct mechanism of deposition of contaminants around the mouth and into the oral cavity. In the first case, the amount of contamination available for ingestion can be estimated by sampling the airborne extra-thoracic size fraction, i.e. the coarsest part of

the inhalable aerosol. In the second case the assessment of exposure is relatively straightforward because the consumption of food is purposeful and predictable, so exposure can be assessed by measuring the amount of chemical contamination in the food and the quantity of food consumed. As the guidance from the ECB notes, exposure by this route may be controlled by appropriate personal hygiene and segregation of consumption from contaminated areas. However, the mechanism identified in the third case describes behaviour that is peculiar to individuals and is therefore less obviously predictable and controllable. There are no suitable methods available to measure the potential for ingestion exposure where the underlying processes are unintentional. Behaviour is also relevant to some extent in relation to direct deposition onto the face, particularly in relation to the transfer to the oral cavity

Ingestion exposure has been considered more important in other exposure situations. This includes environmental exposure where contaminated soil may be ingested by children (Tulve *et al*, 2002) and consumer situations where there may be ingestion of small quantities of food packaging, utensils or cosmetic products (ECB, 2003). The perceived importance by scientists and regulators working in these areas almost certainly reflects the greater importance of ingestion in these situations compared with most workplace exposure scenarios. There is a considerable body of research in these areas of human exposure compared to workplace exposure and although the circumstances of exposure are very different it is likely that some of the lessons from this work can be used in relation to workplace ingestion exposure.

This report is the first of three volumes that describe a research project undertaken jointly by the Institute of Occupational Medicine in Edinburgh (IOM) and the University of Aberdeen, Department of Environmental and Occupational medicine (DEOM). The overall objectives of the research project were to:

- a) undertake a review of published literature and other information sources to identify chemicals and industries where ingestion exposure contributes a significant fraction of total body burden;
- b) describe workplace and behavioural factors influencing ingestion exposures in a range of simulated exposure scenarios, together with the development of a validated method to measure ingestion exposure;
- c) formulate of a simple theoretical model as a means of describing ingestion exposure;
- d) evaluate and refine the model using observations and measurements carried out in relevant workplaces; and
- e) present the findings and provide an evaluation of the need for future research.

The main aim of this report is to evaluate the likely importance of inadvertent ingestion exposure to chemicals for people at work and those who may be exposed as a consequence of work activities, e.g. bystanders or neighbours. The evaluation has been made by reviewing the available scientific literature on all aspects of human exposure and by considering the conceptual framework of this exposure route. The review does not consider the contribution to ingestion from inhaled contamination that may ultimately end up in the gut or the contribution from deliberate consumption. We have chosen to put some particular emphasis on carcinogenic substances because of the importance of any additional exposure in such cases.

The review has been published in a peer-review scientific journal and we have based this report on an abbreviated version of that paper (Cherrie *et al*, 2006).

2 IDENTIFICATION OF SUBSTANCES AND TASKS WHERE INGESTION EXPOSURE MAY BE SIGNIFICANT

2.1 INTRODUCTION

Searches of the scientific literature using key word combinations such as ‘ingestion and occupation’ or ‘ingestion and toxic’ revealed a variety of published material. These were filtered using the information contained in the abstract and the publications most relevant to this review were studied. A great majority of the published material contained details of case study reports where accidental or inadvertent ingestion of toxic substances had caused some directly observable health effect. However, there were additional studies where the ingestion route was identified as a significant contributory factor based on information derived from biological monitoring. The exposure scenarios that were most widely published can be categorised in terms of substances, i.e. metals, pesticides, pharmaceuticals, pathogens and radionuclides.

2.2 METALS

In occupational settings, metals are one of the few categories of materials where the ingestion route has received some attention. This is partly because toxic effects are well understood and that there are well defined exposure assessment methodologies available.

For example, removal of lead paint has the potential to cause significant ingestion exposure via hand-to-mouth contact and food contamination (Sen *et al.*, 2002; Enander *et al.*, 2004). The effect of transfer by hand-to-mouth contact while eating in the workplace is exemplified in a comparative study between Chinese and Malay workers in a lead battery production plant. The increased lead in blood levels in the Malay workers was attributed to their cultural tendency to eat food using the hands (Chia *et al.*, 1991). Also in another study, urinary arsenic levels were increased during maintenance semiconductor manufacturing and this was judged to be mostly due to ingestion of contamination on the hands (Hwang and Chen, 2000).

One Japanese study of lead refinery workers demonstrated that lead facial wipes and lead in fingernails produced high correlations with blood lead levels ($r = 0.73$ and $r = 0.59$, respectively). The study concluded that lead ingestion from the contaminated face and fingers contributed to elevations in the blood lead levels among workers (Karita *et al.*, 1997). The Hwang and Chen (2000) study showed a high correlation between blood lead levels and the mass of lead detected on the lips of workers.

Various studies of electroplating workers have shown poor correlation between airborne levels and urinary nickel levels (Cattani *et al.*, 2001; Kiilunen *et al.*, 1997). It has been suggested that this might be due to dermal uptake, although personal hygienic behaviour might be a more important factor than overall cleanliness (Cattani *et al.*, 2001; Makinen and Linnainmaa, 2004).

2.3 PHARMACOLOGICALLY ACTIVE AGENTS

Pesticides and other pharmacologically active agents are used for a wide variety of agricultural, non-agricultural and therapeutic purposes and most can be absorbed through the gut to a greater or lesser extent. The dangers of accidental ingestion of pesticides are well known (Zavon (1964), and steps to prevent accidental ingestion of large quantities of pesticides are well described in official precautionary advice (e.g. DEFRA, 2004).

Inadvertent ingestion of biocides or pesticides was identified by Garrod *et al.* (1999), who compared dermal and inhalation exposure of timber treatment biocides with biological

monitoring data, and in a study of Australian pesticide workers using chlorpyrifos (Cattani *et al.*, 2001). Both studies highlighted the role of eating and/or smoking in contaminated areas. Professional application of chlorpyrifos in the home may result in contamination of the hands of children in the house (Freeman *et al.*, 2004), where the amount of pesticide on the hands was associated with surface contamination and the child's hand-to-mouth behaviour. The children put their hand to their mouth ten times per hour on average and placed possibly contaminated objects in their mouth about 4.5 times per hour. Shalat *et al.* (2003) investigated hand contamination and urinary pesticide metabolites in children and found a statistically significant correlation between these measures. They attributed the elevated urinary pesticide metabolite levels to inadvertent ingestion of pesticide from hand-to-mouth events.

While we have not been able to identify any research that explicitly investigates inadvertent ingestion of pesticides by adults as a consequence of hand-to-mouth or object-to-mouth events we believe that this is a likely route of exposure in adult workers or bystanders, but probably relatively less important than for young children. However, it is not possible to say how important this type of ingestion may be in relation to other routes of exposure.

While there is some anecdotal evidence of ingestion exposure during manufacturing and administration of pharmaceutical products, there is little published in the literature. However, there has recently been interest in workplace exposure to pharmaceutical agents used in chemotherapy. The ingestion route has been identified as potentially significant during the preparation of cytotoxic drugs by hospital pharmacists (Bauer and Fuortes, 1999; McDevitt *et al.*, 1993).

2.4 INFECTIOUS AGENTS

There are three main groups of workers who are at significantly increased risk of work-related disease from ingestion of micro-organisms: agricultural workers dealing with animals; health care workers; and laboratory workers handling pathogenic agents. The main occupational infections amongst agricultural workers are zoonoses, where the causative agents may be viral, bacterial, fungal, protozoan or parasitic. There are about 20 relatively common infectious agents found in the UK where the transmission routes include ingestion.

Laboratory, health care and health-related workers are at risk of a number of infectious agents, including mycobacterium tuberculosis, human-immunodeficiency virus (HIV) and hepatitis B virus but most of these are not spread by ingestion. The main issue in the healthcare sector is infection control, i.e. transmission of infection from staff to patient or patient-to-patient. Methicillin-resistant staphylococcus aureus (MRSA) is of great topical interest, together with the various forms of hepatitis. These are all transmittable infections, for which ingestion is a possible route, generally by the faecal-oral route. MRSA is likely to be transmitted by person-to-person contact, but the exact mechanisms of infection remain unclear (Muto *et al.*, 2003).

Ross *et al.* (1998) summarised data from occupationally acquired infections in the UK for one year from October 1996. They recorded 1,037 new cases of disease, with the highest rates being found among workers in food production, catering, farming and those employed in care homes. The majority (89%) of reports were of diarrhoeal disease. For a subset of these reports the agent of interest was known: mainly campylobacter, salmonella or small round structured viruses, including Norwalk virus.

2.5 RADIONUCLIDES

There are very few occupational groups that are likely to be exposed to radionuclides, and even fewer where the potential for ingestion exposure exist. However, exposure to radionuclides is of special concern given their known carcinogenic potential. Data from the Central Index of Dose Information (CIDI) in the UK indicates that situations for which ingestion (and other) exposure is possible are those such as nuclear power, nuclear fuel fabrication and nuclear facility decommissioning. These represent a little over 50% of the persons exposed to radionuclides in the UK. In addition, many healthcare workers handle radionuclides used for tracers and radiotherapy treatments often in relatively uncontrolled settings.

2.6 RELEVANCE OF INGESTION EXPOSURE TO ALLERGENS

Exposure to allergens may occur via inhalation, dermal absorption or by ingestion, and has been widely reported in food processing industries (Cadot *et al.*, 1996; Jeebhay *et al.*, 2001). Some people may become sensitised and when re-exposed develop skin or respiratory symptoms, and very rarely, anaphylaxis.

Exposure to allergens may affect the aetiology of allergy in two ways; it is an important risk factor for sensitisation and subsequent re-exposure may influence the expression of symptoms of allergy (such as respiratory, skin and gastric symptoms). Studies of bakery and animal research workers found that new symptoms and sensitisation were related to exposure intensity, although there is very little information about the significance of the ingestion route.

The prevalence of self-reported food-allergy is relatively common in the general population, where inhalation exposure is less likely than in work situations. However, IgE-mediated sensitisation to foods in adults is low - estimated at 1-2% (Kagan, 2003). The agents causing food allergy in adults are peanuts, tree nuts, fish and shellfish. Reports of food allergy attributable to food agents encountered at work include seafood and spices but there are no reports of occupational nut allergy. The prevalence of sensitisation is likely to be higher in food industry workers where the exposure to food allergens is greatest. However, it is not completely clear whether sensitisation occurs due to occupational ingestion or inhalation. The study of the occupational allergy is unique as exposure can be well characterised, but it is difficult to assess the influence of the route of allergen exposure on disease aetiology. For adults there is limited data on the epidemiology of food allergy, and less about the relationship between exposure to food allergens and indicators of disease.

HOW MIGHT PEOPLE BE EXPOSED BY INADVERTENT INGESTION

3.1 SCOPE AND TERMINOLOGY

The processes leading to inadvertent ingestion of hazardous substances must involve transfer of the substance from the environment into the mouth. For this to be a realistic proposition the contaminant substance or the mixture that it is contained in must be a relatively non-volatile solid or liquid, so that it may remain available during the transfer processes. The processes of transfer must include movement of contaminated hands or objects into the mouth, or contact of contaminated hands or objects with the skin around the mouth (the *peri-oral* area) followed by migration of this contamination into the mouth. Splashing into the mouth or onto the face are also relevant mechanisms, although probably much less important.

As we indicated at the outset, our review does not consider the contribution to ingestion from inhaled contamination that may deposit in the nose or upper airways and ultimately end up in the gut, or the contribution from deliberate consumption of contaminated food or drink. In many cases the contribution of inhaled aerosol to ingestion of chemicals will not be insignificant, but we believe that it is easily predicted from knowledge of the aerosol concentration and size distribution. In addition, we consider that this process is part of understanding the toxicokinetics of substances taken into the body rather than part of the exposure assessment process, i.e. it is translocation within the body.

The International Programme for Chemical Safety (IPCS) have prepared a glossary of terms used in exposure assessment (WHO, 2002). At the heart of their approach is the idea that exposure is “contact between an agent and a target”, where the contact takes place at some exposure surface over some defined time period. In this scheme the exposure surface is not seen as some definite or even real surface but is an adaptable concept. For our purposes we have defined the exposure surface for ingestion as a hypothetical surface covering the mouth, including the lips. We have chosen this definition because we believe it is appropriate to focus on the *peri-oral* area given that we hypothesise that material deposited there may easily be transported into the mouth for ingestion.

Two further terms are important for us to construct a clear conceptual picture of ingestion exposure: intake and uptake. In the IPCS glossary the term “intake” is defined as the “process by which an agent crosses an outer exposure surface of a target without passing an absorption barrier”, such as the gastro-intestinal wall. The term “uptake” refers to the “process by which an agent crosses an absorption barrier”. We have attempted to follow this scheme throughout this report.

3.2 DEVELOPMENT OF A CONCEPTUAL MODEL OF INADVERTENT INGESTION EXPOSURE

It is possible to construct a simple conceptual model of exposure processes leading to ingestion uptake. From our analysis we believe this should comprise two main routes: the direct pathway where the contamination is introduced into the mouth by either the subject’s hand or an object and the indirect pathway where contamination is transferred to the *peri-oral* area and then into the mouth. Transfer will be determined by the subject’s personal behaviour (e.g. hand-to-mouth contact, licking lips etc.) or flow of sweat. In all cases we believe that the hands play a central role in the exposure process. The conceptual model is shown graphically in Figure 1.

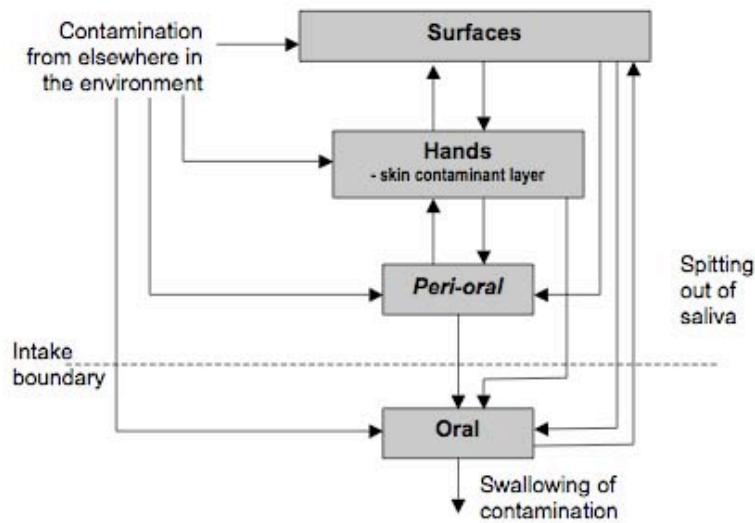


Figure 3.1 Conceptual model of inadvertent ingestion exposure of hazardous substances

The model comprises four compartments (surfaces, hands, *peri-oral* and oral cavity) that may contain a mass of contamination that can be exchanged with other compartments. It is clear that for some of the compartments there may be a two-way exchange of contamination while for others there is only flux of material in one direction. Contamination can enter the system from the air or directly from sources onto surfaces. We exclude material being inhaled and then depositing in the upper airways and being swallowed, although we do allow for the possibility of contamination being transferred directly from a source to the *peri-oral* or oral compartments, for example by splashing. We assume that once in the mouth the contamination can only be swallowed or spat out.

We have deliberately chosen to consider the oral compartment as part of the exposure process, but it is shown below the dotted line on the figure indicating that it is an internal compartment (the dotted line represents the boundary for “intake”). The *peri-oral* area is shown above the intake boundary since we consider it an external exposure compartment, although within the “uptake” boundary.

Transfer between compartments is from episodic events, i.e. as mass transfer per event. Transfer events are not all identical and even for a single transfer pathway. The mass exchanged will be a function of many variables: some related to the substances involved (e.g. physical state, solubility volatility, stickiness of the material), some to the process (e.g. method of handling the object, the pressure of contact) and perhaps also to the duration of the transfer process. We have no *a priori* view about whether the transfer process will result in a fixed proportion of the contaminant in the compartment moving (which corresponds to the use of a “transfer efficiency”) or some other relationship.

The frequency and duration of contacts plus the type of contacts will be determined by the personal characteristics of the subject and the constraints of the process. For example, certain people will be more likely to bite their nails, some people may be more likely to touch their face. In some situations where people are more anxious they may engage in nervous habits such as face touching or in situations where they are busy with a task then they may touch their face

or mouth less frequently. Human behaviour as determined by personality traits is likely to be particularly important in determining who is at risk from inadvertent ingestion.

3.3 THE ROLE OF HANDS AND OBJECTS IN TRANSFERRING CONTAMINATION TO THE MOUTH

There is a considerable body of work on children and infants frequency of mouthing their fingers and objects, e.g. Reed *et al.* (1999), Juberg *et al.* (2001), Steenbekkers (2001), Tulve *et al.* (2002) and Kranz *et al.* (2004). Most studies show a clear trend in decreasing mouthing with age, although there is substantial unexplained variation in mouthing between children. For example, Tulve *et al.* (2002) found that children less than 24 months had on average 81 events per hour while children older than 24 months had on average 42 events per hour. However, because of the differences in methodology used by the different research studies and the divergence between metrics (e.g. number of events per hour and total mouthing time) it is difficult to generalise findings from these studies further.

The frequency that adults touch their face or place objects in their mouth is almost certainly less than young children. A study amongst 44 university students evaluated the proportion of 10-second time intervals that they touched their face or mouthed an object (Woods and Miltenberger, 1996). When the experimental conditions were “neutral” the subjects touched their face on average 3.9 times per hour (Standard Deviation, SD = 6%) and mouthed objects 1.6 times per hour (SD = 5.8%). Making the subjects anxious increased the proportion of time they engaged in these behaviours (9.5 per hour for face touching and 2 per hour for mouthing), with the difference in face self-touch being statistically significant. Interestingly the standard deviation for both habits also increased in the anxious state suggesting that some subjects may be more affected than others by the increased anxiety.

Data on hand-to-face contacts for adults in three situations: laboratory and pesticide workers, manufacturing and engineering workers and office workers were obtained by Zainudin (2004). The average number of contacts differed significantly for the three groups, with the office workers showing the greatest number of contacts (6 per hour on average) and the laboratory and pesticide workers showing the lowest (almost none). The author hypothesised that the differences between the three groups was due to the tasks that they had to undertake. The laboratory personnel and pesticide workers were almost constantly using their hands to complete their work tasks, whereas the office workers had only occasional need to use their hands to control their work tasks. The manufacturing and engineering workers were intermediate.

Some people have a greater tendency to exhibit repetitive habits such as finger sucking or nail biting that would increase the likelihood of inadvertent ingestion. Woods and Miltenberger (1996) found that 10% of students reported that they bit their nails and Long and Miltenberger (1998) report between 23% and 40% of the general population bite their nails, with the peak ages for nail biting being between 10 and 19 with a gradual reduction in the prevalence after the age of 40. The results of a questionnaire study of about 2,500 Italian high school students showed that 55% of pupils reported some nail biting, with 5.5% reporting that nail biting interfered “a lot” with their daily life (Maggini *et al.*, 2001). It is unclear exactly what factors are involved in maintaining such behaviour. It has been suggested that it may be some form of autonomic negative reinforcement, e.g. anxiety reduction, or autonomic positive reinforcement, e.g. sensory stimulation (Miltenberger *et al.*, 1998).

1. Relevant exposure metrics for ingestion

Exposure measurements must be practicable and related to the risk to the individual. It is not practicable to measure the mass of a contaminant hazardous substance passing through the gastrointestinal wall and so it is necessary to focus on earlier stages in the process of uptake and intake. We believe the conceptual compartmental model that we have elaborated provides a sound basis to consider the possibilities for measurement.

The first compartment to offer some information about exposure potential is the level of contamination on surfaces. This is a measure that describes the exposure environment of the person and is similar in concept to the measurement of room air concentration of a chemical in relation to personal exposure. While it is a valuable descriptor of environmental contamination, it does not provide a good indication of exposure. A standardised form of wiping the contaminated surface with a swab may be a suitable approach to assess the mass of contaminants on surfaces. We have not considered the strategy for selecting surfaces to sample, but clearly this is an important consideration.

The next relevant measure is the amount of contamination on the hand. There is much experience in undertaking this type of measurement for dermal exposure studies, although there is an important conceptual difference between the two measures. For dermal exposure it is most relevant to measure those parameters that are related to the flux of chemical through the skin, e.g. the concentration of the contaminant, whereas for ingestion the mass of the contaminant on the hands is more important. A wipe system may also be appropriate to assess the mass of a chemical in the skin contaminant layer, although an absorbent patch would not. It may also be important to measure the mass of a contaminant in inaccessible locations such as under fingernails.

The next compartment to consider is the *peri-oral* area of the face. We hypothesise that some of the contaminant in the *peri-oral* area will eventually transfer to the mouth and so it is a more direct measure of ingestion exposure than either surface or hand contamination. In addition, we believe that there may be a good correlation between the amount of a hazardous substance ingested by direct hand-to-mouth contacts and the indirect hand-to-*peri-oral*-to-mouth route. The mass of contaminant in the *peri-oral* area may therefore be a good surrogate for all routes of exposure by inadvertent ingestion. The *peri-oral* contamination could again be assessed by wiping the skin on this area of the face.

The contents of the mouth compartment might intuitively be expected to be the best measure of ingestion exposure, but it must be remembered that there is a considerable flux of saliva through the mouth that will wash contamination away. Also, physico-chemical properties of the contaminant such as water solubility may also influence residence time in the mouth. However, it is likely that the flow of saliva through the mouth is not uniform and there will be a proportion of contaminant that has a longer residence time and so measuring the contamination in the mouth may provide useful information. Two approaches to assess the mouth compartment are a mouthwash and saliva spit samples.

For all of these measures it is important to collect relevant contextual data along with the measurements. The conceptual model also helps us to define the contextual parameters that should be measured, for example, the number of transfer events by each route, the characteristics of the process involved, the type of materials and perhaps the duration and area of contacts.

Lastly, it is important to recognise that biological monitoring has an important role in assessing aggregate exposure by all routes – inhalation, skin contact and ingestion. Measurements of the concentration of substances or their metabolites in urine can provide useful data to assess

inadvertent ingestion, but only in conjunction with measures of external exposure by all relevant routes.

2. Discussion

The main aim of this review was to evaluate the importance of inadvertent ingestion exposure to hazardous substances from work activities. We concluded that the key substance groups likely to pose a risk to health from inadvertent ingestion are metals, pesticides, pharmaceuticals, some infectious agents, radionuclides and some high molecular weight materials that evoke allergenic responses. Not all substances in these groups will have the potential to be taken up through the gut but many will and for them, this route of exposure will add to the risks to health. Many of the substances we identified in these categories are carcinogens or suspected human carcinogens and so any additional exposure is particularly important to control.

We think it is likely that one of the main reasons that the ingestion route is under-reported is that there are no standardized metrics for measuring and characterizing exposure. In the absence of measurement we have little information to say when this route is important. There is some circumstantial evidence to suggest the importance of ingestion exposure at work for metals and infectious agents. However, development of appropriate monitoring methods for inadvertent ingestion of hazardous substances is an important prerequisite for a proper systematic investigation of this route of exposure.

There has been some progress in evaluating the ingestion of chemicals in non-occupational scenarios. While levels of exposure and uptake in such environmental scenarios are likely to be orders of magnitude lower than in occupational settings, the fact that a small fraction of the body burden in such situations comes from inhalation has encouraged those involved to focus more on developing methods to characterize dermal and ingestion routes. Models that use details of micro-activity, finger, hand and object mouthing frequency and transfer between the various exposure compartments are central to our understanding of non-occupational ingestion of hazardous substances. We need to recognize that there is a wealth of scientific material available in environmental exposure assessment and we should develop ways to utilize this in occupational exposure assessment.

We have identified a number of possible measurements that could be used to characterise inadvertent ingestion of hazardous substances. These range from *peri-oral* wipes, saliva samples, mouth-rinses, hand-wipes or under-nail scrapings. Just as we have seen in inhalation and dermal sampling, it is unlikely that one method will prove suitable for all types of hazardous materials. For example saliva sampling may not be a good measure of that day's ingestion exposure to a chemical with a long half-life in the body and is endogenously secreted in extracellular fluids such as saliva. In this case the material measured in the mouth compartment would be a mix of that day's ingestion exposure (i.e. transferred from the workplace to the mouth) and the mass that was being endogenously produced. Similarly, substances that are rapidly absorbed through the skin or are volatile would not be suitable for skin wiping, and are probably therefore less important for uptake by ingestion.

There is a need for research to examine the behavioural characteristics that increase or decrease the frequency of hand and object-to-mouth activity, both within and between people. The published research on children in relation to non-occupational exposures and our initial observations in the workplace seem to indicate that there are complex interaction between the individual's activity, the requirement and frequency of hand-use to perform tasks, external stressors, and the presence of respiratory protective equipment or spectacles on the face. Young children may have greater hand-to-mouth activity than adults or older children, although the data are equivocal in this respect. We know from inhalation and dermal monitoring that behavioural factors can play a very important part in determining exposure levels. Kromhout *et al.* (1993) showed that as many as two-thirds of workers with the same job tasks have exposure level differences spanning more than ten-fold. Most of these differences in exposure will be due to differences in worker behaviour. We consider it likely that we will see at least this level of

variability when examining occupational or bystander ingestion exposures, although behaviour may be even more important for ingestion because of the central role of hand-to-mouth actions. Understanding the behavioural influences controlling ingestion exposure will allow us to target interventions to reduce risks from this route.

We believe that ingestion exposure is primarily from hand-to-mouth contact. Key to our understanding of this process are the parameters that influence transfer of a material from a surface or object to the hand and then transfer from the hand to the mouth or *peri-oral* area. These factors can be sub-divided into the following groups: surface factors; material factors; vehicle factors, hand factors and *peri-oral* factors. The characteristics of a surface (e.g. rough/smooth; impervious/porous) will have a bearing on how readily the material can be removed during contact with the hand. The physical properties of a material will play a major role in the transfer. Similarly, the vehicle that the material is contained within will determine the degree of transfer, for example a highly viscous fluid may transfer more easily from surfaces to the *peri-oral* area. The condition of the hand and *peri-oral* skin may also regulate transfer. Dry-skin may be less able to retain contamination than skin that is moist. Sweating may also influence retention and transfer of a substance. All of these parameters require study and we need to increase our understanding of how they impact on ingestion exposure. This investigation might best, or at least initially, be undertaken by controlled laboratory investigations. When exposure measurements are made, information about such explanatory variables should also be collected.

We believe that this review has provided a rigorous examination of the importance of the ingestion route of exposure in occupational settings. With the success of control measures to reduce inhalation and dermal exposure, the fraction of total body burden arising from the ingestion route may increase. This may be particularly true where the interventions are focused on modifying the source rather than changing the process of the work environment or in reducing the mass of material taken up through the skin.

The remaining two reports describe further work to evaluate the processes involved with inadvertent ingestion, and to develop and validate a model for ingestion of hazardous substances.

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Inadvertent ingestion exposure in the workplace

Phase II

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During Phase I of this study we obtained evidence suggesting that the inadvertent ingestion exposure in the workplace could be an important route of exposure in a number of industries. A conceptual ingestion exposure model was developed. In this study we have investigated the mechanisms involved in inadvertent ingestion exposure to hazardous substances in occupational settings. We have developed a preliminary conceptual model of ingestion exposure. This model describes pathways by which a contaminant may enter the oral cavity and identifies hand-to-mouth and hand-to-face (peri-oral region) contacts among the important mechanisms in the process. We undertook a series of laboratory experiments to explore the parameters influencing exposures in each compartment of the model and the relationships, reported as transfer efficiencies, between model compartments.

The outcome was a development of the conceptual model into a multiplicative deterministic model that can be used to estimate ingestion exposure to solids. This model is used to estimate ingestion exposure for a workplace scenario previously estimated using expert judgement. The model predictions resulted in exposure levels in excess to those originally obtained. This suggests that the contribution from the oral route of exposure could be underestimated in the absence of more realistic estimates of transfer from surfaces into the oral cavity. This work brings further understanding to the mechanisms involved in exposure via the oral route. The model will be validated using results from actual workplace measurements of oral exposure in Phase III of the study.

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SUMMARY

The oral route of exposure is often given a low priority within occupational hygiene. This is because of the perception that this route contributes the lowest proportion to total exposure levels in most occupational settings. However, in Phase I we estimated that up to 4.5 million workers in the UK could have some regular non-trivial intake of hazardous substances by inadvertent ingestion exposure (Cherrie *et al.*, 2006; Christopher *et al.*, 2006a). In general, an *ad hoc* approach is taken to assess risks in the absence of more detailed knowledge of the mechanisms by which inadvertent ingestion exposure occurs. This approach is probably sufficient for the vast majority of workplace settings, but in some situations it may not be adequate e.g. where even very low ingestion exposure may be able to produce health effects, for example cytotoxic drugs in the pharmaceutical industry and health care sector. The aim of this project was to elucidate the mechanisms involved in inadvertent ingestion exposure and to provide more substantive information for setting control measures against this exposure route.

In this study we investigated the mechanisms involved in inadvertent ingestion exposure to hazardous substances in occupational settings and their relation to the dermal route of exposure. In Phase I of this project a preliminary conceptual model of ingestion exposure was designed (Cherrie *et al.*, 2006; Christopher *et al.*, 2006a). This model described the possible pathways by which a contaminant may enter the mouth and identified hand-to-mouth and hand-to-face (peri-oral region) contacts among the important mechanisms in the inadvertent ingestion exposure process. In this phase of the study we have investigated the parameters influencing exposures in each compartment of the model and the relationships, reported as transfer efficiencies, between compartments.

A series of laboratory experiments was conducted in order to calculate the transfer efficiencies among model compartments (surfaces, hands, peri-oral and oral cavity). Given the limited previous research conducted on assessing exposure in the oral cavity a novel method, exploiting the spectrophotometric properties of the food-flavouring substances, quinine and saffron, was developed. This method involved the measurement of these analytes in saliva by spectrophotometric analysis. To estimate dermal exposure, previously established methods involving hand washes followed by chemical analysis of the hand wash solution and fluorescent imaging of dermal surfaces were used. Unfortunately, due to interference in the saliva samples with the quinine analyses, the corrected results for oral exposure to quinine (i.e. post minus pre-experiment) were very low and in many cases less than zero. The original intention had been to develop two separate models – one for solid and one for liquid exposures. However, due to measurement technique difficulties it was only possible to develop a model for solids.

The resulting output is a simple multiplicative model defined by transfer efficiencies between compartments. The contamination in the hand compartment was central to the oral exposure process and investigation of parameters influencing hand loading indicated that surface load levels, number of hand/surface contacts and the moisture level of the skin influenced mass of contaminant on the hand for a saffron contaminant. Only a limited number of the parameters investigated in this study directly affected exposure in and around the oral cavity. We looked at the influence of the number of hand/face contacts and duration of the finger in the oral cavity. The influence of wearing gloves during hand to face contacts was also investigated and was found to facilitate transfer of powdered solid to the peri-oral region, however, this was not statistically significant and therefore not included in the final model.

The mean transfer efficiency from surfaces to hands was 28%, from hands to the peri-oral region 37%, whilst from peri-oral region into the oral cavity the transfer efficiency was 38%. We were unable to establish accurately the transfer efficiencies from the hands to the oral cavity

and we decided to apply a worst-case estimate for the transfer efficiency between the hands and the oral cavity of 95%.

Use of the model to estimate ingestion exposure levels for a workplace scenario resulted in exposure levels in excess to those originally obtained through expert judgement. This suggests that the contribution from the oral route of exposure could be underestimated in the absence of more realistic estimates of transfer between surfaces.

The model is based on limited data; however, it was still possible to establish, with some degree of confidence, algorithms to estimate exposure in the oral cavity. The models represent potential ingestion exposure and are mainly concerned with factors affecting loading of the oral cavity. We believe that they are a good starting point to begin to understand the mechanisms involved in oral exposure. Further work to validate the models has been carried out, and results are presented in the accompanying report (Christopher *et al.*, 2006b).

1 INTRODUCTION

1.1 BACKGROUND

Historically, investigations into occupational exposures to hazardous substances have concentrated on inhalation exposure. In recent years the importance of other routes of exposure has been realised. A considerable amount of research has been conducted within the last two decades on dermal exposure. Among the significant outputs has been the development of dermal exposure models. Noteworthy among these are the conceptual model devised by Schneider *et al.*, (1999) and the predictive dermal exposure models developed under the Risk Assessment of Occupational Dermal Exposure to Chemicals (RISKOFDERM) funded by the European Union 5th Framework Programme (van Hemmen, 2003). These models have shed light on the processes and mechanisms by which dermal exposure takes place. They have also contributed towards standardising methods for assessing and describing exposure via the dermal route as well as confirmed that the dermal route of exposure can be a significant contributor to total exposure.

The priority given to the oral route of exposure can be likened to that given to dermal exposure prior to the 1980s. Risks associated with ingestion exposure have been recognised for specific industries and substances. For example, the realisation that health risks exists from exposure through the ingestion route for substances such as lead, pharmaceuticals and pesticides has led to the establishment of occupational hygiene programmes designed to minimise and control the spread of contamination. This has been done without a comprehensive knowledge of the mechanisms by which inadvertent ingestion exposures occurs (Cherrie *et al.*, 2006). Some control measures are obvious precautions - washing hands before eating and segregating workplace and eating facilities as recommended by the European Chemical Bureau (ECB, 2003). However, more in depth studies are required when serious adverse health effects can occur if control measures are inadequate. In addition, risk may be underestimated due to poor understanding of the mechanisms of ingestion exposure.

It is under the premise that exposure via the oral route may be more important than is generally believed that the present study was undertaken. We investigated the potential importance of inadvertent ingestion exposure in the workplace and the mechanisms that cause such exposure.

1.2 AIMS AND OBJECTIVES

Our primary aim of the study was to provide a knowledge-base on the mechanisms of ingestion exposure in order to develop and validate a model for occupational ingestion exposure. To achieve this aim we had the following objectives:

1. To carry out a literature review indicating what is currently known about ingestion exposure
2. To identify a list of industries and scenarios for which ingestion exposure is especially relevant
3. To develop a validated measurement method for quantifying exposure via ingestion
4. To develop a well described generic model that can be used to assess ingestion exposure over a range of substances and scenarios.
5. To validate this model using real exposure scenarios.

The project was been divided into three phases with each phase guiding the subsequent work (Figure 1.1). Within the first phase an extensive literature review was conducted to identify the relevant industries and exposure scenarios where ingestion exposure may be of importance as well as to identify the main determinants of ingestion exposure. The results of this part of the study have already been presented in the Phase I report (Christopher *et al.*, 2006a) and by

Cherrie *et al* (2006) and will therefore not be discussed in detail here. Within the first phase of the project, observations were made in the field to identify processes leading to ingestion exposure. This included the collection of micro-activity data, i.e. detailed actions that occur within a general activity, such as hand-to-surface and hand-to-mouth behaviour (Cohen Hubal *et al.*, 2000). These data helped inform the construction of a preliminary model and hence which factors needed to be investigated during phase II - the laboratory experiments.

The purpose of the laboratory experiments was to quantify and refine the main processes identified in the model for a range of scenarios. It required the development of a measurement technique to quantify ingestion exposure, use of previously established methods for quantifying dermal exposure and following on from this, the calculation of transfer efficiencies between compartments of the model. The information from the literature review together with the output of the laboratory experiments has resulted in the construction of a simple deterministic model of ingestion exposure.

This report will focus mainly on the Phase II laboratory experiments and how the outputs from the laboratory experiments have been used to refine the preliminary model.

The final part of the study involved workplace investigations in facilities involved in metal production and use (exposure to nickel or lead) and results of the validation and subsequent model refinement are presented in the accompanying report of this study (Christopher *et al.*, 2006b).

PROJECT OVERVIEW

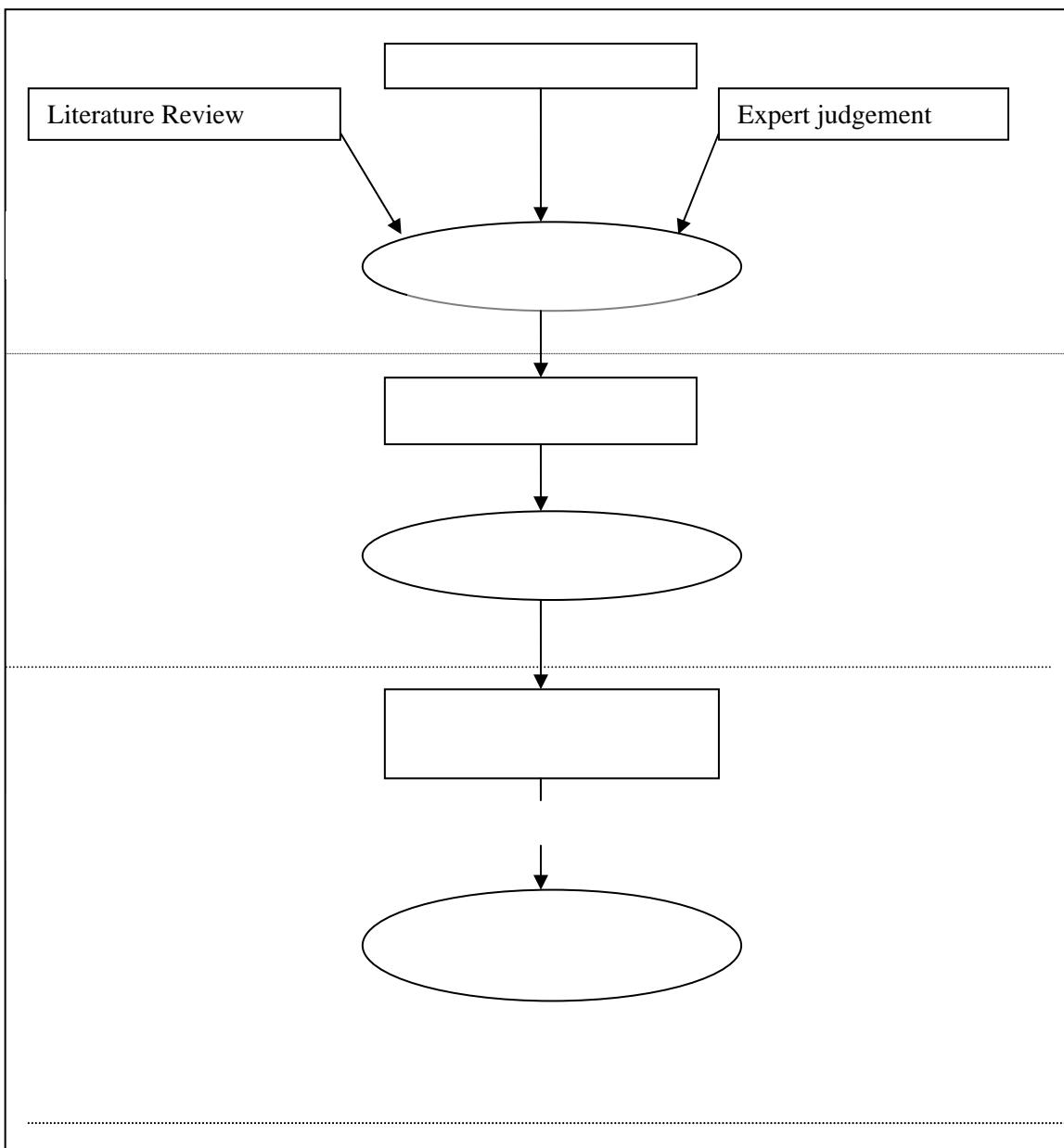


Figure 1.1 Project Overview

2 METHODOLOGY

2.1 FIELD WORK – MICROACTIVTY DATA COLLECTION

Micro-activity data were collected in a number of different workplaces. This was achieved by closely observing workers as they went about their work tasks using a standardised field observation form (see Appendix 1). Each observation was made over a 10-20 minute period. The observer stood within 5 metres of the subject and noted the number of times a worker brought his hand or a tool into contact with different areas of his face. Prior to carrying out the observations, workers were informed that we were making some general observations. Immediately before each observation the worker was approached and permission to observe him/her was requested. The fact that data were being collected on hand-surface and hand-mouth activity was not explicitly revealed to the worker. The worker was advised to work in his usual way and told that we were just observing work practices. Data were not collected within the first few minutes thus allowing the worker time to grow accustomed to being observed. Supplementary information, such as workplace characteristics, personal traits of the worker and use of personal protective equipment, was also collected via observations and during a brief interview with the worker (Appendix 1), usually just after collecting micro-activity data.

2.2 LABORATORY EXPERIMENTS

The laboratory experiments were devised based on the preliminary conceptual model that was developed as part of this study (Cherrie *et al.*, 2006). Figure 2.1 shows a simplified version of the conceptual model and indicates the elements that were investigated in the laboratory experiments (bold) and the exposure metrics used (hand washes, face washes and saliva samples).

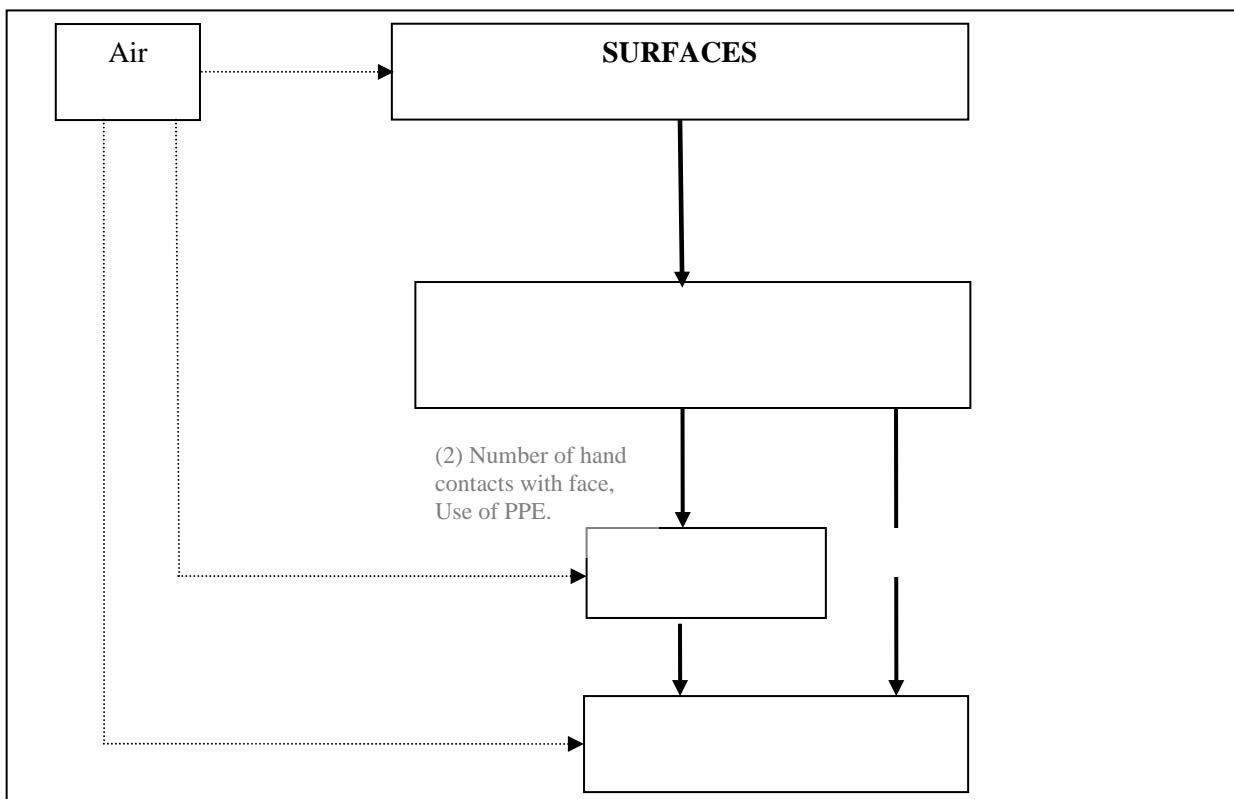


Figure 2.1 Elements of the preliminary model further investigated in the laboratory.
The exposure metric used and the parameters investigated are also indicated.

2.2.1 Experimental Design

The primary objective of this phase of the project was to obtain data to refine the preliminary model. This required a means of measuring the mass of contaminant transfer between compartments as well as a means of quantifying the effect of parameter values on mass transfer. A ‘standard’ scenario was firstly defined and the transfer efficiencies associated with this scenario estimated. A battery of experiments was then conducted changing one parameter of the standard scenario at a time. In this way it was possible to determine the effect of a particular parameter on analyte mass within each compartment and hence on the transfer efficiencies between the relevant compartments. Transfer efficiency was defined as the proportion of a contaminant transferred from one surface to the next or from a dermal surface into the oral cavity. We set out to examine the transfer of both liquid and saffron contaminant among model compartments.

The parameters investigated fell into one of three groups: (1) parameters that might influence hand exposure; (2) parameters that might influence peri-oral exposure; and (3) parameters that might influence oral exposure. Within the first group were parameters related to the condition or nature of the surface compartment (surface load and surface type), followed by parameters related to the nature of the hand compartment (skin moisture content) and finally parameters described by the interaction between these two model compartments (duration and number of hand contacts with the surface and for a saffron contaminant the type of contact - hand press or smudge). The second group of parameters included the number of hand contacts with the face and the influence of wearing gloves. The third group of parameters included the influence of a direct transfer into the oral cavity (finger-licking) or an indirect transfer (via the peri-oral

region). The effect of the time period between transfer and collection of the oral sample was also examined but for direct type transfers only.

The variations in the parameters are described in Table 2.1. The standard scenario is indicated in **bold** and can be described as follows: A single, five-second press of the palm of the bare hand onto a glass plate with a surface loading of 0.05 mg saffron/cm² for solid exposure and 0.001 mg quinine/cm² for liquid exposures, respectively. This was followed by simulation of direct transfer into the oral cavity by sucking the index finger (little finger for liquid exposures) for five seconds. The moisture level of the skin of the palmar surface of the hand just prior to conducting each trial was also measured using a corneometer (DermaLab, Cortex Technology). The details of each scenario are indicated in Tables 2.2 and 2.3. Eighteen different scenarios were investigated for liquid exposures and 19 different scenarios for solid exposures. Where possible we carried out 4 repeat measurements for each experiment.

Table 2.1 Study Parameters

Parameter	Parameter values			
Surface Load (mg/cm ²)	low	high		
Surface Type	glass	wood		
Type of hand contact with surface (saffron only)	press	smudge	carpet	
Duration of hand contact with surface (seconds)	5	1	10	17
Number of hand contacts with surface	1	2	3	4
Number of hand contacts with peri-oral region of face	1	2	3	
Use of PPE (gloves) during hand contacts with peri-oral region	no	yes		
Type of transfer from hands into oral cavity	direct	indirect		
Duration of transfer between hands and oral cavity (saffron) (seconds)	5	10	15	
Duration of transfer between hands and oral cavity (quinine) (seconds)	5	30	60	120

Note: The “standard” scenario is indicated in bold

Table 2.2 Parameter values for experiments involving exposure to liquid.

Scenario Number	Surface Type	Surface Load (mg quinine/cm ²)	Contact duration (seconds)	Frequency surface contact	Frequency face contact	Oral transit Time (seconds)	Gloves	Transfer Type
1	glass	0.001	5	1	0	5	No	direct
3	glass	0.002	5	1	0	5	No	direct
4	glass	1	1	1	0	5	No	direct
5	glass	1	10	1	0	5	No	direct
7	glass	1	17	1	0	5	No	direct
8	glass	1	5	2	0	5	No	direct
9	glass	1	5	3	0	5	No	direct
10	glass	1	5	4	0	5	No	direct
11	glass	1	5	1	1	5	No	indirect
12	glass	1	5	1	2	5	No	indirect
13	glass	1	5	1	3	5	No	indirect
14	glass	1	5	1	0	30	No	direct
15	glass	1	5	1	0	60	No	direct
16	glass	1	5	1	0	120	No	direct
17	carpet	1	5	1	0	5	No	direct
18	wood	1	5	1	0	5	No	direct
19	glass	1	5	1	1	5	No	indirect
20	glass	1	5	1	1	5	Yes	indirect

Note: Scenario number 11 and 19 are identical experiments

Table 2.3 Parameter values for experiments involving exposure to a fine solid.

Scenario Number	Surface	Surface load (mg saffron/cm ²)	Contact duration (seconds)	Frequency surface contact	Frequency face contact	Oral transit time (seconds)	Gloves	Transfer Type
21	glass	0.05	5	1	0	5	No	direct
22	glass	0.10	5	1	0	5	No	direct
23	glass	0.05	1	1	0	5	No	direct
24	glass	0.05	10	1	0	5	No	direct
25	glass	0.05	17	1	0	5	No	direct
26	glass	0.05	5	2	0	5	No	direct
27	glass	0.05	5	3	0	5	No	direct
28	glass	0.05	5	4	0	5	No	direct
29	glass	0.05	5	1	1	5	No	indirect
29b	glass	0.05	5	1	1	5	Yes	indirect
30	glass	0.05	5	1	2	5	No	indirect
30b	glass	0.05	5	1	2	5	Yes	indirect
31	glass	0.05	5	1	3	5	No	indirect
31b	glass	0.05	5	1	3	5	Yes	indirect
32	glass	0.05	5	1	0	10	No	direct
33	glass	0.05	5	1	0	15	No	direct
35	carpet	0.05	5	1	1	5	No	direct
36	wood	0.05	5	1	1	5	No	direct
37	glass	0.05	5	1	1	5	No	indirect
38	glass	0.05	5	1	1	5	Yes	indirect
40	glass	0.05	5	1	1	5	No	direct

Note: Scenario number 29 and 37 and numbers 29b and 38 are identical experiments.

2.2.2 Tracer properties

There are no standardised methods for assessing exposure within the oral cavity. It was therefore necessary to devise a quantitative method that would allow measurement of exposure in the oral cavity that could be related to the dermal exposure. The method devised exploited the use of the spectrophotometric properties of two commonly used food additives. – saffron and quinine. They were chosen because they were safe to ingest in the quantities we proposed to use on our study volunteers and had well-described spectrophotometric properties which allowed them to be quantified. Further, they were both efficiently removed from dermal surfaces without the need for desquamation, and from the oral cavity; hence a volunteer could participate in more than one trial in one day.

Risk assessments were conducted for both these substances (Appendix II). In brief, given that both quinine and saffron are safely used as food flavouring additives in the food industry and the relatively low levels of saffron and quinine used in the experiments, it was concluded that these experiments pose no threat of negative health effects to persons participating. Subjects were asked whether they were hyper-reactive to quinine, prior to the experiments. A study information sheet was prepared and provided to all study participants.

Saffron

To investigate exposure to a fine powdered solid within the oral cavity, saffron was used as a tracer in a saffron/icing sugar mix. Saffron is a naturally occurring dye obtained by drying the

stigmas from the flower *Crocus sativus L.* It is a food additive and is also known for its therapeutic properties. Saffron is reasonably stable under a range of conditions. Vickackaite *et al* (2004) reported that the absorption and fluorescence spectra of a freshly prepared solution, a solution stored in the dark at room temperature for 75 days, and a solution irradiated for 2 hours were quite similar and few changes were detectable.

