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An occupational hygiene assessment of dermal nickel exposures in primary production and primary user industries

Phase 2 Report

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The object of this study was to measure the levels of soluble and insoluble nickel in the skin contaminant layer of nickel refinery workers and primary users of nickel products. This work followed on from initial investigations carried out in two nickel refineries, which was reported as Phase 1 of this study in IOM Technical Memorandum TM/04/05.

For Phase 2 of this study, workplace surveys were carried out in one nickel refinery, a stainless steel production plant and a company involved in the production of AlNiCo magnets. The main task of interest for these sites were packing of nickel chloride crystals (nickel refinery), handling nickel metal briquettes and nickel cathodes (stainless steel production) and handling nickel powder products (magnet production), although in all three sites additional tasks were monitored.

Dermal exposure samples were collected using a removal method, using commercial moist wipes to recover nickel deposits from measured areas of skin. The test procedure was the same as that used during Phase 1 and had a combined nickel recovery efficiency for the sample preparation and analysis of approximately 95% for insoluble nickel and 87% for soluble nickel compounds.

A total of 33 sets of dermal exposure measurements were collected from 29 different workers. Of the total 755 dermal exposure measurements, 140 were less than the LOD of 0.02 $\mu g/cm^2$. The highest actual dermal exposures were recorded for the nickel refinery workers and a subgroup of workers in magnet production who had direct contact with nickel powder. In these cases the workers' hands, arms, face and neck all received more surface contamination compared with other jobs. In the case of the nickel chloride packers, the median and 90th percentile combined hand/arm dermal total nickel exposures were 4.01 and 10.86 $\mu g/cm^2$. The corresponding results for the nickel powder exposed workers in the magnet company were 4.56 and 19.69 $\mu g/cm^2$. In the latter case the levels of soluble nickel on the skin were much lower than nickel chloride workers, which is due to the relatively low solubility of the nickel powders used in this industry. The nickel exposures for the workers in the stainless steel production plant were very low, which was mainly due to the use of mechanical handling methods for the nickel metal being used in the process.

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1 INTRODUCTION

This report is concerned with the evaluation of dermal exposure to nickel and nickel compounds in primary production industry and also in primary user industries. The work reported here is the second phase of a two-phase study concerned with the evaluation of occupational dermal exposure in the nickel production industry and specific user applications. The background to the work and the detailed description of the sampling strategy and method development are contained in the Phase 1 report issued as 'An occupational hygiene assessment of dermal nickel exposures in primary production industries', IOM Research Report TM/04/05 (Hughson, 2005).

In summary, the main purpose of this work is to collect dermal exposure data for inclusion in the EU regulatory risk assessment for nickel metal and nickel compounds, carried out as part of the Existing Substances Regulations (CEC, 1993). These assessments require that all routes of exposure are assessed for human health risks (ECB, 2003). Where there are no existing exposure data, default levels of exposure are used based either on analogous data sets or from exposure models such as EASE (HSE, 1996).

In Phase 1 of this study, dermal exposures were measured in two different European nickel refineries. Measurements were obtained from a range of different production processes and tasks. The study was designed to differentiate between soluble and insoluble nickel exposures in order to aid comparison with known threshold levels for elicitation or induction of nickel sensitisation. This is important for a meaningful risk assessment, since it is the soluble nickel content and nickel ions released from insoluble nickel compounds in contact with the skin that are biologically relevant. The workers monitored as part of this assessment were involved in refinery processes such as leaching and electro-winning, plus packaging of the final products which included nickel cathode squares, nickel powder, nickel briquettes, nickel sulphate hexahydrate and nickel hydroxycarbonate.

Overall, the dermal exposure results from Phase 1 were low, and certainly very much less than predicted values generated by the EASE model. In addition, the dermal nickel levels were much lower than levels of exposure previously obtained by us from the zinc industry. It was concluded that this was largely due to the much higher levels of engineering controls applied to the nickel production processes generally, combined with specific hygiene measures such as the consistent use of personal protective equipment.

Nevertheless there were measurable nickel deposits on the hands, arms, face, neck and chest areas of all workers monitored and there was a high degree of correlation between the different anatomical areas.

For Phase 2 of this study, three other sites using or producing nickel compounds were identified by the sponsor. These were a nickel refinery, which produced nickel chloride crystals, a stainless steel production plant which used nickel briquettes and nickel cathode plate in the process, and a company using nickel powders to produce AlNiCo magnets. This report describes the results of the workplace surveys for these three companies.

2 AIMS AND OBJECTIVES

The main aim of this study was to supplement knowledge about the levels of occupational dermal exposure in nickel chloride production and in primary user industries.