The absorption spectra of saffron solutions are characteristic of carotenoids. They exhibit a double-peaked band between 400 and 500 nm in the visible region and bands in the UV region, around 260 nm, attributed to the glycosidic bonds of crocins (Vickackaite *et al*, 2004). Quantification of dermal and saliva sample solutions was performed by measuring the absorbance of sample solutions at a wavelength of 431 nm using a Unicam 8625 UV/VIS Spectrometer.

Saffron was obtained from a retail supplier as saffron filaments. These were then ground to a fine powder in a McCrone Micronising Mill (McCrone Research Associates Limited). The saffron powder was then mixed with icing sugar at a ratio of saffron:icing sugar of 1:25 (w/w). This mix was used to load the test surfaces.

Quinine

Quinine was used to investigate ingestion exposure to liquid. Quinine, as quinine salts or extracts from cinchona bark, is used as a bittering agent in tonic type drinks, usually at a concentration of approximately 80 mg quinine hydrochloride per litre. Quinine is also used in some bitter alcoholic beverages and to a small extent in flour confectionery.

Quinine is a strongly fluorescent compound in dilute acid. It has two absorption bands that are used for excitation centred at 250 and 350 nm. Its peak fluorescence occurs at 350 nm. Quantification of dermal and saliva samples was performed by measuring the absorbance of sample solutions at a wavelength of 348 nm using a Unicam 8625 UV/VIS Spectrometer.

For these investigations tonic water concentrate was obtained from a wholesale supplier (Soda-Club Worldwide Trading Company).

2.2.3 Sampling methods

Oral Sampling

Saliva samples were collected in plastic 50-ml Sterilin centrifuge tubes and (in case of sampling for saffron) frozen for 24 hours. Salivary quinine samples were not frozen as they were analysed on the day of the sample collection. A blank saliva sample was collected at the beginning of each test procedure.

Prior to analyses, the salivary saffron samples were thawed at room temperature; 3.5 ml of water was added to each sample and subsequently centrifuged for 20 – 25 min at 25,000 rpm. Three and a half millilitres of the supernatant was then removed using a micropipette and absorbance readings of the solution at the appropriate wavelength for the analyte was obtained. The initial volume of the pure saliva was noted.

A standard curve relating absorbance to the concentration of the analyte of interest (quinine or saffron) was prepared for each day of sampling. A fresh standard solution was prepared for each day of experiments. For saffron samples, the standard solution was frozen alongside the samples collected for that day.

Dermal Sampling

Dermal exposure measurements were obtained using a removal method. For hand exposure measurements, each hand was immersed in a Ziploc®, polyethylene, re-sealable bag (200 cm x 300 cm or 120 cm x 250 cm) containing 70 to 250 ml of water, depending on the size of the study participant's hands, for 10 seconds during which the volunteer rubbed the fingers together to assist the removal of the contaminant. The absorbance reading at the appropriate wavelength for the analyte was then obtained using a Unicam 8625 UV/VIS Spectrometer.

Face exposure measurements were obtained by applying a spray of water from a wash bottle onto the face for 15 seconds. The rinse water was collected via a funnel into a dark-coloured sample bottle. This was to limit photodegradation of the photosensitive analytes. The rinse solution was then analysed for the presence of saffron or quinine using UV/VIS spectrometry.

Hand wash and face wash volumes were quantified using a measuring cylinder. Blank hand wash and face wash samples were collected prior to obtaining hand wash and face wash samples.

2.2.4 Test Surfaces and surface loading

Three different types of test surfaces were used, glass, low-pile commercial carpet and wood (plywood). The area of each surface was 21 cm x 19 cm (399 cm²). Carpet and wood plates were discarded after one use. Glass plates were washed in warm water to remove any traces of residue and re-used. The efficiency of removal of contaminant from the surface of the glass plates by washing was 100%. This was determined by rinsing blank plates collecting the rinse solution and analysing the solution for presence of the saffron or quinine.

Loading of plates with powdered residue took place in a plastic surface loading box with a base area of 60 cm x 45 cm with a removable lid. The loading box was fitted along the width of its upper edges with a pipe perforated along its length. These pipes were each connected to two conical flasks with side-arms containing the powdered mix – saffron/icing sugar at a ratio of 1:25. These were in turn connected to a compressed air supply. A rotameter was also fitted along the line with which the flow rate through the conical flask could be adjusted (Figure 2.2).

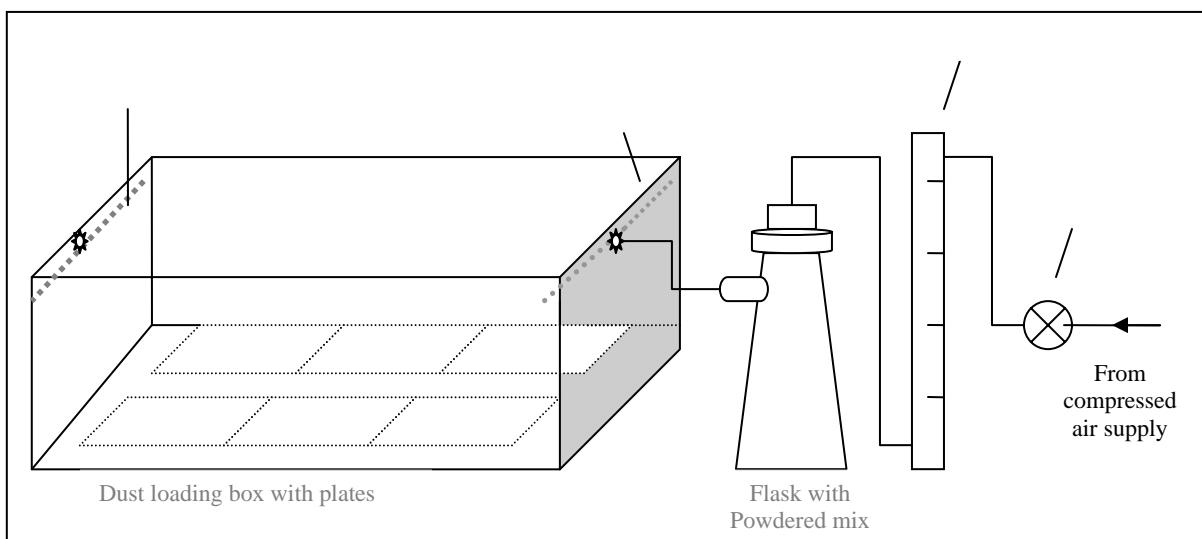


Figure 2.2 Dust loader

Following loading of six plates, the dust was allowed to settle for a few minutes prior to removing the plates from the loading box and onto plate storage racks especially designed for this purpose. A flow rate of 50 litres per min for 4 minutes resulted in a surface loading of 1.3 mg powdered mix per cm² (0.05 mg saffron/cm²). Variability in plate loading with saffron averaged 23% between plates (N=5).

A plate loading stand was designed for loading of quinine onto the test surfaces. This consisted of two wooden platforms placed horizontally and held separate but parallel to each other by four threaded metal posts (Figure 2.3). Screws on either side of both platforms allowed vertical movement of the platforms so that the distance between them could be adjusted. The upper plate was perforated at each corner and at its centre with small holes through which solution could be applied using an atomiser spray bottle. Loading was achieved by spraying twice through each hole in the upper plate onto a test plate lying on the lower platform. In this way the distance of the spray bottle from the surface was kept constant and variability of surface loading minimised. To obtain different levels of loading the concentration of the quinine solution, not the volume of spray applied, was adjusted. Variability in plate loading with quinine averaged 25% across one plate and 12% between plates (N=7).

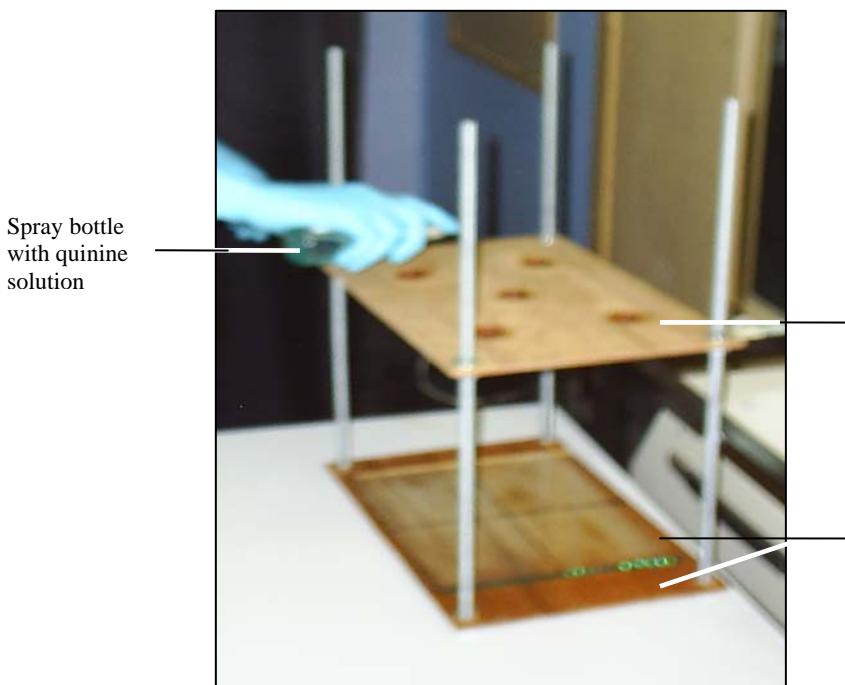


Figure 2.3 Plate loading stand for application of quinine solution

2.2.5 Contact trials

Nine volunteers participated in the trials involving quinine exposures and twelve volunteers participated in the trials involving saffron exposures. Prior to each separate experiment volunteers thoroughly rinsed their mouth and hands. Tables 2.4 and 2.5 and Figure 2.4, show the sequence of steps performed by volunteers for trials involving both quinine and saffron exposures. For all trials hand moisture measurements using a corneometer (DermaLab, Cortex Technology) were obtained immediately prior to hand contact with the loaded surface. For trials involving saffron, test plates were pre-loaded. However, for those involving quinine, test plates were loaded just prior to hand contact with the surface to limit evaporation. For saffron exposures blank images were not taken for the face or hands.

Direct transfer from hands to oral cavity

The sequence of events for experiments involving direct type transfer of quinine from the hand into the mouth started with the volunteer washing and drying his hands and rinsing his mouth using still water (Table 2.4). This was followed by collection of blank hand wash and saliva samples. After drying of the hands, skin moisture readings were taken of each of the five digits of the hand and the average recorded. In addition, skin moisture readings of five different points on the palm – one on each corner and one in the middle of the palm – were taken and the average recorded as the skin moisture of the palm. An image of the clean hand was taken at this stage. The palm of the hand was then brought into contact with the loaded surface for 5 seconds (or the time stipulated by the scenario number) by pressing onto the surface. An image of the loaded hand was taken. Quinine residue was removed from the little finger of the hand by sucking on the finger for five seconds. A second saliva sample was collected and a third image of the hand was obtained. The remaining residue of the hand was recovered by a second hand wash.

The sequence of events for experiments involving direct type transfer of saffron from the hand into the mouth was essentially the same as those for quinine with the exception that the index finger (rather than little finger) was put in the oral cavity to simulate direct transfer. In addition, no pre-loading image of the hands (hand image 1) was taken.

Indirect transfer from hands to oral cavity

The sequence of events for experiments involving indirect type transfer of saffron or quinine from the hand was similar to that for direct type transfers with the following variations (Table 2.5). A blank face wash sample was also collected alongside blank hand and saliva samples and a blank face image was taken. Following hand contact with the loaded surface, the hand was pressed against the peri-oral region of the face once, twice or three times depending on the scenario. The volunteer licked his lips for 5 seconds immediately following hand/face contact. A second face image, face wash, hand wash and saliva samples were collected post hand/face contact.

Generally, the duration of contact between the hand and the surface and between the hand and the face was 5 seconds. Hence for trials involving a different number of surface or face contacts the duration of hand contacts for 2, 3 and 4 contacts lasted a total of 10, 15 and 20 seconds, respectively. There were two different types of surface contacts – hand press and smudge. For the hand press, the volunteer pressed his/her palm onto the loaded surface for 5 seconds. For a smudge contact the volunteer pressed the palm onto the loaded surface and with a twist of the wrist and while still maintaining contact with the plate, the palm of the hand was rotated approximately 45 degrees.

Table 2.4 General sequence of steps performed during the laboratory trials for direct type transfers (finger sucking).

Action sequence	Sample
Volunteer washes and dries hands	-
Volunteer rinses mouth in still water	-
Collection of hand wash sample followed by drying	Hand wash 1
Collection of saliva sample	Saliva 1
Moisture readings of hand obtained	-
Fluorescent image of hand obtained (quinine only)	Hand image 1
Palm of hand onto pre-loaded surface for 5 seconds	-
Fluorescent image of loaded hand obtained	Hand image 2
Direct transfer to oral cavity by finger-sucking of little finger of loaded hand for 5 seconds	-
Saliva sample collected	Saliva 2
Fluorescent image of the hand obtained	Hand image 3
Collection of hand wash sample	Hand wash 2

Table 2.5 General sequence of steps performed during the laboratory trials for indirect type transfers (via peri-oral region)

Action sequence	Sample
Volunteer washes and dries hands	-
Volunteer rinses mouth in still water	-
Collection of hand wash sample followed by drying	Hand wash 1
Collection of saliva sample	Saliva 1
Collection of face wash sample	Face wash 1
Moisture readings of hand obtained	-
Digital image of hand obtained (quinine only)	Hand image 1
Digital image of face obtained	Face image 1
Palm of hand onto pre-loaded surface for 5 seconds	-
Digital image of loaded hand obtained	Hand image 2
Indirect transfer to oral cavity by placing loaded palm onto peri-oral region for 5 seconds	-
Digital image of face obtained	Face image 2
Lips licked for 5 seconds	-
Collection of saliva sample	Saliva 2
Collection of face rinse sample	Face wash 2
Collection of hand wash sample	Hand wash 2

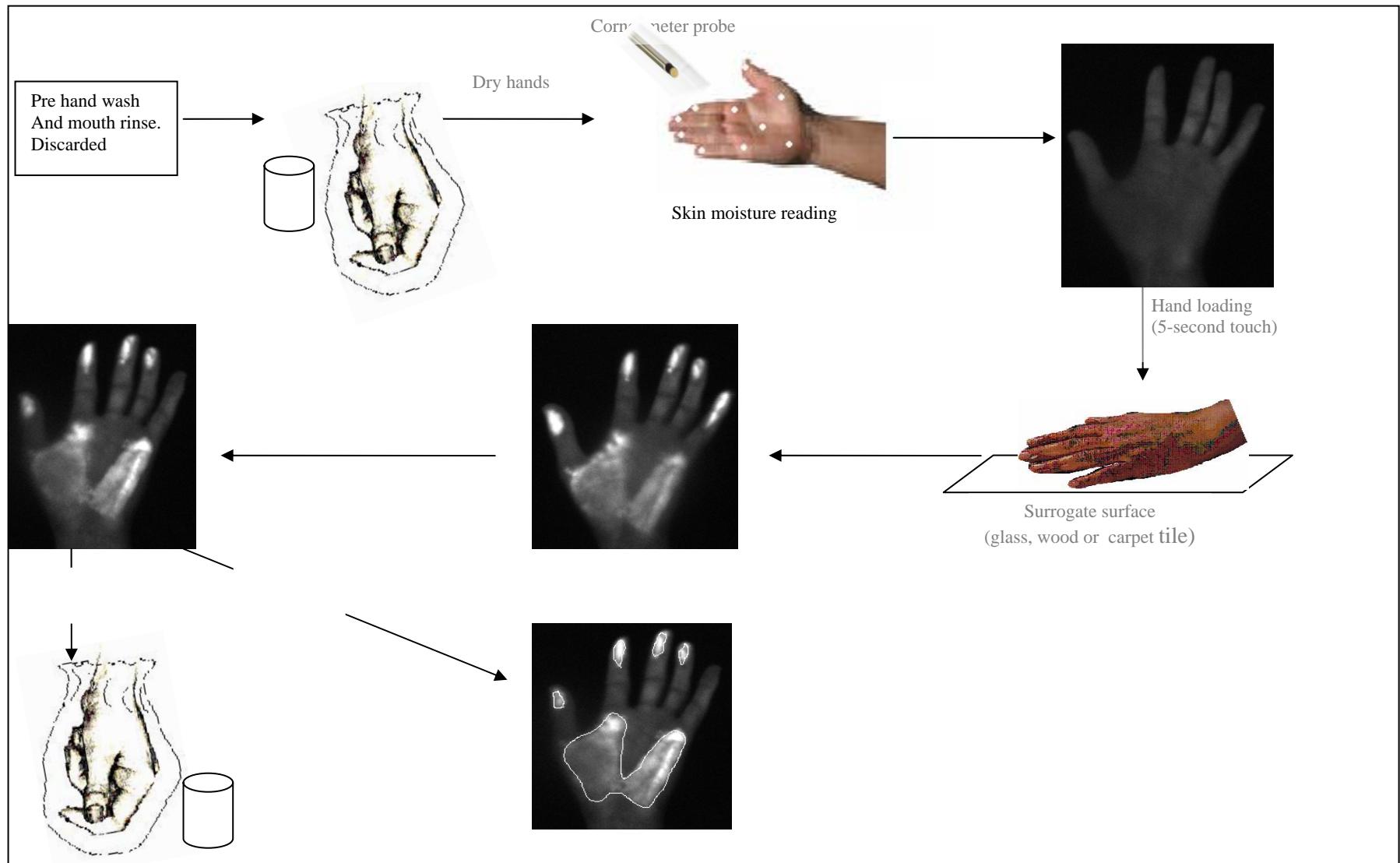


Figure 2.4 Experimental sequence for direct type transfers into the oral cavity

2.2.6 Calculations and Data Analysis

The data were analysed using the statistical package SPSS 14 for Windows (SPSS Inc. Chicago, Illinois, USA).

Limit of Detection

Quantitative analyses were performed using linear calibration curves with at least five points. The average of the lowest calibration standard for each analyte from each matrix over the duration of the laboratory experiments was used as the method limit of detection.

The LODs for quinine from saliva, hand-washes and face-washes were identified as 0.002 mg/ml, 0.0005 mg/ml and 0.0005 mg/ml, respectively. The LOD for saffron from saliva, hand-washes and face-washes were 0.003 mg/ml, 0.0015 mg/ml and 0.0015 mg/ml, respectively. The samples with a sample concentration less than that of the limit of detection (LOD) were set at half the value of the LOD.

Area of Exposure to saffron

The area of exposures was determined for the little finger, the remainder of the hand and the face. Each digital image of a dermal surface obtained during powdered exposure investigations was imported into the software program, Corel Draw (Corel Draw Corporation, 2005). The area of exposure was outlined and the exposed area of the hand minus the little finger was filled in with white using the drawing tools of the program. The exposure on the little finger was outlined and filled in with yellow. The resulting image was then imported into Corel Photo Paint, and the colour mode set to a 16-bit greyscale. A facility of the Corel Photo Paint program is a histogram detailing the brightness of different sections of an image with values ranging from 0 (black) to 255 (white). When converted to greyscale the level of brightness in the yellow-coloured regions was 224 but the white and black areas remained the same. The number of pixels occupied by an area of certain brightness is also indicated within the histogram window. The total number of pixels within the view of the camera was 3094768 for saffron exposure images. It was determined that the total photographic area was equivalent to 462 cm². This gave a value of 1.5×10^{-4} cm²/pixel.

Area of Exposure to quinine

For determining the quinine exposure on the hands and face, we utilised the strong fluorescent nature of this substance. We used specifically designed image analysis software, which is part of a custom made fluorescent imaging system designed by The Netherlands Organisation for Applied Scientific Research (TNO). It has been employed in several other studies to measure dermal exposure to pesticides (Aragon *et al.*, 2006; Archibald *et al.*, 1995; Fenske *et al.*, 2002; Ivancic *et al.*, 2004), metal working fluids (van Wendel de Joode *et al.*, 2005) and for modelling exposure to powdered contaminant (Brouwer *et al.*, 1999). The determination of distribution of exposure to quinine was facilitated by the software which generated a readout indicating area exposed in pixels for each outlined area. Following a similar procedure for fluorescent images representing quinine exposures it was possible to determine that the conversion factor of pixels to square centimetres was 5.0×10^{-3} cm²/pixel.

Exposure calculations

For scenarios involving **direct** transfer of substance from the hands to the oral cavity (Table 2.4) the dermal and oral exposure metrics were calculated using the following equations.

Hand exposure

$$E_{pHand} = M_{handwash-2} - M_{handwash-1} \quad (1)$$

where,

- E_{pHand} = Part Hand Exposure (mg)
 $M_{handwash-2}$ = Mass of analyte obtained from hand wash 2 (mg)
 $M_{handwash-1}$ = Mass of analyte obtained from hand wash 1 (mg)

$$L_{hand} = \frac{E_{pHand}}{A_{hand} - A_{finger}} \quad (2)$$

where,

- L_{hand} = Hand load (mg/cm^2)
 A_{hand} = Area of exposed hands (cm^2)
 A_{finger} = Area of exposed finger that was used for direct oral transfer (cm^2)

$$E_{finger} = L_{hand} \times A_{finger} \quad (3)$$

where,

- E_{finger} = Exposure on finger used for direct transfer to oral cavity (index or little finger) (mg)

$$E_{hand} = E_{pHand} + E_{finger} \quad (4)$$

where,

- E_{hand} = total hand exposure (mg)

Oral exposure

$$E_{oral} = M_{saliva-2} - M_{saliva-1} \quad (5)$$

where,

- E_{oral} = Oral exposure (mg)
 $M_{saliva-2}$ = Mass of analyte obtained from saliva sample 2 (mg)
 $M_{saliva-1}$ = Mass of analyte obtained from saliva sample 1 (mg)

For scenarios involving **indirect** transfer of substance from the hands to the oral cavity (Table 2.5) the dermal and oral exposure metrics were calculated as follows:

Peri-oral exposure

$$E_{peri-oral} = M_{facewash-2} - M_{facewash-1} \quad (6)$$

where,

$E_{peri-oral}$ = Peri-oral exposure (mg)
 $M_{facewash-2}$ = Mass of analyte obtained from face wash 2 (mg)
 $M_{facewash-1}$ = Mass of analyte obtained from face wash 1 (mg)

$$L_{peri-oral} = \frac{E_{peri-oral}}{A_{face}} \quad (7)$$

where,

$L_{peri-oral}$ = Peri-oral load (mg/cm²)
 A_{face} = Area of face exposed (from face image 2) (cm²)

Oral exposure

See Eq. (5).

3 RESULTS

3.1 MICRO-ACTIVITY DATA

In total, 86 field observations were made in 6 different types of facilities (Table 3.1). Overall, workers touched the peri-oral area approximately 2.9 times per hour and the oral cavity 2.4 times per hour. The number of peri-oral and direct oral contacts were highest for the workers in the magnet facility, the nickel refinery and the agricultural sector, although for the agricultural sector this was only true for peri-oral contacts. Much less frequent contacts were observed for workers in the secondary smelter and the antimony trioxide production facility.

In order to investigate whether “busyness” during task was associated with hand-to-mouth contact a busyness scale was developed. Busyness was rated on a 4-point scale from 0 to 3 (0 = not busy; 1 = a little busy; 2 = moderately busy; 3 = very busy). ‘Not busy’ is consistent with tasks such as monitoring a process via a computer screen, communicating with colleagues while not performing any work tasks, or observing items on a production line e.g. quality control of a product by primarily visual inspection with only occasional handling of the product. ‘A little busy’ will be consistent with activities that require only occasional use of the hands e.g quality control of a product that requires both visual inspection and measurements of the product (weight, size) being taken at regular but not frequent intervals. ‘Moderately busy’ and ‘very busy’ are related to manual tasks that require frequent and almost constant use of the hands, such as maintenance work that requires handling of tools and equipment, manual packing and manual labour such as shovelling or lifting.

Table 3.1 Facilities where micro-activity data was collected

Description	n	Mean duration (min)	Median busyness	Mean peri-oral contact (hr^{-1})	Mean oral contact (hr^{-1})
Secondary Lead Smelter	13	17	3	0.1	0.3
Powder Metallurgy (Magnet manufacturers)	12	11	1	6.3	5.6
Antimony trioxide manufacturers	23	11	3	0	0.5
Nickel refinery	20	15	2	4.4	4.6
Healthcare sector	9	27	2	2.8	1.8
Agricultural sector	9	17	2	6.6	1.3
TOTAL	86	15	2	2.9	2.4

n: number of observations. Median business scored on a scale from 0 to 3 (0 = not busy, 1 = a little busy, 2 = moderately busy, 3 = very busy)

Table 3.1 shows the median busyness score for the workers during the observations. Busyness was scored on a range from 0 to 3. These results suggest that there is an association between busyness and the number of peri-oral and oral contacts per hour. Table 3.2 shows the distribution of peri-oral and oral contacts for two categories of business (not or a little busy versus moderately or very busy). There was a clear difference between busyness 0 or 1 (peri-oral: 7.8 contacts/hr; oral: 6.3 contacts/hr) and busyness 2 or 3 (peri-oral 1.6 contacts/hr; oral: 1.3 contacts/hr). This difference were statistically significant for peri-oral contact (t-test, with unequal variance: $t=2.22$, $df=18$, $p=0.0396$) and borderline statistically significant for oral contact (t-test, unequal variance: $t=2.05$, $df=18$, $p=0.0555$).

Table 3.2 Micro-activity data and its relation to number of oral and peri-oral contacts

busyness		N	Mean contacts (hr ⁻¹)	Distribution of number of contacts per hour			
				0	1-9	10-19	>19
0, 1	Hand-to-Oral	18	6.3	10 (56%)	3 (17%)	3 (17%)	2 (11%)
	Hand-to-Peri-oral	18	7.8	8 (44%)	6 (33%)	2 (11%)	3 (17%)
2, 3	Hand-to-Oral	68	1.3	56 (82%)	10 (15%)	1 (2%)	1 (2%)
	Hand-to-Peri-oral	68	1.6	56 (82%)	9 (13%)	3 (4%)	1 (2%)

Some of the activities observed in the field that may influence ingestion exposure included:

- eating and drinking at the work desk without prior hand washing;
- speaking with face mask resting on the lip;
- removal of gloves using the teeth;
- removal of gloves to perform work tasks such as writing on report boards.

The data collected confirmed previous findings that when workers were actively engaged in tasks involving their hands, hand-to-face contact almost never occurred. Certain types of respiratory protective equipment (RPE) (e.g. air supply helmets) discouraged hand to face contacts while other types of RPE, such as disposable masks, may promote contact between a contaminated object (the mask) and the mouth since workers tended to slide the mask over the mouth when they wanted to speak.

3.2 LABORATORY EXPERIMENTS

3.2.1 Data Overview

Dermal and Oral Exposure

The dermal and oral exposure data for all scenarios are summarised in Table 3.3. Exposure measurements by scenario can be found in Appendix III. In total, 79 experiments were carried out with quinine (24 indirect and 55 direct) and 81 with saffron (22 indirect and 63 direct), although a few samples were lost and therefore numbers in the Table 3.3 are slightly different. Only a few of the samples for saffron were found to be below the limit of detection, however for quinine the percentage of samples below the detection limit ranged from 20% for the hand exposure to 35-36% for the peri-oral and oral exposure (Table 3.3). The mean hand exposure for saffron was 1.5 mg, and 0.4 mg for both the peri-oral region and oral cavity. The levels for quinine were 0.04 mg for the hand exposure, 0.02 mg for the peri-oral exposure and 0.005 for the oral exposure.

Table 3.3 Dermal and oral exposure

Material	Body Part	N	<LOD (%)	AM (mg)	Range (mg)
Saffron	Hand	71	3 (4)	1.5	0.0 - 8.9
	Peri-Oral	22	0 (0)	0.4	0.1 - 1.0
	Oral	80	2 (3)	0.4	-0.2 - 2.9
Quinine	Hand	76	15 (20)	0.040	-0.01 - 0.15
	Peri-Oral	20	7 (35)	0.020	0.00 - 0.12
	Oral	77	28 (36)	0.005	-0.03 - 0.04

Notes: N – number of samples; AM – Arithmetic mean; <LOD – number of samples that were less than the limit of detection.

The results for quinine were very low and often the pre-experiment oral results were very similar to the post-experiment results. In fact, if a limit of quantification was calculated (mean \times 3 sd of the pre-experiment results (or blanks)) then none of the oral measurements were above the limit of quantification. We will therefore not present any further results for quinine and instead will focus on developing the model for solids using the saffron data.

The oral exposure to saffron was approximately lognormally distributed (Figures 3.1)

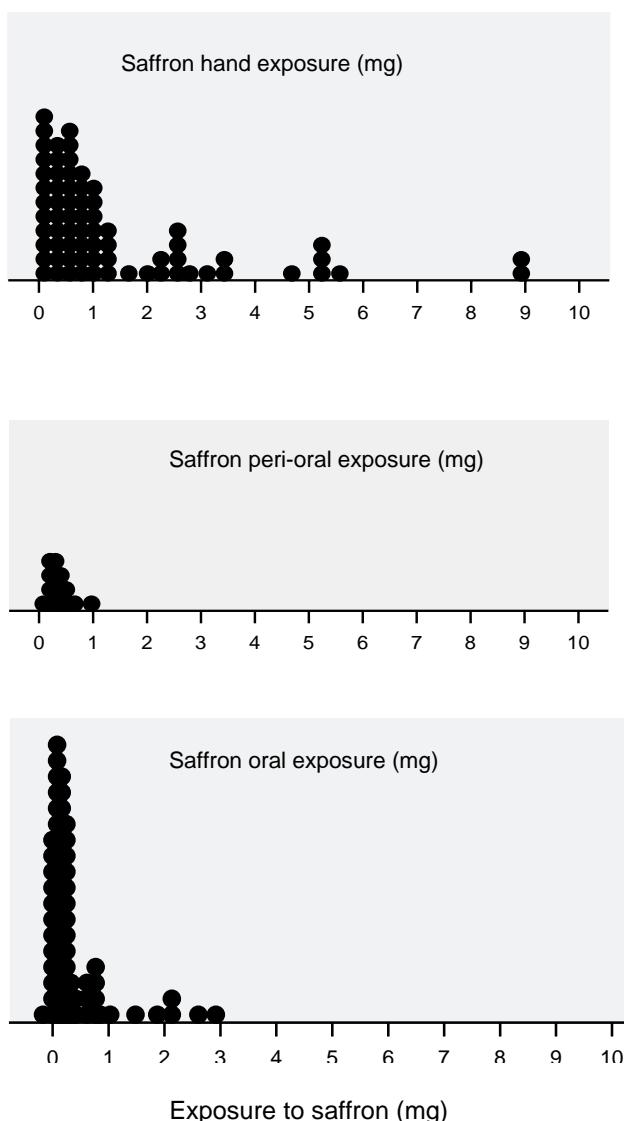


Figure 3.1 Distributions of saffron mass recovered from hands, the peri-oral region of the face and the oral cavity

Skin Moisture

Skin moisture measurements were expressed in micro Siemens (μS). This gives a measure of the conductance across the stratum corneum of the hand. The overall skin moisture of the hand was calculated by taking the average of the skin moisture of the palm and the moisture of the five digits of the hand. The moisture of the digits of the hand was generally greater than that of the moisture of the palm by a factor of approximately 3 (Table 3.4; Figure 3.2). The correlation between the digits and the palm of the hand as assessed using Pearson's correlation coefficient was $r=0.67$ ($p<0.01$ $N=139$). Figure 3.3 shows the overall skin moisture content of the hand for all participants

Table 3.4 Descriptive statistics of the skin moisture measurements for all participants over all scenarios

Hand Part	N	AM (μS)	Range (μS)	GM (μS)	GSD
Digits	141	330	26 -1416	205	2.7
Palm	139	113	10 -1296	53	3.3
Overall	139	222	18 -1301	139	2.7

Notes: N – number of readings, AM - arithmetic mean; GM - geometric mean; GSD - geometric standard deviation.

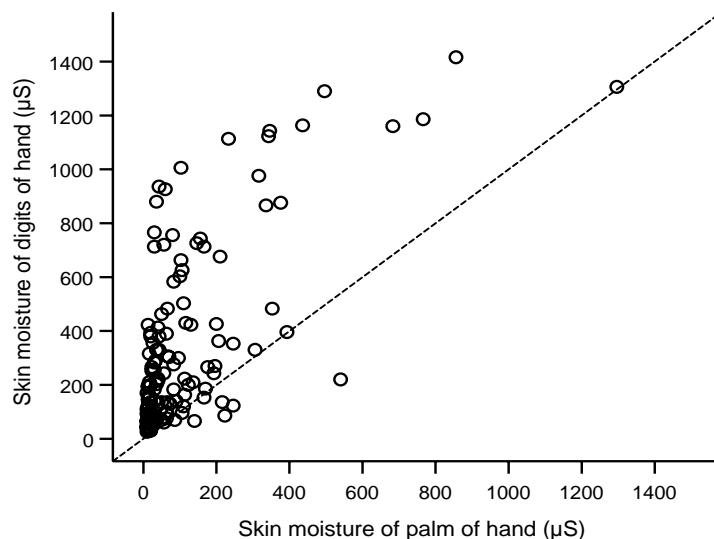


Figure 3.2 Relationship between moisture readings of palm and digits of the hand

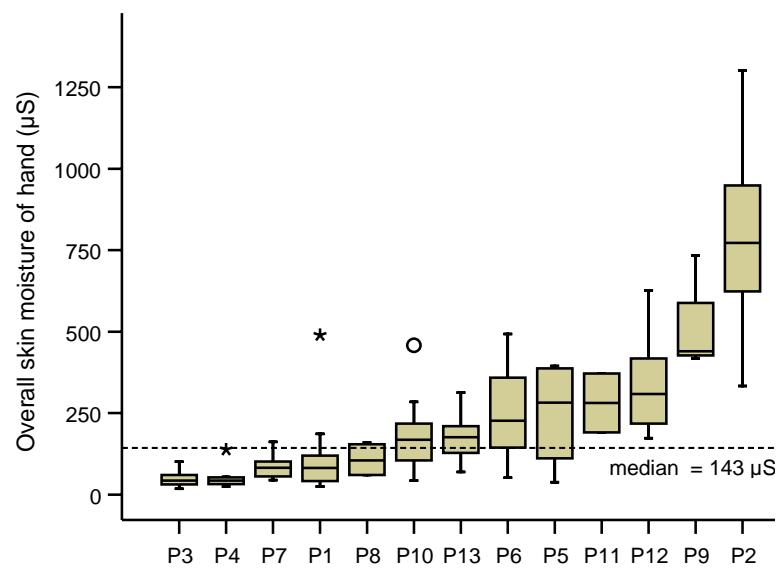


Figure 3.3 Overall skin moisture readings (palm and digits) for all participants.
(P1 to P13 refer to the study participant code)

Exposed Area of Hand and Face

Table 3.5 presents the descriptive statistics for the hand and face areas exposed to saffron. The mean area exposed for the hands was 59.8 cm^2 . There was a moderate but significant correlation between the area of the hand exposed and the mass of substance on the surface of the hand. The Pearson correlation coefficient for the relationship between the mass and area of hand exposure was $r=0.31$ ($p=0.02$, $N=59$) (Figure 3.4). It is clear from Figure 3.5 that face exposure and face area exposed are not correlated ($r=0.17$; $p=0.60$, $n=12$).

Table 3.5 Estimated exposed areas of hand and face

	N	AM (cm²)	Range (cm²)
Hands	71	59.8	1.6 – 134.0
Face	21	12.5	0.4 – 28.3

Notes: N – number of readings, AM - arithmetic mean.

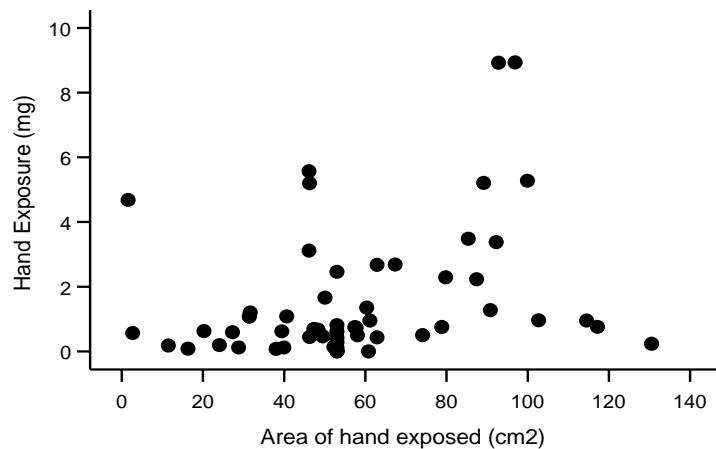


Figure 3.4 Scatter plots of the exposed area of the hand and the amount saffron found on hands

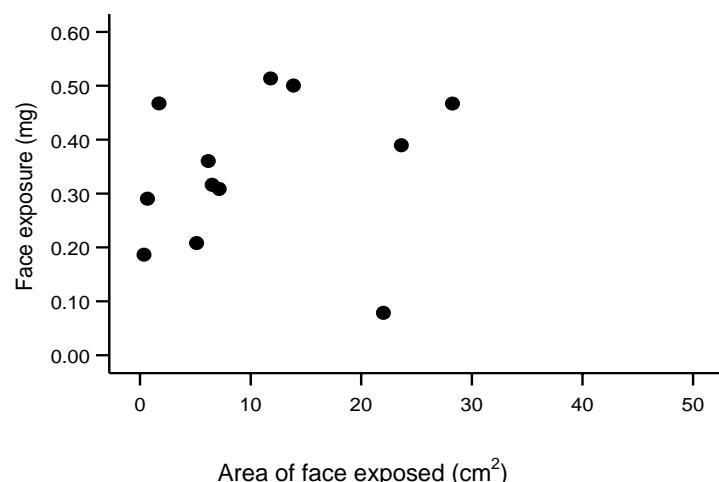


Figure 3.5 Scatter plots of the area of the face exposure and the amount of saffron found on the face.

3.2.2 Transfer from surrogate surfaces to the hand

Skin moisture

The influence of the skin moisture of the palm and the digits of the hand on transfer from a loaded surface to the hand was assessed separately. Data collected with the ‘standard’ scenarios were used to determine the influence of skin moisture on hand exposure. Using these data it was possible to investigate the influence on hand exposure on a smooth surface for at least a 10-fold increase in skin moisture of the digits, the palm and the overall skin moisture (Table 3.6).

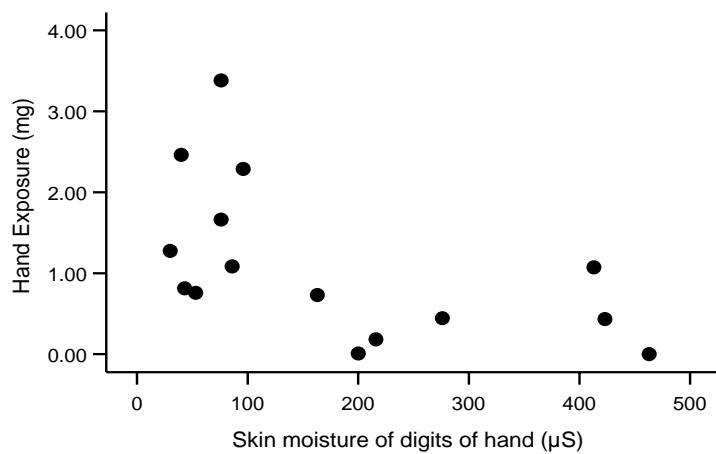
Table 3.6 Skin moisture readings of volunteers who conducted a single five second hand press with a glass surface loaded with saffron.

Hand Part	N	AM (μ S)	Range (μ S)	GM (μ S)	GSD
Digits	15	177	30 - 463	122	2.5
Palm	15	53	10 - 223	33	2.7
Overall	15	115	25 - 257	84	2.4

Notes: N – number of readings, AM - arithmetic mean; GM - geometric mean; GSD - geometric standard deviation.

Correlation analysis using Pearson’s correlation coefficient (r) indicated that there was a decrease in the transfer of saffron to the hand with an increase in skin moisture of the hand. A significant association was seen for the skin moisture of the digits of the hand ($r = -0.54$, $p=0.036$, $N=15$) but not for the palm ($r = -0.33$, $p=0.225$, $N=15$) (Figure 3.6). The correlation between overall skin moisture and hand exposure to saffron was $r = -0.62$ ($p=0.013$, $N=15$) (Figure 3.7).

3.6a



3.6b

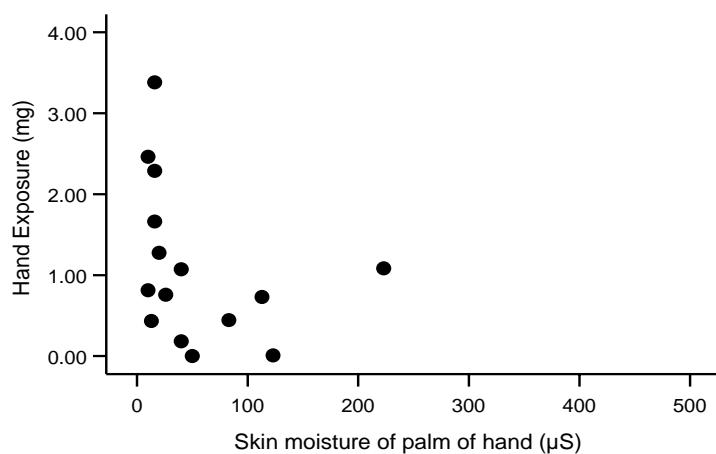


Figure 3.6 Scatter plots of skin moisture of the digits (a) or the palm (b) and hand exposure to saffron.

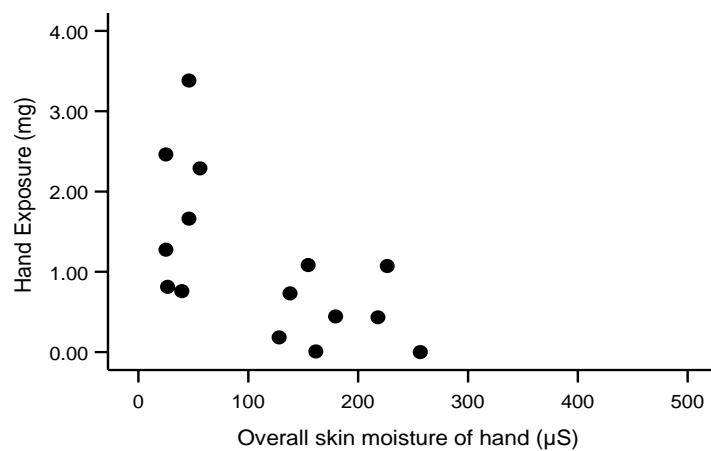
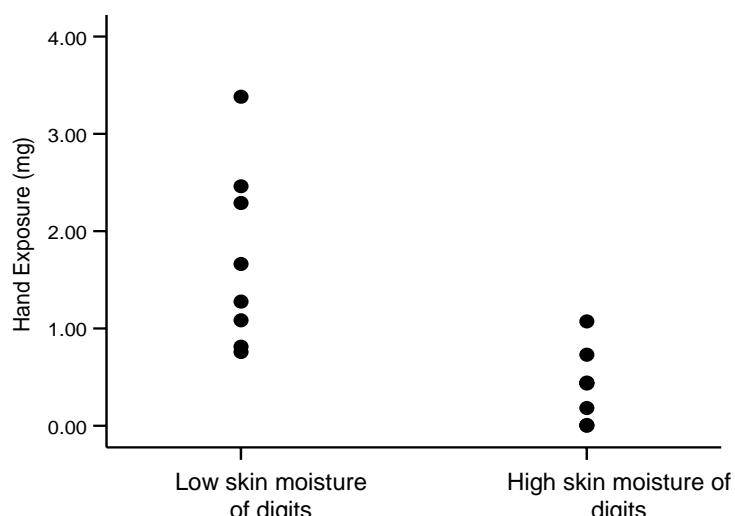


Figure 3.7 Scatter plot of the overall skin moisture of the hand and hand exposure to saffron.

Volunteers were categorised into a low and high skin moisture group, using the median skin moisture value as the cut-off point. Figures 3.8 and 3.9 show the relationships between skin moisture categories (expressed for palm and digits separately – Figure 3.8; and total hand – Figure 3.9) and hand exposure.

The mean hand exposure for the low skin moisture group was 1.6 mg (palm), 1.7 mg (digits) and 1.8 mg (whole hand), compared to 0.5 mg (palm), 0.4 mg (digits) and 0.5 mg (whole hand). These differences were statistically significant.

3.8a



3.8b

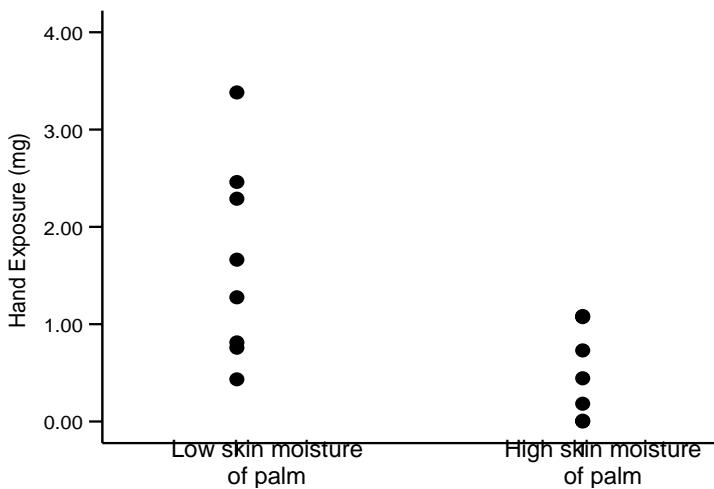


Figure 3.8 Scatter plots of skin moisture categories of the digits (a) or the palm (b) and hand exposure to saffron

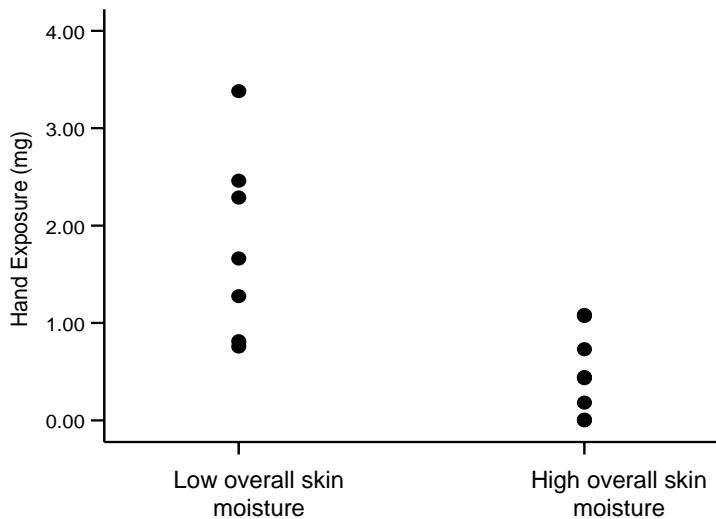


Figure 3.9 Scatter plot of overall skin moisture categories and hand exposure to saffron

Type of surface

The amount of saffron transferred from the surface to the hand, appeared to be influenced by the type of surface (Figure 3.10). After a single contact of the hand for 5 seconds with a surface load of 0.05 mg/cm^2 , the average hand exposure was 1.1 mg (hand), 0.7 mg (wood) and 0.1 mg (carpet). However, using analyses of variance of the data showed that the difference in exposure was not statistically significant ($p=0.20$).

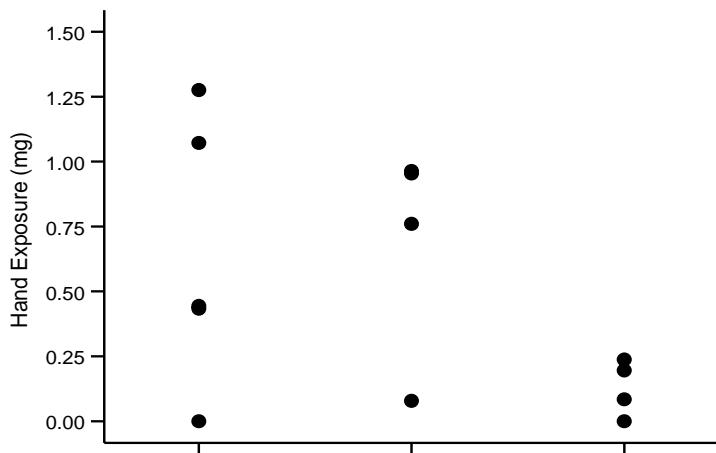


Figure 3.10 Scatter plot of surface type and hand exposure to saffron

Surface Load

Two different surface load levels (0.05 and 0.1 mg/cm²) were investigated for their influence on hand exposure (using glass surface and a single contact of 5s) (Figure 3.11). In the case of saffron residue on a glass surface, doubling the surface load resulted in a greater amount of residue from the surface being transferred to the hand. The resultant hand exposure after contact with a surface load 0.05 mg/cm² was 1.1 mg compared to 3.3 mg for a surface load of 0.10 mg/cm² ($p=0.047$).