To achieve this aim we addressed the following key objectives:

- To measure occupational dermal exposures to nickel and nickel compounds in a nickel refinery producing nickel chloride crystals;
- To measure dermal nickel exposures of workers who were liable to come into contact with nickel metal products used in the production of stainless steel;
- To measure dermal nickel exposures of workers who were liable to come into contact with nickel powder products, used in the production of AlNiCo magnets;
- To express dermal nickel exposure in terms of the level of nickel in the skin contamination layer, averaged over the relevant exposure period.
- To collect corresponding airborne nickel exposure measurements from each worker monitored.
- To differentiate between soluble and insoluble forms of nickel in the dermal exposure assessment.
- To compare measurements of dermal exposures against exposure predictions produced by the EASE model where applicable.

3 METHODS

The sampling and analytical methods were developed and thoroughly validated during Phase 1 of this study. This included testing the recovery efficiency of the sampling method, the recovery efficiency of the sample analysis and evaluation of background exposure levels for non-occupationally exposed human volunteers. The detailed description of the validation procedure and the corresponding results are contained in the Phase 1 report. The sampling strategy, sampling and analytical methods are summarised in the following sections for completeness.

3.1 SAMPLING STRATEGY

The dermal exposure measurements were assessed using a removal method, which used moist wipes to collect samples from the skin contaminant layer. The wipes were used to remove residual contamination from predetermined anatomical areas at three intervals over the working shift. Samples were collected before washing so that they were representative of the level of skin contamination during the working day.

In order to ensure that representative dermal exposure measurements were collected, it was necessary to identify workers who were likely to be involved with the workplace scenarios previously identified. This was done with the assistance of the management of the three companies that participated in the field surveys.

Due to the high level of automation common in modern industrial workplaces, there were a small number of workers available for sampling. In order to obtain sufficient data for meaningful statistical analysis it was necessary to collect measurements over different working shifts and to repeat these over consecutive days.

3.2 DERMAL SAMPLING METHOD

Since there is no standard method for dermal exposure assessment it is usually necessary to validate the sampling method used for the particular workplace situation. The method used for this study was validated to determine the analytical and sampling recovery efficiency during Phase 1 of this study and the detailed methodology and results are described in the Phase 1 report (Hughson, 2005).

Samples of the skin contaminant layer were collected using commercial moist wipes (Jeyes 'Sticky Fingers' Wet Ones) and an acetate template with an open aperture of 25 cm^2 pressed onto the relevant anatomical area at the time of sampling. Each sample comprised three sequential wipes from the anatomical area being sampled.

Wipe samples were collected from the palm and back of each hand and from both forearms prior to leaving the work area. This was done before rest breaks so that contamination was not lost from the skin as a result of washing. Samples of skin contamination were collected at three different intervals over the working day in order to assess contamination while at work.

The wipe samples from the palms and backs of the hands were collected in separate containers. The samples for the left and right forearms were bulked together into a third container. These were kept separate from other samples collected at different times of the day to enable an assessment to be made of the variability of exposure across the working shift.

Since the aim of this study was to produce exposure measurements for comparison with known levels for elicitation or induction of nickel sensitisation, it was assumed that the best measure of this would be an average value of the three different sample sets collected for the hands and/or forearms. Furthermore, workers were known to regularly wash their hands and forearms as part of their normal hygiene procedure, so an average value of the three sample sets was considered to be representative of what would be present on the skin over the course of the working shift.

Additional samples were collected from the side of the neck, face (perioral region) and chest. The neck and face samples were used to provide an estimate of exposure for the head and also help make informed estimates about the potential for ingestion exposure. The sample from the chest was used to assess the degree of contamination under work clothes. The face, neck and chest samples were collected once, near the end of the shift usually before the worker showered at the end of the day.

It was not possible to use the acetate template for collecting the sample from the perioral region. In this case, the sample was collected by wiping around the mouth, under the nose and above the chin. This area of the face was estimated to be equivalent to 25 cm^2.

The sampling procedure is summarised in Table 1, below:

Table 1 Summary of sampling schedule for each subject

Anatomical Region	**Sample type**	**Sampling times**			**No. of samples**
		First break	**Mid-shift break**	**End of shift**	
Palms of both hands	Moist wipes	✓	✓	✓	3
Backs of both hands	Moist wipes	✓	✓	✓	3
Forearm (left and right)	Moist wipes	✓	✓	✓	3
Neck (preferred side)	Moist wipes			✓	1
Face (perioral region)	Moist wipes			✓	1
Chest	Moist wipes			✓	1
TOTAL no of samples per subject (excluding blanks)					12

A field blank sample was obtained for each subject sampled. This was done in order to check for contamination introduced during the sampling procedure. The field blanks comprised a series of thee wipes that were handled in the same way as the exposed samples but without being wiped over the workers' skin. The nickel level in the field blank was subtracted from the measured values for the corresponding set of samples.

3.3 ANALYSIS

All samples were analysed by inductively coupled plasma atomic emission spectroscopy (ICP/AES) for nickel. The samples were analysed at the IOM analytical laboratory, which holds accreditation for the analysis of nickel and other metals, by ICP/AES. The documented in-house method, based on OSHA method 121 (OSHA 1991) is accredited by the United Kingdom Accreditation Service (UKAS) under UKAS accreditation number 0374.

All wipe samples were transferred to the laboratory in 250 ml glass jars. The wipes contained in each sample jar were analysed to determine the soluble and insoluble nickel content using a variation of a published method (Zatka *et al.*, 1992).

Initially, the wipes in each sample container were covered with 0.1M ammonium citrate and left to soak for three hours in order to recover soluble nickel compounds. This solution was vacuum-filtered through a 1µm membrane filter and then made up to 100 ml using deionised water in a volumetric flask. The filter and remainder of the wipes were then prepared to determine the insoluble nickel content. The samples were covered with 10% nitric acid, heated to near boiling point for three hours, cooled, vacuum filtered, rinsed then made up to 100 ml volume in the same way as before. In each case, 1% anti-foaming agent was added to the sample jars to counter the effects of the detergents contained in the wipes.

Calibration standards were prepared using known weights of analytical grade reagents and the sample masses were determined with reference to these calibration standards. All sample masses were corrected for blank levels and for analytical and sample recovery efficiency where appropriate, using the results from laboratory blanks, spike samples and recovery test samples. Due to the large number of field samples processed it was necessary to prepare fresh laboratory blanks and spike samples for each day's batch of samples processed in the laboratory.

The quantity of nickel in each sample was used to calculate the dermal surface loading for each anatomical area, expressed in terms of mass per unit area (µg/cm^2). All field samples were corrected for field blank levels. In the case of the hands and forearms three samples were collected from each of these areas. The skin surface loading for each sample was calculated and an average of each set of three was also calculated.

The results are expressed separately for soluble and insoluble nickel content. Individual measurements were calculated, for each subject, for the hands, forearms, neck, face and chest. In addition, an average value was calculated for the hands and arms combined as this is the relevant metric for comparison with predicted exposures obtained from the EASE model. In doing this the average for the hands and arms combined is weighted to take into account the relative surface areas of the different anatomical areas. The average value is calculated using the mean surface areas for hands (840 cm^2) and the forearms (1140 cm^2) (EPA 1997) as follows:

$$\text{Average value Hands \& forearms} = \frac{(hands \times 840) + (forearms \times 1140)}{(840 + 1140)}\ \mu g/cm^2$$

3.4 SAMPLING FOR INHALABLE DUST AND NICKEL COMPOUNDS

At the request of the study sponsor, airborne dust sampling was carried out in addition to the dermal sampling previously described. The objective was to collect an air sample for each worker monitored for dermal nickel exposure so that the relationship between air and dermal exposures could be investigated.

The air samples were collected using personal sampling apparatus in accordance with Health and Safety Executive method MDHS 14/3 (HSE, 2000). This involved using an IOM inhalable dust sampler loaded with a pre-weighed cassette containing a 25 mm quartz fibre filter. The sampling flow rate was set to 2.0 litre/min, measured using a calibrated flow meter. The IOM sampler was connected to a battery operated sampling pump, which was worn on a belt, and the sampling head was attached to the subject's lapel so that it lay within the breathing zone.

The sampling apparatus was fitted to the worker at the start of the working shift and left running for the majority of the working shift. The sampling flow rate was checked at the beginning and end of sampling and periodically over the course of the shift. The start and stop times were recorded so that the sample volume could be calculated.

The IOM cassettes were re-weighed at IOM to determine the total inhalable dust concentration and the samples were then shipped to an independent laboratory nominated by the sponsor for analysis of soluble/insoluble nickel species. The quartz fibre filter was selected to enable this analysis to be carried out according to the published method (Zatka *et al.*, 1992).

3.5 STATISTICAL METHODS

The workplace dermal exposure data for each exposure scenario were summarised in terms of maximum and minimum values, median and the upper 90th percentile level using Microsoft Excel 2002. This is the summary data normally required for EU regulatory risk assessments (ECB, 2003). The associations between exposures for different anatomical areas were investigated by calculating the Pearson correlation coefficient using SPSS for Windows version 12.01. In addition, correlations between dermal exposure and inhalable dust concentrations were investigated in the same way. Since the data was log-normally distributed, it was log transformed prior to analysis.

The data was summarised using SigmaPlot V8.0 computer software to produce box-whisker plots showing dermal exposure for different anatomical areas and by different work areas.

In order to summarise the data properly it was necessary to adjust data values that were below the limit of detection. For samples which were less than the limit of detection, the exposure value was set to a level of ½ the limit of detection, in accordance with the approach suggested by Rajan-Sithamparanadarajah *et al.*, 2004.

3.6 EVALUATION OF TASK-BASED DERMAL EXPOSURES USING THE EASE MODEL

The various observed tasks in each of the workplaces were categorised in terms of the EASE model, so that the exposure measurements could be compared with the EASE predictions. Information about the working practices and control measures were used as inputs to the EASE model and this provided predicted exposure levels for each category of task. The categorisation was done after consideration of the dermal contact level and pattern of use, and is a matter of professional judgement, assisted by on-line help embedded in the EASE computer program. The categorisation was done by an experienced user (GWH) of the EASE model, before the results of the dermal exposure results were known.