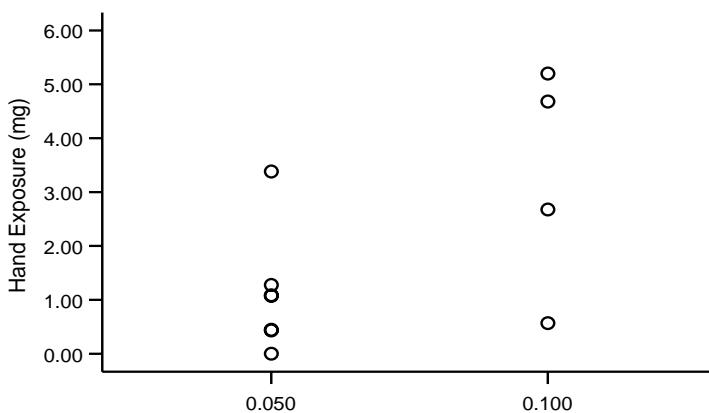


Figure 3.11 Scatter plots of saffron surface load and hand exposure to saffron

Duration of contact between the hand and the surface

There was no association between duration of hand contact with the surface and transfer of saffron to the hand (Figure 3.12)

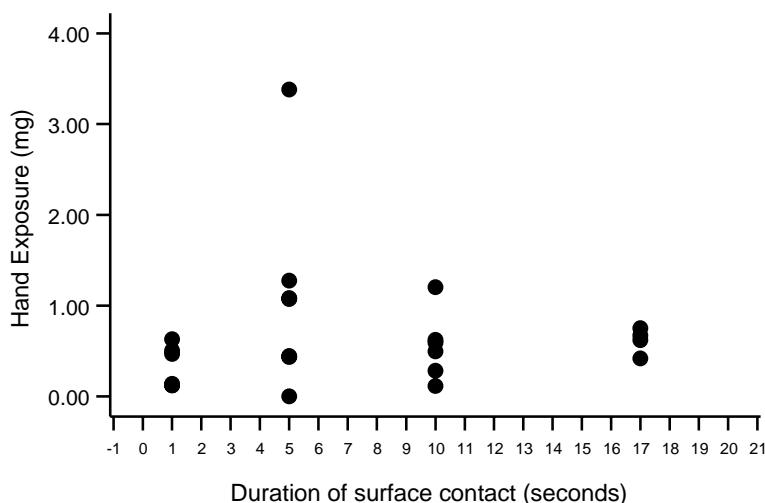


Figure 3.12 Scatter plots of the duration of contact with the surface and hand exposure to saffron

Number of hand contacts with surface

The number of hand contacts with the surface increased the amount of saffron transferred to the hand up to three, five-second contacts (Figure 3.13). From Figure 3.13 and after using the Bonferroni test for pairwise multiple comparisons, it was clear that the four contact groups could be collapsed into two categories with one category comprising data from one and two contacts and the other category comprising data from three and four contacts. The mean hand exposure after 1 or 2 contacts was 1.2 mg, while for 3 or 4 contacts the hand exposure was 5.4 mg. This difference is highly statistically significant ($p < 0.0001$)

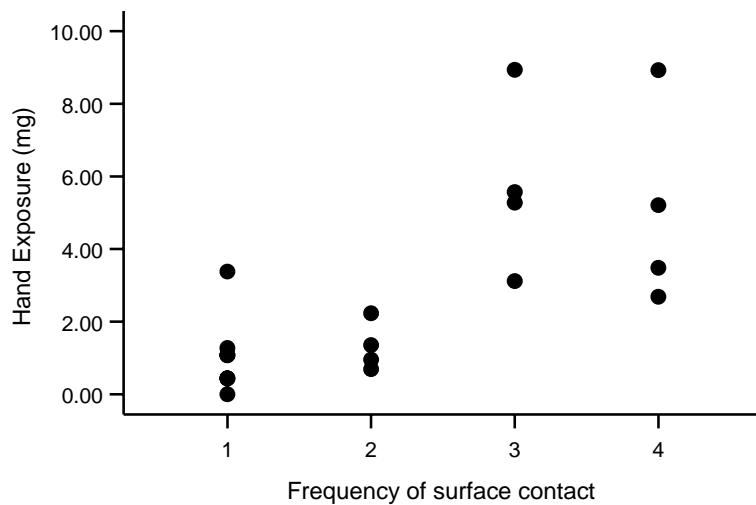


Figure 3.13 Scatter plots of the number of hand contact and hand exposure to saffron

Type of contact between the hand and the surface

The influence of two different types of hand contacts (hand press and smudge) with the surface on exposure to saffron was investigated. There was only a marginal difference between the two types of contact. A smudge type contact resulted in a 40% greater amount of mass transferred on average to the hand when both types of contacts are made with identically loaded surfaces; for a smudge type contact the hand exposure after a single 5s contact, with a surface load of 0.05 mg/cm^2 was 1.5 mg ($n=4$), while that for hand press it was 1.1 mg ($n=7$). However this difference was not found to be statistically significant.

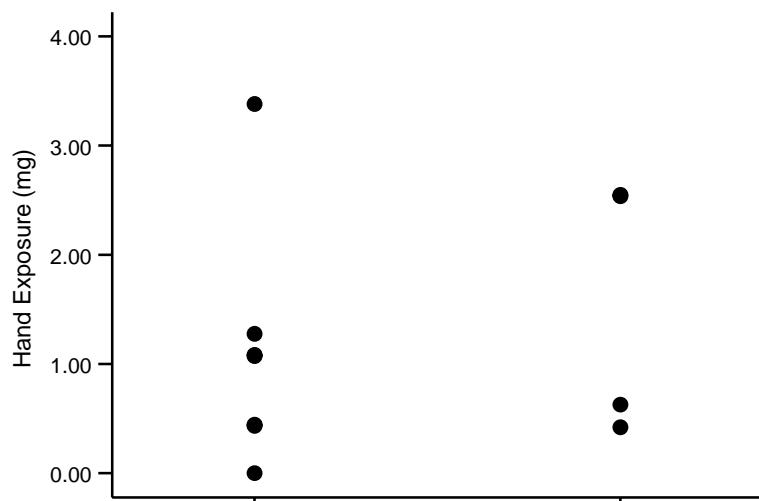


Figure 3.14 The influence of different types of hand contacts with the surface on the level of saffron exposure on the hand

Multiple Linear Regression Analysis for prediction of hand exposure

The influence of the different parameters on hand exposure was investigated by multiple linear regression analysis. All parameters with the exception of overall skin moisture were entered as categorical variables into the model. The number of surface contacts was re-categorised and investigated as the influence of ‘two or less contacts’ and ‘more than two contacts’.

The resulting model for hand exposure to saffron showed that the most influential of the parameters investigated was the number of times the hand came into contact with the loaded surface with a regression coefficient of 4.038 and accounting for 46.9% of the variation in the model (Table 3.7). This was followed by surface load and overall skin moisture of the hand. An increase in overall skin moisture of the hand resulted in a small but significant decrease in hand exposure for the range of skin moistures investigated (regression coefficient =-0.003; p=0.002). Duration of hand contact with the surface, the type of surface and the type of contact were not retained as significant predictors of hand exposure to saffron. Overall the resulting model explained approximately 68% of the variation in hand exposure (Table 3.7).

Table 3.7 Result of multiple linear regression analysis to determine the predictors of hand exposure to saffron.

Predictor	Parameter Estimate	Std. Error	p-value
Constant	1.247	0.201	0.000
Number of hand surface contacts	4.038	0.420	0.000
Surface Load	2.852	0.555	0.000
Overall skin moisture of hand	-0.003	0.001	0.002
Strength of model	R ² =68.3%		

Regression Equation for hand exposure to saffron is:

$$E_{\text{hand}}^* = 1.25 + 4.04 \cdot N_{\text{hand/surface}} + 2.85 \cdot L_{\text{surface}} - 0.003 \cdot S_{\text{hand}} \quad (8)$$

where

- E_{hand}^* = Estimated hand exposure (mg)
- $N_{\text{hand/surface}}$ = Number of hand to surface contacts (0: ≤ 2 contacts; 1: >2 contacts)
- L_{surface} = Surface load (0: low; 1: high)
- S_{hand} = Average skin moisture of the hand (palm and digits) (μS)

Since actual skin moisture data is rarely available, an alternative form of the model in which skin moisture was categorised into low and high skin moisture is also presented. This version of the model explained roughly the same amount of the variation in hand exposure ($R^2 = 67\%$).

$$E_{\text{hand}}^* = 1.15 + 4.09 \cdot N_{\text{hand/surface}} + 2.73 \cdot L_{\text{surface}} - 0.80 \cdot S_{\text{group}} \quad (9)$$

where

- S_{group} = Skin moisture group (0 = low; 1= high skin moisture)

3.2.3 Transfer of residue from peri-oral region to oral cavity.

Hand exposure before face touch

No information on hand exposure was available from the laboratory experiments of indirect exposure. Therefore, the above regression equation for hand exposure to saffron was used to estimate the hand exposure. Estimated hand exposures before face contact was not correlated with face exposure (Figures 3.15).

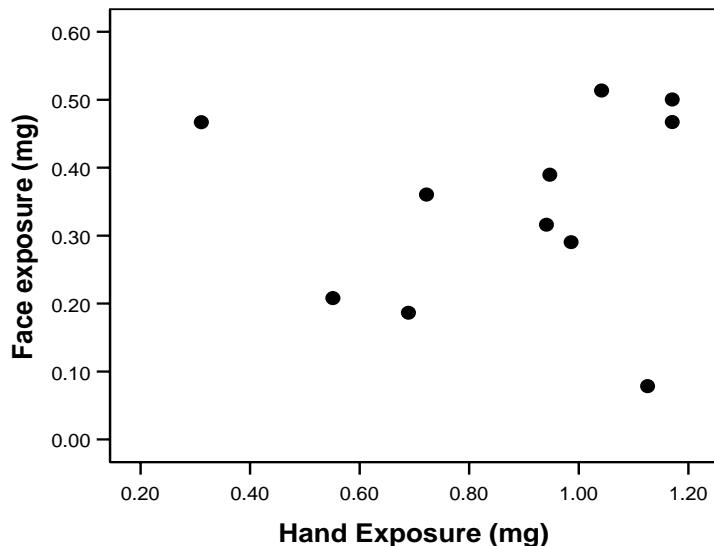


Figure 3.15 Relationship between hand and face exposure.

Number of hand contacts with the peri-oral region of the face

The mass of saffron transferred to the peri-oral region of the face appeared to increase with increasing number of contacts between the hand and the face (without re-loading of the hand) (Figure 3.16). The mean mass transfer of saffron to the peri-oral region increased from 0.28 mg (n=3) after a single contact with the contaminated hand, to 0.38 mg (n=3) after two contacts and 0.41 mg (n=3) after three contacts. However, the difference in peri-oral exposure was not statistically significant.

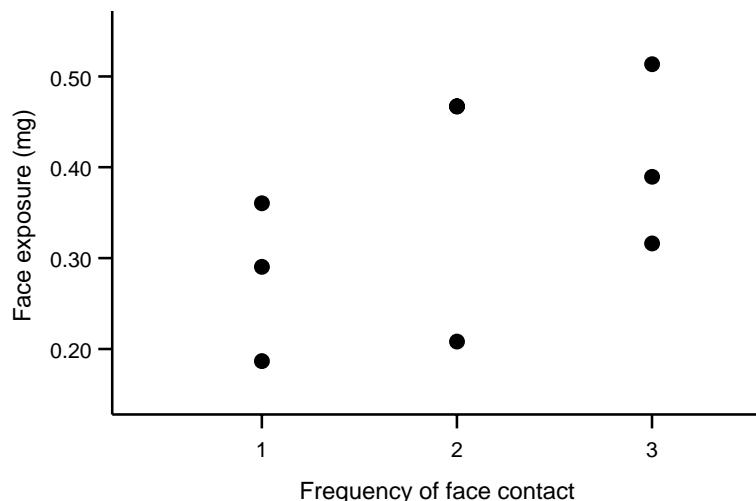


Figure 3.16 Scatter plots of the frequency of hand contact with the face and transfer of saffron to the peri-oral region

Use of gloves during hand contacts between hands and the peri-oral region

The use of nitrile gloves increased the mass of saffron transferred to the peri-oral region by approximately thirty percent (Table 3.8, Figure 3.17). However, this difference was not statistically significant ($p=0.2$).

Table 3.8 Saffron face exposure after hand to face contacts with and without gloves

Use of gloves	N	AM (mg)	Range (mg)	GM (mg)	GSD
No gloves	12	0.34	0.08 – 0.51	0.31	1.7
Yes gloves	10	0.44	0.22 – 0.97	0.40	1.6

Notes: N – number of readings, AM - arithmetic mean; GM - geometric mean; GSD - geometric standard deviation.

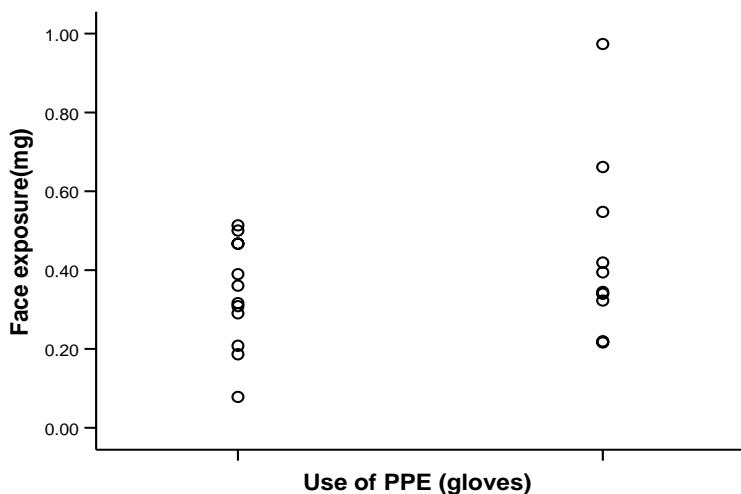


Figure 3.17 Scatter plot of the use of PPE during face contact and transfer of saffron to the peri-oral region

3.2.4 Determinants of oral exposure

Duration of time of finger spends in the oral cavity

The influence of duration in the oral cavity was investigated by sucking the contaminated finger for 5, 10 and 15 seconds (Figure 3.18). The mean oral exposure was 0.29 mg (n=7) for 5 sec, 0.26 mg for 10 sec and 0.14 mg for 15 sec. The difference in oral exposure between the groups was not statistically significant and there was no correlation between duration of finger sucking and oral exposure.

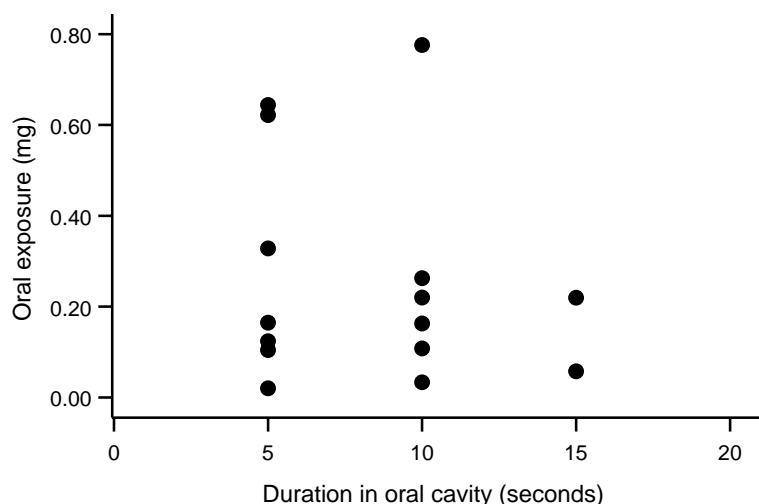


Figure 3.18 Scatter plots of the duration the finger spends in the mouth and oral saffron exposure

3.3 REFINEMENT OF THE PRELIMINARY MODEL

3.3.1 Determinants of exposure in model compartments

Table 3.9 lists the parameters that were retained as important for assessing oral exposures to saffron based on the pathways defined in the preliminary exposure model. Justification for inclusion or exclusion was guided by research results and their statistical significance, experience of other researchers in this field and expert judgment.

Surface load, skin moisture and number of hand contacts with the surface were found to be significant for transfer of saffron from surfaces to hands. These results reflected the findings of Brouwer *et al.*, (1999). Surface type, duration of hand contact with the surface and the type of hand contact with the surface were not found to be significant predictors of transfer from surface to hands for saffron.

The number of hand contacts with the face was the only parameter investigated as having potential to influence exposure to saffron in the peri-oral region. However, this was not found to be a significant determinant of face exposure and was excluded. The use of gloves during face contacts did not have a statistically significant influence on the amount of saffron transferred to the face and was therefore not included in the models. The duration the finger is kept in the oral cavity was not included in the models for solids.

Table 3.9 List of parameters investigated and indication of their status in a model for ingestion exposure

Parameters investigated	Relevance	Justification
Hand Exposure		
Surface Load	included	Statistically significant contributor of hand exposure. Statistically significant contributor of hand exposure to liquids based on findings of Cohen Hubal <i>et al.</i> , (2004)
Skin moisture	included	Statistically significant contributor.
Surface Type	excluded	No clear trend or statistical significance could be established based on our data.
Number of hand contacts with surface	included	
Duration of contact between hand and surface	excluded	No clear trend or statistical significance could be established based on our data. Similar results also reported by Brouwer <i>et al.</i> , (1999).
Oral Exposure		
Type of hand contact with surface	excluded	No clear trend or statistical significance could be established based on our data.
Number of hand contacts with peri-oral region	excluded	No clear trend or statistical significance could be established based on our data.
Use of PPE during hand contacts with peri-oral region	excluded	Trend observed but not statistically significant.
Type of transfer from hands to oral cavity	included	Different transfer mechanisms involved, and as such should be taken into account in the model
Duration in oral cavity	excluded	No clear trend or statistical significance could be established based on our data.

3.3.2 Calculation of transfer efficiencies

Transfer efficiencies, expressed as the proportion of contamination transferred from one compartment to the next were calculated using the following equations (Table 3.10):

Transfer between surface and hands:

$$TE_{hand/surface} = \frac{E_{hand}}{M_{surface}} \times 100 \quad (10)$$

where,

$TE_{hand/surface}$ = Transfer efficiency between contaminated surface and the hand (%)

E_{hand} = Hand exposure (mg) (See Eq. 4)

$M_{surface}$ = Mass of analyte on contaminated surface available for transfer (mg)

$$M_{surface} = A_{hand} \times L_{surface} \quad (11)$$

where,

A_{hand} = Area of exposed hands (cm^2)

$L_{surface}$ = Contaminated surface load (mg/cm^2)

Transfer between hands and face:

$$TE_{peri-oral/hand} = \frac{E_{peri-oral}}{E_{hand}^*} \times 100 \quad (12)$$

where,

$TE_{peri-oral/hand}$ = Transfer efficiency between hand and peri-oral region (%)

$E_{peri-oral}$ = Peri-oral exposure (mg) (See Eq. 6)

E_{hand}^* = Estimated hand exposure (estimated using Eq. 9)

Transfer between hands and oral cavity:

$$TE_{oral/hand} = \frac{E_{oral}}{E_{finger}} \times 100 \quad (13)$$

where,

$TE_{oral/hand}$ = Transfer efficiency between hand and oral cavity (%)

E_{oral} = Oral exposure (mg) (see Eq. 5)

E_{finger} = Exposure on finger used for direct transfer to oral cavity (index or little finger) (mg) (see Eq. 3)

Transfer between peri-oral region and oral cavity:

$$TE_{oral/peri-oral} = \frac{E_{oral}}{E_{peri-oral}} \times 100 \quad (14)$$

where,

$TE_{oral/peri-oral}$ = Transfer efficiency between peri-oral region and oral cavity (%)

Table 3.10 Transfer efficiencies for transfer of a saffron among the different model compartments

	N	Transfer Efficiencies	
		AM	90 th percentile
Surfaces to Hands (TE_{Hands/Surface})	59	12	28
Surface Loading*			
Low	43	10	40
High	4	21	36
Number of hand/surface contacts			
≤ 2	47	10	25
≥ 2	8	17	28
Skin Moisture**			
Low	22	14	36
High	25	8	25
Hands to peri-oral region (TE_{Peri-oral/Hands})	11	37	91
Peri-oral to oral (TE_{Oral/Peri-oral})	11	38	82
Hands to oral cavity (TE_{Oral/Hands})****	8	>100	>100

* Based on scenarios with one hand contact.

** Based on scenarios with surface load 0.05 mg/cm² (i.e. low surface load). Skin moisture was categorised into low and high using the median of the group as the cutoff value

*** Two samples with transfer efficiencies greater than 100%

**** Observed transfer efficiencies were in excess of 100%

The transfer efficiencies detailed in Table 3.10 provide a measure of the effect of a parameter change on mass transfer between model compartments while maintaining values of other parameters to that of the standard scenario. For instance, an increase in the surface load by a factor of 2 resulted in a 100% increase in the amount of saffron transferred from the surface to the hands. Increasing the number of hand contacts from one or two contacts to greater than two contacts resulted in a 75% increase in the transfer efficiency between the surface and the hands. The average transfer efficiency from surfaces to hands, taking into account all possible values of the parameters investigated, was approximately 12% (90th percentile 28%) for saffron.

The mean transfer efficiency from hands to the peri-oral region was 37%. When gloves were worn during hand/face contacts there was a 30% increase in transfer of saffron. Mass transfer from peri-oral region to the oral cavity was 38% for saffron.

The transfer efficiencies from hands to the oral cavity representing direct transfers were grossly overestimated. This may be due in part to the inaccuracies surrounding estimation of the exposure on the sucked finger. In estimating exposure on the finger it was assumed that the distribution of exposure was uniform across the entire surface of the palm. However, based on the outcome of the regression model for hand exposure to saffron, as well as visual analysis of the hand exposure images, it was clear that this is not the case in reality. Visual analysis of the hand images showed that higher loading was on the digits and palm area at the base of the thumb, despite the digits of the hand generally having higher skin moisture content. Other factors such as the contact area with the surface of the digits compared to the palm and the accuracy of the image analysis are probably among the factors contributing to the overall error in estimating exposure on the sucked finger. An estimate for transfer of contaminant from the hands into the oral cavity of 0.95 was used.

3.3.3 Model description

Based on the indicative data and the transfer efficiencies, algorithms for oral exposure to saffron contaminant have been defined below. These have been used to update the conceptual model. This is based on information on determinants of saffron exposure obtained during the laboratory

experiments. The relationships between the different compartments have been described primarily using transfer efficiencies between compartments. However, where sufficient data were available to more precisely describe exposure parameters within a particular compartment, this has been indicated.

Oral exposure to solids:

$$E_{oral,direct} = E_{hand}^* \times F_{hand} \times TE_{oral/hand} \quad (15)$$

$$E_{oral,indirect} = E_{hand}^* \times TE_{peri-oral/hand} \times TE_{oral/peri-oral} \quad (16)$$

where,

$E_{oral,direct}$ = Oral exposure to by direct contact (mg)

$E_{oral,indirect}$ = Oral Exposure by indirect contact (mg)

F_{hand} = Proportion of the hand that enters oral cavity (%)

The resulting models are simple with multiplicative changes in oral exposure occurring depending on the compartments through which the contaminant moves prior to reaching the oral cavity. The model is defined primarily by transfer efficiencies between compartments. However, the mass in the ‘hands’ compartment has been defined by the regression equation for hand exposure. It can be used if parameter details are available. A more practicable version of this equation includes a dichotomous variable for skin moisture (low or high) as actual skin moisture data is rarely present.

In previous studies investigating surface to hand transfers, the number of hand/surface contacts has been described as a significant determinant of hand loading with loading reaching a saturation level after a certain number of contacts (Brouwer *et al.*, 1999; Cohen Hubal *et al.*, 2004). Loading levels may even decrease at higher numbers of contacts. In this study saturation occurred after three contacts. Brouwer and his co-workers reported saturation at the fourth contact and Cohen Hubal *et al.*, at the fifth contact. In our model two categories are defined for ‘number of hand contacts’ with the first category being ‘less than or equal to two contacts’ and the second category being equivalent to ‘greater than two contacts’. This does not take into consideration a loss of contaminant from the hand at very high numbers of contacts so will represent an over-estimation of hand exposure for higher number of contacts. There are particulates for which this relationship between number of hand contacts and hand surface loading has not been observed. (Hughson and Cherrie, 2002) investigated the effect of repeated hand/surface contacts on hand exposure to zinc oxide and found no significant difference for 1, 2, 4 or 8 repeat contacts. They indicated that the majority of the particulate accumulated after the first contact and suggested that a possible explanation of this could be the tendency of Zinc Oxide to agglomerate and fall off once a critical mass is reached. Ideally, a subjective relation between type of dustiness and adherence to dermal surfaces should be defined. Surface load is also dichotomised into low and high surface loadings.

In the absence of detailed information to estimate hand exposure to saffron, a default value for transfer efficiency of 28% (90th percentile of TE_{hand/surface}) can be used. The transfer efficiencies for transfer from hands to oral cavity which represented direct transfer to the oral cavity were grossly over-estimated. Direct transfer was simulated by direct sucking of the contaminated finger, it is reasonable to assume that most of the material present on the finger will be transferred into the oral cavity by this method. Under this assumption the transfer efficiency was assumed to be 95%. The actual amount of contaminant transferred into the oral cavity would then be determined by the fraction of the hand that enters the oral cavity.

Data on surface loading or hand loading are key data required for use of these models. Starting with surface load one can determine the mass of transfer among the different compartments. Table 3.11 gives the resulting exposure levels for surface loadings of 0.05 and 0.10 mg/cm² when each of the two different methods for assessing hand exposure is used. Figure 3.19 provides a graphical overview of the ingestion models.

Table 3.11 Dermal and oral exposure levels estimated using the model.

	Hand exposure estimates 1* (mg)	Oral exposure 1*** (mg)		Hand exposure estimates 2** (mg)	Oral exposure 2*** (mg)	
		Direct	Indirect		Direct	Indirect
Low loading (0.05 mg/cm ²)	0.354 – 5.237	0.034 – 0.498	0.050 – 0.736	2.961	0.279	0.413
High loading (0.10 mg/cm ²)	3.084 – 7.967	0.293 – 0.797	0.434 – 1.120	5.922	0.559	0.827

* Hand exposure estimates 1 are the ranges of values obtained using the regression equation to calculate hand exposure levels. Fraction of hand into mouth was assumed to be 10%. Palm area was assumed to be 210 cm².

** Hand exposure estimates 2 are point estimates calculated using the 90th percentile of the Transfer efficiency for surfaces to hands i.e. 28 %.

*** Oral exposure 1 and oral exposure 2 are the oral exposure estimates associated with hand exposure estimate 1 and hand exposure estimate 2, respectively.

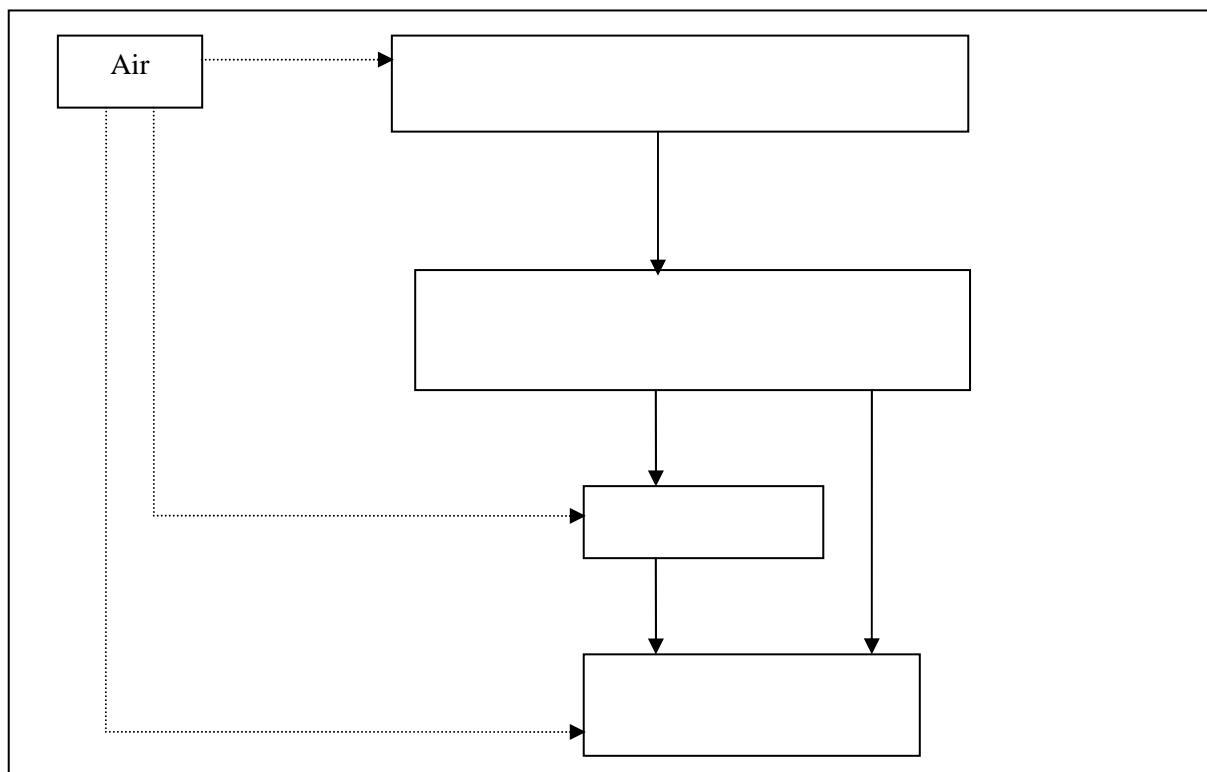


Figure 3.19 Exposure model for ingestion exposure to saffron contaminant

4 DISCUSSION AND CONCLUSIONS

Discussion of results

The main objective of the laboratory experiments was to refine the preliminary model of ingestion exposure put forward in phase I of this project. The final models are centred on hand exposure and the transfers to and from the hands are described as transfer efficiencies. Significant parameters for the hand exposure model for saffron were surface loading, skin moisture of the hand and number of hand contacts with the surface. This result is similar to that obtained by Brouwer *et al.*, (1999) who looked at the influence of several parameters on hand loading of a finely powdered solid (Tinopal). Using multiple linear regression they investigated the influence on hand exposure of the parameters, duration and number of hand contacts with the surface, skin moisture and surface loading. In their resulting model, duration of hand contacts was not retained as a significant contributor to hand exposure while the other determinants were. However, skin moisture approached significance ($p=0.052$). The variation in their resulting model for hand exposure was explained primarily by the number of surface contacts (35%), with skin moisture and the surface loading accounting for the remaining 3 percent. Likewise, the variation in our model was explained primarily by the number of hand contacts (47%) with the surface load and the skin moisture accounting for the remaining 14%. These parameters were all highly statistically significant ($p<0.01$).

From our experiments there was an indication that differences in the three types of surfaces – “smooth non-porous”, “smooth, porous” and “textured” – influenced the efficiency of transfer of the solid to the surface of the hand. A smooth non-porous surface, such as glass, appeared to facilitate transfer onto the hand with the greatest efficiency, followed by a smooth porous surface such as wood. Transfer from a textured surface such as carpet appeared to be the least efficient facilitator of transfer from surface to hand of the different types of surfaces investigated. However, the difference in hand exposure from the different surfaces was not statistically significant. Cohen Hubal *et al.*, (2004) investigated the transfer efficiencies of a residue applied as a liquid onto surfaces in a series of spraying and drying cycles and found that surface type was not a significant determinant of hand exposure. However, others investigating the influence of transfer from surfaces onto dermal surfaces (Rodes *et al.*, 2001) or food surfaces (Rohrer *et al.*, 2003) found that rough surfaces such as carpet did limit the transfer of substances. This would imply that the influence of surface type is very much dependant on the nature of the contaminant and how it is applied to the surface.

The effect of skin moisture on transfer of powdered solid to the hand was unexpected since one would expect moisture to facilitate uptake. Observations during the laboratory tests indicated that the powdered mix was compacted onto the plate after contact trials involving participants with high skin moisture levels (Figure 4.1). Other researchers have reported a similar influence of skin moisture on hand surface loading of solids (Brouwer *et al.*, 1999; Rodes *et al.*, 2001).



Figure 4.1 Hand print images on a saffron loaded plate formed from a 'dry'hand (left) and a 'moist' hand (right)

Few factors appear to directly influence exposures in the peri-oral region or in the oral cavity. Though the significance of the number of face contacts on face exposure to saffron was low, the trend observed in the scatter plot suggests that with each successive contact a greater mass of contaminant was transferred from the hands to the face. The lack of statistical significance implies that most of the transfer takes place at the first hand/face contact, although it could also be due to lack of statistical power. The overall transfer efficiency of saffron from hand to face was 38% for this study. Bearing in mind that the mechanisms of transfer between dermal surfaces is expected to be different to that between a dermal surface and an inanimate surface, it is interesting to note that the decrease in surface load from loaded hand to a clean plate (Brouwer *et al.* 1999) was comparable to transfer efficiency from a loaded surface to an uncontaminated dermal surface.

There are even fewer factors for investigating transfers into the oral cavity from the peri-oral region or the hands primarily because actions like finger-sucking and lip-licking or how a contaminant behaves once it enters the oral cavity, are difficult to control experimentally. We assumed that the type of transfer into the oral cavity, direct or indirect transfer, is an important determinant of oral exposure.

The mean hand-to-face transfer efficiency was 38% for saffron, which is very similar to the finger to lips transfer efficiency for micro-organisms of 34% to 41% reported by Rusin *et al.* (2002).

Although the effect of wearing nitrile gloves on the transfer from the hand to the peri-oral region was not statistically significant in this study, there appears to be a suggestion that using these types of gloves may increase transfer. This is a potentially important and interesting finding in that it highlights how a control implemented to protect against exposure from one route may enhance exposure via another route. Whether this contribution results in an overall increase in total exposure is not known but for certain hazardous substances (e.g. pathogens, cytotoxic formulations) it may represent the opportunity for a more potent effect to be brought about which could be comparable with the effect of a higher exposure level on the skin. The increased transfer efficiency to the peri-oral region due to the wearing of nitrile gloves may be comparable with transfer from a relatively dry skin. A gloved hand may be similar to a dry hand with respect to moisture content and thus may become more effectively loaded following contact with a contaminated surface. In general, protective clothing, such as coveralls and

gloves, although acting as a barrier for dermal exposure, can act as a source for transfer to peri-oral region and oral cavity (Boeniger 2003).

The role of PPE in facilitating increased exposure, especially due to inappropriate use, was also observed during the micro-activity fields surveys. While respiratory protective equipment may decrease inhalation exposure and limit the amount of hand-to-mouth contacts, it may increase the number of object-to-mouth contacts. For instance, when workers pulled contaminated disposable masks over their mouths to rest on their lower lip and chin in order to chat with colleagues, the contamination on the masks may enter directly into the mouth thus facilitating ingestion exposure.

The estimated efficiencies for hand to mouth transfer were in excess of 100%. This may be due in part to the uncertainty surrounding estimation of the exposure on the sucked finger. In estimating exposure on the finger it was assumed that the distribution of exposure was uniform across the entire surface of the palm. However, based on the outcome of the regression model for hand exposure, as well as visual analysis of the hand exposure images, it was clear that this is not the case in reality. Higher overall skin moisture caused a lowering of the exposure on the hand and there was a considerable difference in skin moisture of the digits and the palm. However, this factor explained only 3.5% of the variation in hand load. Visual analysis of the hand images showed that higher loading was on the digits despite the digits of the hand generally having the higher skin moisture content. Other factors such as the contact area of the digits compared to the palm and the accuracy of the image analysis are probably among the factors contributing to the overall error in estimating exposure on the sucked finger.

The micro-activity data were collected under field conditions and bring useful information required for use of the model development. The actual number of hand-to-mouth and object-to-mouth contacts was clearly influenced by the nature of the tasks. In tasks where the hands were very much engaged, the frequency of hand-to-face contacts was very low. In fact, workers rarely touched their faces at all during activities which required the use of their hands. During more passive tasks the frequency of hand-to-face contacts was, on average 1 time in 15 minutes. Generally, the micro-activity data we collected were in the metal industry which is characterised by batch processes. The workers were often engaged in a flurry of activity followed by periods of reduced activity between batches. This often resulted in the worker's hands becoming loaded with contaminant which was then available for transfer to the face during any hand-to-face contact that occurred during the more passive moments in the process.

These observations were consistent with that of Zainudin and Semple (2005). However, they collected micro-activity data in a wider range of occupational settings. They found that the frequency of hand-to-peri-oral area contact was higher in office settings (mean frequency= 3.4 times per hour) compared to Manufacturing and Engineering (mean frequency = 1.8 times per hour) and laboratory settings (mean frequency = 0 times per hour). They also found that there was a relationship between the level of hand activity and the frequency of hand contact to the peri-oral area.

When using the model, an adequate description of the scenario is therefore necessary to provide input model data such as the number of hand-to-face contacts and the possibility of re-loading of the hand in between face contacts.

Discussion of the method

Use of fluorescent tracers in combination with video imaging has been successfully employed to describe dermal exposures. In this experimental approach it was intended to extend this application to describe oral exposure, by making use of the fluorescence of the test substance

quinine to investigate oral exposure to liquid exposures and that of saffron for oral exposure to saffrons. The Video Imaging Technique for Assessment of dermal Exposures (VITAE) system is designed to quantify exposure on surfaces by correlating the intensity of light emitted by a fluorescent substance with the mass of that substance on a particular area of the body. For this study the fluorescent imaging technique was used for obtaining distribution of exposure only. The form of quinine used in these experiments made calibration with a reasonable degree of accuracy impossible and the fluorescence of saffron was insufficient for use with the available system. Consequently, exposure masses were obtained using a chemical analytical method.

Preliminary investigations employed the use of a fluorometer to quantify quinine exposures; however, due to equipment breakdown it was necessary to employ spectrometry which was less sensitive and specific for the analyte quinine. This may have affected the results obtained for the quinine exposure experiments. However, measures were taken to ensure that this lack of sensitivity did not affect the accuracy of results and the limit of detection was set at a fairly high value. The spectrophotometric properties of saffron allowed its quantification with no loss of power.

A high number of negative data points were obtained for the quinine exposure data with 19% of the oral exposure values being negative. The final exposure value for each data point was the resulting difference in the values of two estimates - the blank sample and the sample collected after the studied intervention. These negative values may represent instances where material in the blank samples absorbed incident light at the same wavelength as the quinine which we were trying to detect resulting in the blank sample being recorded as having a higher content of quinine than the sample itself. Also, the salivary quinine samples had not been frozen prior to quantitative analysis. Freezing and thawing saliva has been reported to be an effective way of promoting breakdown of cellular components and suspended particles, leaving a clear liquid that is easier to process (Wolff *et al*, 1991). The presence of particles in the salivary quinine sample would have affected the absorbance of the sample and resulted in a very low sensitivity in the analyses of these samples. Consequently, it was decided to focus on the saffron data for model development for ingestion exposure of saffrons.

Exposure assessment using the ingestion exposure model

Cherrie *et al* (2006) estimated the contribution to total uptake from the ingestion route for two different exposure scenarios using the preliminary ingestion exposure model. Here we re-assess the ingestion exposures using the refined model. The original and revised estimates are detailed below.

Scenario 1 description:

Short description: A worker involved in the demolition of lead-painted steelwork using flame cutting gear.

Duration of tasks: 8 hours

Inhaled volume per 8-hour shift = 10m³

RPE: Protection factor of 10

Airborne concentration: 1000 µg/m³

Dermal lead exposure: 100 µg/cm²

Proportion of hand that contacts the peri-oral region during an indirect transfer: 5%

Number of hand/mouth contacts per hour: 5

Palmar surface area: 210 cm²

Re-cap of original estimates

Inhalation uptake based on an inhaled volume of 10 m³ per shift, a protection factor of 10 and an absorption efficiency of 70% was 700 µg (100 µg x 10 x 0.7).

To estimate ingestion uptake the exposure in the peri-oral region was first estimated from the mass loading of contaminant on the skin as 42 mg. This was based on a hand/mouth contact area of 10.5 cm² (5% of the palmar surface) and five hand/mouth contacts per hour with re-loading between contacts ($100 \times 10.5 \times 5 \times 8$). Assuming a 10% transfer from the peri-oral region to the gastrointestinal tract and absorption of 15% the estimated uptake arising from lead ingestion was 630 µg.

Dermal uptake was assumed to be negligible

Total uptake is estimated to be 1330 µg with 47% of the received dose being contributed by the ingestion route.

Estimates of ingestion exposure using Model 1 for saffron exposure:

Assuming, as above, that transfer into the oral cavity is indirect and using similar values for scenario parameters but using the model value for transfer efficiency between hands and peri-oral region of 37% will give an estimate of peri-oral exposure of 15.5 mg ($100 \times 10.5 \times 5 \times 8 \times 0.37$). Based on transfer efficiency values for transfer between the peri-oral region and the mouth the exposure in the oral cavity is estimated to be 5.9 mg (15.5×0.38). An absorption efficiency of 15% would result in an estimated ingestion uptake of 886 µg of lead. The revised estimate of contribution from the ingestion route was 56%.

Conclusions

The ingestion exposure model developed is based on limited data and may not be applicable to every different type of scenario. However, it should have a reasonable range of applicability given the different parameters investigated.

There is a fairly small part of the model that deals directly with transfer into the oral cavity; the number of times a contaminated hand comes into contact with the peri-oral region and the number of times the hand comes into contact with the mouth will largely determine the oral exposure level. These parameters are partly determined by psychological factors and will have to be monitored under field conditions but their effect on transfer between model compartments has been determined. It was not possible to establish, with these experiments, the fate of the contaminant once it enters the oral cavity. It is assumed that once the contaminant enters the system it is available for absorption. While there is a possibility of contribution to total ingestion exposure from inhaled particles which may become deposited and transferred into the gut, this has not been considered here.

The model therefore estimates the potential of ingestion exposure and is mainly concerned with factors affecting loading of the oral cavity, which is a good starting point towards understanding the mechanisms involved in ingestion exposure in the workplace.

In the final phase of this project we will compare estimates from the model with actual oral exposure measurements obtained from a number of different workplaces.

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APPENDIX I – FIELD OBSERVATION FORM

0.0 Site Details

Site Name _____ Site Number _____

Description _____

0.1 Record Details

Employee Name: _____

Employee/Record Number: _____

Job title _____

Work

Department/Section _____

Years served at plant _____

Gender Male Female

Date : _____ (DD/MM/YY)

Sampling done: Dermal Inhalation Oral None

1.0 Workplace

1.1 Cleanliness of workplace surfaces:

Low Medium High

Very dirty
(layers of dust clearly
visible on surfaces)

Very Clean
(like hospital surfaces)

1.2 Housekeeping - Method of cleaning surfaces:

Sweeping/brushing shovelling wiping
 vacuuming

1.3 Hygiene facilities available:

Hand wash facilities: at workstation >1 min walk away none

Showering facilities: yes no

If yes, state frequency of showering per day _____

Date _____

Initials _____

1.4 Laundry facilities: yes no

If yes, state frequency of laundering:

daily weekly

other,

Explain _____

Other comments about the workplace _____

2.0 Worker - Individual traits and behaviour

2.1 Facial hair: Yes No (Long Short)

2.2 Hair on Head: Yes No (Long Short)

2.3 Smoker: Yes No

2.4 Washes hands before smoking: Yes No

2.5 Dominant Hand: Left Right

2.6 Goes home with any item of
clothes worn on site? Yes No

State which items _____

Other comments about worker _____

3.0 Use of PPE:

Hard Hat Gloves State type of gloves _____

Coveralls RPE State the type of RPE _____

Boots

Date _____

Initials _____

4.0 Tasks performed and details

4.1 Task Title and Description_____

4.2 Use of tools Yes No

If yes, state which type of tools are used_____

4.3 Nature of contact with source:

None incidental
 (rare incident one-off) intermittent frequent continuous
 (irregular occurrence) (constant contact)

4.4 Kinetic energy of source : 0 1 2 3
 stationary(low) agitated(high) e.g. sweeping
 dust

5.0 Contaminant

5.1 Nature of contaminant	<input type="checkbox"/> Saffron	<input type="checkbox"/> Liquid	<input type="checkbox"/>
Both			
5.2 Particulate size (saffron)	<input type="checkbox"/> fine grain	<input type="checkbox"/> medium	<input type="checkbox"/> Coarse
5.3 Handling Temperature	<input type="checkbox"/> up to 60°C	<input type="checkbox"/> >60°C	
5.4 Containment	<input type="checkbox"/> Fully	<input type="checkbox"/> Partial	<input type="checkbox"/> Open

6.0 Record of micro-activity of worker (See table attached)

Instruction: On the monitoring form below indicate the number of times within a 15 minute period, the right hand, the left hand and the tool of the worker touched the different parts of the face or the work surface, indicated in the column on the left.

7.0 Collection of saliva sample.

Date_____

Initials_____

Task carried out during observation _____

Time of observation from _____ to _____

	Left Hand	Right Hand	Tool/object
Forehead			
Nose/Eyes			
Perioral region			
Other e.g. ears/neck/hair			
Tools			
Surface			

8.0 Additional information

Take note of the following details:

- Items eaten (or drunk) prior to sampling. Note what has been eaten (or drunk) and time of eating.

APPENDIX II – RISK ASSESSMENT FOR LABORATORY EXPERIMENTS

Risk Assessment for Laboratory Experiments

A2.1 Introduction

A risk assessment has been conducted to assess the potential risk to individuals who will be involved in the laboratory experiments. It consists of a description of the exposure scenario wherein subjects will be exposed to a powdered icing-sugar/saffron mix and quinine-containing tonic water. Rough estimates of dermal, inhalation and oral exposure to the tracers, quinine and saffron, have been calculated and together with the health effects associated with those levels of exposure a risk evaluation has been done. It should be noted that in the absence of data on factors required to more accurately quantify exposure levels, there is a considerable amount of uncertainty surrounding the exposure levels estimated. However, where accurate data was absent, conservative values of these factors were chosen resulting in very conservative estimates of exposure thereby erring in the direction of safety.

A2.2 Exposure Assessment

Description of exposure scenario

Volunteers will be required to place the palm of one hand onto a surface (glass, wood or carpet) containing an icing-sugar/saffron powder, mixed in a 25:1 ratio or quinine-containing tonic water. The loaded palm will then be brought into contact with the peri-oral region of the face. Hence dermal exposure onto the palm and the peri-oral region will occur. Following loading onto the peri-oral region via hand contact, subjects will then lick their lips, thereby transferring some of the substance on the peri-oral region into the oral cavity. Alternatively, subjects will transfer saffron or tonic water directly into the oral cavity by loading the palm as described above, followed by sucking on a one finger.

The surfaces which subjects will handle will be pre-loaded by the researcher. Loading of surfaces with powder saffron/icing sugar mix will occur inside a closed loading box placed within a hood equipped with exhaust ventilation. The dust on the plates will be allowed to settle prior to removal from the loading box and prior to participants' hand contact with the loaded surface. Loading of surfaces with quinine-containing tonic water will occur just prior to volunteers' contacting the surface. The surfaces will be loaded with quinine by spraying five times (approx 0.5 mls) directly onto the plate using an atomiser spray bottle held horizontal and facing downwards approximately 25 cm from the horizontally placed plate. The surface loadings will range from 0.05 to 0.10-mg/cm² for powdered flour-saffron and from 0.001 to 0.002-mg/cm² for tonic water. It is not foreseen that exposure to subjects will occur during the loading of surface plates.

Quantification of Exposure

Inhalation exposure – Saffron and Quinine

The inhalation exposure of volunteers' to saffron powder is expected to be negligible given the absence of any factor which will cause the dust on pre-loaded plates to become airborne. The inhalation exposure to quinine is expected to be negligible given the low vapour pressure of tonic water.

Exposure to the researcher to powdered substance during loading the plates will be negligible given the controls used for containment during plate loading of saffron. Exposure during loading of the plates with quinine will be negligible due to the low volume of the spray used, the orientation of the spray bottle and the proximity of the spray plume to the horizontal surface.

Dermal Exposure - Saffron

To assess the reasonable worse case dermal exposure level, the possible exposure proceeding from handling the most heavily loaded surface i.e. surfaces loaded to a concentration of 0.10 mg saffron/cm², was firstly determined. Assuming an exposed area of 420 cm² (the palm of one hand) and a 90% transfer efficiency from the loaded surface onto the hand, the estimated dermal exposure to saffron after conducting one trial is estimated to be 37.8 mg ($0.1 * 420 * 0.9$). Each volunteer will conduct at most 4 trials in one day, giving a total reasonable worst case estimate of hand exposure dose of 151.2 mg.

There will be 20 different scenarios (80 experiments) performed; 95% of these will use a surface loading of saffron of 0.05 mg saffron/cm². Assuming a proportionate decrease in the dermal exposure to saffron based on this lower surface loading, the exposure dose to saffron after conducting 4 trials is estimated to be 75.6 mg saffron. Hence, typical dermal exposure dose to quinine during most days of experiment is estimated to be 75.6 mg.

Dermal Exposure – Quinine

To assess the reasonable worse case dermal exposure level to quinine, the possible exposure proceeding from handling the most heavily loaded surface i.e. surfaces loaded to a concentration of 0.002 mg quinine/cm² surface area, was firstly determined. Assuming an exposed area of 420 cm² (the palm of one hand) and a 90% transfer efficiency from the loaded surface onto the hand, the estimated dermal exposure to quinine on the hand is 0.76 mg ($0.002 * 420 * 0.9$). Each volunteer will conduct at most 4 trials in one day, giving a total reasonable worst case estimate of hand exposure dose of 3.04 mg.

There will be 20 different scenarios (80 experiments) performed. 95% of these will use a surface loading of saffron of 0.001 mg quinine/cm². Assuming a proportionate decrease in the dermal exposure to quinine based on this lower surface loading, the exposure dose to quinine after conducting 4 trials is estimated to be 1.5 mg. Hence, typical dermal exposure dose to quinine during any day of experiment will be 1.5 mg.

Oral exposures

Saffron

Assuming an area of 3% of the loaded area of the hand enters the mouth and assuming that there is 100% transfer efficiency from the finger into the oral cavity a reasonable worst case estimate of oral exposure per experiment will be 1 mg saffron based on the reasonable worst case estimate of dermal exposure to saffron calculated above. Each volunteer will conduct at most 4 trials in one day, giving a total reasonable worst case estimate of oral exposure dose of 4.5 mg.

The typical exposure dose to saffron based on the typical dermal exposure to saffron calculated above is 2.25 mg.

Quinine

Assuming an area of 3% of the loaded area of the hand enters the mouth and assuming that there is 100% transfer efficiency from the finger into the oral cavity a reasonable worst case estimate of oral exposure per experiment will be 0.1 mg quinine based on the reasonable worst case estimate of dermal exposure to saffron calculated above. Each volunteer will conduct at most 4 trials in one day, giving a total reasonable worst case estimate of oral exposure dose of 0.4 mg.

The typical exposure dose to quinine based on the typical dermal exposure to quinine above is 0.2 mg.

A2.3 Risk Evaluation

Saffron

Tinctures and dried saffron products are used in the formulation of compounded oils and extracts for flavouring liqueurs and sauces. The dried product is used for seasoning special dishes, such as risotto Milan style and bouillabaisse. The dried stigma from which the saffron powder is produced contains picrocrocin, crocin, vitamins B1 and B2 and a small amount of essential oil{(Furia and Bellanca, 1975) as quoted in the Hazardous Substances Database (HSDB)}.

Saffron is described as being non-toxic with a minimal fatal dose level of 5-15 mg/kg body weight {(Gosselin *et al.*, 1976) as quoted in the HSDB}.

Given the established safe use of saffron as a flavouring agent in foodstuff and the relatively low level of exposures to saffron estimated, it can be concluded that these experiments pose no threat of negative health effects to persons participating.

Quinine

Quinine, as quinine salts or extracts from cinchona bark, is used as a bittering agent in tonic type drinks, usually at a concentration of approximately 80 mg quinine hydrochloride per litre. Quinine is also used in some bitter alcoholic beverages and to a small extent in flour confectionery. Quinine and its derivatives have also been widely used therapeutically in the treatment of protozoal infections, such as malaria, and of nocturnal leg cramps (<http://www.inchem.org/documents/jecfa/jecmono/v30je06.htm> - accessed 13 November 2006). A risk evaluation of quinine in soft drinks conducted by IPCS concluded that 'no treatment-related effects on audition or clinical biochemical abnormalities were observed at doses up to 160 mg of anhydrous quinine hydrochloride per day'. However, a small group of consumers have an idiosyncratic hyper-reactivity to quinine (<http://www.inchem.org/documents/jecfa/jecmono/v30je06.htm> - accessed 13 November 2006).

Given the established safe use of quinine as a flavouring agent in foodstuff and the low level of exposures to quinine expected, it can be concluded that these experiments pose no threat of negative health effects to persons participating. In consideration to persons who may have a hyper-reactivity to quinine, subjects would be questioned with respect to their status.

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APPENDIX III – EXPOSURE DATA BY SCENARIO

Table A3.1 Exposure data for quinine exposure experiments. Descriptions are expressed as deviations from the standard scenario, T1.