4 WORKPLACE DESCRIPTIONS

The following sections describe the observed workplace conditions and working practices for each of the two companies included in this assessment. Also, the various tasks or jobs included for sampling are described, together with any exposure controls used by the workforce. Each task is categorised in terms of the EASE model and the predicted dermal exposures are included to enable comparison with the measured results.

4.1 NICKEL REFINERY

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. 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.

Due to the relatively high level of control for all the tasks carried out, these can be categorised in terms of EASE as non-dispersive use with intermittent direct contact, which has a predicted exposure level of 0.1 – 1 mg/cm^2 per day.

4.2 STAINLESS STEEL PRODUCTION

The production plant included in this survey produced stainless steel from scrap stainless steel, high nickel content alloy material and various high purity metals including nickel in the form of briquettes or as nickel plate. These materials were melted together in an electric arc furnace. The furnace charges were made up by loading 50 tonne capacity charge baskets with the scrap stainless steel, alloys and nickel plate from the scrap yard area. The charge baskets were loaded with these materials in an outdoor yard area where all the raw materials were stored. This was done using a mobile crane with grab attachment. Once the furnace was in operation, molten metal was tapped off and transferred to a convertor vessel where impurities were removed by the introduction of oxygen and argon into the melt. Final adjustments were made to the melt composition by adding high purity metals including nickel, molybdenum and chromium by direct feed from high level silos. Once the correct metal composition was achieved the molten metal was tapped off and diverted to the continuous casting unit where the steel was cooled and formed into plates. All of the alloy loading and transfer operations relating to the furnace convertor operations were computer-controlled by operators located within a remote control room.

The main area where workers had some potential for contact with nickel products was in the alloy handling area during delivery and transfer of the raw materials. There were two groups of workers involved in this area. These were the alloy handler (1-2 operator per shift) and raw materials inspectors (1-2 operators per shift). The alloy handlers were responsible for transferring nickel briquettes and nickel alloys together with a range of other high purity metal additives from stock to the loading hoppers for the process conveyor system. The raw material inspectors were responsible for supervising and checking the delivery of scrap metal, nickel briquettes, nickel plate and the whole range of other metals used in the process. These operators were required to manually check the contents of the bulk loads for non-metallic items, so were considered to have some potential for nickel exposure.

The scrap metal and high nickel content alloys were delivered to the site in tipper trucks and these loads were discharged into various stock bays in an open yard. Similarly, loads of pure nickel and other metal products were delivered to the yard area. Nickel briquettes were delivered in bulk from a tipper truck or in 1,000 kg big-bags. Nickel cathode plates were delivered on pallets and were stored in the outdoor yard area. As previously explained, the quality and delivery of these materials to the stock yard areas was checked and supervised by the raw material inspectors.

The loose nickel briquettes were also stored in stock bays inside the alloys building and needed to be transferred to the process via a loading hopper located in the alloy handling area. The loose nickel briquettes were transferred using a mechanical loader and simply scooped up and dumped into the hopper when required. The alloy handler was located within an enclosed cab while carrying out this task and did not have any direct physical contact with the nickel briquettes. For briquettes contained in big-bags, it was necessary to attach the loops of the bag onto the forks of a fork-lift truck. The truck was then used by the alloy hander to take the bag to the loading hopper where it was lowered down onto a spike located inside the hopper. The spike caused the bag to split and the contents were disgorged into the hopper. Thus any contact with the nickel briquettes was minimal and simply related to the handling of the outer surfaces of the big-bags.

The bulk of the scrap metal and large items such as pallets of nickel cathode were added to the furnace charge baskets using a mobile crane with grab attachment. This work was carried out by the furnace operators and was not observed.

Although the alloy handlers had negligible contact with nickel in the form of nickel briquettes, nickel cathodes and nickel alloys, it should be noted that the general area of the alloy building was very dusty. Presumably this was due to the long-term use of nickel alloys, which was of a granular appearance and appeared to be dusty and hence could be considered to be relatively mobile. Also, there was evidence of dust deposition due to migration of dust and fumes from the furnace area to the alloys area. The operators were therefore exposed to these dusty surfaces and the outer clothing, hands and other exposed areas of skin were seen to be contaminated due to incidental contact with the outer surfaces of the vehicles and other machinery in this area.

There was a third group of workers in the general area of the alloys area, known as DC Arc technicians. These workers were involved with recovery of metallic residues from recovered flue dust and other maintenance work on furnaces. The DC Arc technicians were not directly involved with handling nickel products but worked in an area nearby. Some of these workers were observed to be heavily contaminated with dust from the process.

All of the workers were equipped with coveralls, hard hats and protective gloves and safety shoes. Other thermal protective equipment was provided for hot work when required. The raw materials inspectors worked outdoors for most of their shift and were provided with waterproof clothing to protect them from rain and cold.