Trial Code	Standard scenario or deviation from standard scenario	Body Part	Exposure (mg)				
			N	Range	AM	GM	GSD
T1	Standard scenario: One 5-second hand press on a glass surface loaded to a surface load of 0.001 mg quinine/cm ² , followed by direct transfer into the oral cavity by a 5-second finger lick of the little finger	Hands	5	0.000 - 0.06	0.036	0.042	1.605
		Oral	5	0.001 - 0.01	0.006	0.005	2.668
T3	Surface load =0.002	Hands	4	0.013 - 0.103	0.062	0.048	2.557
		Oral	4	0.001 - 0.011	0.006	0.004	2.837
T4	Duration of hand/surface contact:1 second	Hands	4	0.004 - 0.100	0.041	0.023	3.993
		Oral	4	0.001 - 0.016	0.007	0.003	4.303
T5	Duration of hand/surface contact:10 seconds	Hands	4	0.009 - 0.035	0.026	0.023	1.855
		Oral	3	0.001 - 0.015	0.006	0.002	4.862
T7	Duration of hand/surface contact:17 seconds	Hands	4	0.033 - 0.096	0.065	0.060	1.603
		Oral	4	0.001 - 0.015	0.009	0.006	3.503
T8	Number of hand contacts with surface :2	Hands	4	0.044 - 0.087	0.058	0.056	1.35
		Oral	4	0.001 - 0.012	0.005	0.004	3.141
T9	Number of hand contacts with surface :3	Hands	4	0.013 - 0.051	0.034	0.03	1.795
		Oral	5	0.001 - 0.014	0.006	0.004	2.567
T10	Number of hand contacts with surface :4	Hands	4	0.000 - 0.142	0.08	0.023	18.02
		Oral	5	0.001 - 0.015	0.007	0.005	3.275
T11	Type of transfer : indirect, one hand/face contact, 5-seconds of lip-licking	Hands	4	0.000 - 0.065	0.031	0.011	11.275
		Face	4	0.031 - 0.115	0.059	0.052	1.8
		Oral	4	0.000 - 0.035	0.011	0.006	5.884
T12	Type of transfer : indirect, two hand/face contacts, 5-seconds of lip-licking	Hands	4	0.0003 - 0.0003	0.0003	0.0003	1.008
		Face	4	0.000 - 0.039	0.01	0.001	11.362
		Oral	4	0.001 - 0.007	0.002	0.002	2.558

Appendix III - Table 1 (continued)

Trial Code	Standard scenario or deviation from standard scenario	Body Part	Exposure (mg)				
			N	Range	AM	GM	GSD
T1	Standard scenario: One 5-second hand press on a glass surface loaded to a surface load of 0.001 mg quinine/cm ² , followed by direct transfer into oral cavity by a 5-second finger lick of the little finger	Hands	5	0.000 - 0.06	0.036	0.042	1.605
		Oral	5	0.001 - 0.01	0.006	0.005	2.668
T13	Type of transfer : indirect, three hand/face contacts, 5-seconds of lip-licking	Hands	4	0.000 - 0.062	0.029	0.011	10.89
		Face	4	0.007 - 0.053	0.022	0.017	2.34
		Oral	4	0.001 - 0.015	0.008	0.005	3.397
T14	Time in oral cavity : 30 seconds	Hands	3	0.005 - 0.03	0.022	0.016	2.926
		Oral	3	0.001 - 0.007	0.004	0.003	2.684
T15	Time in oral cavity: 60 seconds	Hands	4	0.009 - 0.054	0.034	0.026	2.372
		Oral	4	0.001 - 0.026	0.008	0.003	4.658
T16	Time in oral cavity: 120 seconds	Hands	4	0.000 - 0.046	0.029	0.012	9.578
		Oral	4	0.001 - 0.017	0.009	0.005	3.884
T17	Type of surface: carpet	Hands	4	0.004 - 0.091	0.038	0.022	3.7
		Oral	4	0.001 - 0.012	0.004	0.002	3.417
T18	Type of surface: wood	Hands	4	0.000 - 0.093	0.042	0.014	13.219
		Oral	4	0.001 - 0.043	0.02	0.009	5.695
T19	Type of transfer: indirect, one hand/face contact, 5-seconds of lip-licking	Hands	8	0.000 - 0.036	0.007	0.001	7.342
		Face	4	0.000 - 0.000	0.000	0.000	1.000
		Oral	8	0.001 - 0.030	0.007	0.003	3.854
T20	Type of transfer: indirect, one hand/face contact, PPE use (nitrile glove), 5-seconds of lip-licking	Hands	4	0.062 - 0.147	0.091	0.086	1.458
		Face	4	0.005 - 0.032	0.016	0.013	2.215
		Oral	4	0.001 - 0.001	0.001	0.001	1.201

Table A3.2 Exposure data for saffron exposure experiments. Descriptions are expressed as deviations from standard scenario, T21.

Trial Code	Standard scenario or deviation from standard scenario	Body Part	Exposure (mg)			
			N	Range	AM	GM
T21	Standard scenario: One 5-second hand press on a glass surface loaded to a surface load of 0.05 mg saffron/cm ² , followed by direct transfer into the oral cavity by a 5-second finger lick of the little finger	Hands	7	0.001-3.381	1.099	0.36
		Oral	7	0.020-0.644	0.287	0.178
T22	Surface load: 0.100 mg saffron/cm ²	Hands	4	0.568-5.200	3.281	2.466
		Oral	4	0.128-1.869	0.776	0.483
T23	Duration of hand/surface contact: 1 second	Hands	6	0.121-0.630	0.33	0.259
		Oral	6	0.000-0.212	0.103	0.071
T24	Duration of hand/surface contact: 10 second	Hands	6	0.114-1.203	0.552	0.438
		Oral	6	0.048-0.213	0.1	0.084
T25	Duration of hand/surface contact: 17 second	Hands	4	0.418-0.751	0.615	0.601
		Oral	4	0.164-0.296	0.238	0.233
T26	Number of hand/surface contacts: 2	Hands	4	0.692-2.233	1.309	1.189
		Oral	4	0.132-0.800	0.364	0.292
T27	Number of hand/surface contacts: 3	Hands	4	3.117-8.935	5.725	5.349
		Oral	4	0.002-2.604	1.440	0.304
T28	Number of hand/surface contacts: 4	Hands	4	2.686-8.925	5.076	4.566
		Oral	4	0.032-2.916	1.641	0.739
T29	Type of transfer : indirect, one hand/face contact, 5-seconds of lip-licking	Hands	3	0.264-0.826	0.582	0.523
		Face	3	0.187-0.36	0.279	0.269
		Oral	3	0.043-0.181	0.089	0.07
T30	Type of transfer : indirect, two hand/face contacts, 5-seconds of lip-licking	Hands	3	0.342-2.011	0.916	0.647
		Face	3	0.208-0.467	0.381	0.357
		Oral	3	0.036-0.404	0.206	0.137
T31	Type of transfer : indirect, three hand/face contacts, 5-seconds of lip-licking	Hands	3	0.418-0.937	0.723	0.683
		Face	3	0.316-0.514	0.406	0.398
		Oral	3	0.068-0.212	0.163	0.144

Appendix III - Table 2 (continued)

Trial Code	Standard scenario or deviation from standard scenario	Body Part	Exposure (mg)				
			N	Range	AM	GM	GSD
T21	Standard scenario: One 5-second hand press on a glass surface loaded to a surface load of 0.05 mg saffron/cm ² , followed by direct transfer into the oral cavity by a 5-second finger lick of the little finger	Hands	7	0.001-3.381	1.099	0.36	16.059
T29b	Type of transfer : indirect, one hand/face contact, PPE use (nitrile gloves); 5-seconds of lip-licking	Hands	0	-	-	-	-
		Face	2	0.216-0.662	0.439	0.378	2.203
		Oral	2	0.14-0.164	0.152	0.151	1.121
		Hands	0	-	-	-	-
T30b	Type of transfer : indirect, two hand/face contacts, PPE use (nitrile gloves); 5-seconds of lip-licking	Face	2	0.323-0.419	0.371	0.368	1.203
		Oral	2	0.004-0.312	0.158	0.035	21.773
		Hands	0	-	-	-	-
T31b	Type of transfer : indirect, three hand/face contacts, PPE use (nitrile gloves); 5-seconds of lip-licking	Face	2	0.219-0.34	0.28	0.273	1.363
		Oral	2	0.013-0.394	0.203	0.072	10.969
		Hands	0	-	-	-	-
T32	Time in oral cavity : 10 seconds	Hands	6	0.001-2.288	0.937	0.262	18.962
		Oral	6	0.033-0.776	0.26	0.172	2.833
T33	Time in oral cavity: 15 seconds	Hands	2	0.812-2.461	1.637	1.414	2.19
		Oral	2	0.058-0.22	0.139	0.112	2.575
T35	Type of surface: carpet	Hands	4	0.001-0.238	0.13	0.043	14.182
		Oral	4	0.002-0.103	0.061	0.028	7.398
T36	Type of surface: wood	Hands	4	0.079-0.963	0.689	0.485	3.37
		Oral	4	0.076-0.248	0.144	0.131	1.643
T37	Type of transfer: indirect, one hand/face contact, 5-seconds of lip-licking	Hands	3	0.175-1.258	0.797	0.595	2.913
		Face	3	0.078-0.5	0.296	0.23	2.615
		Oral	2	0.104-0.124	0.114	0.113	1.136
T38	Type of transfer: indirect, one hand/face contact, PPE use (nitrile gloves); 5-seconds of lip-licking	Hands	0	-	-	-	-
		Face	4	0.345-0.974	0.565	0.519	1.588
		Oral	4	0.007-0.097	0.033	0.019	3.137
T40	Type of contact: smudge	Hands	4	0.421-2.549	1.533	1.143	2.554
		Oral	4	0.152-0.762	0.557	0.471	2.149

Inadvertent ingestion exposure in the workplace

Phase III Model validation

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This is the third and final report of a study investigating the inadvertent ingestion exposure to hazardous substances in the workplace. During Phase I and II we estimated the potential for inadvertent occupational ingestion in the UK and developed a model for estimating ingestion exposure. In the final part of this study we have compared model predictions with actual dermal and oral exposure measurements in five facilities producing or using nickel or lead (three nickel refineries, a powder metallurgy plant and a lead smelter). Three occupational hygienists provided the values for the model parameters, based on detailed descriptions of the workplace, job description, task and some personal information from the workers.

The results showed that for hand and peri-oral exposure there was a reasonably good association between measurements and model estimates. As oral measurements were highly variable and will only reflect the exposure that occurred within a very short time period, we believe that peri-oral exposure is a better measure for estimating oral exposure. We also tested the model for use as a screening tool in a hospital (cytotoxic drugs) and pesticide spraying company. The results suggest that the model provides conservative estimates for exposure. We believe that the model could be used for screening purposes in risk assessment procedures, although further work will need to be carried out to confirm that the model is a sufficiently reliable and conservative tool.

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SUMMARY

Very little is known about the prevalence and intensity of inadvertent ingestion exposure in the workplace in the UK. This study was carried out to determine the importance of occupational ingestion exposure and to develop a model for determining the level of ingestion exposure. In Phase I of this study we estimated that up to 4.5 million workers in the UK may have some regular non-trivial intake of hazardous substances by inadvertent ingestion exposure (Cherrie *et al.*, 2006; Christopher *et al.*, 2006a). A conceptual model for ingestion exposure was developed involving the transfer of contaminants from hand to the mouth, either directly or indirectly via the peri-oral region. In Phase II of the study we investigated the mechanisms involved in inadvertent ingestion exposure to hazardous substances in occupational settings and their relation to the dermal route of exposure. We undertook a series of laboratory experiments to explore the parameters influencing exposures in each compartment of the model and the relationships, reported as transfer efficiencies, between model compartments. The outcome was the development of the conceptual model into a multiplicative deterministic model that can be used to estimate ingestion exposure. Initial application of the model suggested that the contribution from the oral route of exposure could be underestimated in the absence of more realistic estimates of transfer from surfaces into the oral cavity.

In the third and final phase of the study we validated the model by comparing the predictions with actual dermal and oral exposure measurements carried out in five facilities producing or using nickel or lead (three nickel refineries, a powder metallurgy plant and a lead smelter). In addition, the model was applied as a screening tool for cytotoxic drugs in a number of wards and pharmacy in a hospital and for sprayers and mechanics in a pesticide spraying company.

Dermal exposure measurements of the hand and peri-oral region were carried out using wipes, whilst saliva and mouth wash samples were collected to determine the amount of contamination in the oral cavity. In addition to personal sampling, wipe samples were collected from different surfaces of the hospital wards and pharmacy and in the pesticide spraying company. All metal samples were analyses for nickel or lead using inductively coupled plasma atomic emission spectroscopy (ICP/AES). The cytotoxic drugs were analysed using gas chromatography with mass spectrometric detection (GC/MS) (cyclophosphamide, ifosfamide) or inductively coupled mass spectrometry (ICP/MS) (cis- and carbo-platin). Samples from the pesticide spraying company were analysed using GC/MS (chlorothalonil), liquid chromatography with mass spectrometry (LC/MS) (mancozeb after hydrolysis to ethylene thiourea (ETU) and ethylene urea (EU)), liquid chromatography with tandem mass spectrometry (LC-MS/MS) (glyphosphate) and gas chromatography with mass selective detection (GC/MSD) (chlorpyrifos).

Three occupational hygienists provided the values of the input parameters of the ingestion model developed in Phase II of the project. They were provided with detailed descriptions of the workplace, the job description, tasks, control measures, personal protective equipment, and personal habits (smoking, hand washing) and facial hair. The assessments were carried out independently and blind to the results of the exposure measurements. The model developed in Phase II of the study was converted into time dependent algorithms and applied using MATLAB software (version 7.0).

Dermal and oral exposure measurements for nickel or lead were collected from 43 different workers. The arithmetic mean for cumulative hand exposure for nickel ranged from 570 µg to 11,500 µg. The arithmetic mean lead exposure on hands in the lead smelter was 14,000 µg. The peri-oral exposure at the end of the shift for nickel ranged from 11 µg to 170 µg, whilst in

the lead smelter the peri-oral lead exposure was 99 µg. For the oral exposure, the exposure to nickel ranged from 0.6 µg to 13 µg, whilst the oral lead exposure in the lead smelter was 9.2 µg. There was a reasonably strong association between hand and peri-oral exposure and to a lesser extent between the peri-oral and oral exposure. No relationship was observed when directly comparing hand and oral exposure. Within the health care sector dermal and oral measurements were collected from 18 workers. In addition, 23 surface wipes and 8 gloves were also collected. Except for the platinum coordinated cytotoxic drugs, levels on the hand, face and oral region were generally below the limit of detection, although levels on surfaces and gloves were higher. Dermal and oral exposure measurements for pesticides were obtained from eight different workers, seven sprayers and one mechanic. Highest dermal exposures for pesticides were observed for glyphosate and chlorpyrifos, with generally lower levels observed on the face compared to the hand. Fewer oral measurements were collected, with the majority being below the limit of detection.

In general there was good agreement between the model predictions using the parameter estimates from the three assessors (intra-class correlation coefficient ranging between 0.74 and 0.99). This is a reflection of the structure of the model and the relatively limited range of options available to the assessors in selecting the model parameters. The systematic differences between assessors were generally less than a factor of two, which is good in comparison with other modelling approaches for inhalation exposure or dermal exposure (e.g. Cherrie and Schneider, 1999).

Comparison of the measured and estimated exposures showed a statistically significant association between the estimated contamination on the hand and the measured value and between the estimated and measured exposure in the peri-oral area, with the correlation coefficients in the latter being between 0.57 and 0.61. Despite the model being developed using conservative assumptions the measured and estimated peri-oral exposures were quite similar. The correlation between estimated and measured oral exposure was poor, but in general the measured exposures were lower than the estimates. These results are encouraging and suggest that the algorithm has some predictive power for peri-oral exposure.

Finally, we tested the model for use as a screening tool in a hospital (cytotoxic drugs) and pesticide spraying company. The outcomes suggested that the model provides conservative estimates for exposure, especially for the cytotoxic drugs. For pesticide exposure the model over estimated the peri-oral exposure by a factor between 10 and 500 depending on the compound and circumstances involved. We believe that this magnitude of “safety” factor is appropriate for screening tools in risk assessment procedures, although further work will need to be carried out to test whether the model is a sufficiently reliable and conservative tool.

1 INTRODUCTION

1.1 BACKGROUND

This is the third and final report from a project to investigate the role of ingestion in workplace exposure to hazardous substances. During the first phase of the study a comprehensive literature review of inadvertent ingestion exposure to hazardous substances was carried out. The results of this literature review were published in the Annals of Occupational Hygiene (Cherrie *et al.*, 2006) and as the first report from this project (Christopher *et al.*, 2006a).

Exposure by ingestion has been rarely considered as a significant contributor to total exposure in the workplace. Research of ingestion exposure has primarily focussed on non-occupational ingestion exposure, particularly in infants arising from mouthing behaviour. However, it was identified that inadvertent ingestion in the workplace could possibly represent a significant contributor to total exposure to metals and metal compounds, pharmaceuticals, pesticides, infectious agents and radionuclides (Cherrie *et al.*, 2006). After review of all occupations in the Standard Occupational Classifications by three experienced occupational hygienists it was estimated that approximately 4.5 million workers in the UK (15% of the total working population) are potentially exposed through inadvertent ingestion to any of these five groups of hazardous substances.

A preliminary conceptual model of ingestion exposure was designed and this was also published by Cherrie *et al.*, (2006). The model and the literature review highlighted the role of transfer from hand to mouth or peri-oral region (area around the mouth) and transfer from object to mouth or peri-oral region as important processes along the ingestion exposure pathway. These processes were found to have a psychological component that is difficult to quantify, for example, repeated nail biting. The model comprised four exposure compartments (i.e. surfaces, hands, peri-oral region and oral cavity), with the hands playing a crucial central role.

During phase II of the study the conceptual model was elaborated by investigating the transfer processes between the various compartments of the model (Christopher *et al.*, 2006b). A series of laboratory trials were conducted to investigate the factors affecting the transfer of solid and liquid contaminants among the different compartments. The parameters investigated included levels of surface loading, hand moisture levels and the duration and number of hand contacts with the oral and peri-oral regions. The relationships between the exposure compartments were reported as transfer efficiencies where the transfer efficiency was defined as the proportion of contaminant in one compartment that was transferred to another compartment under a defined set of conditions. Although the experiments with the liquid contaminant were largely unsuccessful, it was clear that a lesser proportion of liquid was transferred than solid. Consequently, the final model is based on data from the experiments with solids, although we are confident that it does not underestimate the exposure for either liquids or solids. Detailed description of the laboratory tests and results are provided in the Phase II report (Christopher *et al.*, 2006b)

The final part of this project, which is reported here, comprised studies undertaken to validate the refined ingestion exposure model. This report will describe the methods and results for the validation tests and will provide an overall discussion of the relevance of occupational ingestion exposure and the usefulness of the ingestion model for risk assessment and epidemiological studies

1.2 AIMS AND OBJECTIVES

The overall aim of this project was to determine the importance of ingestion exposure to hazardous substances in the workplace and to develop a model for determining the level of ingestion exposure. Specifically to:

- a) undertake a review of published literature and other information sources to identify chemicals and industries where ingestion exposure contributes a significant fraction of total body burden;
- b) describe workplace and behavioural factors influencing ingestion exposures in a range of simulated exposure scenarios, together with the development of a validated method to measure ingestion exposure;
- c) formulate a simple theoretical model as a means of describing ingestion exposure;
- d) evaluate and refine the model using observations and measurements carried out in relevant workplaces; and
- e) present the findings and provide an evaluation of the need for future research.

The aim of the third phase of the study was to validate and, if necessary, improve the ingestion model (item d, above). We also present an overall discussion of the project and an assessment of what further research should be undertaken.

2 METHODS

2.1 VALIDATION STRATEGY

The validation strategy consisted of comparing outcomes of the model algorithms to assess dermal and oral workplace exposure with actual dermal and oral measurements obtained from seven different workplace facilities representing three different occupational sectors: (a) metal production or use; (b) the health care sector and (c) the agricultural sector. We initially used the data from metals industries to validate and refine the model for risk assessment purposes, and then used the data from the remaining sectors to help validate the final model as it would be used in a risk assessment context. Three experienced occupational hygienists who had no prior knowledge of the exposure levels obtained during field measurement surveys at the metalworking facilities were asked to apply the model to predict the dermal and oral exposure using detailed descriptions of tasks and workplace. The final model validation was undertaken by one of these hygienists, again without prior knowledge of the measurement data.

2.2 EXPOSURE MEASUREMENTS

2.2.1 Choice of Workplaces

Oral and dermal samples were collected from three different workplace sectors. These sectors were targeted based on their known potential for dermal exposure which, based on our conceptual model, is linked to ingestion exposure. In addition, it is recognised that for some of these toxic substances – metals, pesticides and cytotoxic drugs - any additional contribution to total exposure from inadvertent ingestion could significantly increase the potential for adverse health effects.

2.2.2 Sampling strategies

Personal Sampling

The sampling strategy varied depending on the facility being investigated to ensure the most practical strategy for each sector was used. Dermal and oral samples in the facilities in the metal industry and the health care sector were collected at different points during the work-shift: around the first break during the shift or the beginning of the shift, mid-shift and at the end of the work-shift (Tables 2.1 and Table 2.2). Workers involved in activities such as packing and handling of metal containing dusts or solutions were targeted for sampling.

Table 2.1 Sampling for each worker in the metal production/use sector

Anatomical Region	Sample type	Sampling times			N
		First break/begin	Second break	End of shift	
Palms of both hands	Moist wipes*	✓	✓	✓	3
Backs of both hands	Moist wipes*	✓	✓	✓	3
Face (peri-oral region)	Moist wipes*			✓	1
Oral cavity	Saliva sample	✓	✓	✓	3
Oral cavity	Mouth rinse sample	✓	✓	✓	3
Total number of samples per person					13

*Dermal sample method 1 used for all wipe samples (see section 2.2.3)

N: Number of samples

In the hospital ward exposure monitoring was focussed on medical staff who were directly involved in handling cytotoxic drugs, either administering drugs, handling patients receiving chemotherapy or disposing of body fluids from patients who had received chemotherapy treatment. A similar sampling strategy was undertaken for monitoring in the Pharmacy where cytotoxic drugs were handled, with the exception that sampling was done at four different time-points during the work shift (Table 2.2). The first sample was taken at the very beginning of the shift before any of the pharmacy workers entered the cytotoxic unit to help assess whether there was any residual contamination from previous exposure. In the Pharmacy the persons monitored were those handling the prescriptions, those sterilizing the items prior to passing into the sterilized room and those preparing drug formulations in the sterile room.

Table 2.2 Sampling for each worker in the health care sector

Anatomical Region	Sample type	Sampling times				N
		Begin shift	First break	Second break	End of shift	
Hospital Wards						
Palms of both hands	Moist wipes*		✓	✓	✓	3
Face (peri-oral region)	Moist wipes*		✓	✓	✓	3
Oral cavity	Saliva sample		✓	✓	✓	3
Total number of wipe and oral samples per person						9
Hospital Pharmacy						
Palms of both hands	Moist wipes*	✓	✓	✓	✓	4
Face (peri-oral region)	Moist wipes*	✓	✓	✓	✓	4
Oral cavity	Saliva sample	✓	✓	✓	✓	4
Total number of wipe and oral samples per person						12

*Dermal sample method 2 used for face wipes, for hand wipes dermal method 1 used (see section 2.2.3).

N: Number of samples

For the agricultural sector two different sampling strategies were followed: task-based and full-shift monitoring (Table 2.3). The strategy used varied according to the way the pesticide was used by the sprayer. Where the sprayer was applying the same pesticide all day, samples were collected at three different points of the spraying task: at the beginning of the day; at the middle of the day (usually when the sprayer took a break or just after re-loading his spray tank); and at the end of the day. When the pesticide was changed between spraying of fields, samples were collected at the beginning and end of each spraying session.

Table 2.3 Sampling for workers in the agricultural sector using two different sampling strategies

Anatomical Region	Sample type	Sampling times during task			N
		Begin	Middle	End	
Strategy 1					
Palms of both hands	Moist wipes*	✓		✓	2
Face (peri-oral region)	Moist wipes*	✓		✓	2
Oral cavity	Saliva sample	✓		✓	2
Total samples per worker using strategy 1					6
Strategy 2					
Palms of both hands	Moist wipes*	✓	✓	✓	3
Face (peri-oral region)	Moist wipes*	✓	✓	✓	3
Oral cavity	Saliva sample	✓	✓	✓	3
Total samples per worker using strategy 2					9

*Dermal sample method 2 used for all wipe samples

N: Number of samples

Notes were made of the tasks undertaken by each worker during each task or session and a record of the substances and preparations handled was made.

Environmental Sampling

Samples were also collected from surfaces with which workers were likely to come into contact. This was done in the health care and agricultural sectors only. The purpose of the environmental monitoring was to identify the contamination levels of potential sources of exposure and to investigate if there was a spread of contamination to 'clean areas'.

On the wards, surface wipe samples were collected from around the nurses' station, the trays on which cytotoxin-containing intra-venous bags and syringes were placed prior to being administered to patients, and on various surfaces in the toilets (Table 2.4). In the Pharmacy surface samples were collected from the desktops in the prescription room and various different surfaces in the cytotoxic unit where drugs were reconstituted. Wipe samples of the flow cabinet where drugs were prepared were provided by the technician formulating the drugs (Table 2.4).

Table 2.4 Surface sampling in the health care sector over two monitoring surveys

Area	Description of surface areas sampled	N
Hospital Ward		
Short-stay unit	Patients' toilets (floor)	1
	Nurses' station (desktop)	1
	Intra-venous bag	1
Day unit	Coffee table	1
Outpatient clinic	Coffee table (Room1)*	1
	Desktop (Room1)	1
	Desktop (Room 2)	1
	Drug tray (Room 2)	1
	Toilet I (floor)	1
	Toilet I (door handle & door knob)	1
	Toilet II (floor)	1
	Toilet II (door handle & knob)	1
Total number of surface wipes taken on wards		12
Pharmacy		
Prescription Room	Outer sleeve of IV bag	1
	Surface of IV bag	1
	Desktop (2 samples)	2
	Surface of pen	1
Clean Room	Surface of pen	1
	Bench top (2 samples)	2
	Bench top	1
Sterile Room	Surface of flow cabinet (end session) (2 samples)	2
Total number of surface wipes taken in pharmacy		11

N: Number of samples taken in area.

*Room I was a room where non-cytotoxic drugs were administered and some patients were prepared for chemotherapy treatment. No cytotoxic drugs were prepared here and nurses sometimes took their breaks and had lunch in this room. Cytotoxic drugs were administered in Room 2

Toilet II was the designated nurses' toilet, but in practice nurses' used both toilets.

For pesticide sprayers, samples were collected from several surfaces within the cab and on the external surfaces of the sprayer (Table 2.5). Surface samples in the agricultural sector were collected at the same time as the personal dermal wipe samples.

Table 2.5 Surface sampling in the Agricultural Sector

Description of surfaces sampled	Sampling times			N
	Begin task	Mid-task	End of task	
<i>Strategy 1</i>				
<i>Inner cab</i>				
Steering wheel	√		√	2
Door bar	√		√	2
Key ignition*	√		√	2
<i>Outer cab</i>				
Door handle	√		√	2
Vertical bar just outside cab	√		√	2
Hopper handle**	√		√	2
Valve handle**	√		√	2
Maximum number of wipe samples per cab				14
<i>Strategy 2</i>				
<i>Inner cab</i>				
Steering wheel	√	√	√	3
Door bar	√	√	√	3
<i>Outer cab</i>				3
Door handle	√	√	√	
Vertical bar just outside cab	√	√	√	3
Hopper handle	√	√	√	3
Valve handle	√	√	√	3
Maximum number of wipe samples per cab				18

Notes: *Surface wipe of area around key ignition was done for one sprayer only.

**Wipes of the hopper and valve handle were done for three sprayers only – once with a sprayer who was sampled on a shift basis and twice with sprayers who were sampled on a task basis.

Gloves

Eight were collected from workers within the healthcare sector. They were collected from nurses and pharmacy workers at the end of work sessions.

2.2.3 Sampling methods

Dermal Sampling Method

Two different dermal sampling methods were applied depending on the sector to facilitate the different analytical methods required for the various substances to be analysed.

Dermal sampling method 1 was applied in the ‘metal production and use’ facilities. It employed the use of commercial wet wipes (Jeyes ‘Sticky Fingers’ Wet Ones). An acetate template was used to ensure a wipe surface area of 25 cm². This area was wiped three times to ensure good recovery of the substance from the skin. Hand wipes were then pooled together into one sample for analysis. Facial wipes involved wiping the area around and over the mouth three times with three wet wipes.

Dermal sampling method 2 was applied for the measurements in the health care and agricultural sectors. This method employed the use of commercial dry wipes (Kleenex[®]) wetted with 10 mls of sodium bicarbonate solution (10 mM) in the case of the healthcare facilities and the use of commercial wet wipes (Jeyes 'Sticky Fingers' Wet Ones) for the agricultural sector. The wetted wipe was applied to the entire palmar surface of the hand and wiped in a consistent and systematic way. This was repeated three times as before to ensure good recovery. Facial wipe sampling was as described above for the metals use and production facilities.

Surface sampling method

Wipe samples were collected from surfaces with which workers were likely to come into contact. Commercial wet wipes, identical to those used for dermal sampling were used.

Surface sampling method 1: Commercial wet wipes (Jeyes 'Sticky Fingers' Wet Ones) were used to wipe a known area of the selected workplace surface. This was repeated three times for each surface area sampled. This method was used in the agricultural sector. Surface sampling method 2: A small volume of sodium hydrogen carbonate (2-10 ml depending on the area of the surface being sampled) was applied directly onto the surface and a dry wipe (Kleenex[®]) was used to wipe the sampling area demarcated using an acetate template. Each surface was wiped three times with three different wipes until the surface was dry. Method two was used in the healthcare sector.

The area of the surface wiped ranged from 25 cm² to 6500 cm² depending on the area being sampled. The upper end of this range was for samples collected inside the flow cabinet provided by the drug formulation technician.

Oral sampling method

Oral sampling in the metals industry involved the collection of both saliva and mouth rinse samples. Each worker was asked to first deposit approximately 0.5 to 1.0 ml of saliva directly into a 20 ml Sterilin[®] centrifuge tube. A mouth rinse sample was collected directly after. The worker was provided with a 20-ml Sterilin[®] centrifuge tube containing 10 - 15 ml of water with which to rinse his mouth for 5 seconds before depositing the mouth rinse back into the sample container. Oral sampling in the agricultural and health care sector involved collection of saliva samples only.

2.2.4 Sample analysis

Metals

Details of the analytical methods used to quantify nickel and lead in dermal samples have been described by Hughson (2004a, 2004b and 2005). Briefly, wipe samples were analysed for nickel and lead using inductively coupled plasma atomic emission spectroscopy (ICP/AES). Nickel wipe samples were analysed for both soluble and insoluble nickel content using a variation of a published method (Zatka *et al.*, 1992).

Oral samples were also analysed by ICP/AES. The volume of the saliva rinse sample was measured and the sample was then filtered. The filtrate was made up to 25 ml with deionised water. The filter was digested in concentrated nitric acid and also made up to 25 ml with deionised water. The samples were analysed using a modification of OSHA ID121 by ICP/AES.

Cytotoxins

Cyclophosphamide and ifosphamide were extracted in water. The extracts were then analysed by liquid chromatography with mass spectrometric detection (LC-MS). The platinum-coordinated drugs, cis-platin and carbo-platin were analysed by measuring platinum by inductively coupled mass spectrometry (ICP-MS).

Pesticides

Chlorothalonil

Wipe samples and saliva samples were extracted with 10 and 2 ml of dichloromethane, respectively. All extracts were dried over calcium chloride and analysed by gas chromatography with mass selective detection (GC/MS). The GC was fitted with a 30 metre DB5-MS capillary column and programmed to heat from 150 to 260°C. The MS was set in selected ion monitoring (SIM) mode for the specific ions. Calibration standards were prepared from known weights of Analar grade chemicals in the desorption solution.

Mancozeb

The wipes were desorbed and the saliva samples were diluted into water. The samples were then left for 48 hr to allow for hydrolysis of mancozeb. The extracts were then analysed by LC-MS for ethylene thiourea (ETU) and ethylene urea (EU).

Glyphosate

The wipes were desorbed and the saliva samples were diluted into water. The extracts were then reacted with fluorenylmethyloxycarbonyl chloride (FMOC-Cl) to provide the FMOC derivative, which was then analysed by liquid chromatography with tandem mass spectrometric detection (LC-MS/MS). Samples were analysed for glyphosate and the metabolite aminomethylphosphonic acid (AMPA) using the same procedure.

Chlorpyrifos

The wipes were desorbed and the saliva samples were diluted into cyclohexane. The samples were then analysed by GC-MS.

2.2.5 Limit of detection and sample recoveries

The limit of detection and sample recoveries reported for the various different types of analyses are indicated in Tables 2.6, 2.7 and 2.8 for analysis of metals, cytotoxic drugs, and pesticides, respectively. The limit of detection for the analyses of mancozeb, glyphosate and chlorpyrifos was estimated as three times signal-to-noise ratio from the lowest calibration level (LCL). Values for limit of detection and recoveries for the pesticide analytes are given in Table 2.8. The recoveries for AMPA and EU were not determined. They were assumed to be the same as for glyphosate and ETU, respectively. Results for pesticide and cytotoxin wipe samples were expressed as the total weight of analyte on the wipe sample.

Table 2.6 Limits of detection and recoveries for metal analyses

Analyte	Limit of detection		Recoveries	
	Wipe ($\mu\text{g}/\text{cm}^2$)	Saliva ($\mu\text{g}/\text{L}$)	Wipe	Saliva
Lead	0.3	10	NA	NA
Nickel	0.019	10	NA	NA

NA: Not available

Table 2.7 Limits of detection and recoveries for cytotoxin analyses.

Drug	Limit of detection		Recoveries	
	Wipe (ng)	Saliva (ng/L)	Wipes (percent)	Saliva (percent)
Cyclophosphamide/ Ifosfamide	25	500	NA	NA
Platinum coordinated drugs	0.1	2	NA	NA

NA: Not available

Table 2.8 Limits of detection and recoveries for pesticide analyses

Pesticide	Analyte	Limit of Detection		Recoveries	
		Wipe (µg/sample)	Saliva (ng/mL)	Wipe (percent)	Saliva (percent)
Chlorothalonil	Chlorothalonil	0.1	200	105.8	NA
Mancozeb	ETU	0.2	40	68	59
	EU	0.4	70	68	59
Glyphosate	Glyphosate	0.3	70	89	82
	AMPA	0.2	40	89	82
Chlorpyrifos	Chlorpyrifos	0.03	4	98	95

NA: Not available

2.3 PREDICTING EXPOSURE

The model developed in the Phase II report (Christopher *et al.*, 2006b) was applied. In brief, we assumed that inadvertent ingestion exposure can arise from:

- a) direct transfer of contaminant from the hand into the oral cavity;
- b) indirect transfer of contaminant into the oral cavity (i.e. hand to peri-oral followed by transfer from the peri-oral region into the mouth).

Model parameter values were estimated by three occupational hygienists and subsequent calculations were carried out using the software package MATLAB (Section 2.3.2). The following two sections describe the methods used for this part of the study.

2.3.1 Estimating model parameter values

Three occupational hygienists were asked to independently provide estimates for each parameter in the model based on detailed descriptions of the workplace, job description, tasks, control measures, personal protective equipment (PPE) and some personal information (smoking habits, facial hair). The results of the dermal and oral measurements were not provided to the assessors. For hand exposure determination, estimates of the number of hand-to-surface contacts, the surface load and the skin moisture were required. For determining the direct oral exposure, the assessors were required to estimate the fraction of the hand that entered the oral cavity and the number of hand-to-mouth contacts, while for indirect contact the assessors estimated the fraction of the hand that came into contact with the peri-oral region and the number of hand to peri-oral region contacts.

General guidance was provided on how each parameter in the model should be rated (Appendix I). Conducting the assessments of exposure was further facilitated by providing a spreadsheet listing each parameter to be assessed (Appendix II). The spreadsheet was constructed in such a way that it was possible to gather information on parameter values subdivided into different activities (i.e. sessions and tasks within each session). Table 2.9 shows the model parameters that the assessors were asked to estimate. Information on the duration of the tasks and the concentration of the contaminant substances in the exposure medium was provided.

Table 2.9 Model parameter values

Parameters	Parameter values	Conversion of parameter values for use in model algorithms
Task duration (hours)	(provided to assessor)	-
Surface load (mg/cm ²)	Low, Medium, High	0 = low or medium; 1 = high
Number of hand/surface contacts (contacts/hour)	≥0	No conversion
Skin moisture	Low, High,	0 = low; 1 = high
“Busyness”	0, 1, 2, 3,	-
Hand/mouth fraction contact	0 - 1	No conversion
Number direct contacts (contacts/hour)	≥0	No conversion
Hand/face fraction contact	0 - 1	No conversion
Number indirect contacts (contacts/hour)	≥0	No conversion
Concentration of contaminant substances (weight/weight %); (volume/volume %)	0 – 1 (provided to assessor)	-

Descriptions for 43 different workers in 18 different jobs (Table 2.10) were prepared by the main author of this report. Detailed information on the jobs was gathered as part of workplace surveys during which workers were closely observed and questioned on their activities. In addition to information on the workplace and activities, the descriptions also included information on smoking habits, facial hair and information on washing of hands. Appendix III gives the descriptions provided to the assessors.

Table 2.10 Number of jobs for which workers' exposure was assessed

Facility	Agent	N-jobs	N-workers
Nickel Refinery 1	Nickel	5	15
Nickel Refinery 2	Nickel	2	5
Nickel Refinery 3	Nickel	2	4
Powder Metallurgy	Nickel	3	4
Lead Smelter	Lead	6	17

N-jobs: number of jobs; N-workers: number of workers

Each day was divided into three sessions (i.e. time periods) and a description of the different tasks the worker did during each session was included. The sessions were determined by the timing of the dermal and oral measurements; the end of session 1 coincided with the first dermal and oral sample, the end of session 2 with the second sample, and the end of the third session coincided with the end of the sampling period.

2.3.2 Exposure model calculations

The model predictions were obtained using MATLAB software (version 7.0). The equation for hand loading and direct and indirect transfer of contaminants that were provided in the Phase II report (Christopher *et al.*, 2006b) were transformed into time dependent algorithms. First the hand loading was calculated for the area relevant for direct or indirect transfer, ignoring any transfer of contaminant from the hand to the oral region:

$$E_D(i+1) = E_D(i) + \Phi_D \cdot dt \quad (1)$$

where

- $E_D(i+1)$ = hand loading for area of the hand relevant for direct contact at time, $t=i+1$ (ignoring transfer to oral region);
- $E_D(i)$ = hand loading for area of the hand relevant for direct contact at time, $t=i$ (ignoring transfer to oral region);
- $\Phi_D \cdot dt$ = transfer of contaminant from surface to hand during 1 minute.

$$\Phi_D = E_{hand}^* \cdot F_D \quad (2)$$

where

$$E_{hand}^* = 1.15 + 4.09 \cdot N_{hand/surface} + 2.73 \cdot L_{surface} - 0.80 \cdot S_{group} \quad (3)$$

- F_D = the estimated fraction of the hand that is in direct contact with oral region.
- $N_{hand/surface}$ = Number of hand to surface contacts (0: ≤ 2 contacts; 1: > 2 contacts)
- $L_{surface}$ = Surface load (0: low; 1: high)
- S_{group} = Skin moisture group (0 = low; 1 = high skin moisture)

Taking into account the direct transfer of the contaminant from the hand to oral region, equation (1) becomes:

$$E_{D,corrected}(i+1) = E_{D,corrected}(i) + (\Phi_D \cdot dt) - (TE_{oral/hand} \cdot E_{D,corrected}(i) \cdot dU) \quad (4)$$

where

- $E_{D,corrected}(i+1)$ = total hand exposure available for direct transfer to oral region at $t=i+1$;
- $E_{D,corrected}(i)$ = total hand exposure available for direct transfer to oral region at $t=i$;
- $TE_{oral/hand}$ = transfer efficiency from hand to oral region for each contact ($=0.95$);
- dU = is a random variable determining whether hand to mouth contact occurred during $t=i+1$. This was estimated through a Poisson process using the estimated frequency of hand to mouth contact (λ_D) provided by the occupational hygienists.

The transfer of contaminant by the direct route was subsequently described as:

$$O_D(i+1) = O_D(i) + (TE_{oral/hand} \cdot E_{D,corrected}(i) \cdot dU) \quad (5)$$

where

- $O_D(i+1)$ = total cumulative oral exposure from the direct route at $t=i+1$;
- $O_D(i)$ = total cumulative oral exposure from the direct route at $t=i$.

Similarly, for indirect contact, the relevant hand loading, ignoring transfer from the hand to the peri-oral region, was calculated as:

$$E_I(i+1) = E_I(i) + \Phi_I \cdot dt \quad (6)$$

where

- $E_I(i+1)$ = hand loading for area of the hand relevant for indirect contact at $t=i+1$ (ignoring transfer from hand to peri-oral region);
- $E_I(i)$ = hand loading for area of the hand relevant for indirect contact at $t=i$ (ignoring transfer from hand to peri-oral region);
- $\Phi_I \cdot dt$ = transfer of contaminant from surface to hand during 1 minute.

$$\Phi_I = E_{hand}^* \cdot F_I \quad (7)$$

where

- F_I = the estimated fraction of the hand that is in contact with peri-oral region.

As before, equation (6) was corrected for the transfer of contamination from the hand to the peri-oral region:

$$E_{I,corrected}(i+1) = E_{I,corrected}(i) + (\Phi_I \cdot dt) - (TE_{peri-oral/hand} \cdot E_{I,corrected}(i) \cdot dD) \quad (9)$$

where

- $E_{I,corrected}(i+1)$ = total hand exposure available for transfer to the peri-oral region at $t=i+1$;
- $E_{I,corrected}(i)$ = total hand exposure available for transfer to the peri-oral region at $t=i$;
- $TE_{peri-oral/hand}$ = transfer efficiency from hand to peri-oral region for each contact ($=0.37$);
- dD = is a random variable determining whether hand to face contact occurred during $t=i+1$. This was estimated through a Poisson process using the estimated frequency of hand to face contact (λ_I) provided by the occupational hygienists.

For the indirect route the transfer of contamination from the hand to the oral region was calculated as:

$$O_I(i+1) = O_I(i) + TE_{oral/peri-oral} \cdot (TE_{peri-oral/hand} \cdot E_{I,corrected}(i) \cdot dD) \quad (10)$$

where

$O_l(i+1)$	= total cumulative oral exposure from the indirect route at $t=i+1$
$O_l(i)$	= total cumulative oral exposure from the indirect route at $t=i$
$TE_{oral/peri-oral}$	= transfer efficiency for peri-oral to oral region (=0.38)

The total cumulative oral exposure at the end of the period under consideration is subsequently calculated as:

$$O_{tot,t=final} = O_{D,t=final} + O_{I,t=final} \quad (11)$$

Appendix IV shows an example of the MATLAB programme used for calculating the oral exposure. The programme calculates the hand exposure on the area of the hand that comes into contact with the mouth and/or the face, rather than the total hand. The estimates were corrected using the estimated fraction of the hand to obtain total hand exposure. However, when the assessors determined that no hand to mouth or hand to face contacts occurred, then hand exposure was estimated as zero, and no correction was possible.

The processes of direct and indirect transfer of contaminant were calculated as random processes. Hence, the calculations for each task and assessor were repeated 10 times, and the average result used in subsequent analyses. Task-based exposures were then summed to provide estimated hand, peri-oral and oral exposure by session.

2.4 MODEL AS SCREENING TOOL

To test the suitability of the model as a screening tool for risk assessment purposes we used the results of the measurements of cytotoxic drugs in the ward and pharmacy of a hospital and the measurements of pesticides in a pesticide spraying company. Both these workplace settings and the contaminants associated with them were among those identified in the initial phase of this study, as having the oral route as a potential route of exposure. Furthermore, exposure to cytotoxins is particularly important being among a group of hazardous substances considered as very toxic due to their carcinogenic potential. Hence, the identification of pathways that will increase exposure levels, howsoever small, is useful. Based on a general description of the workplace and activities (Appendix V), the overall model parameters were determined. This is different from the previous exercise, where detailed data on specific tasks were used together with some personal information on the employees (facial hair, smoking habits,). For each department (ward and pharmacy in the health care sector; and sprayer and mechanic in the agricultural sector) one (mean) prediction of the ingestion exposure (hand, peri-oral and oral) was compared with all the results from the measurements from these workplaces. The model parameters were estimated by one of the authors of the report (MvT).

2.5 STATISTICAL ANALYSIS

Descriptive data analyses were performed using the *Minitab* statistical software package, and for statistical modelling *Genstat version 9* was used. The normality of the log transformed predicted and actual exposure data was tested using the Shapiro-Wilks statistic. Further analyses were performed on the log-transformed data.

Inter-assessor agreement was examined graphically and summarised using intraclass correlation coefficients, which contrasts the between-assessor variability with the between-task variability. Scaling factors between assessors were calculated using a paired t-test for each pair of assessors.

Comparison between assessors' exposure estimates and actual measured exposures as well as between measured exposures at different sites were examined graphically and summarised using correlation coefficients, to show the strength of linear association. Statistical regression analyses were used to quantify the relationships between the variables.

3 DESCRIPTION OF WORKPLACES

Detailed descriptions of the workplace, job titles and tasks carried out during the measurements survey can be found in the Appendices III and V.

3.1 METAL INDUSTRY

Exposure to nickel was measured in three nickel refineries and a powder metallurgy plant, whilst lead was measured in a secondary lead smelter. Comprehensive descriptions of the facilities can be found in the following published reports - Hughson (2004a), Hughson (2004b) and Hughson (2005). The following sections 3.1.1 to 3.1.3 were partly excerpted from these reports. In addition, Appendix III provides further details of the process and job descriptions for these five facilities.

3.1.1 Nickel refineries

The first nickel refinery produced nickel metal and nickel compounds by recovering elemental nickel from nickel matte using an electrolytic process. Three operators were involved with controlling the production process, mainly from within a control room. They carried out routine inspection of the plant and various cleaning tasks. The surfaces in the leaching area, particularly around the filter press, became contaminated with nickel sulphate residue and were hosed down regularly to remove any residual contamination from the floor and work surfaces. The cathode lifter and cathode stripper operators worked in the electro-winning plant. This was a very dirty area with damp residues of nickel sulphate on surfaces.

Briquette packers worked in the hydrogen reduction plant their main function being to monitor the process from a control room and carry out movement of stock by forklift truck. The briquettes were packed into 1000 kg flexible intermediate bulk containers (FIBC) or 200 kg drums; and the workers were simply involved with loading the fill point with the empty container and waiting until it was filled.

The chemical packers worked within the chemical plant, which was very clean. The process was automated and the sources were generally contained except during quality control sampling. The workers had only incidental contact with the packing equipment and final products.

The second nickel refinery produced nickel metal and nickel powder products using the Mond process, although in this study measurements were only made in the nickel powder production area. Nickel carbonyl was produced by heating the nickel concentrates in the presence of carbon monoxide in a series of rotary kilns. The nickel carbonyl then decomposed to form nickel powders of a uniform particle size range. The nickel powder was transferred from a hopper to semi-automatic powder packing stations through a series of conveyors to storage and automatic weigh-cells. Measurements were mostly made on powder packing operators.

The third nickel refinery produced nickel metal and nickel chloride hexahydrate crystals by recovering elemental nickel from nickel matte in a hydrometallurgical process. While it was only the nickel chloride crystals packing workers that were identified for sampling, a number of other workers were included in the study since they were also potentially exposed either to nickel chloride solution, nickel metal or nickel matte.

3.1.2 Powder metallurgy plant

The powder metallurgy company was involved in the production of various types of magnets used in automotive instrumentation and mobile phone technology. The magnets were produced using a mixture of metal powders including nickel. The front end of the process involved weighing out batches of metal powders and other ingredients into batch containers, which were used to feed each of the presses. The batch container was suspended above a hydraulic or mechanical press and the powder was fed into the input hopper by gravity. The powder passed through the feed to enter into a series of rotating dies; the compressed powder parts were ejected into a tray. The preparation and setting of the machine was a skilled job, carried out by 1-2 setters each shift. However, once in operation the presses required only minimal supervision. Measurements were made on nickel powder operators who weighed out nickel and other metal powders; setters who loaded the powder mixtures to the presses, prepared and then monitored the mechanical presses, and grinding machine operators who set-up and monitored the grinding machines.

3.1.3 Lead smelter

The lead smelting company produced lead ingots by smelting and refining lead concentrates and lead scrap. There were extensive hygiene procedures in place to prevent contamination of personal clothing, or eating and drinking areas. There were dedicated washing and showering areas, clean rest zones and a daily supply of clean work clothing. Workers wore air fed visor respirators. Measurements were made on the raw materials operators, furnace operators, refinery operators, maintenance men, the quality control technicians and the security guard.

3.2 HOSPITAL

Within the health care sector two measurement surveys were carried out to determine dermal and oral exposure to cytotoxic drugs on two wards and in the pharmacy that served both these wards. In the first survey, investigations were conducted in a Short-Stay Unit (SSU) and a Day Unit (DU) and within the Pharmacy Department. During the second survey investigations were carried out in an Outpatient Clinic (OC) and again within the Pharmacy.

The section of the SSU that was involved in the monitoring survey consisted of a large, open room with about 15 beds. Also contained within this area was a nurses' station where administrative tasks took place and where drug preparations were delivered. The OC was served by a reception area where the drugs from the pharmacy were delivered. The administration area, which held the patients records, was separate from the treatment area. The main treatment room was a fairly small area that held about 10 seated treatment stations. Generally, drugs were administered either using intravenous bags or more directly using a syringe.

The Pharmacy was a centralized, recently refurbished, unit that serviced the whole hospital. The monitoring survey was conducted within the section of the Pharmacy that was responsible for the distribution of all cytotoxic drugs. The area comprised a cytotoxic unit as well as a non-sterile prescription room where prescriptions were received and items necessary for each prescription were documented and labels for tagging the finished product were printed. The cytotoxic unit was situated a short distance from the prescription area. It comprised an ante-room where personnel donned or discarded outer garments, including gloves and over-shoes. The outer packaging of the drug preparations were wiped down with a sterile cloth and the labels checked before being passed to the prescription room technician.

Drug reconstitution was done inside a laminar flow cabinet that exhausted outside the building. The technician in this area was also responsible for removing the waste such as contaminated sharps, gloves and any other contaminated material. Special sterile wipes saturated with seventy percent isopropanol were used to wipe down the laminar flow cabinet after each session.

3.3 PESTICIDE SPRAYING

Monitoring surveys for dermal and oral exposure to pesticides were carried out within an organisation providing pesticide spraying services, although one farmer who conducted his own pesticide spraying was monitored during one day of the survey.

The facility consisted of a large open area that housed two buildings. The larger of these consisted of two areas, a storage warehouse where pesticides were stored and an office area where sprayers reported for work. Several metres from the warehouse there was a loading bay with a water supply. Generally, mixing and loading of the spray tanker took place in this open air area; however, it was observed that occasionally, particularly for solid pesticides, loading took place just outside the warehouse entrance. Sprayers also had access to storage warehouses and loading facilities off-site where they could re-load their spray tanks.

Sprayers arrived at the facility where they were given their instructions for the day. They then mixed the pesticide formulation, loaded their spray tankers and drove to the spray site. During most of the surveys, spraying for control of potato blight using mancozeb was being conducted. The sprayers were generally of the self-propelled type and all but one had a closed cab with air-conditioning.

Exposure monitoring was conducted during mixing and loading of the spray tanker and during spraying of the fields. In total seven different sprayers were monitored and for two of these repeat sampling was undertaken. One mechanic working on the boom of pesticide spray tankers was also included in the monitoring survey.

4 RESULTS

4.1 EXPOSURE MEASUREMENTS

Exposure data were collected from the three different occupational sectors. The following sections report the results of the measurements for dermal (hands and peri-oral) and oral exposure, along with data from surface samples (health care and agricultural sector).

4.1.1 Metal Industry

Dermal and oral exposure measurements were collected from 43 different workers in five facilities (three nickel refineries, one powder metallurgy, and one secondary lead smelter). Table 4.1 provides the results of the measurements. Total full-day results are provided, which means that results from the individual measurements during the day have been summed for each individual. This was done taking the conservative assumption that hand and peri-oral sampling would have removed all contamination from these dermal surfaces, whilst during a normal working day this would have accumulated over the entire shift. It is far from clear that this assumption is realistic but it is certain that the actual exposure would not be underestimated using this approach. Due to missing data, cumulative exposure results were not available for all workers for all exposure metrics. Total hand exposure results were available for 35 workers, for peri-oral exposure results were available for 34 workers, whilst for cumulative oral exposure, results were available for 42 workers. No full day cumulative peri-oral results were available for nickel refinery 3 or for the powder metallurgy plant.

There were a relatively small number of measurements taken in the nickel refinery 3 ($N=3$) and the powder metallurgy plant ($N=4$). Consequently, despite the data for the other facilities being log-normally distributed, the results are described here for the non-transformed data. However, Table 4.1 presents descriptives for both transformed and log-transformed data where appropriate. The arithmetic mean for total cumulative hand exposure for nickel ranged from 570 μg in nickel refinery 1 to 11,500 in Nickel refinery 3. The arithmetic mean lead exposure on hands in the lead smelter was 14,000 μg . The peri-oral exposure at the end of the shift for nickel was 11 μg in nickel refinery 1 and 170 μg in nickel refinery 2. In the lead smelter the peri-oral lead exposure was 99 μg . For the cumulative oral exposure, the exposure to nickel ranged from 0.6 μg in nickel refinery 3 to 13 μg in refinery 2. The cumulative oral lead exposure in the lead smelter was 9.2 μg . It is interesting to note that although the highest hand exposure for nickel was observed in refinery 3, the oral exposure in this facility was the lowest of the four nickel producing facilities. Log-transformed exposure data for exposure to nickel and lead by facility are shown in box-plots (Figures 4.1 a, b and c). The length of the box in these and other box plots represents the interquartile range (the distance between the 25th and the 75th percentiles), the + in the box interior represents the mean, the horizontal line in the box interior represents the median and the vertical lines issuing from the box extend to the minimum and maximum values of the variable analysed.

Table 4.1 Description of cumulative exposure across a shift in the nickel refineries, powder metallurgy and lead smelter

Facility	Metal	Cumulative hand exposure ¹					Peri-oral exposure ²					Cumulative oral exposure ¹				
		N	AM (µg)	GM (µg)	GSD	Range (µg)	N	AM (µg)	GM (µg)	GSD	Range (µg)	N	AM (µg)	GM (µg)	GSD	Range (µg)
Refinery 1	Ni	11	570	340	2.9	52 – 2,600	11	11	5	5.4	0.3 - 32	11	4.4	3.7	1.8	1.2-12.0
Refinery 2	Ni	6	2,900	1,400	3.7	280 – 9,000	7	170	84	4.0	12 – 560	7	13.0	11.0	1.8	5.4-23.0
Refinery 3	Ni	3	11,500	-	-	4,600 – 19,000	0	3	0.6	0.6	1.6	0.4- 1.0
Pow. Met. ³	Ni	4	8,600	-	-	800 – 30,000	0	4	1.4	1.0	3.0	0.4- 2.6
Pb Smelter ⁴	Pb	11	14,000	4,800	7.5	40 – 58,000	16	99	42	4.8	3.1 – 340	17	9.2	6.7	2.5	0.5-32.0

¹ The cumulative hand and oral exposure (µg) over a shift, which was calculated for each individual by summing the three measurements that were carried out during the shift

² Peri-oral exposure at the end of the shift.

³ Powder Metallurgy plant

⁴ Lead smelter

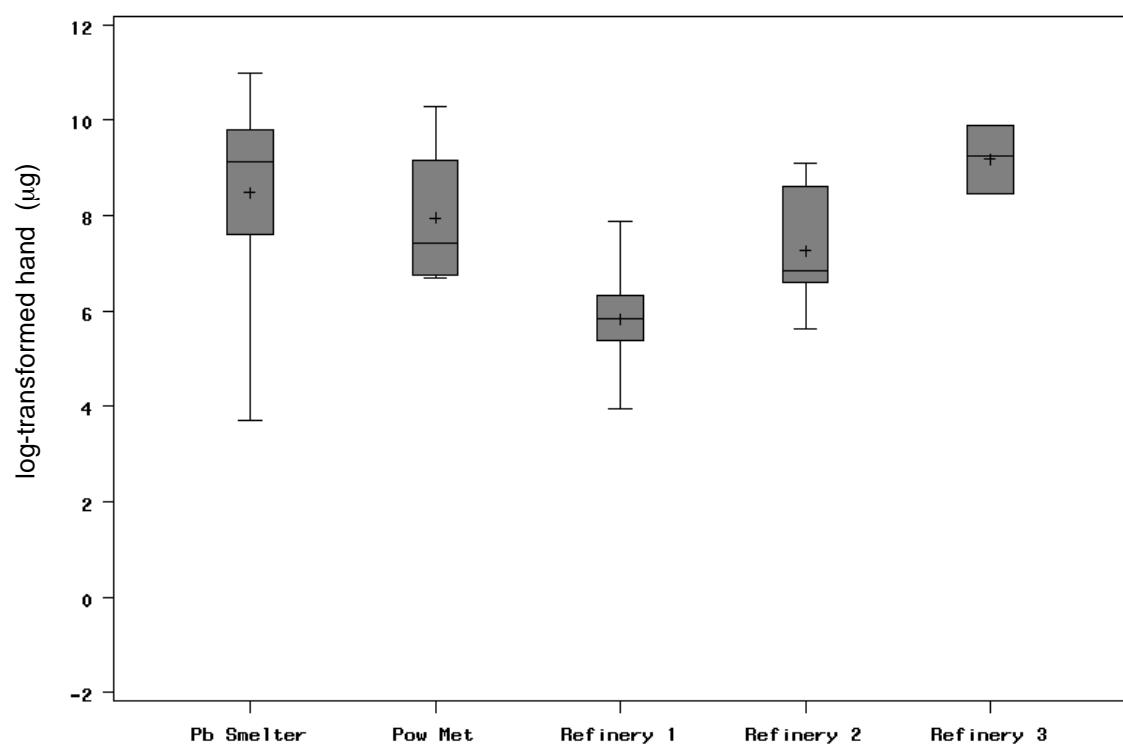


Figure 4.1a Box plot of log-transformed total hand exposure (μg) by facility.

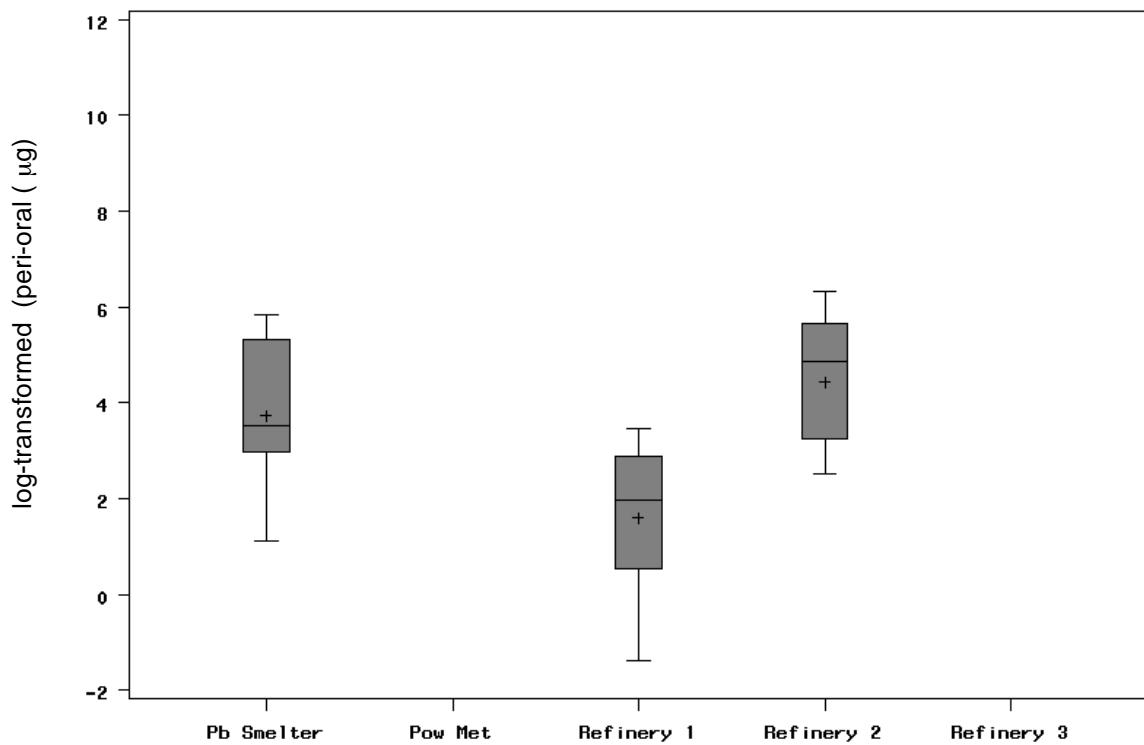


Figure 4.1b Box plot of log-transformed face (peri-oral) exposure (μg) by facility.

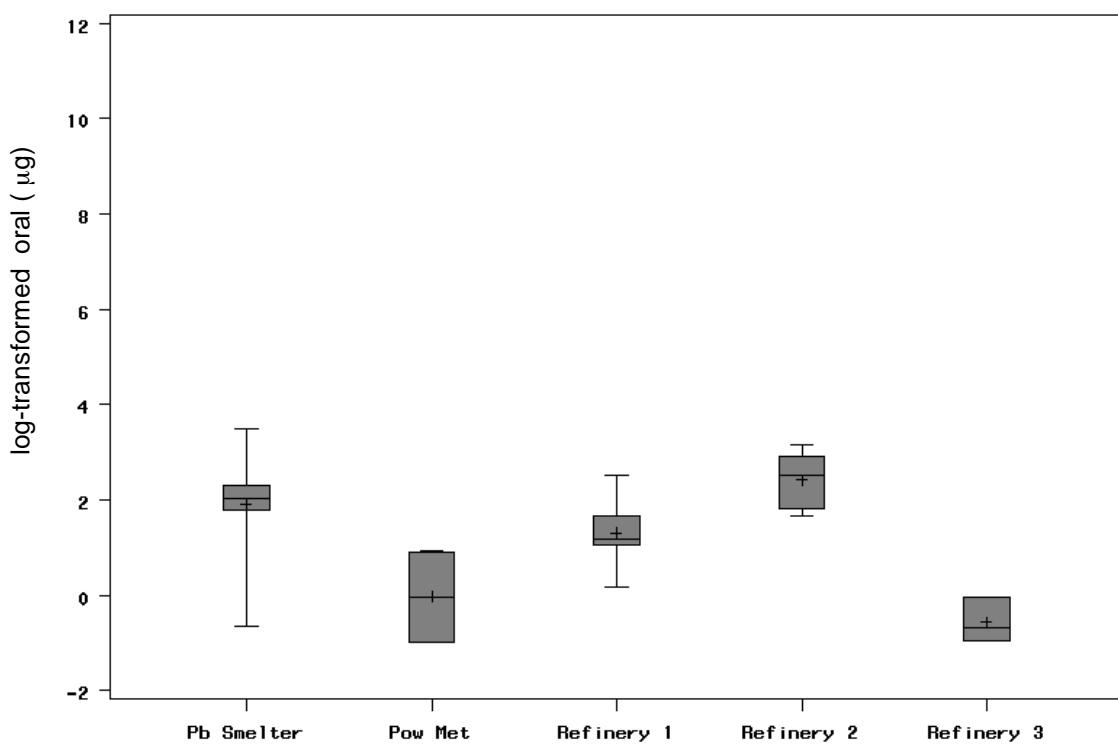


Figure 4.1c Box plot of log-transformed oral exposure (μg) by facility.

Figures 4.2 a, b, and c show the association between the results of the measurements in the various compartments. The correlation between the log-transformed hand and oral exposure is low ($r=0.311$) (Figure 4.2a). The results of a simple linear regression analyses (using log-transformed data) shows that the association between exposure to nickel or lead on the hands and oral exposure in these five metal working facilities can be described as follows:

$$\log(A_{Oral}) = 0.106 - 0.0211 \cdot \log(A_{Hands}) \quad (12)$$

Where,

A_{Oral} = Actual oral exposure

A_{Hands} = Actual hand exposure

The slope is not significantly different from zero ($p>0.05$), suggesting that there is no association between the actual hand and oral exposure levels.

In contrast, there appears to be an association between the levels found on the hand and those found in the peri-oral region (Figure 4.2b). The correlation coefficient between the log-transformed hand and face exposure is 0.666. The association between log-transformed hand and peri-oral exposure can be described as follows:

$$\log(A_{Face}) = -0.711 + 0.811 \cdot \log(A_{Hands}) \quad (13)$$

Where,

A_{Face} = Actual peri-oral exposure

The slope of the association is statistically significant ($p<0.05$) with the intercept (-0.711) being borderline statistically significantly different from zero ($p=0.09$). If the constant factor is omitted from the regression the equation becomes:

$$\log(A_{Face}) = 0.555 \cdot \log(A_{Hands}) \quad (14)$$

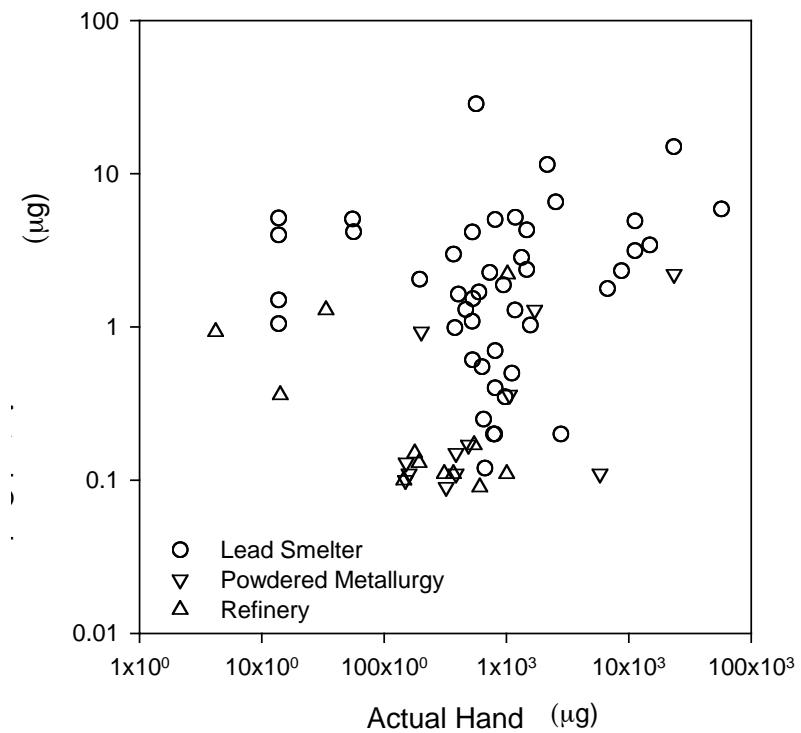
There is also a statistically significant correlation ($r=0.485$) between the peri-oral exposure and the oral exposure (Figure 4.2c). The regression equation is as follows:

$$\log(A_{Oral}) = -0.042 + 0.261 \cdot \log(A_{Face}) \quad (15)$$

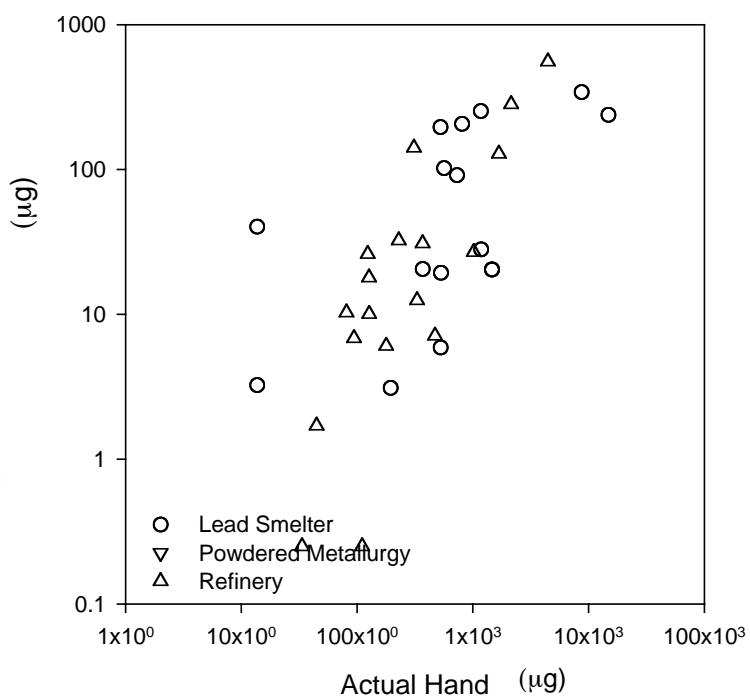
The constant term (-0.042) is not significantly different from zero and if this is omitted then the regression equation becomes as follows:

$$\log(A_{Oral}) = 0.238 \cdot \log(A_{Face}) \quad (16)$$

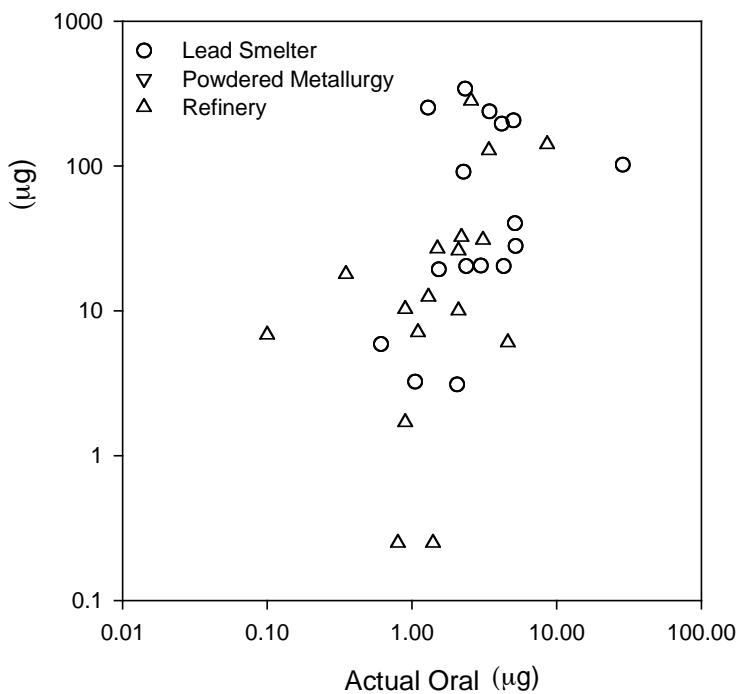
There appears to be a discrepancy in these regression results, as according to equation (12) there is no association between oral and hand exposure. However upon combining equations (14) and (16) there does appear to an association between hand and oral exposure. No peri-oral measurements were available for one of the nickel refineries or the powder metallurgy plant. In addition, peri-oral exposure measurements in the remaining facilities were only carried out at the end of the day. Therefore, the results for the hand to face and face to oral region transfers are not directly comparable with the direct transfer to the mouth. However, it should be noted that the end-of-shift peri-oral measurement is likely to be approximately equal to a cumulative exposure measurement, especially since, unlike the hands, there are fewer opportunities for removal processes that may influence the exposure levels of peri-oral loading during the day.



Figures 4.2a Comparison between measured hand and oral exposure



Figures 4.2b Comparison between measured hand and peri-oral exposure



Figures 4.2c Comparison between measured peri-oral and oral exposure

4.1.2 Cytotoxic Drugs

Dermal and oral measurements for cytotoxic drugs were collected from 18 workers from a few wards and the pharmacy within a hospital. In addition, 23 surface wipes and 8 gloves were also collected. Results from the personal dermal (hand and peri-oral) and oral measurements are provided in Table 4.2. Except for the platinum based cytotoxic drugs (Pt), levels on the hand, face and oral region were generally below the limit of detection. For the platinum based drugs, the mean hand levels were 0.16 ng for the Ward and 0.54 ng for the Pharmacy. For the peri-oral exposure this was 0.55 ng and 0.23 ng, respectively for the Ward and Pharmacy, whilst for the oral exposure this 0.49 and 0.16 ng, respectively.

Table 4.3 gives the results of the surfaces measurements in the wards and pharmacy. The results are reported as total amount and surface concentration. For some surfaces sampled, the surface area was unknown, and hence surface concentration could not be calculated. For the platinum based drugs the levels of surface concentrations were generally higher in the ward (AM 0.9 ng/cm²) than in the pharmacy (AM 0.1 ng/cm²). For the other cytotoxic drugs (cyclophosphamide – Cp and ifosfamide – IF) the levels were generally below the limit of detection. However, when they were detected, the levels were generally very high, resulting in high overall mean levels.

Table 4.4 shows some results of measurements made of cytotoxic drug contamination of gloves used by nurses and pharmacy workers. Much higher levels were found on the gloves compared to what was found on the hands, and this could potentially be a source of ingestion exposure due to hand-to-mouth contacts while wearing gloves.

Table 4.2 Dermal and oral exposure to cytotoxic drugs in a hospital ward and pharmacy.

Analyte	Area	Hand exposure					Peri-oral exposure					Oral exposure				
		N	<LoD	Mean (ng)	Median (ng)	Range (ng)	N	<LoD	Mean (ng)	Median (ng)	Range (ng)	N	<LoD	Mean (ng)	Median (ng)	Range (ng)
Pt	Ward	21	11	0.16	0.05	<LoD - 2.1	21	4	0.55	0.31	<LoD - 1.60	16	1	0.49	0.02	0.00 - 2.1
	Pharmacy	16	9	0.54	0.05	<LoD - 4.3	15	2	0.23	0.17	<LoD - 1.00	14	0	0.16	0.01	0.00 - 1.1
Cp	Ward	8	8	-	-	-	8	8	12.0	12.5	-	8	8	0.10	0.10	-
	Pharmacy	14	14	-	-	-	15	15	12.0	12.5	-	14	14	0.10	0.10	-
IF	Ward	2	2	-	-	-	2	2	12.0	12.5	-	2	2	0.10	0.10	-
	Pharmacy	6	5	30.0	12.0	<LoD -120.0	6	5	20.0	12.5	<LoD - 57.0	5	5	0.10	0.10	-

Table 4.3 Results from surface sampling for cytotoxic drugs in the pharmacy and ward

Analyte		Pharmacy					Ward				
		N	<LoD	Mean (ng)	Median (ng)	Range	N	<LOD	Mean (ng)	Median (ng)	Range (ng)
Pt	Surface contamination (ng)	4	0	346.3	86.4	1.1 - 1,211.3	4	0	123.20	94.1	0.3 – 304.4
	Surface concentration (ng/cm ²)	3*	0	0.1	0.0	0.0 - 0.2	4	0	0.9	0.1	0.0 – 1.8
CP	Surface contamination (ng)	7	6	1,896.4	12.5	<LoD – 13,200.0	8	6	95.6	12.5	<LoD – 645.0
	Surface concentration (ng/cm ²)	5**	4	1.0	0.9	<LoD – 2.0	6**	4	1.4	0.3	0.0 – 6.5
IF	Surface contamination (ng)	7	6	10,439.3	12.5	<LoD – 73,000.0	-	-	-	-	-
	Surface concentration (ng/cm ²)	5***	4	2.9	1.3	<LoD – 11.0	-	-	-	-	-

* wipe used to wipe a few intra-venous bags before they were passed for transfer to the wards - no surface area information

** surfaces of two door handles were wiped - no surface area information

*** surfaces of two pens were wiped - no surface area information

Table 4.4 Results from measurements of cytotoxic drugs on gloves used in the ward and the pharmacy

Analyte	Area	N	<LoD	Mean (ng)	Median (ng)	Range (ng)
Pt	Ward	5	0	22	5.5	3.0 – 71
Pt	Pharmacy	8	0	41	24.0	0.2 – 170
Cp	Pharmacy	4	1	3,200	22,000	12.0 – 8,600
IF	Pharmacy	2	0	7,700	7,700	67.0-15,000

4.1.3 Pesticide Spraying

Within the agricultural sector eight different workers were monitored – seven sprayers and one mechanic. Results for four different pesticides are provided in Table 4.5 for dermal and oral measurements and Table 4.6 for surface measurements. Results from the dermal exposure measurements suggest that the levels on the hand of the sprayer are generally higher than on the face. Highest levels were observed for glyphosate with a mean hand exposure of 650 µg and a mean peri-oral Exposure of 39 µg. Results from the salivary measurements suggest that the oral exposure can be relatively high, although some of this is due to the high limit of detection for the salivary analyses.

Dermal exposure results for the mechanic were only available for ethylene thiourea and ethylene urea (markers for exposure to Mancozeb). The results of these measurements suggest that the dermal exposure levels on the hands of the mechanics was higher than that of the sprayers, although there was little or no difference in the peri-oral exposure.

Results of the surface measurements (Table 4.6) were comparable with the results of the dermal hand exposure measurements.

Table 4.5 Description of average actual exposure data in the agricultural sector

Job Title	Pesticide	Analyte	Hand					Peri- oral					Oral				
			N	<LoD	Mean (µg)	Median (µg)	Range (µg)	N	<LoD	Mean (µg)	Median (µg)	Range (µg)	N	<LoD	Mean (ng)	Median (ng)	Range (ng)
Sprayer	Chlorpyrifos	Chlorpyrifos	2	0	23.1	23.1	0.1- 46.0	2	1	6.0	6.0	<LoD - 12.0	2	1	1.4	1.4	<LoD - 2.0
	Chlorothalonil	Chlorothalonil	4	1	0.6	0.2	<LoD - 4.0	4	3	0.1	0.2	<LoD - 0.2	4	4	-	-	-
	Mancozeb	ETU	10	5	1.0	0.1	<LoD - 13.0	11	9	0.1	0.1	<LoD - 0.4	10	5	311.8	15.2	<LoD - 1,000.0
		EU	10	10	-	-	-	11	8	0.3	0.2	<LoD - 0.7	0	-	-	-	-
	Glyphosate	Glyphosate	5	0	646.8	452.0	83.0 – 2,081	5	0	39.5	25.0	2.6 - 91.0	5	2	140.0	56.0	14.0- 440.0
		AMPA	5	0	1.1	1.0	0.4-1.7	5	2	0.2	0.2	<LoD - 0.3	5	5	-	-	-
Mechanic	Mancozeb	ETU	3	1	5.3	2.8	<LoD - 13.0	3	1	0.3	0.4	<LoD - 0.4	3	3	-	8.0	-
		EU	3	2	0.6	0.2	<LoD -1.4	3	3	0.2	0.2	-	0				

Table 4.6 Results of surface measurements in the agricultural sector

Analyte	N	<LoD	Mean (µg)	Median (µg)	Range (µg)
Chlorpyrifos	5	0	12.0	1.7	0.4 - 55.0
Chlorothalonil	13	3	3.3	0.3	0.1 – 32.0
Ethylene thiourea	44	24	1.0	0.1	0.1 - 14.0
Ethylene urea	41	28	0.5	0.2	0.2 - 3.3
Glyphosate	23	0	480.0	190.0	4.1- 2,900.0
AMPA	23	2	4.3	1.1	0.1- 45.0

4.2 PREDICTED EXPOSURE VALUES

4.2.1 Descriptive Results

Three occupational hygienist (A, B, C) were asked to estimate the values of factors such as surface load, number of hand to face and hand to mouth contacts, percentage of the hand in contact with the face or mouth and skin moisture. These assessments were carried out independently and blind to the results of the exposure measurements described in the previous sections. Based on these estimates and the model that was developed in the second phase of this study (Christopher *et al.*, 2006b), hand, peri-oral and oral exposure levels were predicted for the nickel refineries, the powder metallurgy plant and the lead smelter.

These assessments were done for each task that was carried out during the day for which measurement data were available. In total, the assessors were asked to estimate these factors for 178 different tasks carried out by 43 workers with 18 different job titles (Table 4.7).

Table 4.7 Number of workers and tasks by job title used in validation study

Facility/Job title	N workers	N tasks
<i>Nickel Refinery 1</i>		
Leaching Operator (LO)	3	16
Cathode Lifter (CL)	3	15
Cathode Stripper (CS)	3	12
Cutter (CUT)	2	6
Briquette Packer (BP)	2	6
Chemical Packer (CP)	2	9
<i>Nickel Refinery 2</i>		
Powder Packer (P210, P255)	4	14
Decomposer/Packer (DO)	1	9
<i>Nickel Refinery 3</i>		
Nickel chloride packer (NCP)	3	9
Raw Material Handler (RMH)	1	3
<i>Powder Metallurgy</i>		
Nickel Powder Operator (NPO)	1	3
Setter (SET)	2	8
Grinding machine operator (GO)	1	3
<i>Lead Smelter</i>		
Raw material operator (RMO)	4	17
Furnace operator (FO)	4	12
Refinery operator (RO)	2	15
Maintenance worker MW)	3	11
QC technician (QCT)	3	7
Security guard (SG)	1	3

Table 4.8 provides the summary of predicted exposures for total hand (assuming no transfer to face or mouth), peri-oral and oral exposure. Figure 4.3 shows box plots of the log-transformed total hand exposure levels by job for assessor A, B and C, respectively. Figures 4.4 and 4.5 show box plots for peri-oral (face) and oral exposure, respectively

Table 4.8 Predicted Total hand, Peri-oral and Oral exposure for Nickel and Lead by Facility and Assessor

Assessor	Facility	Hand			Peri-oral			Oral					
		N	Mean (µg)	Median (µg)	Range (µg)	n	Mean (µg)	Median (µg)	Range (µg)	N	Mean (µg)	Median (µg)	Range (µg)
A	Refinery 1	63	210	13	1 – 1,400	64	22	0.4	0.0 - 160	64	15	0.2	0.0 - 100
	Refinery 2	23	890	780	71 – 2,600	23	44	37	0.2 - 150	23	27	22	0.1 - 94
	Refinery 3	12	330	180	150 – 1,100	12	30	20	7.3 - 100	12	20	13	4.8 - 65
	Powder Metallurgy	14	950	810	120 – 2,300	14	80	70	2.7 - 250	14	52	46	1.8 - 160
	Lead Smelter	65	400	320	0.5 – 1,100	65	31	15	0.1 - 130	65	20	9.6	0.0 - 87
B	Refinery 1	50	260	14	0.3 – 1,500	64	34	0.9	0.0 - 320	64	34	0.7	0.0 - 330
	Refinery 2	23	730	690	33 – 1,900	23	82	46	0.5 - 430	23	69	29	0.3 - 430
	Refinery 3	12	480	290	180 – 1,900	12	110	66	24.0 - 450	12	110	66	25.0 - 460
	Powder Metallurgy	14	850	690	82 – 2,600	14	170	140	3.3 - 600	14	110	112	2.0 - 370
	Lead Smelter	50	480	440	0.5 – 1,200	64	66	27	0.0 - 290	64	63	27	0.0 - 300
C	Refinery 1	64	210	11	0.0 – 1,400	64	60	2.6	0.0 - 420	64	46	2	0.0 - 320
	Refinery 2	23	640	600	71 – 1,700	23	160	130	1.7 - 490	23	130	110	1.7 - 380
	Refinery 3	12	440	270	170 – 1,700	12	130	79	24.0 - 510	12	97	61	17.0 - 390
	Powder Metallurgy	14	980	920	110 – 2,300	14	220	140	12.0 - 680	14	240	210	9.8 - 530
	Lead Smelter	59	430	350	0.5 – 1,100	62	93	49	0.0 - 330	62	73	41	0.0 - 260

Note: Results for refinery 1, 2 and 3 and for powder metallurgy are for nickel; results for lead smelter are for lead

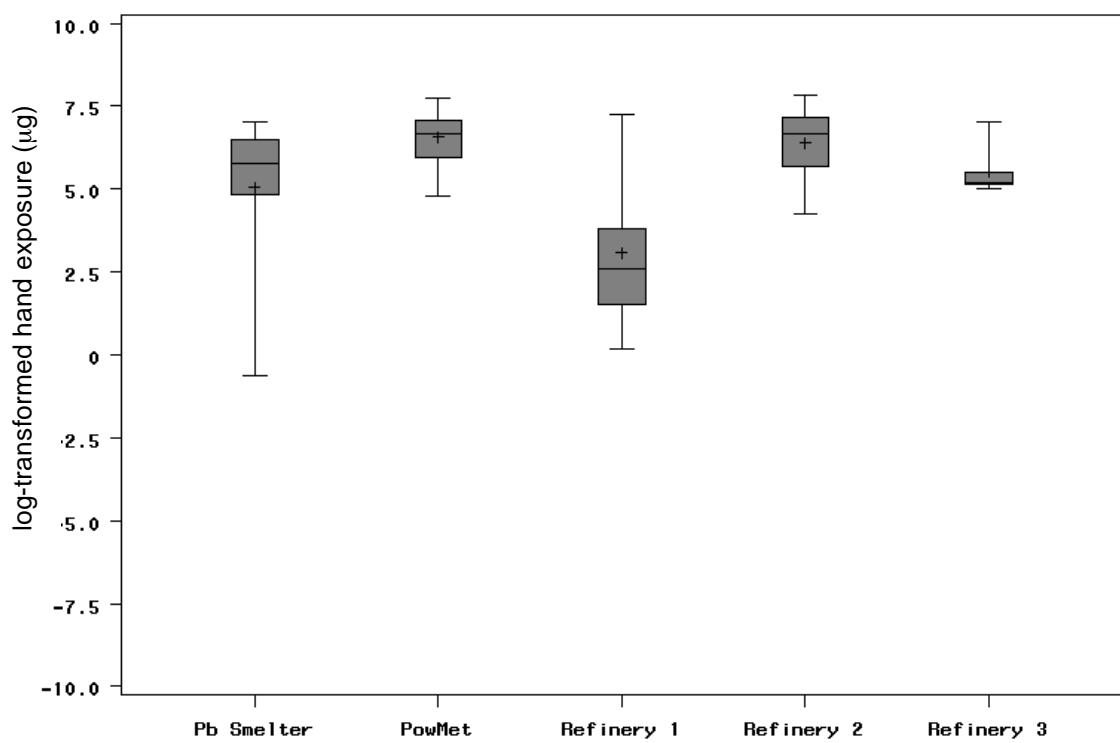


Figure 4.3a Predicted total hand Exposure (assuming no transfer to face or mouth) for assessor A

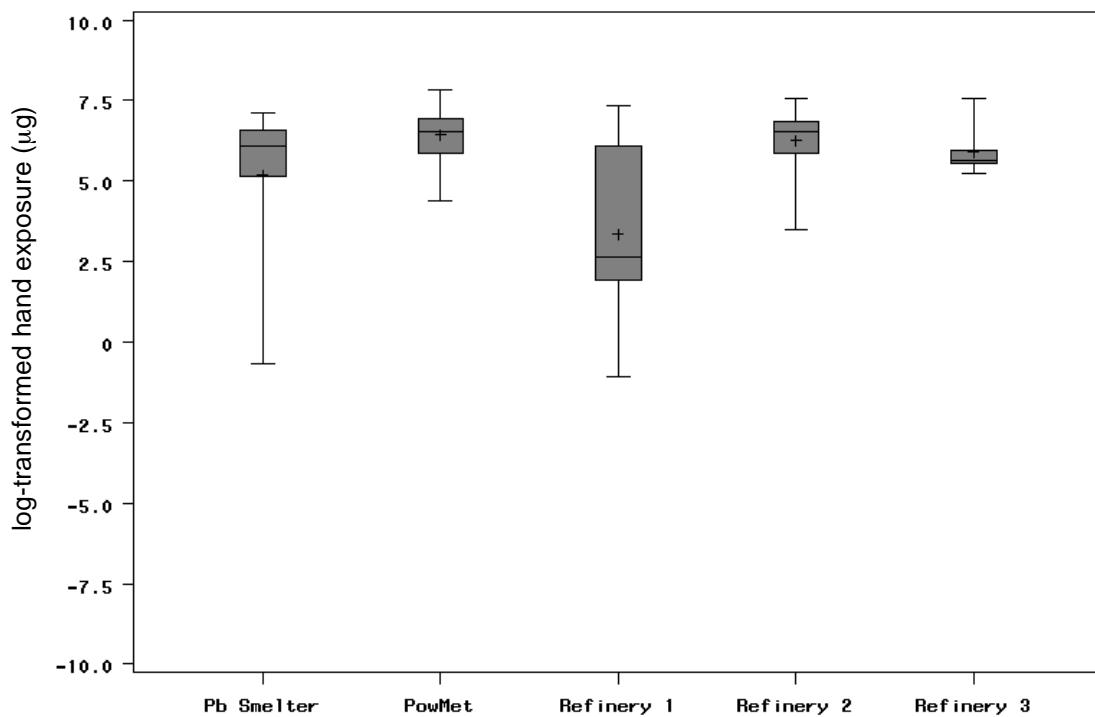


Figure 4.3b Predicted total hand Exposure (assuming no transfer to face or mouth) for assessor B

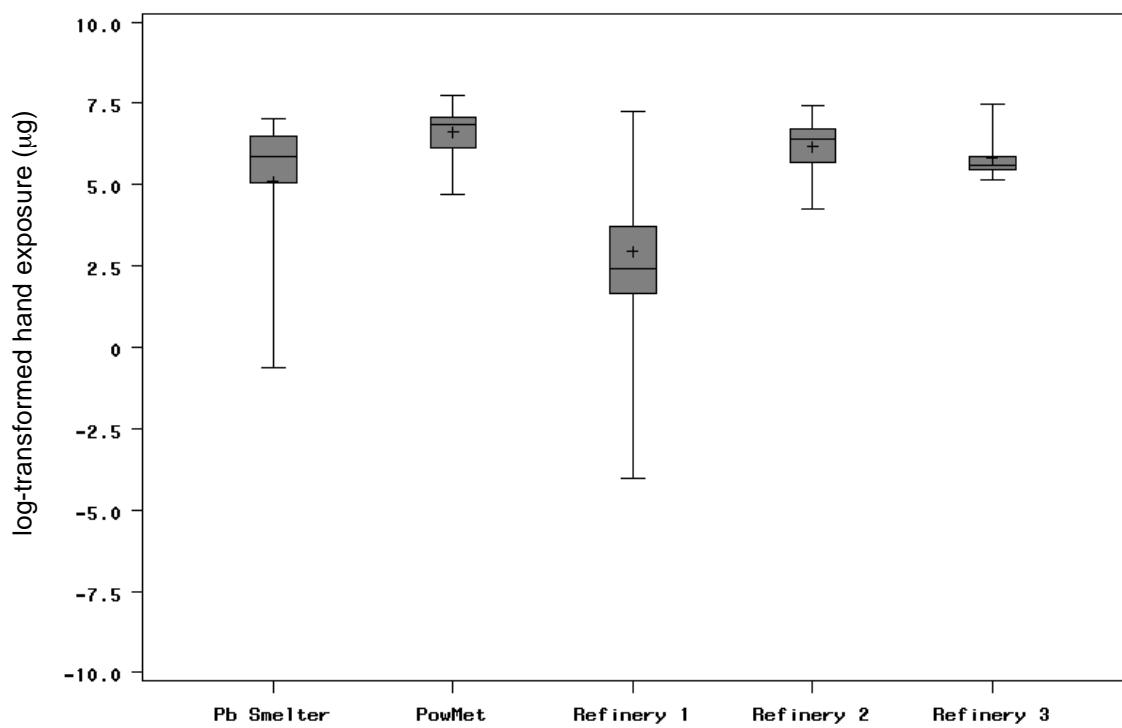


Figure 4.3c Predicted total hand Exposure (assuming no transfer to face or mouth) for assessor C

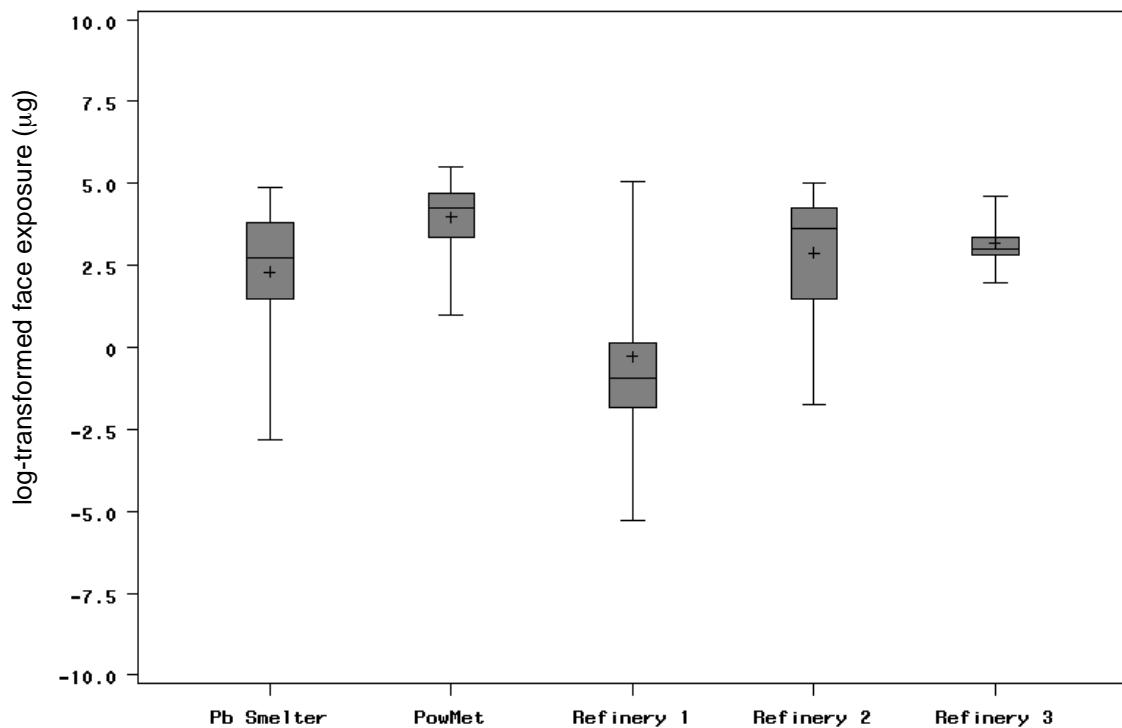


Figure 4.4a Predicted peri-oral exposure for assessor A

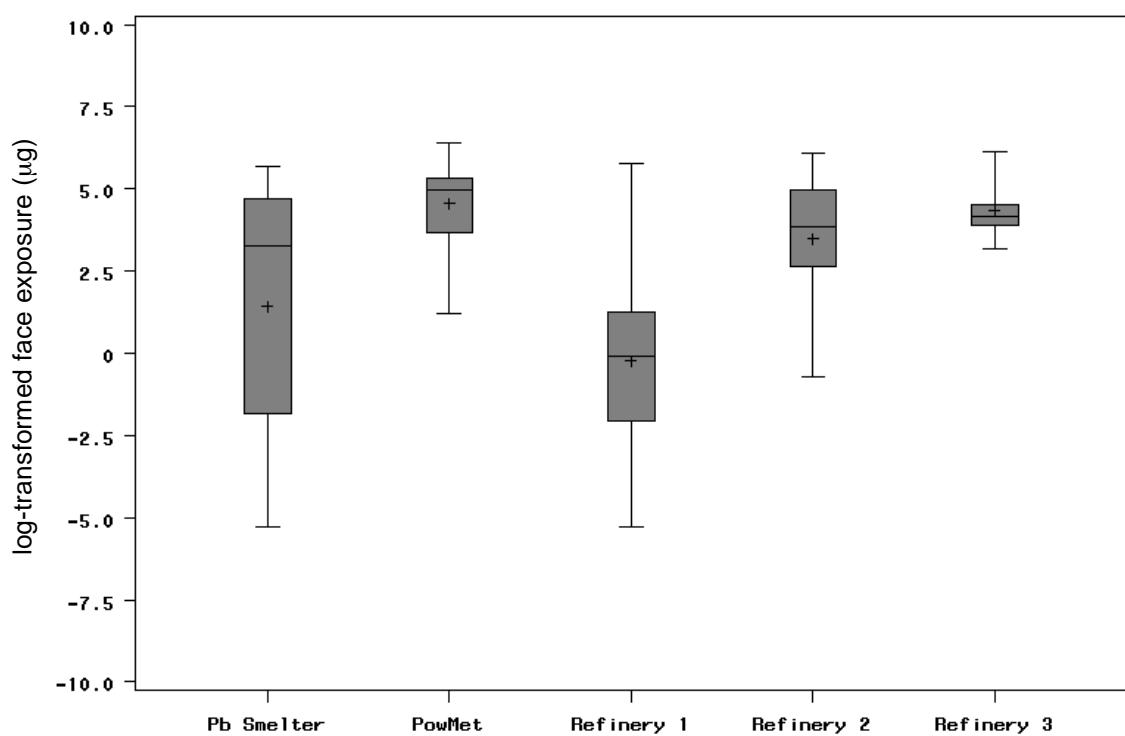


Figure 4.4b Predicted peri-oral exposure for assessor B

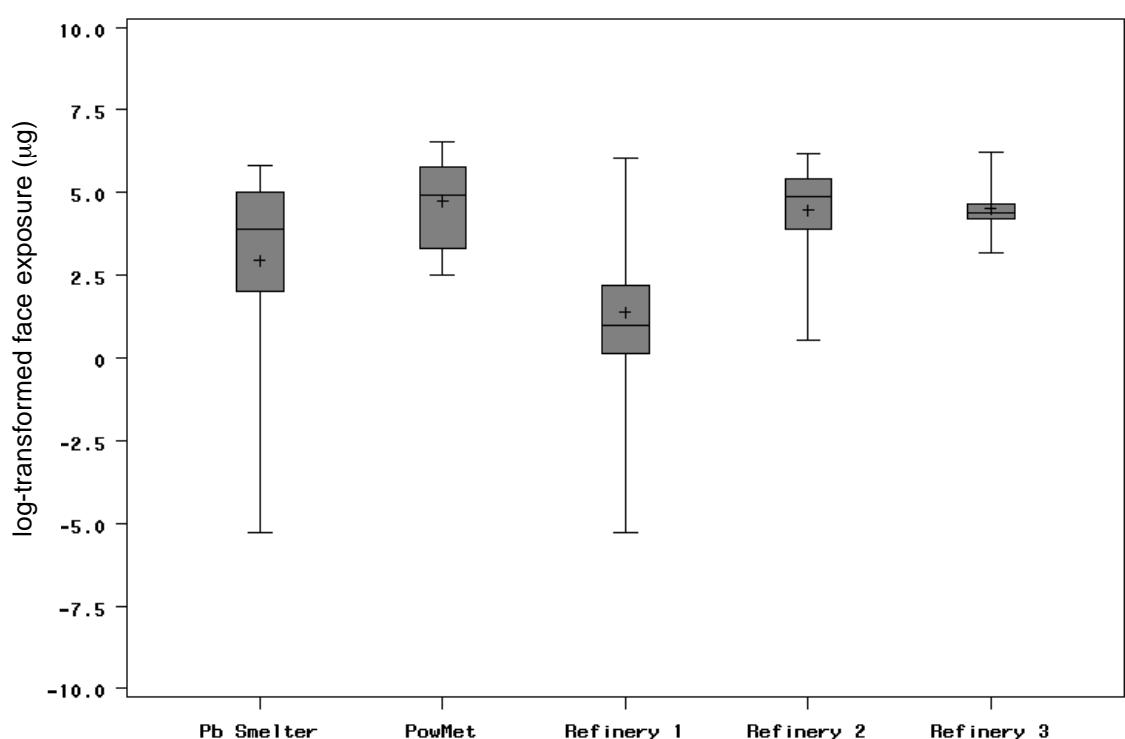


Figure 4.4c Predicted peri-oral exposure for assessor C

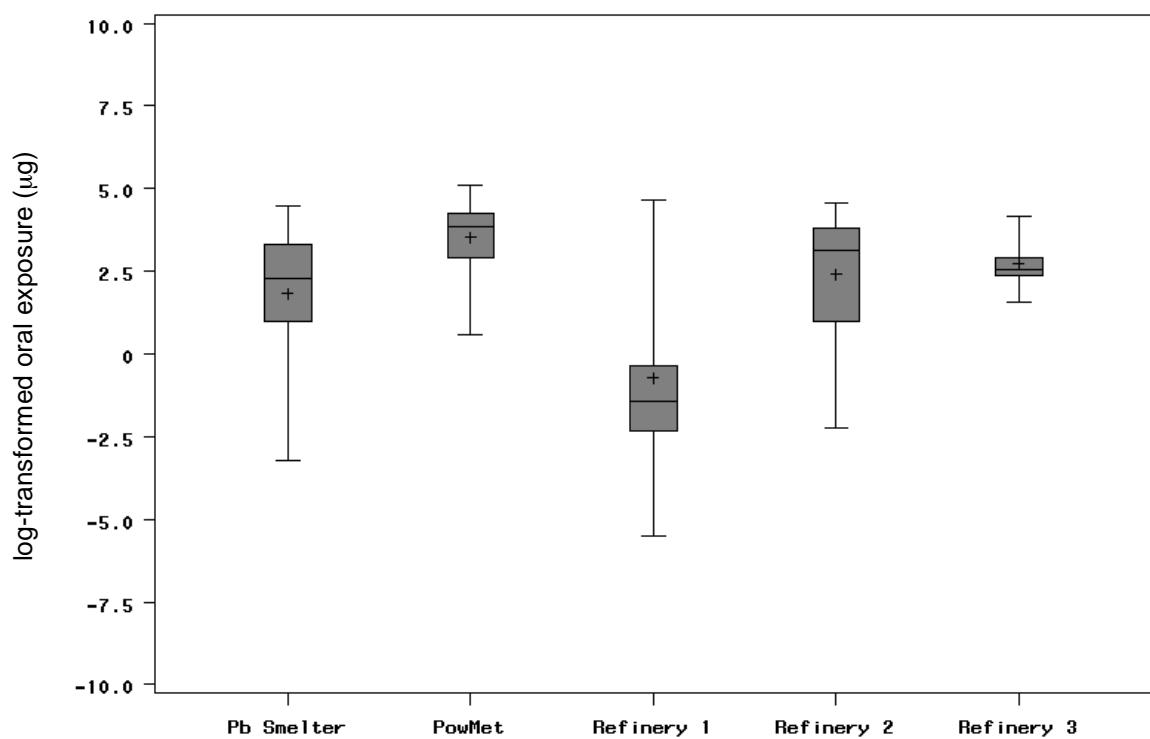


Figure 4.5a Predicted oral exposure for assessor A

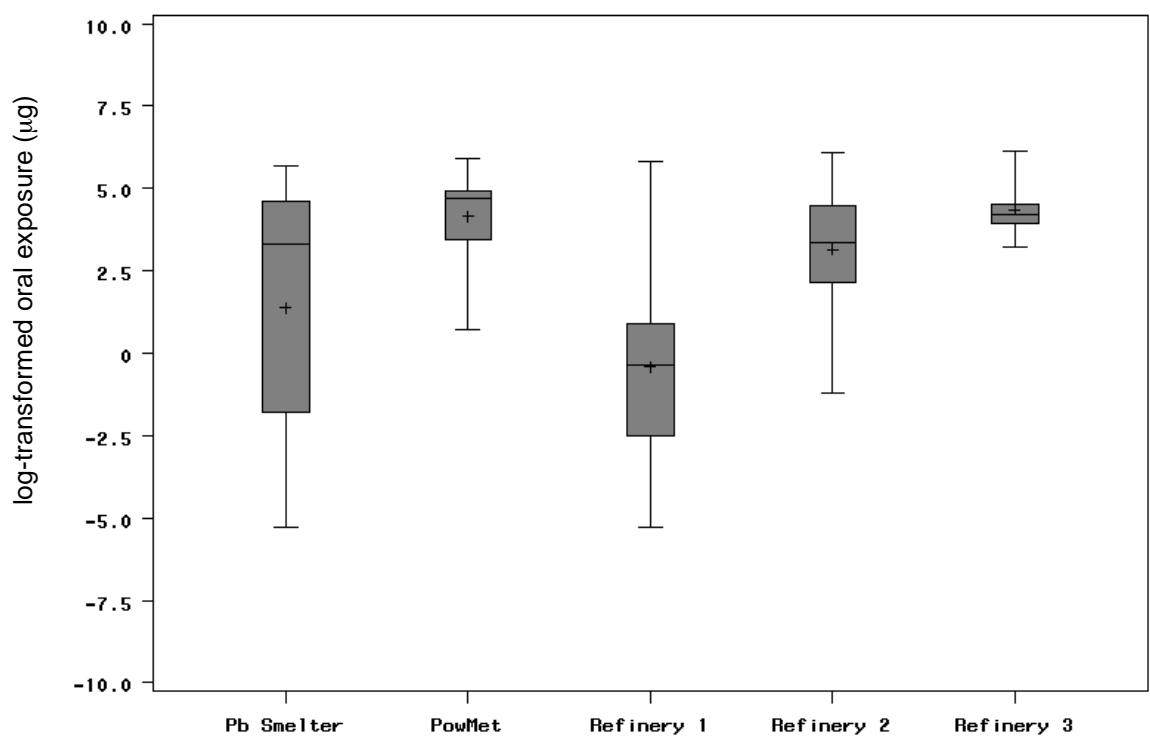


Figure 4.5b Predicted oral exposure for assessor B

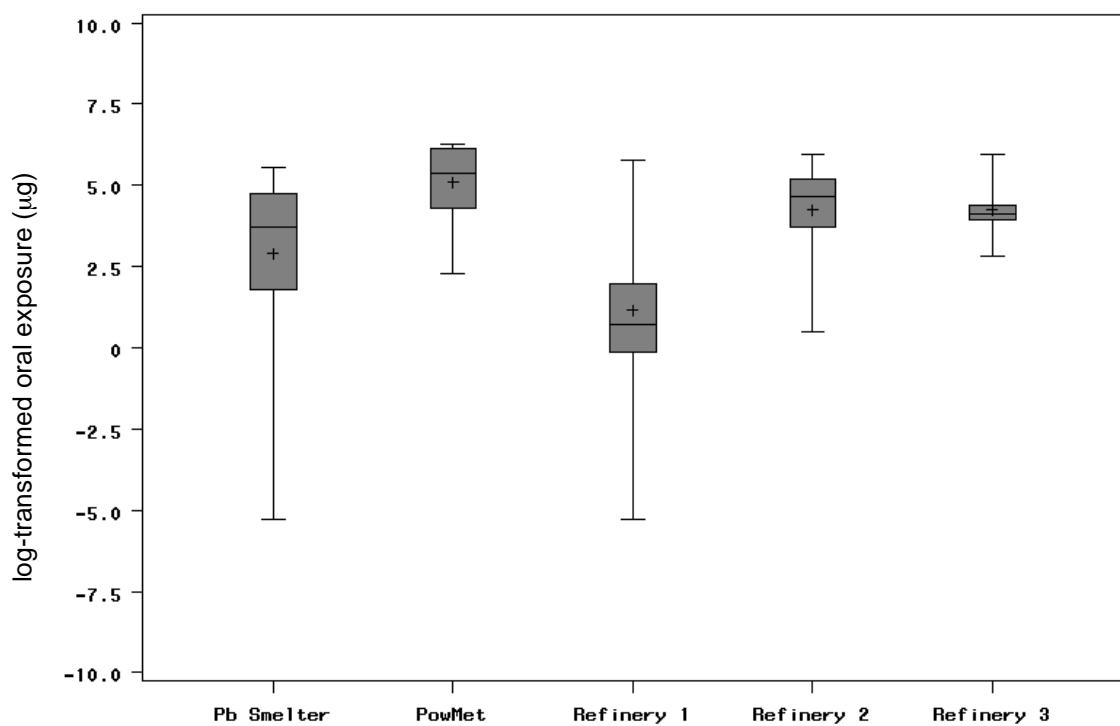


Figure 4.5c Predicted oral exposure for assessor C

4.2.2 Within assessor comparisons

The four estimated variables for each assessor were not independent. In particular there was a very strong relationship between peri-oral and oral estimated exposure for each assessor. Figures 4.6a to 4.6c show the association between face and oral exposure for each of the assessors. The strong linear association between these variables means that any inter-assessor comparison will be almost identical for each of these variables. Total hand exposure was also strongly associated with face and oral exposure (Figures 4.7a to 4.7c).