The tasks relating to work in the alloy handling area may be categorised in terms of EASE as non-dispersive use with intermittent direct contact, for which EASE gives a predicted exposure level of 0.1 – 1 mg/cm^2 per day.

4.3 POWDER METALLURGY

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 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 to 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

The front end of the process involved weighing out batches of metal powders and other ingredients into containers, which were used to feed each of the presses. The powder operator was involved with weighing out batches of powers 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.

The powder operator 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.

In use, 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. These 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 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.

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.

5 RESULTS

A total of 378 samples (excluding field blanks) were collected for nickel analysis. Each sample was analysed for soluble and insoluble nickel content, making a total of 755 (one part sample was lost in the analysis) dermal exposure measurements. There were 28 complete sets of exposure measurements with five partial sets, collected from 29 different workers. There were 4 workers that were sampled twice, i.e. on consecutive days.

Out of the total 755 dermal exposure measurements, 140 were less than the limit of detection (LOD) of 0.02 $\mu g/cm^2$. For the purposes of the statistical analyses, these measurements were set at a nominal level of ½ of the LOD, i.e. 0.01 $\mu g/cm^2$.

The results of the dermal nickel sampling survey are detailed in Tables 1 - 6. The results are expressed as the dermal nickel loading ($\mu g/cm^2$) for the hands, forearms, hands and arms combined, face, neck and chest. The data for the hands are averages of the separate samples collected for each subject monitored as previously explained. All of the results are expressed in terms of soluble nickel (Table 1), insoluble nickel (Table 2) and total nickel (Table 3). It should be noted that the value for the hands and arms combined is weighted to take into account the relative surface areas of the different anatomical areas. The average value is calculated using the mean surface areas for different anatomical areas (EPA, 1997) as explained in Section 3.3.

The individual measurements for the hands and forearm results used to calculate the average exposures referred to in Tables 1 – 3 are provided in Tables 4 – 6. Again, these are presented in terms of soluble (Table 4), insoluble (Table 5) and total nickel (Table 6) and are expressed as a skin surface loading in $\mu g/cm^2$.

Additional information about the tasks performed for each subject monitored is detailed in the job activity records contained in Appendix A (Tables A1 – A6). This shows the types of activities carried out immediately before each of the three separate sets of dermal exposure measurements were collected.

All samples were corrected for blank levels, field blanks and for analytical recovery efficiency. The results were not corrected for background skin levels, with reference to the control group. The sample results were not corrected for sampling efficiency because the results of the sampling efficiency tests were too variable to be applied universally. However, the sampling efficiency was judged to be sufficiently high, within a range of 92 – 108%, to provide reassurance that the majority of the dermal nickel deposits were being recovered.

Table 1 Dermal nickel exposures for various tasks in nickel user/producer industries
Soluble Nickel Species

Job	Dermal nickel exposure (µg/cm^2)					
	Average Hands	Average forearms	Hands & Arms	Neck	Face	Chest
Nickel refinery:						
Raw materials operator	0.51	0.47	0.48	0.35	0.86	<0.02
Raw materials operator	0.25	0.24	0.24	0.23	0.56	0.11
Raw materials store - loader driver	0.35	0.04	0.17	0.07	1.51	0.37
Electrolysis - Lifting/checking	0.11	0.21	0.17	0.13	1.02	<0.02
Electrolysis - Lifting/checking	1.07	0.11	0.52	<0.02	1.00	<0.02
Electrolysis - Unloading/cleaning	0.42	0.81	0.65	0.12	0.78	0.12
$NiCl_2$ packer	5.89	0.16	2.59	0.07	1.49	<0.02
$NiCl_2$ packer	0.90	0.37	0.60	0.55	1.31	0.28
$NiCl_2$ packer	6.16	0.84	3.10	0.09	0.74	5.77
$NiCl_2$ packer	0.13	0.20	0.17	0.49	0.66	0.32
$NiCl_2$ packer - Supervisor	7.52	0.57	3.52	<0.02	1.86	<0.02
$NiCl_2$ packer - Supervisor	1.49	0.79	1.08	1.92	2.55	0.25
Powder metallurgy:						
Powder mixer op	<0.02	0.05	0.03	<0.02	<0.02	<0.02
Setter, press shop	0.28	0.28	0.28	0.17	0.89	0.32
Setter, press shop	0.26	0.36	0.32	1.39	2.15	0.12
Setter, press shop	0.31	0.13	0.21	0.20	1.68	0.67
Grinding m/c operator	<0.02	<0.02	<0.02	<0.02	<0.02	0.07
Grinding m/c operator	0.07	0.06	0.07	0.17	0.11	0.19
Grinding m/c operator	0.05	0.03	0.04	<0.02	0.13	<0.02
Grinding m/c operator	0.09	0.24	0.18	0.25	0.22	0.06
Stainless steel production:						
Alloy handler	0.04	<0.02	0.02	0.04	0.10	0.03
Alloy handler	<0.02	<0.02	<0.02	<0.02	0.02	<0.02
Alloy handler	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Alloy handler	0.03	<0.02	0.02	<0.02	0.03	<0.02
Alloy handler	<0.02	<0.02	<0.02	0.37	<0.02	<0.02
Raw materials inspector	0.06	0.02	0.04	0.07	<0.02	<0.02
Raw materials inspector	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
DC Arc Technician	0.03	0.04	0.03	<0.02	<0.02	0.05
DC Arc Technician	0.03	0.03	0.03	0.11	0.20	0.18
DC Arc Technician	<0.02	<0.02	<0.02	0.08	0.07	0.05
DC Arc Technician	<0.02	<0.02	<0.02	0.23	0.13	0.16
DC Arc Technician	0.07	0.04	0.05	0.04	0.15	0.04
DC Arc Technician	<0.02	<0.02	<0.02	<0.02	0.06	<0.02