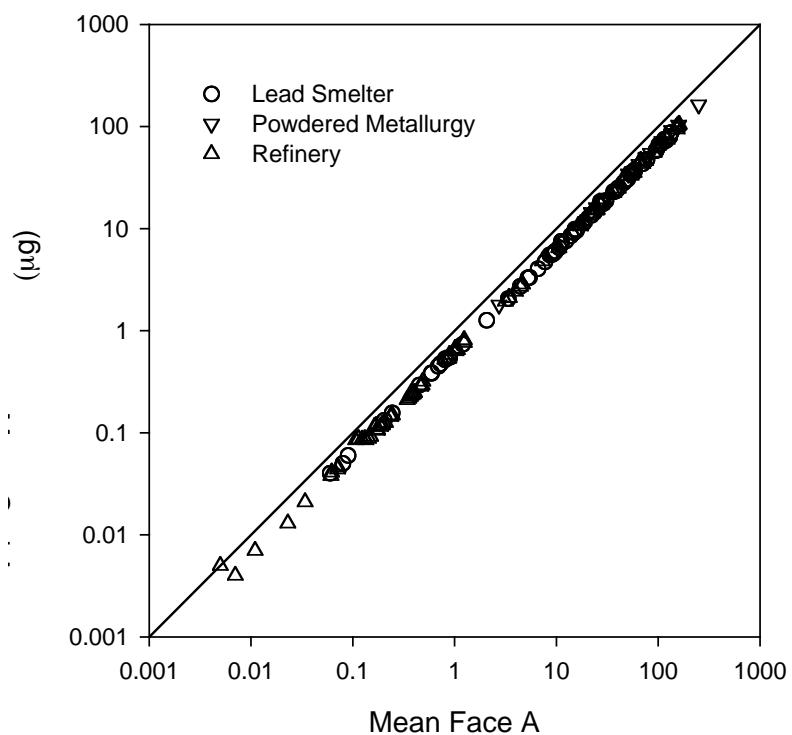


Figure 4.6a Comparison of peri-oral (face) and oral exposure for assessor A.

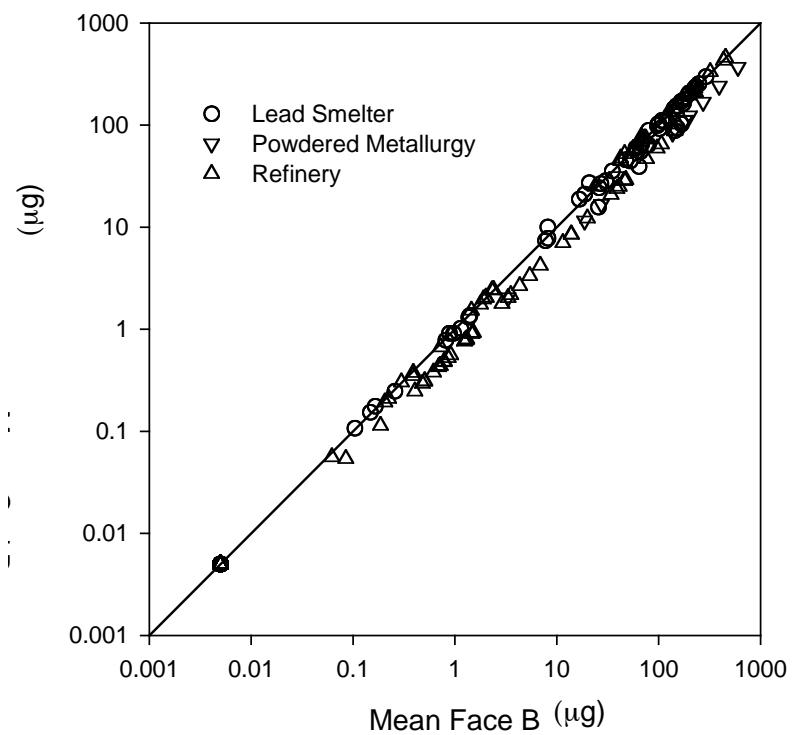


Figure 4.6b Comparison of peri-oral (face) and oral exposure for assessor B

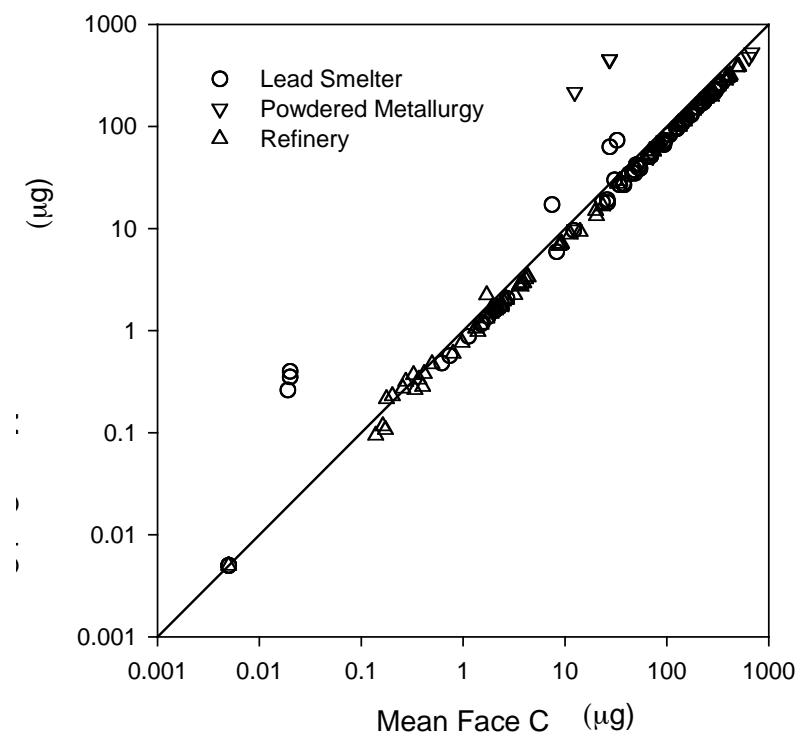


Figure 4.6c Comparison of face (peri-oral) and oral exposure for assessor C

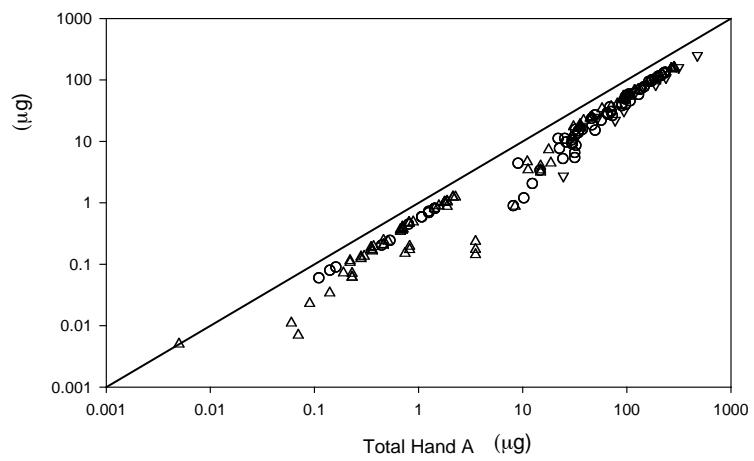


Figure 4.7a Comparison of hand and peri-oral exposure for assessor A.

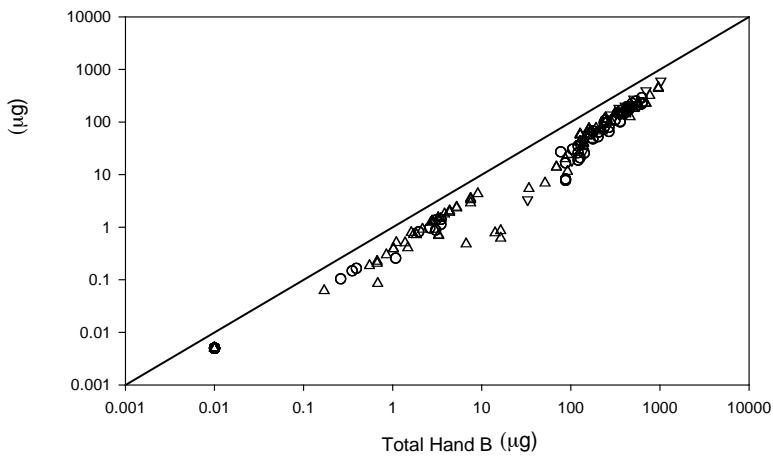


Figure 4.7b Comparison of hand and peri-oral exposure for assessor B.

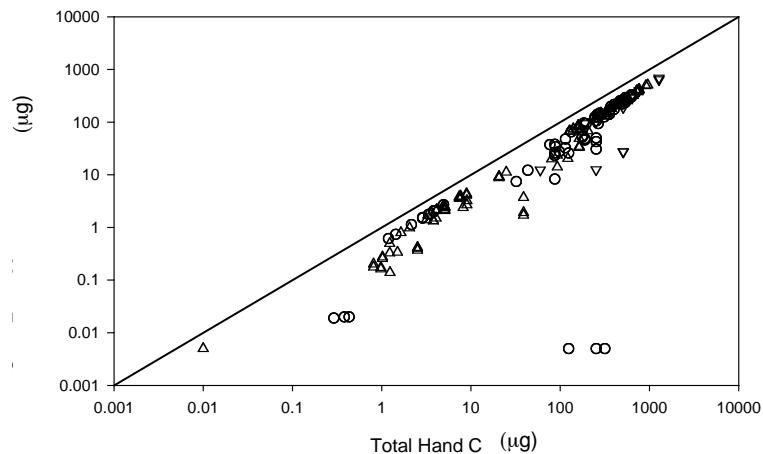


Figure 4.7c Comparison of hand and peri-oral exposure for assessor C.

4.2.3 Comparison between assessors

Comparison between assessors was carried out for hand (assuming no transfer from the hands), peri-oral and oral exposure. The intra class correlation coefficient for hand exposure was 0.99, for peri-oral exposure 0.74 and for oral exposure 0.74. Results for all three variables were similar. In each case assessor B estimated zero values for a group of tasks from refineries (leaching operator and cathode lifter) and lead smelters (raw material operator and maintenance worker) for which estimated exposures from assessors A and C covered a wide range of levels. This was due to assessor B estimating that there was no hand to face contact for these workers.

Other than these tasks, there was generally good agreement among all three assessors in estimating hand and peri-oral exposures. Assessor C tended to estimate the highest exposure levels, followed by assessor B and then assessor A (Figures 4.8 and 4.9). Table 4.9 shows the average ratios of the estimated exposures between the different pairs of assessors. Analysis of variance showed that these varied between workplaces. Consequently, pairwise comparisons are presented for each individual workplace as well as an overall value for all workplaces. For most of the estimated exposures the differences between assessors were more marked at refineries 2 and 3 than for the other workplaces.

Table 4.9. Pair-wise comparison for assessors of predicted exposure levels in the various exposure compartments

	Ratio A:B			Ratio A:C			Ratio B:C		
	Hand	Face	Oral	Hand	Face	Oral	Hand	Face	Oral
Overall	1.01	0.72	0.64	1.00	0.56	0.48	1.00	0.81	0.78
Lead Smelter	0.97	0.73	0.61	0.98	0.65	0.55	1.01	0.93	0.91
Powder Metallurgy	1.06	0.77	0.76	0.97	0.71	0.51	0.92	0.93	0.66
Refinery 1	1.04	0.70	0.64	1.01	0.48	0.44	0.97	0.73	0.73
Refinery 2	1.07	0.76	0.72	1.11	0.50	0.45	1.04	0.65	0.62
Refinery 3	0.85	0.61	0.50	0.88	0.55	0.52	1.04	0.92	1.04

Note: zero values for hand exposure were excluded

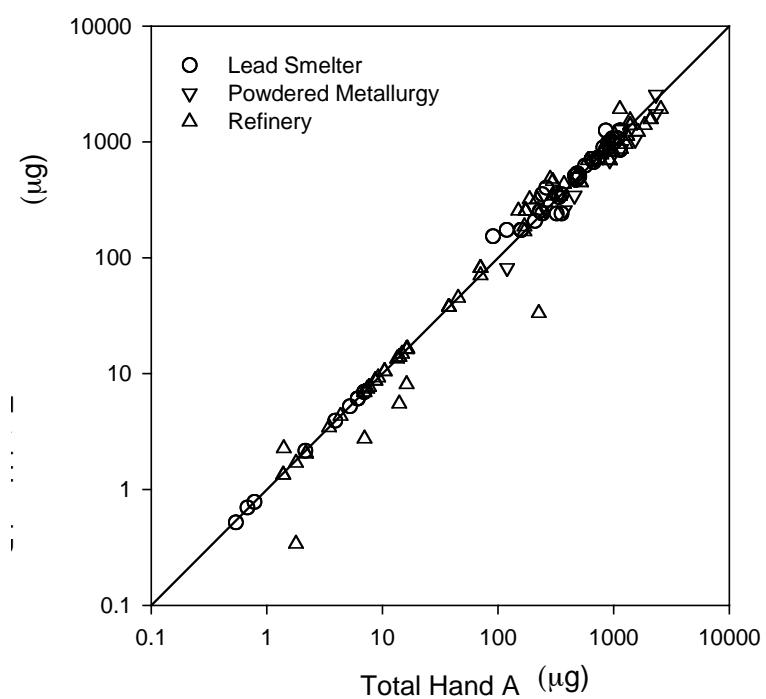


Figure 4.8a Comparison of total hand exposure between assessors A and B (ignoring transfer of contaminant to oral or peri-oral region).

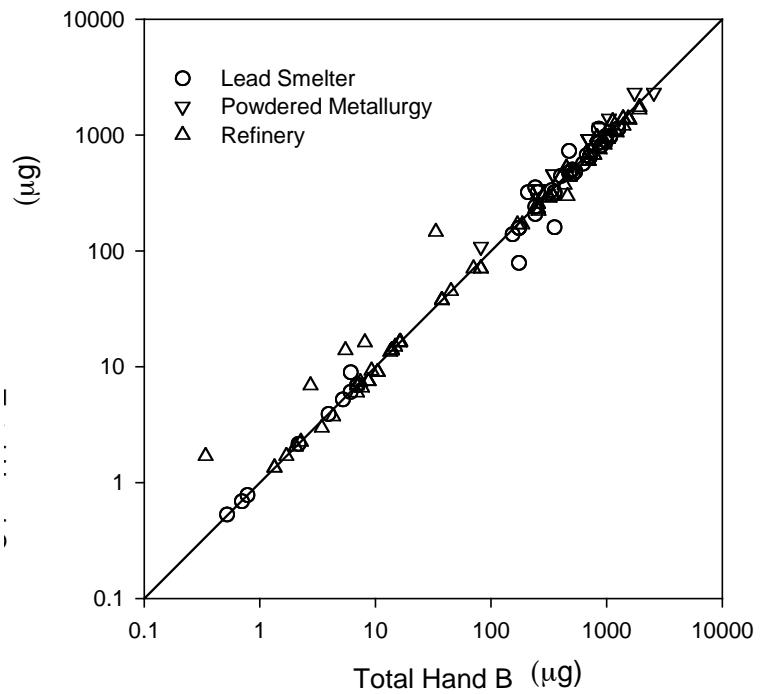


Figure 4.8b Comparison of total hand exposure between assessors B and C (ignoring transfer of contaminant to oral or peri-oral region).

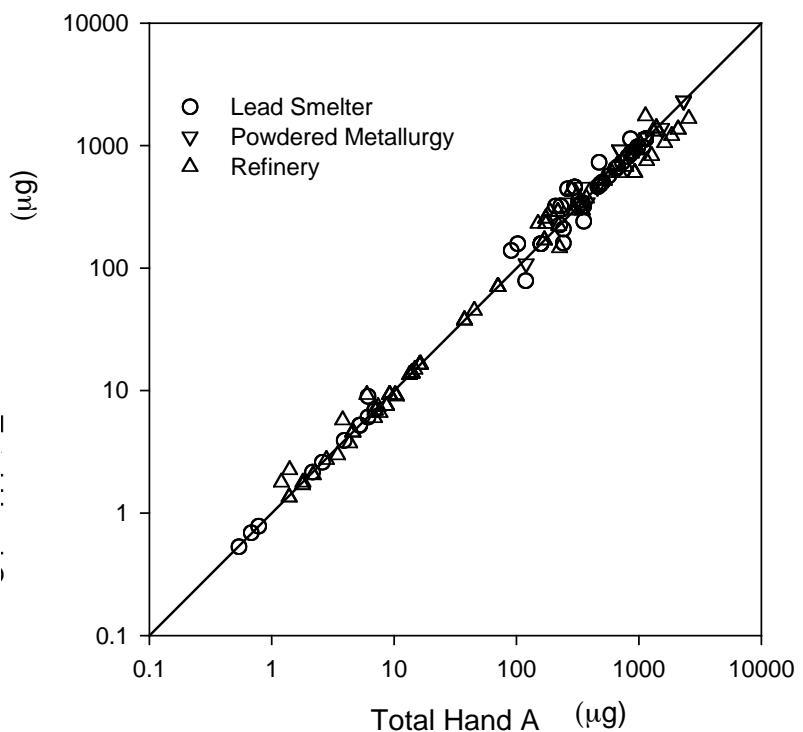


Figure 4.8c Comparison of total hand exposure between assessors A and C (ignoring transfer of contaminant to oral or peri-oral region).

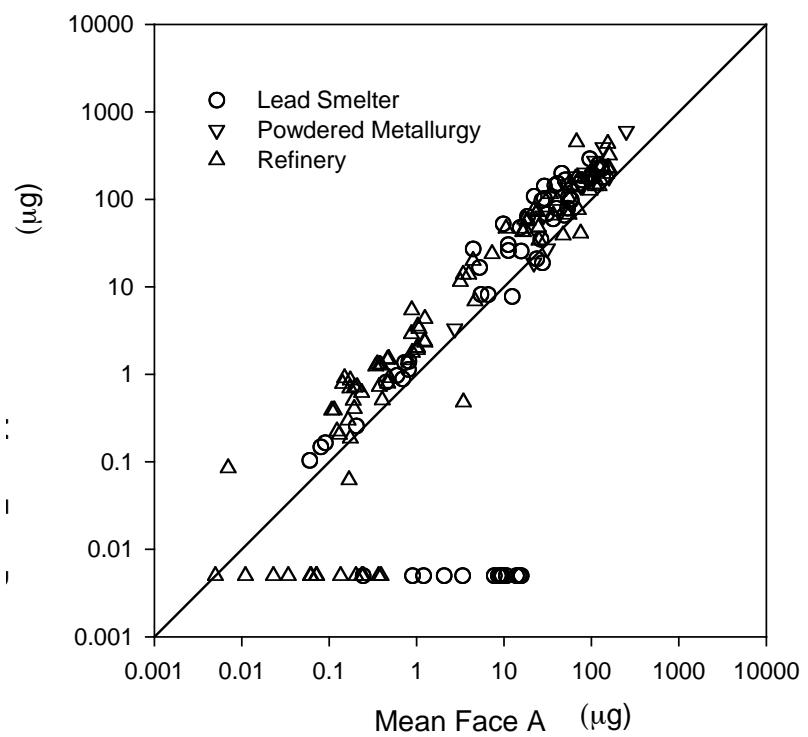


Figure 4.9a Comparison of peri-oral exposure between assessor A and B.

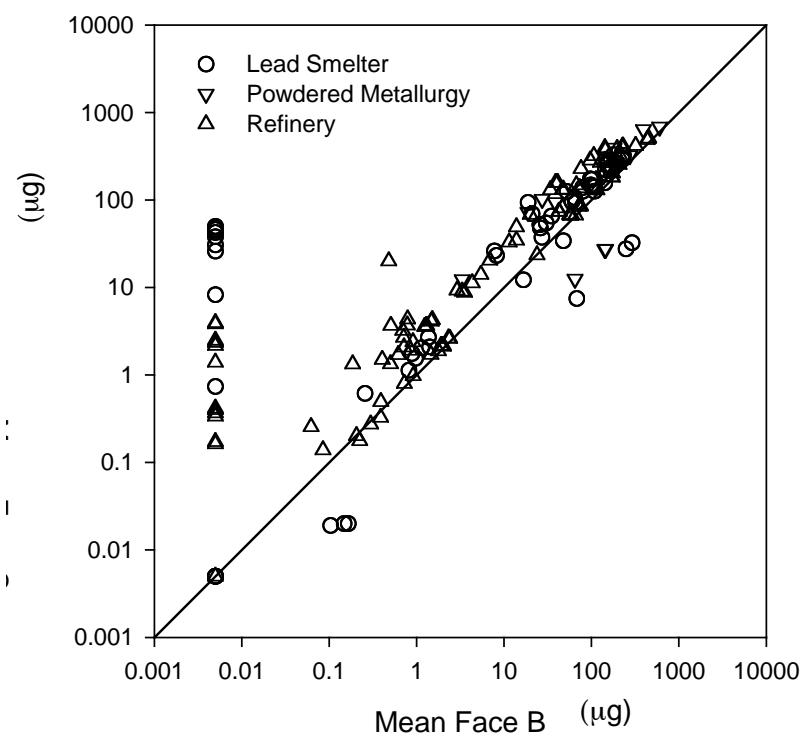


Figure 4.9b Comparison of peri-oral exposure between assessor B and C.

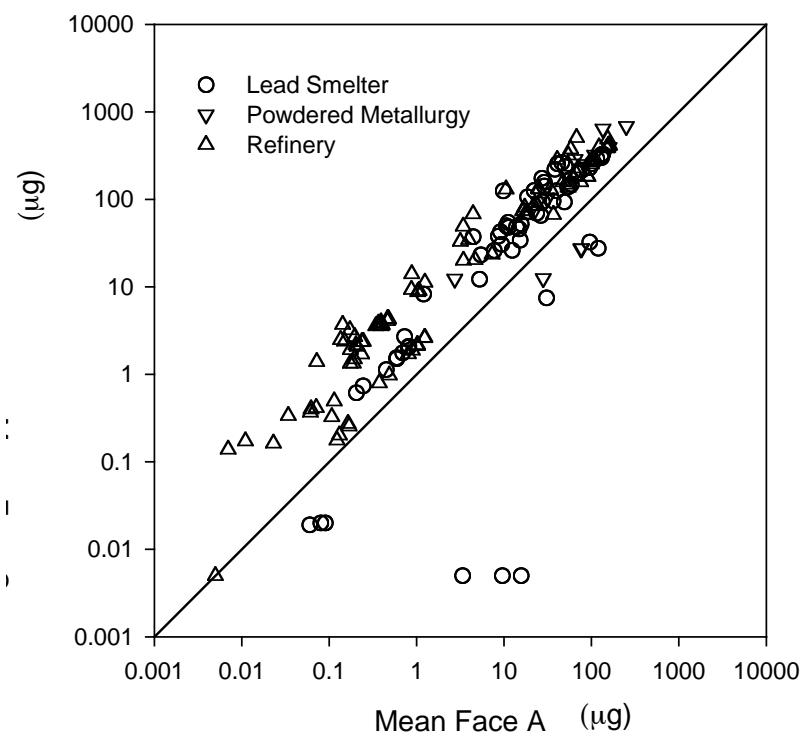


Figure 4.9c Comparison of peri-oral exposure between assessor A and C.

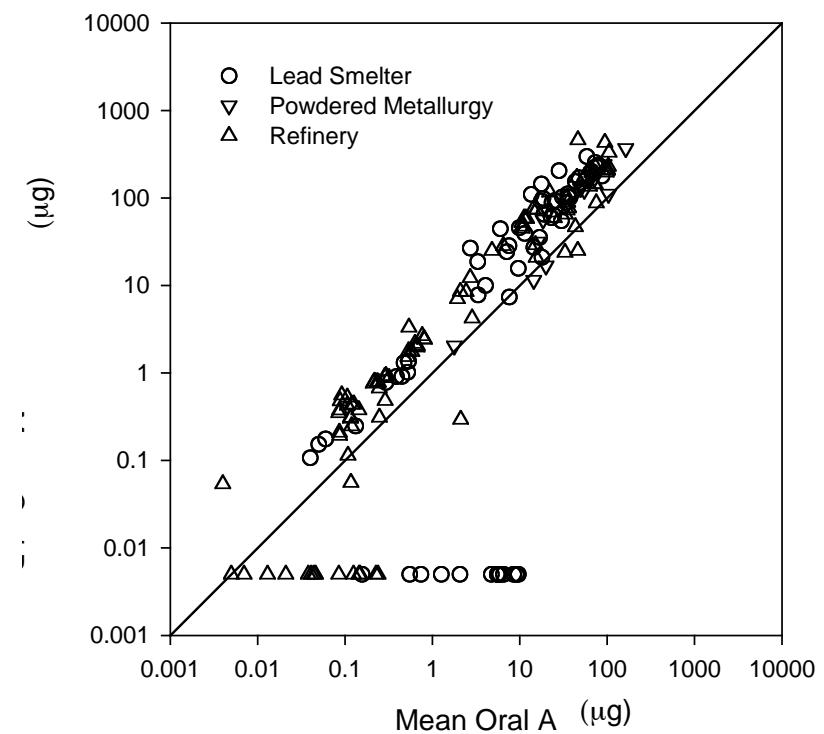


Figure 4.10a Comparison of oral exposure between assessor A and B.

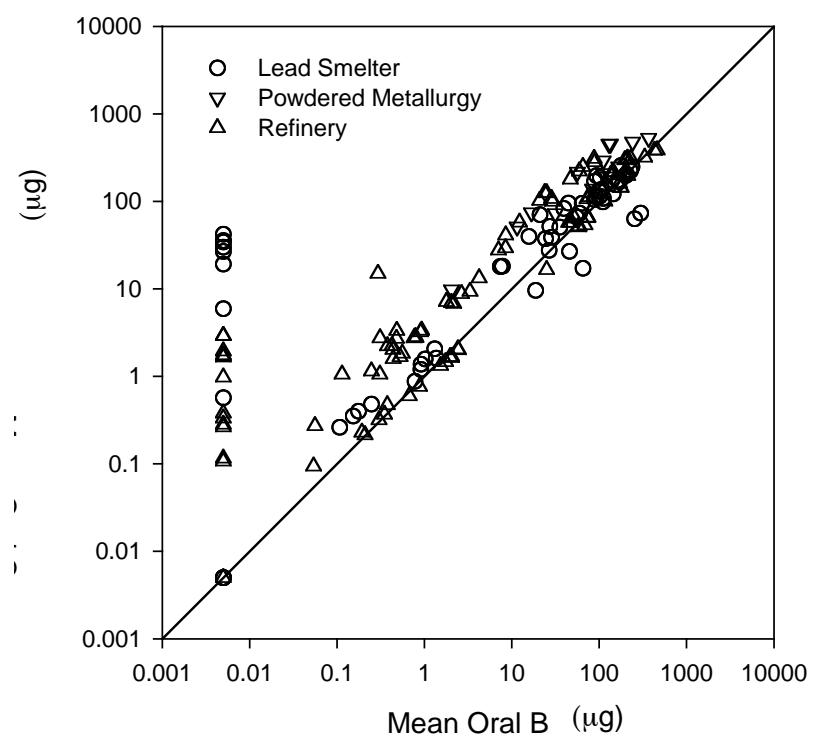


Figure 4.10b Comparison of oral exposure between assessor B and C.

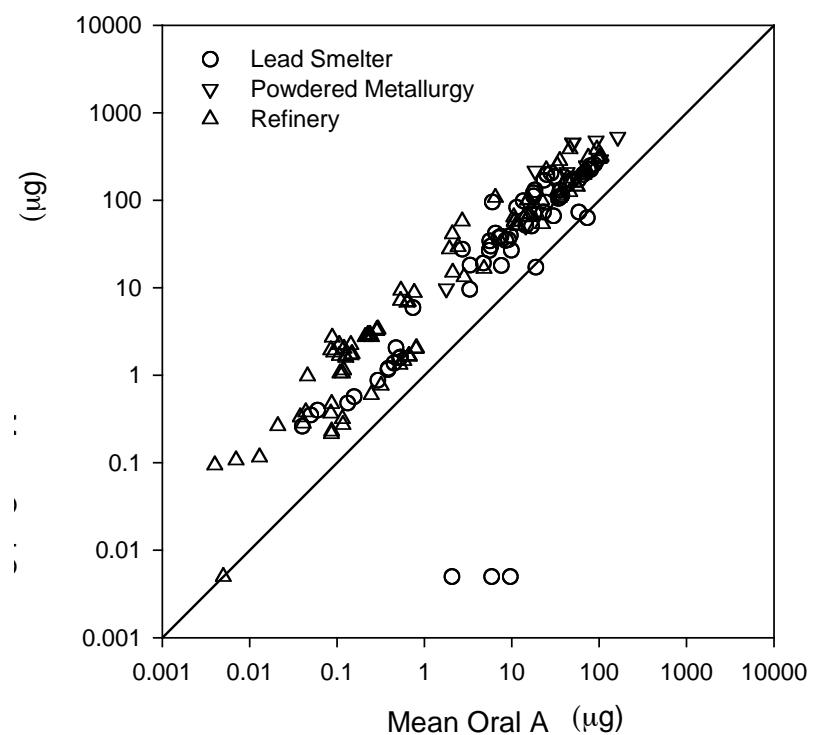


Figure 4.10c Comparison of oral exposure between assessor A and B.

4.3 COMPARING ACTUAL WITH PREDICTED LEVELS

Estimated exposures by the assessors were compared with the actual measurements for hands, face and oral exposure. Actual measurements of face exposure were only available for one of the sessions. Comparisons were made at the level of session so total exposure predicted for each session was compared with actual exposure measurements which were taken at the end of each session. Figures 4.11 to 4.13 show the relationship between actual and estimated exposures for hand, face and oral exposure, respectively. There is no association between actual oral exposures and estimated exposures by any of the three assessors (Figure 4.13). For hand exposure there is a statistically significant association between actual and estimated exposures for all three assessors (Figure 4.11). However, there is substantial scatter and it would not be possible to accurately predict actual exposure from the model estimates. Actual hand exposure was higher than estimated exposure.

The strongest association was for actual versus estimated exposure on the face (Figure 4.12), although this was based on substantially fewer data points. Overall, exposure levels estimated by assessors A and B were lower than those actually measured while levels estimated by assessor C were similar, on average, to the measured values.

The correlation coefficients for measured and predicted levels ranged from 0.57 for Assessor C to 0.61 for Assessor A. When regressing the actual on the predicted levels the following regression equations were obtained:

Assessor A:

$$\log(A_{peri-oral}) = 0.97 + 0.50 \cdot \log(E_{peri-oral}) \quad (17)$$

Assessor B:

$$\log(A_{peri-oral}) = 0.95 + 0.44 \cdot \log(E_{peri-oral}) \quad (18)$$

Assessor C:

$$\log(A_{peri-oral}) = 0.72 + 0.48 \cdot \log(E_{peri-oral}) \quad (19)$$

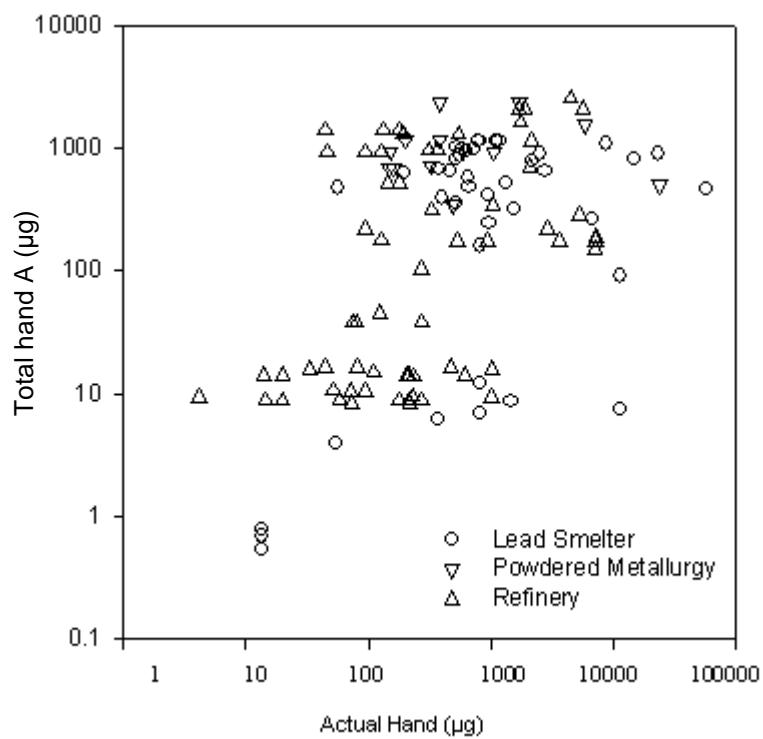


Figure 4.11a Comparison of measured and predicted hand exposure for assessor A

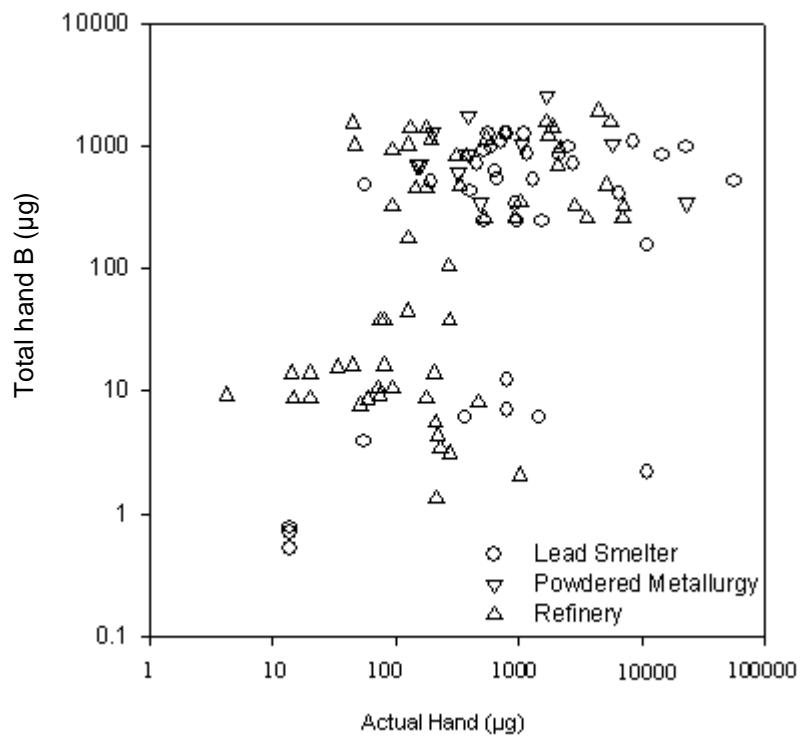


Figure 4.11b Comparison of measured and predicted hand exposure for assessor B

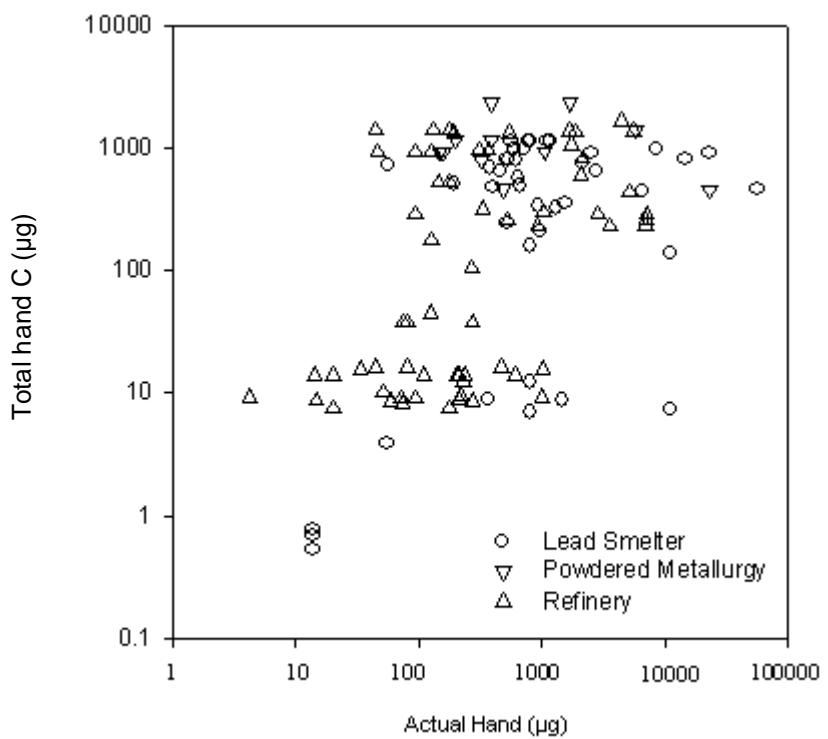


Figure 4.11c Comparison of measured and predicted hand exposure for assessor C

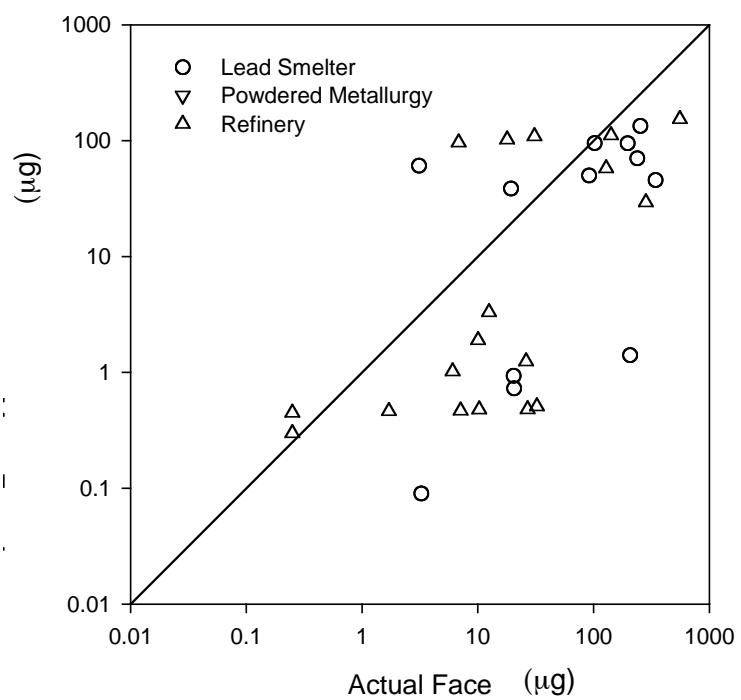


Figure 4.12a Comparison of measured and predicted peri-oral exposure for assessor A

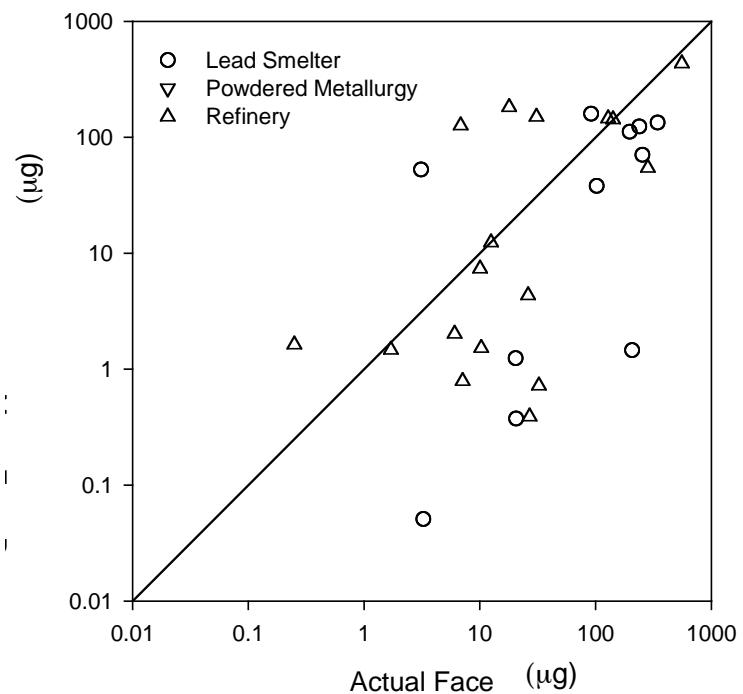


Figure 4.12b Comparison of measured and predicted peri-oral exposure for assessor B

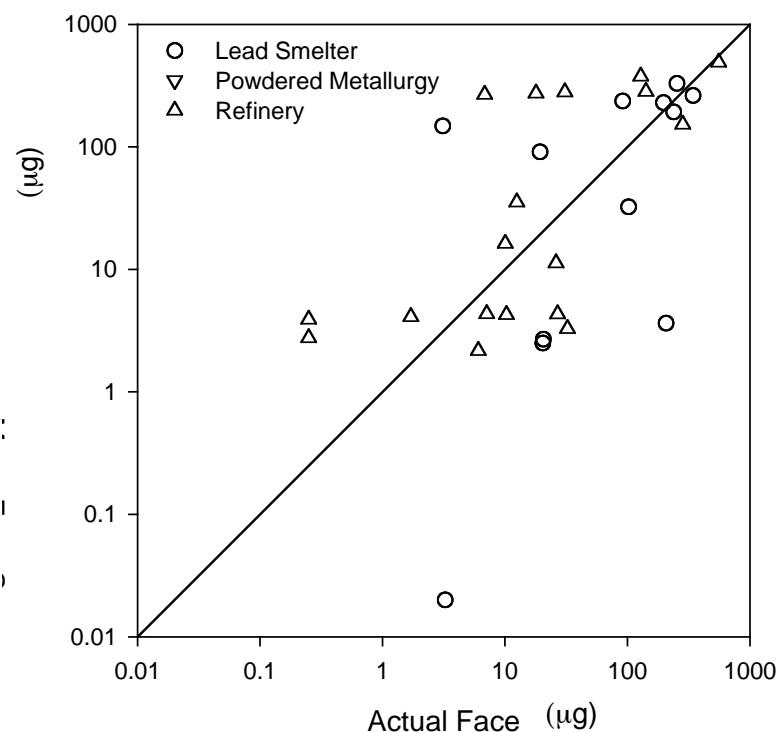


Figure 4.12c Comparison of measured and predicted peri-oral exposure for assessor C

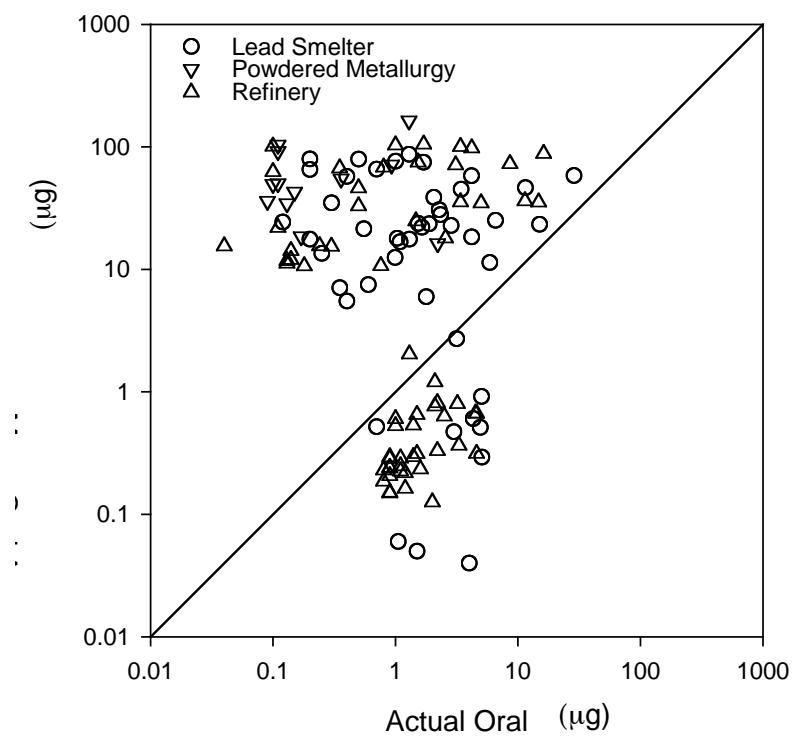


Figure 4.13a Comparison of measured and predicted oral exposure for assessor A

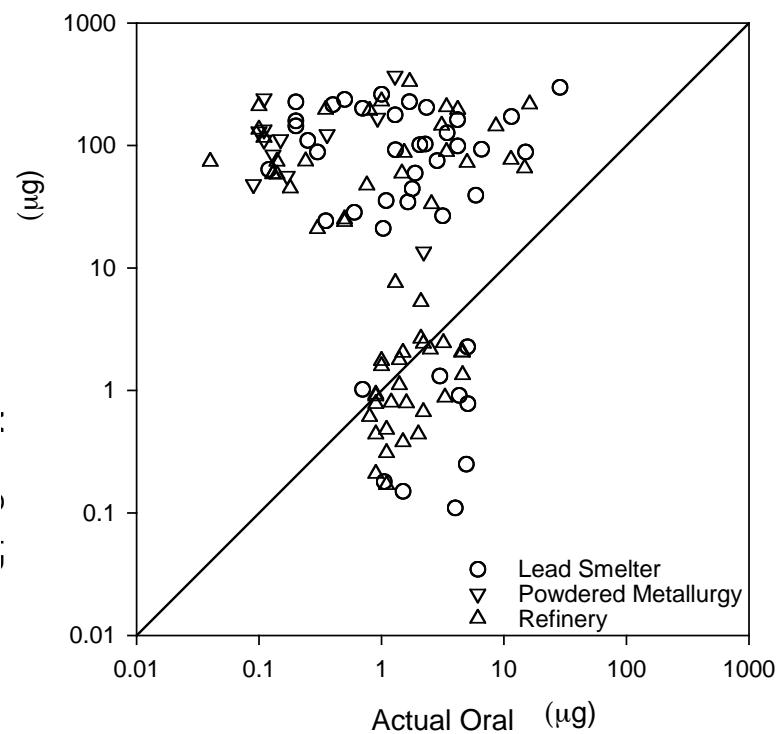


Figure 4.13b Comparison of measured and predicted oral exposure for Assessor B

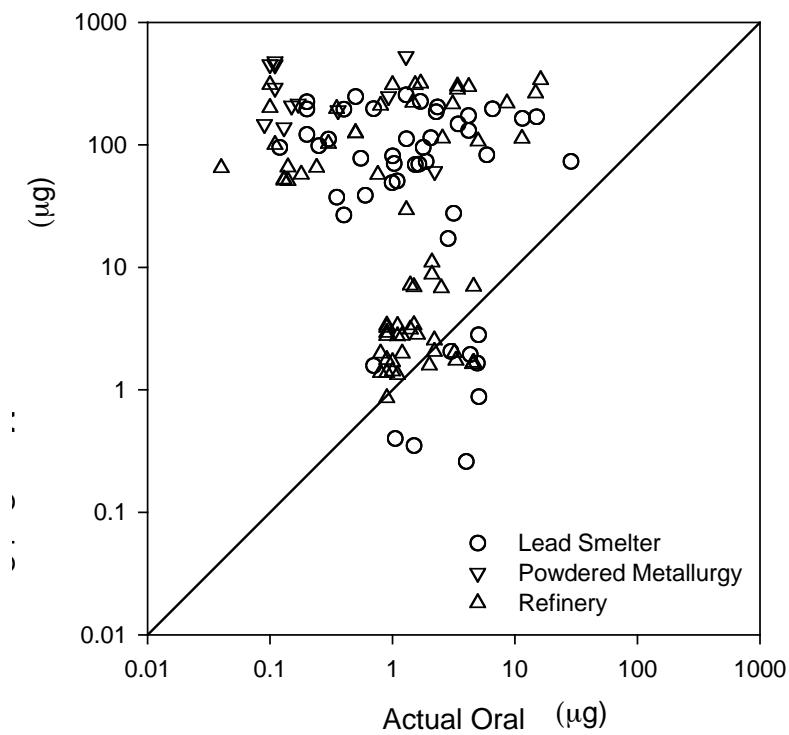


Figure 4.13c Comparison of measured and predicted oral exposure for Assessor C

4.4 MODEL AS A SCREENING TOOL

Based on general descriptions of the wards and the pharmacy in a hospital, the pesticide spraying activity and the work of a mechanic in a pesticide spraying company (see Appendix V) general model parameter values were estimated. The estimates were carried out by one of the authors (MvT) without detailed information on the activities that were available for the model validations and blind to the results of the exposure measurements. Table 4.10 compares the predicted values for peri-oral exposure with the measured peri-oral exposure to cytotoxic drugs in a hospital pharmacy and ward, while Table 4.11 compares the predicted and measured peri-oral exposures to pesticide. It is clear from Table 4.10 that the model vastly over predicts the peri-oral exposure to the cytotoxic drugs. The quantities of cytotoxic drugs used are generally very small. It is possible that the transfer efficiencies that were obtained from the laboratory tests, in which larger quantities were used, may not be suitable for such low levels of contamination.