N/A – Not available, not sampled.

Table 2 Dermal nickel exposures for various tasks in nickel user/producer industries
Insoluble Nickel Species

Job	Dermal nickel exposure (µg/cm²) Average Hands	Average forearms	Hands & Arms	Neck	Face	Chest
Nickel refinery:						
Raw materials operator	1.36	2.58	2.06	0.62	5.44	0.49
Raw materials operator	0.48	0.58	0.54	0.11	0.50	0.13
Raw materials store - loader driver	3.22	0.40	1.60	0.09	5.40	1.23
Electrolysis - Lifting/checking	0.53	0.52	0.52	<0.02	3.30	<0.02
Electrolysis - Lifting/checking	0.79	0.10	0.39	<0.02	<0.02	<0.02
Electrolysis - Unloading/cleaning	0.83	0.09	0.40	0.10	0.16	0.05
$NiCl_2$ packer	24.94	0.45	10.84	<0.02	0.95	1.08
$NiCl_2$ packer	4.54	1.22	2.63	0.18	0.73	<0.02
$NiCl_2$ packer	1.20	0.30	0.68	0.08	0.16	0.46
$NiCl_2$ packer	0.14	0.09	0.11	0.26	0.51	0.12
$NiCl_2$ packer - Supervisor	9.11	1.57	4.77	0.75	1.03	<0.02
$NiCl_2$ packer - Supervisor	4.85	1.92	3.16	0.51	0.58	0.16
Powder metallurgy:						
Powder mixer op	1.46	0.29	0.78	0.57	0.12	<0.02
Setter, press shop	4.42	7.58	6.24	0.45	2.17	2.72
Setter, press shop	46.74	9.01	25.02	2.95	31.08	4.43
Setter, press shop	4.37	0.94	2.40	0.76	13.04	2.09
Grinding m/c operator	0.20	<0.02	0.09	<0.02	2.80	0.11
Grinding m/c operator	0.65	0.32	0.46	0.51	0.19	0.06
Grinding m/c operator	2.29	1.20	1.66	<0.02	0.09	0.29
Grinding m/c operator	1.17	2.37	1.86	0.79	0.62	<0.02
Stainless steel production:						
Alloy handler	0.07	0.03	0.05	0.04	0.36	0.17
Alloy handler	0.03	0.03	0.03	<0.02	0.04	0.03
Alloy handler	0.07	0.03	0.05	N/A	0.04	0.05
Alloy handler	0.09	0.04	0.06	0.08	0.09	0.11
Alloy handler	0.10	0.06	0.08	0.16	0.27	<0.02
Raw materials inspector	0.05	0.03	0.04	<0.02	<0.02	<0.02
Raw materials inspector	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
DC Arc Technician	0.09	0.21	0.16	0.10	0.04	0.08
DC Arc Technician	0.33	0.32	0.32	0.36	0.64	1.16
DC Arc Technician	0.04	0.07	0.06	0.13	0.24	0.16
DC Arc Technician	0.05	0.16	0.11	0.43	0.09	0.73
DC Arc Technician	1.28	0.42	0.79	0.13	0.32	0.09
DC Arc Technician	0.45	0.27	0.35	0.22	0.33	0.05

N/A – Not available, not sampled.

Table 3 Dermal nickel exposures for various tasks in nickel user/producer industries
Total Nickel