Table 4.10 Comparison of measured and predicted peri-oral exposure for cytotoxic drugs

Area	Analyte	N	<LoD	Measured exposure			Predicted exposure		
				Mean (ng)	Median (ng)	Range (ng)	Mean (ng)	Min (ng)	Max (ng)
Ward	Pt	21	4	0.55	0.31	<LoD -1.60	320	300	340
	IF	2	2	-	-	-			
Pharmacy	Pt	15	2	0.23	0.17	<LoD -1.00	290	280	300
	IF	6	5	20.0	12.5	<LoD -57.0			

The comparison between the measured and predicted pesticide exposure levels was much better. For glyphosate the measured peri-oral exposure was 39 µg, compared to a predicted value of 47 µg. The results for the other pesticides suggest that the model overestimates the peri-oral exposure by a factor of 10 to 500. However, if the model is to be used as a screening tool, then overestimation by a factors within the range of 10 to 100 is probably acceptable.

Table 4.11 Comparison of measured and predicted peri-oral exposure for pesticides

Job title	Analyte	Measured peri-oral exposure				Predicted exposure		
		N	<LOD	Mean (µg)	Median (µg)	Range (µg)	Mean (µg)	Min (µg)
Sprayer	Chlorpyrifos	2	1	6.0	6.0	<LoD - 12.0	47.0	45.0
	Chlorothalonil	4	3	0.1	0.2	<LoD - 0.2		
	ETU	11	9	0.1	0.1	<LoD - 0.4		
	EU	11	8	0.3	0.2	<LoD - 0.7		
	Glyphosate	5	0	39.5	25.0	2.6 - 91.0		
	AMPA	5	2	0.2	0.2	<LoD - 0.3		
Mechanic	ETU	3	1	0.3	0.4	<LoD - 0.4	47.0	44.0
	EU	3	3	0.2	0.2	-		

5 DISCUSSION AND CONCLUSIONS

5.1 INADVERTENT INGESTION OF HAZARDOUS SUBSTANCES

In the past the main route of occupational exposure for most hazardous substances was inhalation, but conditions in workplaces have changed greatly and there is now much more focus on other routes of exposure particularly dermal exposure. There has been little consideration about the risks associated with inadvertent ingestion of hazardous substances. Consequently, ingestion as a route of exposure in the workplace is discounted and our knowledge remains minimal. This research study was conceived to provide greater insight into the relative importance of ingestion exposure, to provide suitable exposure metrics to enable quantitative measurements that are relevant to inadvertent ingestion and to develop a simple model that could be used to estimate ingestion exposure.

In the first phase of our work we carried out a review of the literature that identified five key substance groups where ingestion exposure could be relevant: metals, pesticides, pharmaceuticals, pathogens and radionuclides. We attempted to estimate the number of people at work who are potentially at risk from ingestion of these agents and arrived at an estimate of about 4.5 million people within the UK who may inadvertently ingest non-trivial amounts of hazardous substances at work, approximately 15% of the working population (Cherrie *et al.*, 2006). We judge that relatively few people could ingest radionuclides. Approximately equal numbers of people were estimated to be exposed to metals, pharmaceuticals and pathogens, while about 7% were considered to be potentially exposed to pesticides by ingestion.

These figures are based on subjective assessments from four experienced occupational hygienists on the potential for ingestion exposure for all occupations within the Standard Occupational Classifications and the estimated proportion of the workforce within each occupation where ingestion exposure could occur. We do not pretend that the figure is a precise estimate of the number of people who may be exposed and it may over or underestimate the true number. However, we are confident that a significant fraction of the UK workforce is at risk from inadvertently ingesting hazardous substances at work and the real issue is the magnitude of exposure in each occupational sector.

Our literature review, which is summarised in the first report from this project and in Cherrie *et al.*, (2006), highlights the prior knowledge of the importance of ingestion exposure. There are a number of papers that describe case reports where accidental or inadvertent ingestion of toxic substances had caused some directly observable adverse health effect. Sen *et al.*, (2002) and Enander *et al.*, (2004) highlight the possible risks from ingesting lead paint flakes from hand-to-mouth contacts and contaminated food from remedial activities in some homes. Garrod *et al.*, (1999) compared dermal and inhalation exposure from work with timber treatment biocides with biological monitoring data and Cattani *et al.*, (2001) carried out a similar investigation amongst pesticide applicators in Australia. Both of these studies highlighted the chance of ingesting pesticides when eating or smoking in contaminated areas.

The main limitation of many of these studies is the qualitative nature of the data about ingestion. There is usually a mere inference of a role for ingestion exposure from biological monitoring data and exposure measurements by inhalation and/or skin contact. One notable exception to this was a study by Karita *et al.*, (1997). This study demonstrated that amongst Japanese lead refinery workers, there were high correlations between lead facial wipes and lead in fingernails with blood lead levels ($r = 0.73$ and 0.59 , respectively). The association between these exposure measures suggests an important role for inadvertent ingestion from hand-to-mouth and hand-to-

face contacts.

Most information available about hand-to-mouth and object-to-mouth activity is related to children, where there is a clear reduction in mouthing activity as the children grow up. However, there is also evidence that adults touch their faces and mouth objects a few times per hour and that the frequency of these behaviours increases if the individual is placed in a stressful situation (Woods and Miltenberger, 1996). A substantial fraction of the adult population bites their nails or engages in other behaviours that could transfer contaminants into the mouth. These traits are likely to be specific to a group of individuals. This may imply that the risks associated with inadvertent ingestion of hazardous substances may be focussed in a sub-group of the exposed workers who engage such habits that promote contaminant transfer from the hand into the mouth.

The information obtained from the literature was sufficient to identify that there is potential for exposure via ingestion to make an important contribution to overall exposure. Cherrie *et al.*, (2006) completed some simple hypothetical calculations of the relative contribution of inhalation, dermal and ingestion uptake for a pesticide scenario and for a lead worker. These data suggested that in these specific cases there could be between 20 and 46% of total uptake from inadvertent ingestion. Given these findings, the next step was to try to understand the processes behind ingestion exposure so that we could construct a predictive model that could be used in risk assessment.

5.2 MODEL BUILDING

5.2.1 The conceptual basis for a model

The first stage in formulating a model is the process of conceptualising the processes involved. We have chosen to analyse the situation in terms of a source-receptor model, which we have used for other occupational exposure routes; a dermal exposure being described by Schneider *et al.*, (1999) and an inhalation model by Goede *et al.*, (in preparation).

The model we have constructed has compartments representing either surfaces in the environment, such as objects or building elements, and personal “compartments”, such as hands, peri-oral and the oral compartments. Compartments are characterised by the mass of contaminant material present in them, their volume and surface area. Hazardous substances may pass between compartments either by a continuous process, for example in loading surfaces with contaminant over time, or an episodic process, for example hand-to-peri-oral transfer.

We believe that the conceptual model provides a defensible analysis of the processes involved in inadvertent ingestion exposure and therefore provides a sound scientific basis for model building.

5.2.2 Repeated contact with contaminated surfaces

We have assumed that for episodic transfers a proportion of the available contaminant is transferred from one compartment to the other. For example, when a hand touches a surface a fraction of the mass of contaminant on the surface area contacted is transferred to the hand.

Brouwer *et al.*, (1999) demonstrated that there was a linear relationship between the number of hand/surface contacts and the mass loaded onto the hand as the number of contacts increased from one to six. These authors also noted that the fraction of available contaminant transferred to the hand for a single contact decreased with a higher surface loading, decreasing from 2%

and 0.14% for surface loadings of $6 \mu\text{g}/\text{cm}^2$ and $177 \mu\text{g}/\text{cm}^2$ of the fluorescent chemical Tinopal, respectively. Brouwer *et al.*, (1999) also found that the area of the hand contaminated increased with the number of contacts, to a maximum of about 40% of the palmar surface – mostly finger tips and the ball of palm.

Another group that used Tinopal as a tracer to investigate transfer of contaminants to hands was Zainudin and Semple (2005). Transfer was seen to increase more or less linearly with repeated contacts, up to a maximum of six repeats. The fraction of powder transferred from the surface to the hand was on average 2.1% after one contact and after six contacts it had increased to 39%. For the liquid 32% was transferred after one contact and 75% after six sequential contacts.

Cohen-Habal *et al.*, (2004) investigated transfer of riboflavin from surfaces to hands using surface loadings of $10 \mu\text{g}/\text{cm}^2$ on a laminate surface and $2 \mu\text{g}/\text{cm}^2$ on carpet. They noted that transfer decreased with repeated contacts from about 2.6% (first contact) to 1.4 % (fifth contact) for the high surface loading and from about 7.5% (first contact) to 4.2% (fifth contact) for the lower loading.

Repeated contact tests carried out with large particles ($20 - 40 \mu\text{m}$) also showed a decrease in the mass transfer for each contact, with the transfer per contact decreasing by approximately 50% between one contact and 45 contacts (Rodes, 2001). Contact with a contaminated stainless steel surface produced between 58% and 72% transfer of dust on first contact.

Hughson and Cherrie (2002) investigated the maximum dust loading that could be obtained on a hand that was immersed in a bag of zinc dust or zinc oxide powder. They found that the maximum loading was about $4,800 \mu\text{g}/\text{cm}^2$ for zinc dust and about $730 \mu\text{g}/\text{cm}^2$ for zinc oxide; it was not clear why there was a difference between these materials. They also did not find any indication that the mass of zinc oxide dust increased in tests involving repeated contact with contaminated surfaces, i.e. the average was between 163 and $237 \mu\text{g}/\text{cm}^2$ for between one and four repeated contacts. The surface loading for these tests was much higher than in the other two studies discussed, although it was not measured by the investigators. The absence of any increase in loading with more than one contact may reflect maximal adhesion of powder to the available skin surface on first contact.

In our experiments the data, reported in the phase II report, showed that the number of hand to surface contacts was highly statistically significant in predicting hand exposure and the results were not inconsistent with a constant transfer factor. This was true for up to four repeated contacts, at surface loadings of 50 and $100 \mu\text{g}/\text{cm}^2$.

While the published experimental evidence on the linearity of transfer with repeated contact is mixed there is clear evidence that for low loadings on surfaces, it is not an unreasonable assumption. More importantly, an assumption of linearity should not result in an underestimation of exposure in an exposure model. We therefore believe that it is reasonable to assume that repeated contact would transfer a fixed fraction of the surface contamination to the hand. A similar transfer relationship between hands and peri-oral area is also assumed, although there is no published evidence to support this.

5.2.3 The magnitude of the transfer factors

The published information on transfer of contaminants from surfaces to hands shows that the process is complex and that a number of parameters may alter the percentage transfer. Our own experiments showed that in addition to the number of contacts the surface loading and skin

moisture levels were highly significant predictors of transfer. Other factors that we investigated that did not produce clear evidence of influencing the transfer process were the duration of contact, the mechanism of contact (smudge or press) and the type of surface, although the transfer from carpet did produce the lowest hand loads.

The evidence for surface type influencing transfer is equivocal. Cohen-Hubal *et al.*, (2004) found no differences for riboflavin on laminate or carpet, although Rodes *et al.*, (2001) and Rohrer *et al.*, (2003) both found that rougher surfaces inhibited transfer. We believe that the effect of surface roughness on transfer probably depends on the type of powder and the process of deposition on the surface, but it is likely to be only of secondary importance in the transfer process. Assuming that smooth surfaces provide the greatest potential for transfer, basing a screening model on these data will provide a conservative tool.

Skin moisture has been reported by others as important in transfer, with increased moisture inhibiting transfer (Brouwer *et al.*, 1999; Rodes *et al.*, 2001). In contrast, Cohen-Hubal *et al.*, (2004) showed that deliberately wetted hands or “sticky” hands increased the transfer of contaminants from surfaces.

Generally, reported transfer factors for a single surface contact range widely. Brouwer *et al.*, (1999) showed that transfer was between 0.14% and 2% depending on surface loading. Zainudin and Semple (2005) report average transfer of 2.1% for powder and 32% for liquid. Cohen-Hubal *et al.*, (2004) reported average transfer between 3% and 14%, with the highest factor for “sticky” hands. Rodes *et al.*, (2001) found transfer from smooth steel surface between 58% and 76%. Other models used for dermal exposure risk screening have used transfer efficiencies for surface to skin transfers ranging from 1% to 10 % (CEC, Inc., (1997); Dibasio and Klein, (2003); Paull (1997)). Our data showed a mean transfer factor for powder of 12%, but we have chosen to use the 90th percentile of our data as the basis for the model calculations, i.e. 28% transfer per contact. We believe that this is in line with a conservative strategy appropriate for a screening model and is consistent with the majority of published data.

Transfers between the skin and the oral cavity or the face have been little investigated. A paper summarising models used for dermal risk screening for pesticide residues on warehouse building walls gave transfer values ranging from 1.5 % to 5 percent (Souther, 2005). However, in keeping with an appropriately conservative approach, we have assumed almost complete removal of contaminant when fingers or objects are introduced into the mouth.

5.2.4 Estimates of the number of repeated contacts with the peri-oral area and mouth

Information in the scientific literature about the number of hand-to-mouth or hand-to-peri-oral contacts is generally lacking for adults at work. Zainudin and Semple (2005) noted that the rate of contacts was dependant on the work circumstances with an average 3.4 peri-oral contacts per hour in office environments to 1.8 contacts per hour in manufacturing or engineering settings and zero contacts observed in a laboratory. These authors also noted that the amount of hand activity required for the work, i.e. the “busyness” of individuals, was a key determinant of peri-oral contact rate, with increasing busyness being associated with lower peri-oral contact rates.

During our field studies we observed contact rates for a number of work sectors and found similar results to Zainudin and Semple (2005). The average peri-oral contact rate was 2.9 times per hour and the average oral contact rate was 2.4 times per hour. Within this there were statistically significant differences in the peri-oral contact rates between industrial sectors; highest rates were for powder metallurgy and agricultural work, lowest were seen in lead

smelting and antimony trioxide manufacture. Much of the difference was explained by the “busyness” of the work.

We have used our data to form the basis of an assessment of hand to peri-oral or mouth contacts and we believe that they provide a realistic evaluation. However, there are a number of additional personal factors that influence these behaviours and these are impossible to account for. In the model we have relied on the assessor's judgement to take these factors into account and we have not deliberately sought to build in any conservatism in the model.

5.3 THE RELIABILITY OF THE MODEL AS A SCREENING TOOL

We have attempted to validate the model developed from the laboratory experiments using data collected in the metals industry. There was data available from 43 workers who were employed in five different work situations and in 18 different jobs. These showed a statistically significant positive correlation between the contamination on the hands and the peri-oral area of the face ($r=0.67$) and between the peri-oral contamination and the oral exposure ($r=0.49$). These data suggest that the conceptual model provides a good description of the transfer processes involved with ingestion exposure. The regression analyses provided a better fit to the data when they were log-transformed indicating that there is probably a non-linear relationship between each of the parameters. This does not necessarily invalidate the simple assumption of linearity that we have made in developing the model since it continues to be consistent with a conservative screening model. However, it does confirm the information that others have obtained for transfer between surfaces and hands and suggests that the transfer processes are likely to be relatively complex and dependent on not only the surface contamination but also the “cleanliness” of the hands or face.

When comparing actual and predicted exposures, especially oral exposure, it has to be realised that the measurements may be representative of an exposure ‘snapshot’ of the scenario only. In the case of oral exposure measurements, the result is likely to be highly influenced by the most recent intake of contaminant into the mouth and by personal behaviour. There is a substantial flux of saliva through the oral compartment that will quickly wash away contaminant and the half-life of any contaminant in the mouth will be very short. We believe that the measurements for oral exposure will therefore be more variable than other measures and is likely to be biased towards low exposure estimates. In contrast, the model for ingestion exposure predicts the cumulative ingestion exposure over a period of time that will pass through the mouth. It is therefore not surprising that there is no relationship between the predicted and measured oral exposure. However, there is a much better association between actual and estimated hand exposures and between actual and estimated peri-oral exposures. In general we believe that the peri-oral rather than the oral measure is probably the best indicator of inadvertent ingestion exposure. This indicates that the model developed in this project can be a good and useable tool for determining the level of ingestion exposure.

Model predictions were made for the 43 workers described above undertaking 178 different tasks. Three experienced occupational hygienists independently assessed each task. In general there was good agreement between assessors (intra-class correlation coefficient ranging between 0.74 and 0.99), which reflects the structure of the model and the relatively limited range of options available to the assessors in selecting the model parameters. The systematic differences between assessors were generally less than a factor of two, which is good in comparison with other modelling approaches for inhalation exposure or dermal exposure (e.g. Cherrie and Schneider, 1999).

Comparison of the measured and estimated exposures showed a statistically significant association between the estimated contamination on the hand and the measured value and between the estimated and measured exposure in the peri-oral area, with the correlation coefficients in the latter being between 0.57 and 0.61. Despite the model being developed using conservative assumptions the measured and estimated peri-oral exposures were quite similar. The correlation between estimated and measured oral exposure was poor, but in general the measured exposures were lower than the estimates. These results are encouraging and suggest that the algorithm has some predictive power for peri-oral exposure.

Finally, we tested the model for use as a screening tool in a hospital (cytotoxic drugs) and pesticide spraying company. This was different from the validation exercise as the information provided to the assessor for the screening exercise was very basic compared to the detailed information available in the validation study, which reflects the information that is likely to be available when carrying out an initial risk assessment. The results of this application of the model suggest that the model provides conservative estimates for exposure, especially for the cytotoxic drugs. For pesticide the model overestimated the peri-oral exposure by a factor of between 10 and 500 depending on the pesticide. We believe that this factor is appropriate for screening tools in risk assessment procedures, although further work will need to be carried out to test whether the model is a sufficiently reliable and conservative tool.

5.4 CONCLUSIONS

During this project we have:

- estimated the potential for inadvertent ingestion exposure in the workplace in the UK;
- investigated the process for inadvertent ingestion exposure;
- developed a model for estimating ingestion exposure; and
- carried out some preliminary validation studies of the model.

Inadvertent ingestion exposure is a complex process involving many workplace and personal factors, and therefore it will always be difficult to develop simple and reliable screening and exposure assessment tools for this type of exposure. However, we believe that ingestion exposure has received insufficient attention in occupational exposure assessment and that the model developed in this project provides a good starting point for the development of screening and exposure assessment tools for risk assessment, health screening and epidemiological studies. There are clearly a number of areas where the model will need some further refinement and there may be areas where the model may not be suitable, for example in the case of highly toxic materials handled in very small quantities. In the first instance, we believe that the model could be used for screening purposes in risk assessment procedures, although further work will need to be carried out to test whether the model is a sufficiently reliable and conservative tool.

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APPENDIX I – GUIDANCE PROVIDED TO EXPOSURE ASSESSORS FOR ASSIGNING MODEL PARAMETER VALUES

Subjective exposure assessments - guidance

Introduction

Based on the ingestion exposure model, the information required for conducting subjective assessments of dermal and oral exposure is (1) the nature of the contaminant, (2) the surface load (3) the number of hand-to-surface contacts (4) the skin moisture level (5) the type of transfer from the hand into the oral cavity and (6) the fraction of the hand that enters the oral cavity during hand-to-mouth contact. The number of hand-to-mouth transfers is not indicated in the model, however, this also needs to be assessed. It is assumed that each new hand-to-mouth contact represents new loading of peri-oral region or oral cavity depending on the type of transfer. Additionally, a hand reduction exposure factor needs to be indicated for each task estimated during the subjective exposure assessments.

Table 1 gives the values that are possible for each parameter. A description of each parameter is also given.

Table A1.1 Parameter values for ingestion exposure model

Parameter	Value	Default value
Nature of contaminant	solid; liquid	-
Surface Load	No*, low; medium; high	high
Number of hand-to-surface contacts	≥ 0	
Skin Moisture (for solid only)	low; high.	low
Type of hand-to-mouth transfer	direct; indirect	-
Busyness	0 - 3	-
Number of hand-to-mouth contacts (contacts per hour).	≥ 0	-
Fraction of hand in mouth/in peri-oral region	0 – 0.75	-

*No – if it is considered that there is no contaminant on the surface.

Descriptions of Parameters

In choosing parameter values, the following should be taken into account:

Nature of contaminant

This refers to whether the contaminant is in the form of a solid (particulate, aerosol, bulk or paste) or liquid (liquid aerosol (like water)).

Surface load

This refers to the level of contaminant on work surfaces. There are three possible values for this parameter. These values are based on a visible inspection of surfaces in the workplace. A low surface load for a powdered substance will be consistent with very clean surfaces where the presence of powder on the surface is not visible and a hand passed over the surface will rarely pick up anything e.g. like hospital surfaces. Work areas such as offices of administrative staff who never or rarely access the shop floor or workplaces such as work areas in the health care sector fall under this category. A medium surface load for powder

will be where there is visible evidence of the substance on the surface but it is not immediately apparent. Passing ones hand firmly over such a surface will result in contaminant being transferred onto the hand. A medium surface load is consistent with moderately clean workplaces and may be the condition of control rooms close to the process areas or offices in the vicinity of the process area which process operators frequent. A high surface load will be consistent with obvious layers of dust being clearly visible on work surfaces, even a slight brush against the surface results in ready transfer of contaminant from the surface. An object placed on such a surface will leave a clear imprint in the layers of dust. High surface loads are consistent with workplaces described as very dirty and may be the condition found especially in operations where there is a dirty end where raw materials that feed into processes are stored. High surface loading conditions may also be seen during such tasks as manual packing operations that require manual scooping of powders or during maintenance of packing equipment, or change over to a new product on an automatic or semi-automatic packer.

It is possible that the contaminants exist as bulk material e.g lead ingots or nickel plates. In these circumstances the surface load rating would be dependent on the ease of transferability of the material. Transfer of a hard dense solid to the skin surface is most probably low whereas cutting such a surface will produce particulate, which may then become loaded onto the palmar surface.

For a liquid contaminant, the choice of low, medium or high surface loading is decided largely in the same way as described for solids above – partly based on perception by visual inspection. A medium load will be consistent with spray mist on a surface while a heavy load will be consistent with spray droplets or water puddles on a surface. A low load will refer to a surface that is slightly wet to the touch but not to the eye. The surface load is expressed in mg powder/cm² or µl liquid/cm².

Number of hand-to-surface contacts

This parameter is expressed as contacts per hour and can have any numerical value greater than or equal to zero. The number of hand contacts with a contaminated source (contaminant, tool, machinery, work desk), will be influenced by factors such as the temperature of the surface or the use of tools. A temperature higher than that which is comfortable to the touch (i.e. >60°C) will reduce the number of contacts whereas the use of a tool would usually suggest that contact with the surface is almost continuous. The range of recorded values for hand-to-surface touches is 0 - 363 contacts per hour. However, it is considered that beyond two hand-to-surface contacts there is no further transfer from the surface to the hand. When hand-to-surface contact is continuous this should be indicated on the assessment sheets with the symbol ‘cc’.

Skin moisture

Skin moisture may have values ‘low’ or ‘high’. The influence of skin moisture is relevant to exposure to a solid contaminant only. There are some work conditions that promote increased skin moisture. Factors such as working in a hot, humid, environment, doing heavy manual labour in a humid environment or using gloves would tend to increase skin moisture. Whereas, handling a dry powdered contaminant would tend to decrease it.

When a worker is using PPE, skin moisture is assumed to be about the same as a worker with a dry hand.

Use of Gloves

For most of the job descriptions, gloves were used. However, assessors should ignore the use of gloves at this point except to consider how glove use affects skin moisture levels of the bare hands. A correction factor will be added later for instances where gloves were used.

Type of hand-to-mouth

Type of hand-to-mouth transfer may be direct or indirect. A direct transfer is used to describe the contact when a portion of the hand actually enters the oral cavity e.g. nail- or finger-biting or sucking. An indirect type of transfer is used to describe contact between the hand and the peri-oral region (area of 1.5-cm radius around the mouth (including the lips).

In general there are three main determinants that influence hand-to-mouth activity – (1) **busyness** of the hands i.e. how engaged the hands are during performance of the job tasks (2) work environment – stressed or relaxed (3) involvement of the worker in cognitive processes. The most significant factor, is the **busyness** and hence availability of the hands for hand-to-mouth contacts. However, all three factors operate in concert to influence hand-to-mouth contacts and it is difficult to separate one from the other. In order to rate the availability of the hand for hand-to-mouth contact it is useful to firstly, rate the **busyness** of the hand using the following 4-point scale:

0 = not busy 1 = a little busy 2 = moderately busy 3 = very busy

A **busyness** scale of 0 or 1 will increase the likelihood of hand-to-mouth/face contacts and the number of those contacts. Conversely, ‘moderately busy’ or ‘very busy’ will decrease both the likelihood and number of hand-to-mouth/face contacts.

Busyness refers to the availability of the hands during a task. ‘Not busy’ will be consistent with a tasks such as monitoring a process via a computer screen, communicating with colleagues while not performing any work tasks, or observing items on a production line e.g. quality control of a product by primarily visual inspection with only occasional handling of the product. ‘A little busy’ will be consistent with activities that require only occasional use of the hands e.g. quality control of a product that requires both visual inspection and measurements of the product – weight, size – being taken at regular but not frequent intervals. ‘Moderately busy’ and ‘very busy’ will be consistent with activities that require frequent and almost constant use of the hands. Workers involved in more manual tasks can be classed under one of these categories. Relevant examples will include tasks such as maintenance work that requires handling of tools and equipment, manual packing, manual labour such as shovelling or lifting, driving equipment e.g. bobcat; forklift.

Once the availability of the hand is established it may be useful to consider the worker environment. A more relaxed worker environment would prevail during work breaks, chatting with colleagues, in an area not expected to be contaminated with hazardous substances or during decreased work load e.g. workers standing around while maintenance activities are being done or assisting in maintenance (so they are only sometimes engaged). A more relaxed worker environment would promote hand to mouth/face contacts. Likewise a stressed work environment coupled with low busyness of hands would increase likelihood and number of hand/mouth contacts due to increased nervous and anxious face touching.

The next factor to consider in deciding if hand-to-mouth activity takes place would be the degree of cognitive involvement in the task at hand. Increased cognitive activity often tends to be accompanied by unconscious repetitive activity such as nail or finger- biting or sucking, face-, beard- or lip-rubbing with the hands, fingering of mouth, spectacles, RPE. Again the availability of the hand (busyness) first needs to be considered.

Activities that promote hand-to-mouth/face contacts include - sitting and monitoring equipment, sitting at a control panel, feeding a semi-automatic process. It is also promoted, during problem-solving activities in periods when the hands are not actively engaged e.g. during maintenance of equipment.

The type of transfer (direct, indirect) is partly influenced by accessibility to the mouth and peri-oral region. The use of RPE especially air-fed hoods or full-faced RPE would tend to limit the hands' access to the mouth and peri-oral region. However, this is less so with the use of disposable RPE or half-face RPE. The latter may promote hand-to-peri-oral region contact (indirect transfer) due to the increased likelihood of workers removing and replacing more easily removable RPE when they speak with colleagues or wipe sweat away from their face.

Overall, direct contact is more likely to occur with workers, who do not use RPE, use a work tool (e.g. pen) while performing passive type task and those who smoke. Indirect (peri-oral region) contact is more likely to occur with workers who have facial hair, wear spectacles (or safety glasses) or use easily removable RPE.

Number of hand-to-mouth/face contacts.

The factors that affect the likelihood of contacts also affect the number of contacts. The figure below shows the influence of busyness on the number of hand-to-mouth contacts and number of hand-to-perioral contacts. The influence of busyness on the number of hand-to-oral or hand-to-face contacts is indicated and described in Figure 1 and Table 2.

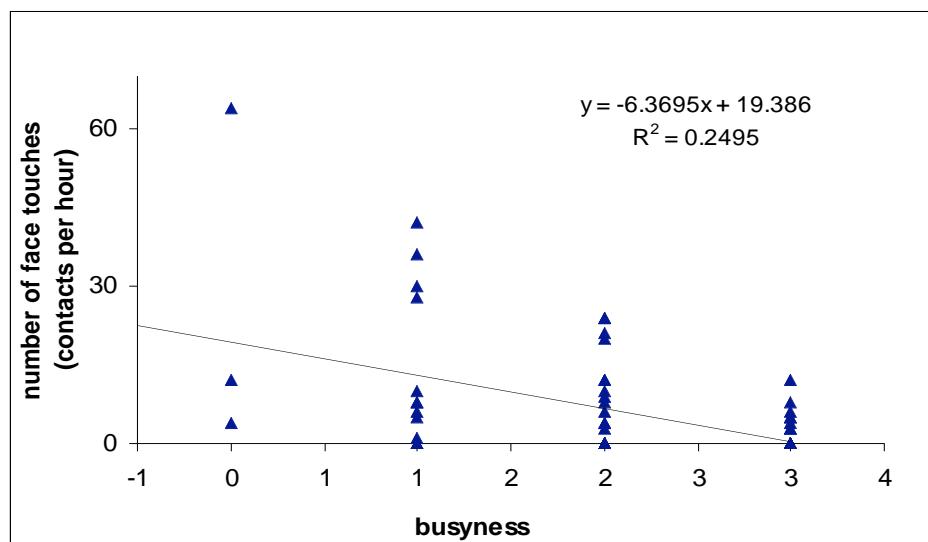


Figure A1.1 Relationship between busyness and number of fact contacts.

Table A1.2 The percentage (%) of touches within 5 different ranges according to the busyness level of the hands.

busyness	N		Percentage of touches within ranges (%)				
			0	1-9	10-19	1-19	>19
0, 1	69	Hand-to-Oral	53	18	18	36	12
	69	Hand-to-Perioral	41	29	12	41	18
2, 3	17	Hand-to-Oral	81	16	1	17	1
	17	Hand-to-Perioral	81	13	4	17	1

When busyness level is 2, 3 (moderately, very busy) there are fewer number of hand/oral and hand/peri-oral touches than when the busyness level is 0 or 1. In 81 % of the cases there are no hand/oral or hand/peri-oral contacts. However, when busyness level is 0, 1 there is a greater likelihood of contacts and the proportion of cases where there is no hand-to-oral contact is 53%; for hand-to-perioral contacts the proportion was 41%.

For a busyness level of 0 or 1, the proportion of hand-to-oral and hand-to-perioral touches that were within the range 1-19 was 36% and 41%, respectively. In 12% of the cases there were >19 hand-to-oral touches and in 18% of the cases there were >19 hand-to-perioral touches. For busyness level of 2, 3 the proportion of hand-to-oral and hand-to-perioral touches within the 1-19 range was 17% and there were very few instances where the number of touches exceeded 19 contacts (1% for both hand-to-oral and hand-to-perioral).

Hand fraction contact

The fraction of the hand that enters the mouth or contacts the face during hand-to-mouth/face transfers may take values from 0 – 0.75.

Assessment Spreadsheet

Each job described in the document entitled ‘Detailed Job Descriptions’, is listed in the Excel worksheets. There is a separate worksheet for each sector. The worksheet is designed so that exposure to both the solid and/or liquid forms of contaminant can be estimated. Assessors are required to provide parameter values for each of the parameters listed and described above.

An exposure assessment template has been designed to collect exposure information at the task level for each job. The working day is divided into three work sessions and each work session is divided into three work tasks to accommodate for instances where a worker conducts more widely varying tasks during a single work session. Work tasks may also include activities such as smoke breaks or lunch breaks.

In addition to the parameters described above the following information should be filled in by the assessor unless otherwise stated.

Base Hand Exposure

The base hand exposure (mg/cm^2 ; $\mu\text{l/cm}^2$) is a measure of the hand exposure level at the beginning of the task. For instance, at the beginning of task 2, the level of hand exposure will probably be equivalent to the final hand exposure of the previous task 1; however, at the beginning of the first task of the first shift, this value is always set to zero. This will be calculated based on the hand exposure reduction factor so assessors need not fill this in.

Hand Exposure Reduction

Hand exposure reduction factor. This is the decrease in hand exposure level as a result of hand washing or any other activity thought to reduce the hand exposure level. Hand washing before taking a smoke may reduce the level of hand exposure to a lesser extent than hand washing prior to lunch or at the end of a work session. This factor takes values within the range 0 – 1, with 0= no reduction and 1= complete removal of contaminant from the hand. If it is considered that an activity results in 70% of the contaminant being removed from the hand, then the *hand exposure reduction factor* will be 0.7.

Analyte concentration

Analyte concentration values need not be filled in by the assessors. The units of surface and hand loading are for amount of powder or liquid per cm².

APPENDIX II – WORKSHEET USED BY ASSESSORS TO RECORD MODEL PARAMETERS

Job title: Leaching operator 1	exposure to solid			exposure to solid			exposure to solid			
	task1	Session 1	task2	task1	Session 2	task2	task3	task1	Session 3	task2
Task name	Control room			Control room	Hosing floor		Control room	Shovelling		
Analyte	NiSO4			NiSO4	NiSO4		NiSO4	Ni Matte		
Task duration (hours)	3			2	0.5		2.5	0.5		
Base hand exposure (mg/cm ²); (μ l/cm ²)	0									
Surface load (mg/cm ²); (μ l/cm ²)										
Number of hand/surface contacts (contacts/hour)										
Skin moisture										
Busyness										
Hand/mouth fraction contact (direct)										
Number direct contacts (contacts/hour)										
Hand/face fraction contact (indirect)										
Number indirect contacts (contacts/hour)										
Concentration of analyte (w/w; v/v)										
Hand exposure reduction factor1 - hand washing during shift										
Hand exposure reduction factor2 - hand washing at end of shift										

Job title: Leaching operator 1	exposure to liquid			exposure to liquid			exposure to liquid		
	Session 1			Session 2			Session 3		
	task1	task2	task3	task1	task2	task3	task1	task2	task3
Task name					Hosing floor				
Analyte					NiSO4				
Task duration (hours)					0.5				
Base hand exposure (mg/cm ²); (μl/cm ²)									
Surface load (mg/cm ²); (μl/cm ²)									
Number of hand/surface contacts (contacts/hour)									
Skin moisture									
Busyness									
Hand/mouth fraction contact (direct)									
Number direct contacts (contacts/hour)									
Hand/face fraction contact (indirect)									
Number indirect contacts (contacts/hour)									
Concentration of analyte (w/w; v/v)									
Hand exposure reduction factor1 - hand washing during shift									
Hand exposure reduction factor2 - hand washing at end of shift									

APPENDIX III – DESCRIPTIONS OF WORKPLACES AND ACTIVITIES PROVIDED TO ASSESSORS

A3.1 INTRODUCTION

The following document provides the information necessary for exposure assessors to conduct subjective exposure assessments of dermal and oral exposure to workplace contaminants. Jobs within several facilities in the the metal-working industry are described.

A general description of the facility is given, followed by a description of the departments or sections within the facility. This is followed by descriptions of the individual jobs. A general description of the job, including within which department it takes place is provided. This is then followed by descriptions of the job tasks conducted within each of three different sessions of the working day. Relevant personal information about the worker is also provided. Links to photographs of the work areas and workers are indicated when these are available.

All descriptions of facilities and job descriptions within the metal-working industry were taken *directly* from the following reports prepared by Graeme Hughson. For the job descriptions, information from these reports was sometimes supplemented with additional information:

- Hughson GW. (2004). An occupational hygiene assessment of dermal nickel exposures in primary production industries. Edinburgh: Institute of Occupational Medicine. (IOM Report TM/04/05).
- Hughson GW. (2005). An occupational hygiene assessment of dermal nickel exposures in primary production and primary user industries. Edinburgh: Institute of Occupational Medicine. (IOM Report TM/05/06).
- Hughson GW. (2004). An occupational hygiene assessment of dermal inorganic lead exposures in primary and intermediate user industries. Edinburgh: Institute of Occupational Medicine. (IOM Report TM/04/06).

A3.2 WORKPLACE DESCRIPTIONS

A3.2.1 Nickel Refinery 1

A3.2.1.1 Work Areas

This nickel refinery produced nickel metal and nickel compounds by recovering elemental nickel from nickel matte using an electrolytic process. The granulated nickel matte from the smelter was ground in ball mills in a wet grinding process. The ground matte was leached in a sulphate-based liquor recycled from the nickel electro-winning process. Nickel sulphide matte was leached in an atmospheric leaching stage using oxygen or air-sparged in leaching vessels with the aid of copper ions. Dissolved iron was oxidised to form iron oxide, which precipitated out and was removed from the process. The residue from the atmospheric leaching was passed to a pressure leaching stage where the nickel content was dissolved and copper precipitated out as copper sulphide. The nickel solution from the atmospheric leaching process was purified by solvent extraction to remove cobalt and other impurities. The purified solution was pumped to the three different production areas: the electro-winning process, the hydrogen reduction plant and the chemical plant. Each of these areas produced different nickel products as detailed below:

Production Plant	Product
Electro-winning	Nickel metal cathodes
Hydrogen reduction	Nickel briquettes
Chemical plant	Nickel sulphate hexahydrate Nickel hydroxycarbonate (powder, paste, or granules)

The workplace conditions and working practices are described in detail for the main process areas in the following sections:

Leaching plant

In the leaching plant, nickel was leached into a solution of nickel sulphate using sulphuric acid and the purified solution was pumped to the three different production areas. The operation of the leaching plant was highly automated.

Electro-winning plant

There were three interlinked halls containing the electrolytic tanks used to recover nickel from solution. There were approximately 10 workers per shift within the tank room area directly involved with the electro-winning process. The process can be divided into two sections: (a) production of starter sheets and (b) production of the main nickel cathodes. Starter sheets were produced using tungsten sheets as cathodes, which were placed into electrolytic tanks containing nickel sulphate solution. Nickel was deposited onto the cathodes and after two days the plated tungsten sheets were removed. Loading and unloading of the cathodes was done using a travelling crane, with the assistance of two to three operators who manipulated the load as it was being loaded or unloaded. The plated starter sheets were washed down with water and transferred to the stripping machine which separated the nickel plate from the tungsten sheet. This was a semi-automatic process and involved two workers who supervised the loading and unloading of the machine conveyors. The tungsten sheets were re-used and the nickel plates were transferred to the main process area where they were used as starter sheets for electrolytic recovery of nickel in the main tank room area. The workers who handled the starter sheets were known as cathode 'strippers'. It was usual practice to rotate around the various tasks in this area so that the time in the tank room area was reduced.

The starter sheets were configured as nickel cathodes on the cathode machine. This was another automatic process, supervised by one or two workers. The machine trimmed the nickel plates to size and fixed a copper electrode bar to one end of each plate. The resultant cathodes were loaded onto racks and then placed into the process tanks using an overhead crane in a similar manner as the stripping area. The workers in this main tank house area were known as cathode 'lifters'. Again, it was usual practice for workers to rotate around tasks in order to limit the time spent in the tank area. The cathodes were left in the tanks for seven days and were removed, washed down and then transferred to the cathode cutting area in a different part of the plant.

The tank house was provided with forced ventilation comprising a series of fresh air input vents mounted along the walls on either side of the central part of the tank house. The ventilation for the other areas was provided by under-floor fresh air input vents. This arrangement depended on the incoming fresh air to dilute the airborne nickel aerosol and to induce an upward flow of contaminated air which was discharged via passive roof vents.

There was no local exhaust ventilation applied to the electrolytic process tanks. Instead, potassium lauryl sulphate (CAS 4706-78-9) was added to the electrolyte, which formed a foam blanket over the surface of the tank. This was intended to suppress emission of nickel aerosol into the workplace. Nevertheless, there was a visible haze and a strong odour in the tank room environment. All workers in the tank house were required to wear an air-assisted filtering visor with P3 filter element (Willson Turbovisor). The workers wore cotton overalls and coated rigger gloves. New gloves were worn at the start of each shift. Gloves were worn continuously in this area due to the risk of cuts from contact with sharp metal surfaces and also due to the corrosive nature of the process liquor.

Cathode cutting plant

The nickel metal cathodes were transferred from the tank house to the cathode cutting area on pallets by fork-lift trucks. The cathodes were cut up into small squares, which was the final product and these were packed into steel drums for dispatch to the customer.

Hydrogen reduction plant

The task of interest in this area was nickel briquette production. Nickel powder was produced by adding ammonia and ammonium sulphate to the purified nickel sulphate solution in an enclosed process. The mixture was reduced in an autoclave using a hydrogen atmosphere. Nickel briquettes were then produced by a totally automated sintering process, which used the nickel powder as a feedstock. The nickel briquettes were transferred from the output stage of the sinter machine while they were still hot, on a series of conveyors to the packaging area.

Chemical plant

The chemical plant used nickel sulphate solution to produce nickel sulphate hexahydrate and nickel hydroxycarbonate. The chemical reactions and transfer of compounds to the packing area was entirely automatic and completely enclosed. The packing area was highly automated with modern robotic packing and bag handling equipment. The nickel compounds (nickel sulphate hexahydrate and nickel hydroxycarbonate) were packed into 25 kg sacks using this equipment and there was no manual involvement with the bag filling operation. The 25 kg sacks were automatically stacked onto pallets by robotic arm and the pallets were automatically shrink-wrapped before being conveyed through to the warehouse area.

Nickel hydroxycarbonate in powder, paste or granular form was also packed into big-bags at a number of fill points. The big-bag filling operation was a fully contained system, with tight fitting joints to the bag spouts. The powder products were allowed to settle in the bags before

they were uncoupled from the system and each unit was fitted with extract ventilation as a means of controlling dust emissions into the workplace.

A3.2.1.2 Job Descriptions

Leaching Operators

Three full time operators were involved with controlling the process, mainly from within a control room. It was necessary for the operators to carry out routine inspection of the plant and carry out various cleaning tasks. Their tasks included regularly checking of pumps via the controls panel (every 15 minutes) and examination of the filters in the filter press area. The filters were part of the purification process and removed suspended particulate matter. These filters required regular checks and manual clearance of the deposited material, e.g. by tapping the filter elements to remove the cake or sometimes a large metal rod was used to remove the iron-cake build-up from the filters. The surfaces in the leaching area, particularly around the filter press, became quite contaminated with nickel sulphate residue and were hosed down regularly (4-20 times per day) to remove any residual contamination from the floor and work surfaces. There were hygiene procedures in place for accessing the control room, involving changing of footwear, outer clothing and hand-washing before re-entry to the clean areas.

Leaching operator 1

He spent most of his time within the first session in control room from where he inspected the workings of the pumps and filters via the control panel. During the second session he inspected the process from the control panel and spent some time hosing down the floor. During the final session he again spent most of his time inspecting the process with 30 minutes spent shovelling nickel sulphate matte was the floor. Sessions 1, 2 and 3 lasted 3, 2.5 and 3 hours, respectively. The worker did not smoke and he had very light stubble. He wore standard PPE for this area – hard hat, coveralls, boots, red-rigger gloves and an air-assisted face visor.

Leaching operator 2

He stayed mainly in the control room throughout work sessions 1 through 3 where he inspected the workings of the pumps and filters every 15 minutes. He washed his hands once during the first session. During the third session he spent some time hosing the floor. Sessions 1, 2 and 3 lasted 3, 2.5 and 3 hours, respectively. The worker did not smoke; he had short facial hair. He wore PPE – coveralls, boots, red-rigger gloves and an air-assisted face visor.

Leaching operator 3

He stayed mostly in the control room but also did some cleaning of leaching filters. He used a large metal rod to remove iron cake from the filters. During session 1 he spent 25 minutes emptying a filter, and 25 minutes washing the floor. He washed his hands once during this first session (40 minutes before dermal sample collection). The rest of the time was spent in the control room. During the second session he spent half his time on the shop floor checking the process and the rest of the session in the control room. There were some problems with the process so he conducted some maintenance of the process (2 hrs) with the help of contractors during the final session. Sessions 1, 2 and 3 lasted 3, 2.5 and 3 hours, respectively. The worker did not smoke; he had short facial hair (goatee). He wore PPE – coveralls, boots, red-rigger gloves and an air-assisted face visor.

Cathode Lifter

The cathode lifters worked in the electro-winning plant within the main tank-house area. The cathode lifting area was very dirty with damp residues of nickel sulphate on surfaces. Nickel was present in two forms - as nickel plated cathodes and as nickel sulphate solution contained within large tanks. The temperature of the plates was $>60^{\circ}\text{C}$. It was an open system. Cathode

lifters' tasks primarily involved handling the controls of travelling cranes which moved bars or plates around - onto racks or into tanks containing nickel sulphate solution. Sampling was performed at the end of each of three sessions. Sessions 1, 2, and 3 lasted 3, 2 and 3.5 hours, respectively.

Cathode Lifter 1

He was operating the cathode machine. It trims the nickel cathode plates and places copper electrode bars onto the cathode. This is called cathode lifting. He frequently moved between the machine and the shop floor. He spent every session lifting cathodes using the cathode machine. He had not washed his hands during the first session. However, during the second session he stopped for lunch (35 minutes), prior to which he washed his hands. He also washed his hands at the end of session 2. The worker did not smoke and did not have facial hair. There were noticeable bits of powder at his wrists during sampling at session 1. He wore standard PPE for this area - hard hat, cotton coveralls, boots, coated rigger gloves and an air-assisted face visor.

Cathode Lifter 2

He remained at the same task all day - lifting plates from production cells using a travelling crane. However, during the second session he stopped for lunch (35 minutes), prior to which he washed his hands. He also washed his hands at the end of session 2. The worker smoked had facial hair (beard) and kept his nails short. He wore standard PPE for this area – hard hat, coveralls, boots, coated rigger gloves and an air-assisted face visor.

Cathode Lifter 3

He remained at the same task all day - lifting plates from production cells and changing filter bags. However, during the second session he stopped for lunch (35 minutes), prior to which he washed his hands. He also used a pole of hose. The worker did not smoke, did not have facial hair and kept his nails short. He wore standard PPE for this area – coveralls, boots, coasted rigger gloves and an air-assisted face visor.

Cathode Stripper

The cathode strippers worked in the electro-winning plant within the main tank-house area. It was a very dirty area with damp residues of nickel sulphate on surfaces. Cathode strippers produced starter sheets i.e. nickel-plated tungsten sheets. The cathode strippers operated travelling cranes that loaded tungsten sheets into an electrolytic tank containing nickel sulphate and unloaded the finished nickel-plated tungsten sheet. The loading and unloading of these tungsten based sheets was assisted by operators who handled the sheets. The nickel-plated sheets were washed down with water and transferred it to a stripping machine which separated the nickel plate from the tungsten sheet. This was a semi-automatic process and the workers supervised the loading and unloading of the machine conveyors. The temperature of the plates was $>60^{\circ}\text{C}$. It was an open system. Dermal and oral sampling was performed at the end of each of three sessions. Sessions 1, 2, and 3 lasted 3, 2 and 3.5 hours, respectively. Generally they took a 30 minute lunch break during the second session.

Cathode Stripper 1

He was operating the crane that lifts starter sheets from electrolytic tanks containing nickel sulphate solution. He spent most of the time during all three work sessions working at the stripper machine. He washed his hands once during the first session and twice during the second session – once just prior to taking a 35-minute lunch break and once at the very beginning of the last session. The worker smoked but washed his hands before smoking. He had no facial hair. He wore standard PPE for that work area – coveralls, boots, coated-rigger gloves and an air-assisted face visor.

Cathode Stripper 2

During the first session he was operating a crane removing starter sheets in tank room. He washed his hands once during this session. He spent the other two sessions working at the stripping machine. He took a 30-minute lunch break within session 2. The worker smoked but washed his hands before smoking. He had short facial hair. He wore the standard PPE for this area – coveralls, boots, rigger gloves and an air-assisted face visor.

Cathode Stripper 3

During the first session he worked at the stripping machine. He washed his hands once during this session. He spent the other two sessions operating a crane removing starter sheets. He washed his hands just prior to his 30-minute lunch break. The worker smoked but washed his hands before smoking. He had short facial hair. He wore PPE – coveralls, boots, rigger gloves and an air-assisted face visor.