Job	Average Hands	Average forearms	Hands & Arms	Neck	Face	Chest
	Dermal nickel exposure (µg/cm^2)					
Nickel refinery:						
Raw materials operator	1.87	3.05	2.55	0.97	6.29	0.50
Raw materials operator	0.73	0.82	0.78	0.34	1.06	0.24
Raw materials store - loader driver	3.57	0.44	1.76	0.16	6.91	1.60
Electrolysis - Lifting/checking	0.64	0.73	0.69	0.14	4.32	<0.02
Electrolysis - Lifting/checking	1.86	0.21	0.91	<0.02	1.01	<0.02
Electrolysis - Unloading/cleaning	1.25	0.90	1.05	0.22	0.94	0.17
$NiCl_2$ packer	30.83	0.61	13.43	0.08	2.44	1.09
$NiCl_2$ packer	5.44	1.59	3.22	0.73	2.03	0.29
$NiCl_2$ packer	7.37	1.13	3.78	0.17	0.90	6.23
$NiCl_2$ packer	0.27	0.29	0.28	0.75	1.16	0.43
$NiCl_2$ packer - Supervisor	16.62	2.14	8.29	0.76	2.89	<0.02
$NiCl_2$ packer - Supervisor	6.33	2.71	4.25	2.43	3.12	0.41
Powder metallurgy:						
Powder mixer op	1.47	0.33	0.81	0.58	0.13	<0.02
Setter, press shop	4.70	7.86	6.52	0.62	3.06	3.04
Setter, press shop	47.00	9.37	25.33	4.34	33.23	4.56
Setter, press shop	4.69	1.07	2.60	0.96	14.71	2.76
Grinding m/c operator	0.21	<0.02	0.10	<0.02	2.81	0.18
Grinding m/c operator	0.72	0.39	0.53	0.68	0.31	0.25
Grinding m/c operator	2.33	1.23	1.70	<0.02	0.22	0.30
Grinding m/c operator	1.27	2.61	2.04	1.04	0.83	0.07
Stainless steel production:						
Alloy handler	0.11	0.04	0.07	0.08	0.46	0.20
Alloy handler	0.04	0.04	0.04	<0.02	0.07	0.04
Alloy handler	0.08	0.04	0.06	N/A	0.05	0.06
Alloy handler	0.13	0.05	0.08	0.09	0.11	0.12
Alloy handler	0.12	0.07	0.09	0.52	0.28	<0.02
Raw materials inspector	0.11	0.05	0.07	0.08	<0.02	<0.02
Raw materials inspector	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
DC Arc Technician	0.11	0.25	0.19	0.11	0.05	0.13
DC Arc Technician	0.36	0.34	0.35	0.47	0.84	1.33
DC Arc Technician	0.05	0.08	0.07	0.21	0.31	0.21
DC Arc Technician	0.06	0.17	0.12	0.66	0.22	0.88
DC Arc Technician	1.35	0.46	0.84	0.17	0.47	0.13
DC Arc Technician	0.46	0.28	0.36	0.23	0.40	0.06

N/A – Not available, not sampled.

Table 4 Individual sample results for the hands and forearms (soluble nickel)

Job	Hands Sample 1	Hands Sample 2	Hands Sample 3	Average Hands	Forearms Sample 1	Forearms Sample 2	Forearms Sample 3	Average forearm
	Dermal nickel exposure (µg/cm^2)							
Nickel refinery:								
Raw materials operator	0.04	0.59	0.90	0.51	<0.02	<0.02	1.38	0.47
Raw materials operator	N/A	0.16	0.33	0.25	N/A	0.29	0.19	0.24
Raw materials store - loader driver	0.43	0.13	0.47	0.35	0.09	<0.02	<0.02	0.04
Electrolysis - Lifting/checking	0.19	0.07	0.06	0.11	0.16	0.34	0.14	0.21
Electrolysis - Lifting/checking	0.56	2.08	0.56	1.07	<0.02	<0.02	0.32	0.11
Electrolysis - Unloading/cleaning	0.41	0.46	0.40	0.42	0.08	0.16	2.21	0.81
$NiCl_2$ packer	11.03	4.35	2.30	5.89	0.45	<0.02	<0.02	0.16
$NiCl_2$ packer	0.38	1.10	1.23	0.90	0.28	0.29	0.54	0.37
$NiCl_2$ packer	0.26	2.89	15.34	6.16	<0.02	0.71	1.79	0.84
$NiCl_2$ packer	0.29	0.04	0.08	0.13	0.21	0.13	0.25	0.20
$NiCl_2$ packer - Supervisor	1.65	19.96	0.95	7.52	0.55	0.72	0.45	0.57
$NiCl_2$ packer - Supervisor	3.21	0.98	0.27	1.49	0.72	1.40	0.24	0.79
Powder metallurgy:								
Powder mixer op	<0.02	<0.02	<0.02	<0.02	<0.02	0.12	<0.02	0.05
Setter, press shop	0.24	0.02	0.58	0.28	0.09	0.21	0.54	0.28
Setter, press shop	<0.02	0.23	0.53	0.26	0.33	0.40	0.36	0.36
Setter, press shop	0.31	0.18	0.45	0.31	0.08	0.07	0.22	0.13
Grinding m/c operator	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Grinding m/c operator	0.11	0.06	0.05	0.07	0.06	0.05	0.08	0.06
Grinding m/c operator	0.05	<0.02	0.07	0.05	<0.02	<0.02	0.06	0.03
Grinding m/c operator	0.18	0.03	0.07	0.09	0.19	0.05	0.48	0.24
Stainless steel production:								
Alloy handler	N/A	N/A	0.04	0.04	N/A	N/A	<0.02	<0.02
Alloy handler	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Alloy handler	<0.02	<0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Alloy handler	<0.02	N/A	0.06	0.03	<0.02	N/A	<0.02	<0.02
Alloy handler	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Raw materials inspector	0.04	0.10	0.05	0.06	0.03	<0.02	0.03	0.02
Raw materials inspector	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
DC Arc Technician	0.03	0.02	0.03	0.03	0.07	<0.02	0.04	0.04
DC Arc Technician	0.03	<0.02	0.05	0.03	0.03	<0.02	0.04	0.03
DC Arc Technician	N/A	<0.02	<0.02	<0.02	N/A	<0.02	<0.02	<0.02
DC Arc Technician	N/A	<0.02	<0.02	<0.02	N/A	<0.02	<0.02	<0.02
DC Arc Technician	0.03	0.10	0.10	0.07	<0.02	0.06	0.04	0.04
DC Arc Technician	<0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