Cutter

Nickel cathode cutting was done by three workers per shift using two different cutting machines. One worker operated the auto-cutting machine and two workers operated the manual cutting machine. In both cases the machines were fitted with lifting apparatus which loaded the cathode plates onto the input conveyors for the machines. The machines first cut the cathode sheets into strips and the operator manually lifted these out of the first stage and threw them into the next section of the cutting machine where they were chopped into squares. The output conveyors carried the nickel squares from the machine and automatically fed them into the drum containers. The manual cutting machine required additional manual involvement and the operators were mainly involved with removing waste material and troubleshooting the process. Other tasks included the transferral of stock by forklift trucks and capping of the drum containers. The process was noisy, and the operators wore hearing protection. Rigger gloves and cotton overalls were also worn. No RPE was required for work in this area. This work area was very dirty. The output was 10 tonnes of nickel packed in total for the day. The contaminant may be in the form of solid plates or poles. Sessions 1, 2 and 3 took 3, 3 and 2 hours.

Cutter 1

He was cutting nickel using an automatic machine. He stayed on this task throughout the day. During session 2 the machine broke down for 1 hour. The worker smoked; he had short facial hair and wore spectacles. He wore PPE – hard-hat, coveralls and boots and grey-rigger gloves. He did not use RPE.

Cutter 2

He was cutting nickel using a manual cutting machine. He stayed on this task throughout the day. The worker did not smoke; he had short facial hair and wore spectacles. He wore PPE – hard-hat, coveralls and boots and grey-rigger gloves. He did not use RPE.

Briquette Packers

Briquette packers worked in the hydrogen reduction plant. Nickel briquette production was supervised by two workers per shift and their main function was to monitor the process from a control room and carry out movement of stock by forklift truck. The briquettes were packed into 1000 kg flexible intermediate bulk containers (FIBC) known as ‘big bags’, or 200 kg drums, and the workers were simply involved with loading the fill point with the empty container and waiting until it was filled. The full containers were sealed and transferred to the warehouse area using a forklift truck. The sessions 1, 2 and 3 lasted 3.75, 1.5 and 2.75 hours, respectively. The

two workers wore the standard cotton overalls with rigger type gloves, when required. No RPE was required for work in this area.

Briquette Packer 1

During session 1 he loaded briquettes into sacks – placing bags for filling, followed by tying up 30 big bags of briquettes. During the second session he used the forklift to pack 16 big bags. He had washed his hands at the beginning of the second session. During session 3 he packed 6 2-tonne bags. He had washed his hands about one and a half hours prior to sampling. The worker had facial hair (a short moustache), smoked and wore spectacles. He wore standard PPE for this area – coveralls, boots and red rigger gloves.

Briquette Packer 2

His tasks were the same as briquette packer 1's. He had no facial or head hair; he did not smoke and wore spectacles. He wore standard PPE for this area – coveralls, boots and red rigger gloves.

Chemical Packers

The chemical packers worked within the chemical plant. The work area of the chemical packers was very clean. The process was automated and the sources were generally contained except for when it was breached for QC sampling. The workers were required to supervise the machinery and correct any faults that developed. They had only incidental contact with the packing equipment and final products. There were four workers on one day shift. All of the workers in the chemical plant wore air assisted filtering visors, cotton overalls and rigger type gloves. The workers returned to the main control room area when they were not required to directly observe the process. There were hygiene procedures in place for entering the control room, involving removal of work footwear and outer clothing, with hand-washing prior to accessing the clean areas. The sessions 1, 2 and 3 lasted 2.5, 2.5 and 2.0 hours long, respectively

Chemical Packer 1 – Filling

He filled large sacks (500 kg) with nickel hydroxycarbonate 'paste'. The work involved removing the spout of the big-bag from the filling nozzle, which was tied up with the cord provided. An empty bag was attached to the filling nozzle and the full bag was transferred to the warehouse area by forklift truck. The forklift truck had an enclosed cab. During the bag replacement task, there was some noticeable spillage of powder onto the surface of the container, but this was a minor amount. He also took a small sample of powder (100g) for quality control using a scoop. Generally, the process was fully contained except for scooping of the 100 g sample for QC. The QC sample was placed in a tin. During the first session he packed 5 500-kg bags of nickel hydroxycarbonate paste and half tonne of powdered nickel salt. He collected the QC sample during this first session. During the second session he packed 2 500-kg bags of nickel hydroxycarbonate paste. In the final session he filled 0.5 tonne bags with nickel hydroxycarbonate powder. There were some problems with the robot packer during this last session and he had some involvement in machine repair work. This involved replacement of a pneumatic cylinder and considerable time was spent preparing the machine for production. The worker did not smoke and had short facial hair. He wore standard PPE – coveralls, boots, red-rigger gloves and air-assisted filtering visors.

Chemical Packer 2 – Monitoring packing line

He was ensuring that the 25-kg bag nickel sulphate line ran smoothly. His tasks included loading up the pallets, removing old bags and adding new bags to the line. The process was fully enclosed. During session 1, he packed 7 tonnes of nickel sulphate. He had washed his hands at the beginning of the session, approximately 2.5 hours before dermal monitoring

Sessions 2 and 3 were more or less repeats of session 1. He washed his hands at the beginning of these sessions also. The worker did not smoke; he wore spectacles and had short facial hair. He wore PPE – coveralls, boots, yellow-rubber gloves and an air-assisted filtering visor.

A3.2.2 NICKEL REFINERY 2

A3.2.2.1 Work Areas

This nickel refinery produced nickel metal and nickel powder products using the Mond process, i.e. by decomposition of nickel from nickel carbonyl gas. This study relates only to the nickel powder production area. The company produces a variety of nickel metal powders. At the time of survey, three types of nickel powders were being produced. These were known as type 123, type 210 and type 255 powders. Type 123 Powder is a high purity nickel with fine, discrete particles in the size range 3.0 – 7.0 µm. The type 210 powder was an extra-fine nickel filamentary metal powder with a three-dimensional chain-like network of extra-fine particles in the range of 0.5 – 1.0 µm. The type 255 powder is also a chain-like filamentary powder, but with larger individual particles, which were in the size range 2.2 – 2.8 µm. Nickel carbonyl was produced by heating the nickel concentrates in the presence of carbon monoxide in a series of rotary kilns. The nickel carbonyl was maintained in gaseous phase and by controlling the thermal conditions the gas was decomposed to form nickel powders of a uniform particle size range. The nickel carbonyl production and decomposition processes were all fully contained due to the highly toxic nature of the gaseous chemicals. The chemical decomposition of nickel carbonyl occurred in a series of reaction chambers known as decomposers

The nickel powder was transferred from the decomposer hopper to the powder packing stations through a series of conveyors to storage and automatic weigh-cells. RPE was provided in the form of air assisted filtering visor fitted with P3 filter. While it was a mandatory requirement to use the RPE during packing work, this was not always adhered to. All packing operators wore cotton overalls, safety boots and rigger-type gloves. Glove use was regular, but generally only when carrying out manual handling tasks, e.g. lifting drums onto the conveyors. There was potential for skin contact with contaminated surfaces when touching handrails, driving the fork lift truck and operating buttons on control panels.

A3.2.2.2 Job Descriptions

Powder Packers

At the powder packing area one operator (per shift) was involved with packing type 255 nickel powder into drums. In a second area known as the Dec 2 powder packer, a second worker was involved with packing type 210 nickel powder, also into drums. The tasks for each operation mainly involved ensuring the semi-automatic powder packing stations were supplied with the necessary empty drums. The workers took the drums from storage and placed them onto the input conveyors for each of the packing machines.

Powder Packer type 255

At the 255 powder packer, the drums would move through the packing machine, which would dispense a measured quantity of nickel powder into the container. The operator checked the drum weights using the scale built into the conveyor. If the drum weight needed to be adjusted, the operator removed excess powder using a hand scoop and placed the surplus material into a storage bin located at the workstation. If any of the drums needed to be topped up, the operator used the scoop to transfer powder from the storage bin to the drum. Each packing station was provided with local exhaust ventilation at the filling points so that any airborne dust generated

was effectively controlled. Each drum was fitted with a lid which had a small diameter aperture (approximately 100mm), through which it was filled. As the drums passed through the packing machine they entered an enclosed booth where a robot arm was used to perform a quality control test. The drums then backed up onto the end of the conveyor system where the operator would fix the sealing cap onto the open aperture. The tops of the drums were then vacuum-cleaned to remove any residual dust and then they were lifted off the conveyor by fork lift truck and transferred to storage.

Powder Packer type 255 (Worker 1)

Sessions 1, 2 and 3 lasted 2, 4.5 and 2.75 hours, respectively. During the first and third sessions he was packing powder, however, details of how much packing he did was not obtained. During the second session he packed powder (126 x 75 kg drums). This worker had no facial hair and was a smoking (despite work rules he was observed smoking). He wore standard PPE for this area.

Powder Packer type 255 (Worker 2)

Sessions 1, 2 and 3 lasted 2.5, 1 and 5.5 hours, respectively. During the first session he packed 56 x 75 kg drums and during the third session he packed 85 x 75 kg drums. His hands were very dirty at the end of both these sessions. During the second session there was not production so he spent his time doing odd jobs in the area. This worker had no facial hair and was a smoker. He wore standard PPE for this area; however, during packing he was not wearing RPE.

Dec 2 Powder Packer type 210 (Worker 1)

The task performed by the Dec 2 powder packer was similar in nature to the main packer except that this worker was only involved with supervising one drum packing machine. The packing machine for this area was contained in a semi-enclosed booth, having local exhaust ventilation applied to it in order to prevent emissions to the general workplace area. Sessions 1, 2 and 3 lasted 2, 4.5 and 2.75 hours, respectively. During the first two sessions he packed powder. During the second session he packed powder (16 x 25 kg) and dropped powder from the decomposer. To drop powders the worker sounds the side of the cone of the hopper to ensure that all of the powder that has been discharged from the decomposer to the hopper, is discharged from the side of the hopper. During the third session he packed powder and was also driving the forklift truck. The worker did not smoke; he had facial hair (goatee & moustache) and during the final session his nails were quite dirty. He changed his coverall everyday. He wore the standard PPE for this area.

Dec 2 Powder Packer type 210 (Worker 2)

Sessions 1, 2 and 3 lasted 2, 3.5 and 4.5 hours, respectively. During the first session there was a plant shut-down and he spent his time doing odd jobs during this time. During the second session he had just started to pack powders. During the final session he packed 25 x 25 kg drums. He also spent time driving the fork-lift truck. The worker did not smoke and had no facial hair. He wore the standard PPE for this area.

Decomposer op/ 123 powder packer

The process conditions for the decomposers were monitored by one operator, who was also responsible for some powder packaging work in a separate area. The main duties for this worker mainly involved routine inspection of control panels, and actuator valves etc. When the decomposers discharged to hoppers, it was necessary for this worker to sound the side of the cone to ensure that all of the powder inside was being properly discharged. This operator also packed type 123 nickel powder into FIBC. The packing operation for type 123 powder was highly automated and well controlled. All that was required for this task was to remove the fill

point of the FIBC from the packing machine and secure the bag by tying it up with the cord provided. A fork lift truck was used to move the full bag to a warehouse area. The operator then installed an empty FIBC onto the fill station and then left the area. This changeover was done two to three times per shift. Sessions 1, 2 and 3 lasted 2, 3.75 and 5.5 hours. During all sessions he was dropping powders from the decomposers. In addition to this, during the second session he changed one big bag of type 123 powder and during the final session he changed one big-bag of waste powder product, and filled 6 drums with type 123 powder. The worker did not smoke. He wore standard PPE for this area.

A3.2.3 NICKEL REFINERY 3

A3.2.3.1 Work Areas

This nickel refinery produced nickel metal and nickel chloride hexahydrate crystals by recovering elemental nickel from nickel matte in a hydrometallurgical process. While it was only the nickel chloride crystals packing workers that were identified for sampling, a number of other workers were included since they were also potentially exposed either to nickel chloride solution, nickel metal or nickel matte. The workplace conditions and working practices are described in detail for the main process areas as follows:

The nickel matte was stored in stockpiles in an indoor warehouse and transferred to loading silos using a mechanical loader. The driver of the loader was located in a closed cabin with filtered air supply and did not ordinarily come in contact with the raw materials except when he needed to collect a raw material sample. The nickel matte was crushed and then added to reaction vessels. The raw material grinding and transfer process was fully automatic and one operator per shift carried out regular checks on the equipment.

The nickel leaching process is done by sparging the nickel matte suspension with chlorine gas. This caused the nickel, lead and cobalt to be leached into solution and converted to metal chlorides. The liquor was purified by removing the cobalt, lead, manganese and other impurities and the high purity nickel chloride solution was pumped to storage vessels. The leaching and purification processes were automatic and the process conditions were monitored and controlled from a remote control room.

The nickel chloride solution was pumped to the electrolysis tanks where nickel metal was collected onto starter cathodes. The electrolysis process liberated chlorine gas at the anode so a very high standard of control was applied to the tank emissions. There was no noticeable odour of chlorine gas and little evidence of liquid spillage from the tanks. There were two or three operators in the electrolysis area who were involved in inspecting, lifting and rinsing the finished nickel cathodes. All the cathode handling tasks were done by mechanical methods and the workers wore PVC coated protective gloves and overalls. There was no requirement for respiratory protection in the electrolysis area.

The purified nickel chloride was converted to nickel chloride hexahydrate crystals by an automatic, enclosed process and the crystals were stored in high level silos. The crystals were transferred to the packing station via a weigh cell that measured out the correct quantity of material to be packed. The crystals were dispensed into 25 kg polyethylene sacks within an enclosed packing machine. This process was highly automated, although three operators per shift were required to monitor the equipment, rectify any problems that occurred and to move stock around the plant by fork-lift truck. The bags that were filled by the machine were manually stacked onto pallets or into 1 tonne capacity cardboard boxes.

Although the packing machine was designed as a fully mechanized and enclosed system, there were a number of mechanical faults that caused spillages from the sacks and airborne dust to be released to the workplace air. The workers had to deal with these problems as best they could, which resulted in frequent contact with contaminated surfaces. In the majority of cases the workers wore lightweight disposable nitrile protective gloves. However, some of the workers did not wear gloves and there were visible deposits of nickel chloride crystals on the hands of these workers.

During the survey some essential maintenance was carried out on the dust extraction equipment fitted to the packing machine. During this time the packing plant was taken out of service and no dermal sampling was carried out. The maintenance work that was carried out on the packing machine was done by external contractors and these workers were not monitored.

A3.2.3.2 JOB DESCRIPTIONS

Nickel chloride packers

The nickel chloride packers packed nickel chloride hexahydrate using an automatic, fully enclosed packing system. The packing unit was regularly breached for trouble shooting. The contaminant was in the form of medium-grained crystals and at a handling temperature of <60°C.

Nickel chloride packer 1

He packed 450 25-kg bags in total during the entire shift. He used a knife and a manual sewing machine to handle the bags. The packing system was breached regularly for troubleshooting. Sessions 1, 2 and 3 lasted 3.75, 2.5 and 2 hours, respectively. During the first session he packed 190 bags, during the second and third sessions he packed 130 bags. The worker did not smoke. He had facial hair. He wore PPE – coveralls, boots and gloves. He sometimes wore disposable RPE. His hands had a slightly green tinge possibly from contact with the nickel chloride.

Nickel chloride packer 2

Sessions 1, 2 and 3 lasted 2.5, 2 and 2 hours, respectively. During the first session he packed 250 bags, during the second session he packed 80 bags. He did some packing in the third session also, however the amount packed is not known. The worker did not smoke. He had no facial hair. He wore PPE – coveralls, boots and gloves (sometimes during bagging).

Nickel chloride packer 3

Sessions 1, 2 and 3 lasted 2.5, 2 and 2 hours, respectively. During the first session he packed 330 bags. He spent the other two shifts doing maintenance work on the packer. His hands had a slight greenish tinge by the end of session 3. The worker did not smoke, had no facial hair and he wore PPE – coveralls and boots.

Raw Material Handler

The raw material handler monitored the material in the raw material area. The area was very dirty. Their tasks may involve driving a loader and shovelling to sample the raw materials. The sampling may involve visual checks and chemical analyses. There was usually direct contact with the raw material. It was an open process. Duration of any actually handling of the raw material was about one hour in an eight hour shift. Sessions 1, 2 and 3 lasted 2.5, 0.5 and 5 hours, respectively. During session 1 he was driving a mechanical loader in the materials store. During session 2 he sampled the raw materials and during session 3 he was charging sulphur. The worker did not smoke; he had no facial hair and his hands were very dirty. He wore PPE – coveralls and boots and gloves. He sometimes wore disposable RPE.

A3.2.4 POWDER METALLURGY

A3.2.4.1 Work Areas

The company included in the powder metallurgy category was involved in the production of various types of magnets, including AlNiCo magnets. These magnets were small devices weighing only a few grams, which were used in automotive instrumentation and mobile phone technology. The magnets were produced using a mixture of metal powders including nickel powder. The rough outline of the magnet was produced by first compressing the powder mixture using a mechanical press and these items were then sintered in a furnace, machined to size and then magnetised. The front end of the process involved weighing out batches of metal powders and other ingredients into batch containers, which were used to feed each of the presses. The batch container was slung above a hydraulic or mechanical press and the powder was fed into the input hopper by gravity. The powder passed through the feed and entered into a series of rotating dies and the compressed powder parts were ejected into a tray. The preparation and setting of the machine was a skilled job, carried out by 1-2 setters each shift. However, once in operation the presses required only minimal supervision.

A3.2.4.2 Job Descriptions

The jobs that involved some contact with nickel powders or nickel dust were identified as follows:

- Nickel powder operator – weighed out nickel and other metal powders into batch containers
- Setters – Loaded the powder mixtures to the presses, prepared and monitored the mechanical presses for each production run
- Grinding machine operators – Set up and monitored the grinding machines.

Nickel Powder Operators

The powder operator was involved with weighing out batches of powders and this was done inside a ventilated booth. The operator scooped out the powders from drums mounted on a carousel located within the booth. The powder was weighed and manually dispensed into a hopper. Once the batch was weighed out the hopper was transferred to the blender, which was located in a separate enclosed cabinet. The hopper was attached to the blender using a close fitting coupling and an empty batch container was fitted to the machine at the other end to collect the powder material after blending. The doors to the enclosure were shut and the blending machine was allowed to operate, during which time the powder was dumped to the empty batch container. On completion the operator simply removed the container from the machine and transferred this to the storage area. Preparation of nickel powder batches was reported to be slow at the time of survey due to the relative low demand for the AlNiCo magnets. It was reported that 2-3 batches of about 150 kg of powder (each containing about 20 kg nickel powder) would be prepared each week. Sessions 1, 2 and 3 lasted 2, 2.5 and 5 hours, respectively. During the first session he prepared raw materials for the process. During the second session he prepared 2 x 150 kg batches and during the final session he transferred AlNiCo load from the mixer to the storage area. The worker had no facial hair and did not smoke. He wore heavy-duty cotton work gloves and a filtering facepiece respirator. Since the work was not carried out frequently the gloves were reused over different days. However, a fresh respirator was used for each shift.

Setters

The setters would monitor the performance of the presses in operation, while they set up other presses for subsequent batch runs. This involved mechanical disassembly of the dies and other components that were in contact with the nickel powder. Consequently, there was potential for contact with nickel powder residues during this work. The residual powder on the machine was vacuumed up during the setting up of the press machine. The setters wore disposable lightweight nitrile gloves for the majority of time when carrying out the setting work. However, these gloves often split or were removed to perform certain delicate tasks requiring an enhanced level of dexterity. During this work it was noted that the hands of the setters would become visibly contaminated. Filtering facepiece respirators were worn from time to time but this was not mandatory for the general setting procedure.

Setter 1

Sessions 1, 2 and 3 lasted 2, 2.5 and 5 hours, respectively. He spent all three sessions setting up a machine. His main tool was a screwdriver. He also used a brush and dust-pan at times to clean up residual powder from the machinery. He had regular contact with the residual powdered contaminant. He had no facial hair, long shoulder-length hair on his head. He was a non-smoker. He wore coveralls, boots, and latex gloves.

Setter 2

Sessions 1, 2 and 3 lasted 1.75, 3 and 1 hours, respectively. He spent the first session stripping parts from the press machine and began re-setting it. He then spent some time monitoring the press machine. The second session was spent setting up a press machine. During the 3 session he completed the setting up of the press machine and added powder to the machine using a scoop. The hopper was not used since it was a small run. He had no facial hair, long shoulder-length hair on his head. He was a non-smoker. He wore coveralls, boots, and latex gloves. Gloves were worn during session one only.

Grinding machine operators

There were three grinding machines used during the survey, each having a different operator in attendance to set up and monitor the production conditions. Setting up the machine was a skilled operation, involving disassembly and adjustment of the grinding heads. However, once in operation the task mainly involved routine checking of sample sizes using a micrometer with occasional clearing of blockages in the machine's input and output feeds. The grinding machines used a metal cutting fluid so the surfaces of the machine and AlNiCo parts were always wet. The grinding machine operators wore thin nitrile gloves from time to time, depending on the tasks that were being carried out, but these were mainly to protect the skin from contact with the metal working fluids rather than the nickel containing parts. Sessions 1, 2 and 3 lasted 1, 2 and 2 hours, respectively. He spent all three sessions supervising the operation of the grinding machines, taking periodical checks on sizes of parts using a micrometer. The worker had no facial hair; he was a smoker and did not wash his hands before smoking. He did not wear gloves during any of the work sessions.

A3.2.5 SECONDARY LEAD SMELTER

A3.2.5.1 Work Areas

This company produced lead ingots by smelting and refining lead concentrates and lead scrap. This company had hygiene procedures in place to prevent contamination of personal clothing, and eating and drinking areas. This comprised dedicated washing and showering areas, clean rest zones and a daily supply of clean work clothing. The company also carried out medical

surveillance of the workforce, comprising regular lead in blood testing, supervised by a company doctor. This company was surveyed in year 2004. All workers are provided with clean overalls, safety boots, hard hat, rigger-type gloves and an air assisted filtering visor. The supplied RPE was a Kemira Pro-Flow 2 visor connected to a belt mounted power pack fitted with twin A2B2E2K2P3 filter cartridges. The general gloves used in the plant were Oldenburg CE Cat 2 EN388 rigger gloves.

Raw Material Handling

The raw materials for the smelting process resulted from recycling of lead batteries and other lead products and the concentrates consisted of a wet dross material. The raw materials were unloaded from barges at a jetty area (concentrates) or from railway wagons (lead scrap). This was done using a crane and grab. A small mechanical 'Bobcat' loader was also used in the hold of the ship to scrape up the remainder of the concentrate into piles so that it could be collected by the crane. The material was transferred by means of a conveyor belt system to open silos within a large storage area and these materials were taken to the blast furnace by mechanical loaders.

Smelting

In this process stage the lead concentrates were reduced in a furnace to lead metal, which was tapped off at the bottom of the furnace in a continuous outflow. The smelting process was monitored from a remote control room area and there was no manual involvement except during maintenance work. The control area was a clean zone, with no requirement to wear protective clothing or RPE. However, the operator was required to don this equipment when leaving the area to carry out inspections.

Refining and casting

The molten lead was transported in crucibles by travelling crane to the refinery area where it was treated with sulphur to remove copper and other unwanted metal elements. The purified lead was then cast into ingots using an automatic casting machine. The raw molten lead arrived at the refinery area in transport vessels, and was transferred to the first reaction vessel. The lead was pumped from one refining stage to the next in a semi-enclosed system. Since the lead was maintained fairly close to its melting point during most of this procedure, potential for exposure was related largely to the various drossing operations. These occurred about once per shift, and when the reaction was complete. The duration of each drossing task was less than one hour, and the amount of waste (i.e., secondary raw material) generated was several hundred kilos. The molten lead was alloyed with other metals to provide the correct customer specification. This was done by tipping solid ingredients into the holding tanks and stirring with long-handled tools. The molten lead was then fed to an automatic casting machine where robotic arms were used to skim off the molten metal and manipulate the ingots onto the automatic conveyor system. The use of gloves was required in this area in view of the high temperatures, and the use of RPE was mandatory. There was no direct manual contact with process materials for this operation, although workers would come into contact with contaminated surfaces and contaminated clothing when the gloves were removed.

Maintenance

There were a number of maintenance workers involved with servicing equipment and mobile plant. These workers were included in the sampling survey because they were involved with dusty tasks and had significant potential for exposure. These workers' exposures were variable due to the intermittent direct contact associated with the work.

Quality Control

There were three quality control technicians who were responsible for collecting samples of raw and process materials and were involved with preparation and analysis of these samples. Tasks such as milling and sieving of dust samples were carried out, which resulted in some potential for exposure. The QC technicians were sometimes stationed in an enclosed office adjoining the analytical area and spent some of their time there using PCs. The analytical area was moderately clean.

Gatehouse

One additional worker was included in the survey in order to gauge background levels for those not directly involved in production work. This worker was the security/gate controller for the plant. Although this worker was located far off from the main production areas, there was potential for some exposure due to the frequent movement of trucks, which could raise airborne dust, possibly containing residual levels of lead.

A3.2.5.2 Job Descriptions

Raw material operator

There were two to three workers involved with the unloading operations, which occurred approximately once per week depending on production rates. Final manual shovelling of the concentrate was necessary in order to fully recover the concentrates or lead scrap from the ship and wagons. In addition, the conveyor system needed to be kept free of blockages and the workers were involved with routine inspection and clearance of the transfer points. During the course of the monitoring survey one of the conveyor points became badly blocked and there was extensive manual shovelling of the concentrates for a major part of the shift. Since the latter work was not representative of routine operations, the exposures encountered under these conditions may be considered to reflect worst-case conditions. The area of the raw material operators was very dusty. They wore respirators but filters became very dirty. They used forklift shovels, trucks, cranes or bobcats to transfer material. The material was coarse-grained lead concentrate and battery metallics. The main task conducted was unloading a ship using a crane and shovels.

Raw material operator 1

During session 1 he was driving forklift truck (1.5 hours), shovelling concentrate and clearing blockages from around a conveyor belt system used to transfer raw material from the dock area into the process building (2 hours). Heavy duty gloves were worn during shovelling and cleaning. He spent all of session 2 shovelling concentrate and all of session 3 driving a small bobcat pushing battery oxide. Sessions 1, 2 and 3 lasted 3.5, 1.5 and 3.5 hours, respectively. The worker was a non-smoker; he had a moustache and some facial stubble. He had longish hair and side burns. He wore PPE – coveralls, boots gloves and filtered RPE.

Raw material operator 2

During session one he was shovelling and clearing lead concentrate blockages from the conveyor belt system. During session 2 his main task was unloading shredded battery metallics from the railway wagon. This was followed by manual shovelling. Session 3 was spent unloading shredded battery metallics from a railway wagon using a crane. Sessions 1, 2 and 3 lasted 3.5, 1.5 and 3.5 hours, respectively. He was a smoker.

Raw material operator 3

His role was primarily supervisory. The first two sessions were spent helping and supervising the cleaning of the conveyor belt system. During session 3 he was observing and controlling

operations in the weighing port area. This was a semi-enclosed space. Sessions 1, 2 and 3 lasted 3.5, 1.5 and 3.5 hours, respectively. The worker was a non-smoker and had facial hair.

Raw material operator 4

He was the crane operator for the ceiling of raw material storage area. He spent all three session working inside a ventilated cab and was isolated from the contaminated environment except when leaving the area to check on the work. He had no direct contact with raw material. He was a non-smoker. There was no break during the first session so the first and second sessions are combined. The duration of the first two sessions was 4 hours. The final session was 3.25 hours.

Furnace operator

The furnace operators worked mainly in the furnace area (see Work Area: Smelting) but also spent time in the raw material handling area. In the raw material area they transferred metallics using forklifts. This material was loaded (slit open and dumped) onto a raw material conveyor belt. The furnace operators also conducted routine checks on the emission filter systems in the furnace area. The potential for exposure in the furnace area occurred mainly at the end of the process, where the slag was removed from the furnace aperture (slagging) and where the molten lead was tapped off into the holding crucibles. The two workers involved with these tasks were provided with thermal protective clothing and wore RPE at all times. Three out of the four workers in this area were involved with various maintenance tasks, including cleaning out the air emission control equipment, which left them visibly very dirty. Furnace operators wore normal work clothes as well as PPE - face mask, gloves

Furnace operator 1

This operator spent all of his time in the control room. It was not required that he wear PPE when within the control area but had to put it on when he went out of the control room to do inspections. Sessions 1 and 2 together lasted about 3.5 hours. The last session lasted 4 hours

Furnace operator 2

He spent the first session doing routine control checks on the emission filter systems in the furnace area. He spent the second session doing maintenance of filter system emissions (electrostatic). For this he wore tyvek coverall, gloves, and hood (but there was heavy leakage through gaps in the hood). His hands, arms, face and neck were quite heavily contaminated. During session 3 he transferred big bags of raw material using a forklift. He dumped the material onto the conveyor belt at raw material feed points. He had showered at the end of session 2 and was attired in normal work clothes, face mask and gloves. Sessions 1, 2 and 3 lasted 2, 2 and 3 hours, respectively.

Furnace operator 3

He spent the first session doing routine control checks on emission filter systems in the furnace area. The second session was spent using air to remove lead from a concrete channel and refurbishing the channel. For this he wore normal work clothes and a disposable mask. During the third session he spent some time in the furnace area control room. He then did some cleaning work around the conveyor belt in the raw material area at the raw material feed points. His hands, arms face and neck were quite dirty at the end of this final session. At the end of the first two sessions he was relatively clean. Sessions 1, 2 and 3 lasted 1.75, 2.75 and 3 hours, respectively. The worker had a moustache and very short hair.

Furnace operator 4

He spent the first session doing routine control tests of the emission filter system in the furnace area. The second session was spent assisting with the maintenance work on the emission

electrostatic fluctuation. The third session was spent in the raw material storage area. Here he was driving a forklift truck and unloading metallics from big bags (slitting open and dumping). Sessions 1, 2 and 3 lasted 2, 2.75 and 3 hours, respectively. The worker was a non-smoker. His face and hands were very dirty at the second session. He had very short fingernails.

Refinery operator

The workareas of the refinery were moderately clean. It was a large open area. There were several hot processes with vats of molten lead. The output area of Pb-alloy ingots was separated and cleaner than other areas. Workers almost always wore air-fed helmets in this area.

Refinery operator 1 - Monitoring Pb ingot machine

He spent most of his time monitoring the machine that produces lead ingots. The output point of the machine where lead alloy ingots were discharged was aside from the general area and was separated by a full wall with an opening, through which the conveyor with molten alloy passed. One entered this area through a door which communicated with the general area but usually remained closed. This side room was cleaner and the safety measures were more relaxed than in the general area. When not sitting observing the machine and doing quality checks of the ingots, the operator would go to the other side of the machine that was in the general area and remove the top layer of 'dross' from heated molten Pb. For each session he spent about 20% of his time removing the top layer of 'dross' (manual shimming) from heated Pb at the ingot stamping machine. For this task he used a long-handled, flat spatula-like knife. He spent the rest of his time sitting before the ingot machine regulating the discharge of Pb alloy ingots and performing visual QC checks of the ingots. This required that he briefly handle the product. Sessions 1, 2 and 3 lasted 2.75, 2 and 3 hours, respectively. The worker had no facial hair. He wore coveralls, boots and heat-resistant gloves on his busy hand (right) hand only, during monitoring of the ingot-stamping machine. When entering the general area and performing skimming of dross from molten Pb-alloy, he also wore an air-fed helmet. He did not use an air-fed helmet during machine monitoring.

Refinery operator 2

During each of the three sessions he divided his time among three different tasks - operating a crane and pumping molten lead from one kettle to another. He also spent time scraping solid lead with a shovel. Sessions 1, 2 and 3 lasted 2.75, 2 and 3 hours, respectively. The worker had some facial hair including a light moustache and longish fingernails. He wore a hard hat with air-fed hood, coveralls, boots. While monitoring Pb-alloy vat he also wore heat resistant gloves.

Maintenance workers

Maintenance workers were responsible for all maintenance from vehicles – cars, large trucks, loaders – to process equipment. Equipment and vehicles used in the process were usually cleaned prior to maintenance workers handling them. They also made up tools for the process in the workshop. They may have been exposed to residual contaminant in the form of particulates deposited on the surfaces of equipment. The maintenance workshops were moderately clean.

Maintenance Worker 1

Maintenance worker 1 never went onto the shop floor but conducted all his work from the store room, tool and car repair shop. He spent session 1 working in the store room area and did some vehicle maintenance. During session 2 he handed out tools from the store room and changed the wheel on very large truck which was a loader used in the raw materials area. The vehicle was cleaned beforehand. During the final session he worked the in tool shop and car repair shop. Sessions 1, 2 and 3 lasted 2, 2.75 and 3.25 hours, respectively. This workers' hands were very dirty and his nails longish and ragged. He also had light stubble on his face. He was a smoker.

Maintenance Worker 2

He spent the first session doing routine checks in the furnace area. The second session was spent doing repairs to the pneumatic system for vibrating apparatus in the raw materials transfer area. The third session was spent making tools in the workshop. This was mainly steel work. Sessions 1, 2 and 3 lasted 0.5, 3 and 3 hours, respectively. This worker had facial hair and was a non-smoker. During repairs to the pneumatic system in session 2, he wore a hooded tyvek suit, gloves and a visor.

Maintenance Worker 3

He spent the first session doing control work in the blast furnace area. His hands were very black and seemed oily. The second session was spent doing maintenance on transfer lines/vibrator system in the blast furnace area. He did not wear gloves and his hands were very black. During the third session he spent all his time in the tool shop, a fairly clean environment. Sessions 1, 2 and 3 lasted 1, 1.25 and 4 hours, respectively. This worker was a non-smoker.

QC technician

The QC technicians take samples and inspect the raw material used in the process. They may also take samples from different stages of the process. The nature of the contaminant to which they are exposed may vary based on its source and the procedures involved in its analysis. Tasks vary from inspection of unchanged bulk raw material, grinding raw product to smelting lead-containing alloys.

QC technician 1

He was handling a particulate form of the contaminant. He split his time between the analytical area and the office. During session 1 he was milling and sieving medium-grained coarse Pb-containing raw material samples for analysis. This resulted in the formation of a fine dry, dusty material. During session 2 he collected samples of raw material – paste and sludge – from the storage rooms. Sessions 1, 2 and 3 lasted 1, 2.25 and 3.5 hours respectively. The worker had no facial hair and did not smoke, he had fingernails. During grinding and sieving he wore disposable RPE and gloves but no hat.

QC technician 2

He was smelting metallic and lead bullion. The metal was reduced to a molten state by intensely heating. During sessions 1 and 2 he smelted metallic and lead bullion and poured the molten metal into small moulds. During the final session he collected samples (slag) off the raw material conveyor belt from the jetty area for analysis. Sessions 1, 2 and 3 lasted 1, 2.25 and 3.5 hours respectively. The worker was a smoker and does not wash his hands before smoking. He had a beard and a moustache. His PPE during sample preparation included air supply face piece and heat resistant gloves.

QC technician 3

He had a supervisory role. He worked the QC area and the jetty area. No information is available for the first session. During the second session he was organising personnel. During the final session he was conducting inspections of the jetty area and other areas. He cycled around on these rounds. Sessions 1, 2 and 3 lasted about 1, 2.25 and 3.5 hours respectively. He was a non-smoker.

Security guard

The gatehouse was situated a considerable distance (~150m) from the main buildings. It was the main thoroughfare for trucks delivering raw materials for the process. The area outside the gatehouse tended to become very dusty, particularly in the summer. Sometimes material fell off

the trucks and needed to be shovelled back on. The raw material on the trucks would usually be bits of scrap metal. The gatehouse itself was of moderate cleanliness. There were hand wash facilities and he washed his hands during the shift. Sessions 1, 2 and 3 lasted 2, 1.5 and 2.25 hours respectively. The gatehouse supervisor was clean shaven, wore normal work clothes and was a smoker. He did not shower before going home and went home with the clothes he wore on site.

APPENDIX IV – MATLAB PROGRAMME USED FOR RUNNING EXPOSURE SIMULATIONS AT TASKS LEVEL

```
load Pbsmeltermvt.dat -ascii;

for n=1:65

hours=Pbsmeltermvt(1,n); % duration of task
x2=Pbsmeltermvt(2,n); % Surface load [0, 1]
x1=Pbsmeltermvt(3,n); % Number of hand/surface contacts [0, 1]
x3=Pbsmeltermvt(4,n); % Skin moisture [0, 1]
A1=Pbsmeltermvt(5,n); % Fraction of hand involved in direct transfer
lambda1=Pbsmeltermvt(6,n); % direct contacts/hr
A2=Pbsmeltermvt(7,n); % Fraction of hand involved in indirect transfer
lambda2=Pbsmeltermvt(8,n); % indirect contact2/hr
Cs=Pbsmeltermvt(9,n); % Concentration of analyte in solid form ( w/w%)
SL =Pbsmeltermvt(10,n); % surface load ( $\mu\text{l}/\text{cm}^2$ ); no=0 low = 1.2  $\mu\text{l}/\text{cm}^2$  high = 2.4  $\mu\text{l}/\text{cm}^2$ 
Cl =Pbsmeltermvt(11,n); % concentration of analyte in liquid form (units w/v%)
dt=1; % time increment in minutes

% This is the end of the data input
-----
% PHI1,2 is the hand exposure ( $\mu\text{g}$  per unit time) on the portion of the hand that
% contacts the mouth or face for solid
PHI1 =((1.15 + 4.09*x1 + 2.73*x2 - 0.80*x3)*(10^3))*(A1*Cs);
PHI2 =((1.15 + 4.09*x1 + 2.73*x2 - 0.80*x3)*(10^3))*(A2*Cs);

% simulation for 3 hrs
tfinal = hours*60; % simulation in minutes

T(1)=0; % initial conditions
ED(1)=0; % Exposure on hand available for direct transfer at t=0
EI(1)=0; % exposure on hand available of indirect transfer at t=0

% model without transfer
for i=1:tfinal
    T(i+1)=i;
    ED(i+1)=ED(i) + PHI1*dt; %total direct exposure
    EI(i+1)=EI(i) + PHI2*dt; %total indirect exposure
end

% frequency of direct transfer (contacts/min)
lambda1=lambda1/60;

% frequency of indirect transfer
lambda2=lambda2/60; % (contact/min)

k1=0.95; % percentage removed from hand to oral
k2=0.37; % percentage removed from hand to face
k3=0.38; % percentage removed from face to oral
```

```

HSD(1)=0; % hand exposure solid available for direct transfer at t=0
HSI(1)=0; % hand exposure solid available for indirect transfer at t=0
FS(1)=0; % face exposure solid at t=0
OSD(1)=0; % oral solid exposure through direct transfer at t=0
OSI(1)=0; % oral solid exposure through indirect transfer at t=0

T2(1)=0;

for i=1:(tfinal-1)

% simulating the Poisson processes
x1=rand;
x2=rand;

if x1 < lambda1*dt
dU=1;
else
dU=0;
end

if x2 < lambda2*dt
dD=1;
else
dD=0;
end

T2(i+1)=T2(i)+ dt;
HD(i+1)=HD(i) + (PHI1 * dt) - (k1 * HD(i) * dU);
HI(i+1)=HI(i) + (PHI2 * dt) - (k2 * HI(i) * dD);
F(i+1)=F(i) + (1-k3)*(k2 * HI(i) * dD);
OD(i+1)=OD(i) + (k1 * HD(i) * dU);
OI(i+1)=OI(i) + k3*(k2 * HI(i) * dD);

end

Etot=ED(tfinal)+EI(tfinal);
Htot=HD(tfinal)+HI(tfinal);
Ftot=F(tfinal);
ODtot=OD(tfinal);
OItot=OI(tfinal);
Otots=OD(tfinal)+OI(tfinal)t;

% write results
Result(n,1)=Etot;
% Total Hand exposure available for direct/indirect tranfer if no removal processes
Result(n,2)=Htot;
% Total hand exposure available for transfer after removal at t=final
Result(n,3)=Ftot;
% Total face exposure at t=final
Result(n,4)=Otots;
% Total oral exposure at t=final;
end

```

APPENDIX V GENERAL DESCRIPTION OF THE WORKPLACES IN THE HEALTH CARE AND AGRICULTURAL SECTORS

HEALTH CARE SECTOR

The measurements from the health care sector can be split into the wards and pharmacy. In the ward three different areas were monitored: (1) a five-day unit; (2) a one day unit; and (3) the outpatient clinic.

Wards

In the five day unit, patients came in for treatment and stayed 2-5 days overnight in order to recover from their treatments. It was a large, open room that held about 15 beds, within which was the main nurses' station for the ward. The administration for the ward took place here. It was an open plan arrangement so the nurses' station was not separated from the general area that held the beds. Drug preparations from the pharmacy were delivered, checked off and placed into separate trays at the nurses' station.

At the one-day unit patients came in for treatments and were able to check out immediately following treatment. The room was very spacious and divided (though no physical barrier) into two areas - an area for the nurses' desk and an area where the patients sat to receive treatment. Behind the nurses' desk there was a counter with tea things and an under-counter fridge. There were about 8 seated treatment stations along the walls of the 1DU. Each of these was separated by a small coffee table. By treatment station is meant a large armchair (similar to a recliner). Depending on the mode of administration (via bolus or IV bag), there may be an IV pole set up beside the chair.

The outpatient clinic was similar to the one-day unit, patients received treatment and were immediately discharged. The work pace in this unit was quite brisk on the day of monitoring. The area was served by a reception area where the drugs from the pharmacy were delivered. The administration area, holding the patients records was out with the treatment area. The main treatment room was a fairly small area which held about 10 seated treatment stations.

The work areas were generally very clean. The drugs were administered either using intravenous bags or more directly using a syringe (bolus) and so were contained. Potential for exposure occurred when the IV bag was punctured and connected to the IV line, when IV bags were removed and possibly from touching potentially contaminated surfaces – patients' skin, outside of IV bags and syringes. The nurses conducted general nursing duties such as preparing patients for chemotherapy and some administrative tasks. Administering chemotherapy was only one of their duties. The different types of nursing tasks 1 – 3, are described. This is followed by a description of the tasks five different nurses conducted during the monitoring period.

Pharmacy

The pharmacy was a centralised unit which serviced a research hospital. The pharmacy area comprised a non-sterile prescription room and a newly built cytotoxic unit within the hospital pharmacy department. To enter the prescription area required the use of a disposable white hat. No gloves were required in this area. Unopened boxes of cytotoxins were stored here. The area had been previously used for drug preparation. It was a very clean work-area.

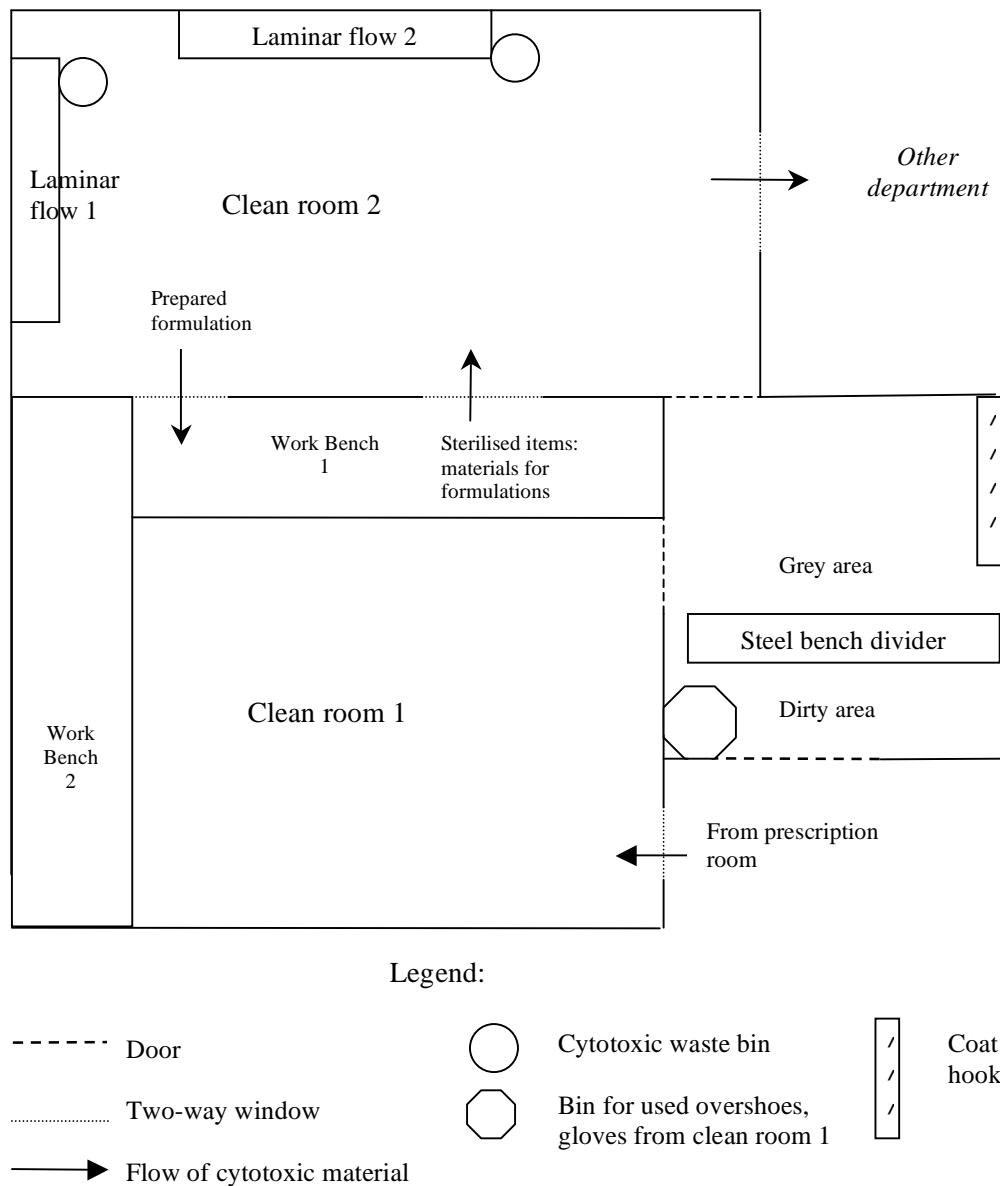


Figure A4.1 Cytotoxic unit - Work Flow

In clean area 1 of the cytotoxic unit (See Figure 1), items were put together on a tray for formulation. To enter this area the clothing required was primarily to contain cell shedding which could contaminate drugs. This included disposable hat, overshoes, blue lab coat, nitrile gloves (glove-end over end of labcoat). Labcoats were used for one week and then laundered. Hands were sterilised with sterilising gel prior to donning gloves.

In clean area 2 (Sterile room) drug formulations were prepared. To enter this area the clothing required was disposable respirator; protective sleeve (forearm); 1 pair thick non-powdered latex surgical gloves and safety glasses in addition to disposable hat, lab coat and overshoes.

Drug reconstitution was done inside a flow hood that expelled to air outside the building. The technician was also responsible for removing the garbage after each session – tying up the garbage bag and placing it into special toxic waste containers for contaminated sharps, gloves. Special sterile wipes were used to wipe down the flow cabinet after each session. Vials containing unused drugs were placed in cinbins for incineration

Generally, aqueous solutions that needed to be diluted were contained in vials with a septum over the mouth of the vial. The drug was then withdrawn using a syringe. For cytotoxic drugs in powdered form that needed to be re-constituted, the required amount of saline was added through the septum and the required volume of reconstituted drug withdrawn via syringe. Any unused amounts were discarded. The concentrated drugs in this unit were contained in the following forms:

Carboplatin: Solution, concentration: 450 mg in 45 ml
Cisplatin: Powdered, 50 mg
Cyclophosphamide: Powdered, 1g
Ifosfamide: Powdered, 1 g
Methotrexate: Solution, 500 mg/20 ml

Work Flow

The flow of work and chain of cytotoxin handling is shown diagrammatically in Appendix I. Items required to be passed to the cytotoxin clean units were prepared in the prescription room, including printed labels etc. This was then placed on a tray and passed through a window to clean room 1 of the unit. These items were checked, sterilised and passed into clean room 2 where the final products for the wards were prepared. There are two double-layered windows between clean room 1 and clean room 2. The technician in clean room 1 passed the items through one window and, following formulation, the product was returned to the clean room 1 via the second. It was then checked and passed by the pharmacist on duty. The final formulations in IV bags and syringes were placed at the window that communicates with the outer environment. These were collected by the prescription room technician, taken to the prescription room area where he double checked the labels and placed the formulated drugs into sealable containers ready to be collected by a messenger who distributed them to the wards.

AGRICULTURAL SECTOR

In the agricultural sector we looked at sprayers of pesticides and mechanics who conducted maintenance and repair on spray booms and other agricultural equipment.

Sprayers

All the spraying equipment was of the self-propelled type and all but one had a closed cab and air-conditioning. The pesticides to be loaded were stored in a large warehouse from which the sprayer selected the ones he required. Mixing and loading was done in the open air. Loading of the spray tank is via a small moveable hopper (opening 0.5m x 0.25m x 0.25m) situated on the lower part of the side of the spray truck. The sprayer pulls this down via a hopper handle to the level of his lower torso. Pesticides are poured into the bowl of the hopper and water is added to flush out the bowl and carry the pesticide to the spray tank where it is diluted many times with water. The cans are washed out using a centrally positioned T-piece rinse nozzle that, when depressed, produces an upward jet of water. This is used to flush out all the concentrated pesticide from the pesticide container. Some pesticides are in granular form and these are also added via the hopper.

There are two levers on the side of the truck that control the flow of water and help create a suction to pull the pesticide from the hopper into the tank. The sprayer firstly adjusts the levers. He then dons gloves (leather or rubber) just prior to loading the containers of pesticide into the hopper. During loading he depresses the hopper pipe with the container and directs the stream of water into the container thus allowing the force of the water to rinse the inside of the container. This sometimes creates spray of water being directed onto his forearms and occasionally, his face.

The mixer-hopper is raised out of the way during spraying but lowered to about 3 feet above ground when loading the sprayer. The condition of the sprayers from one sprayer to the next can vary considerably since the sprayers are responsible for cleaning the sprayer themselves.

The sprayers are seated in enclosed cabs that are usually air conditioned. The duration of spraying is dependent on how large the field is and the type of crop being sprayed. The booms were usually mechanically folded and extended. However, sprayers have been observed to manually handle the boom when there are problems with the mechanism or when the nozzles of the boom become clogged. In between spraying jobs the sprayer may refill the tanker. During refill in between jobs he may contact more heavily contaminated surfaces when adjusting the levers and handling the hopper. The sprayer may eat, smoke or read the newspaper while seated in his cab during work breaks.

Mechanics

The mechanics were repairing the boom of a spray truck that had been used for 3 weeks prior to spray pesticide. They were doing troubleshooting to try to figure out precisely where the problem was. The tasks involved frequent handling of the spray boom with the bare hands. The pipes and spray outlets were tested for leaks. One mechanic climbed atop the spray tanker to load the tank with water while the other observed the spray coming from the nozzles. There is often some residual pesticide in the spray tank.

Inadvertent ingestion exposure in the workplace

Little is known about the relative importance of inadvertent ingestion of hazardous substances from work activities. In this report we review the available scientific literature to help understand whether inadvertent ingestion is an important route of exposure and for which agents. Proposals are made for a conceptual model of the processes involved with this type of exposure and for possible exposure metrics to be used for workplace measurement.

This is the first of three reports dealing with inadvertent ingestion exposure in the workplace.

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