N/A – Not available, not sampled.

Table 5 Individual sample results for the hands and forearms (insoluble nickel)

Job	Hands Sample 1	Hands Sample 2	Hands Sample 3	Average Hands	Forearms Sample 1	Forearms Sample 2	Forearms Sample 3	Average forearm
	Dermal nickel exposure (µg/cm^2)							
Nickel refinery:								
Raw materials operator	2.38	0.90	0.80	1.36	2.04	0.48	5.23	2.58
Raw materials operator	N/A	0.52	0.44	0.48	N/A	0.78	0.39	0.58
Raw materials store - loader driver	3.30	3.04	3.32	3.22	0.07	0.32	0.80	0.40
Electrolysis - Lifting/checking	1.19	0.27	0.14	0.53	0.65	0.22	0.69	0.52
Electrolysis - Lifting/checking	0.69	1.46	0.22	0.79	<0.02	0.27	<0.02	0.10
Electrolysis - Unloading/cleaning	0.67	1.14	0.68	0.83	0.09	0.03	0.14	0.09
$NiCl_2$ packer	13.85	29.91	31.05	24.94	0.21	1.13	<0.02	0.45
$NiCl_2$ packer	3.11	5.18	5.34	4.54	2.71	0.26	0.68	1.22
$NiCl_2$ packer	0.18	1.56	1.87	1.20	<0.02	0.39	0.49	0.30
$NiCl_2$ packer	<0.02	0.09	0.31	0.14	<0.02	0.07	0.20	0.09
$NiCl_2$ packer - Supervisor	12.02	13.69	1.60	9.11	3.53	0.81	0.36	1.57
$NiCl_2$ packer - Supervisor	9.11	2.91	2.52	4.85	1.90	2.76	1.11	1.92
Powder metallurgy:								
Powder mixer op	0.71	1.83	1.83	1.46	0.06	0.79	<0.02	0.29
Setter, press shop	4.81	0.94	7.52	4.42	1.23	5.53	15.98	7.58
Setter, press shop	1.52	27.47	111.23	46.74	<0.02	3.79	23.23	9.01
Setter, press shop	4.79	4.58	3.75	4.37	1.92	0.28	0.62	0.94
Grinding m/c operator	0.02	0.50	0.09	0.20	<0.02	<0.02	<0.02	<0.02
Grinding m/c operator	1.13	0.33	0.48	0.65	0.19	0.43	0.34	0.32
Grinding m/c operator	3.25	2.05	1.57	2.29	0.52	0.45	2.64	1.20
Grinding m/c operator	2.15	0.68	0.69	1.17	6.12	0.36	0.63	2.37
Stainless steel production:								
Alloy handler	N/A	N/A	0.07	0.07	N/A	N/A	0.03	0.03
Alloy handler	0.02	0.05	0.03	0.03	0.05	<0.02	0.03	0.03
Alloy handler	0.05	0.08	0.08	0.07	0.05	0.02	0.02	0.03
Alloy handler	0.11	N/A	0.07	0.09	0.04	N/A	0.05	0.04
Alloy handler	0.09	0.02	0.21	0.10	<0.02	0.03	0.13	0.06
Raw materials inspector	0.07	0.05	0.02	0.05	0.06	<0.02	<0.02	0.03
Raw materials inspector	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
DC Arc Technician	0.08	0.07	0.11	0.09	0.14	0.08	0.40	0.21
DC Arc Technician	0.20	0.05	0.73	0.33	0.11	0.04	0.80	0.32
DC Arc Technician	N/A	0.03	0.04	0.04	N/A	0.05	0.09	0.07
DC Arc Technician	N/A	0.06	0.05	0.05	N/A	0.22	0.10	0.16
DC Arc Technician	0.32	0.47	3.05	1.28	0.32	0.39	0.56	0.42
DC Arc Technician	0.05	0.86	0.43	0.45	0.04	0.55	0.23	0.27

N/A – Not available, not sampled.

Table 6 Individual sample results for the hands and forearms (total nickel)

Job	Hands: Sample 1	Hands: Sample 2	Hands: Sample 3	Average Hands	Forearms: Sample 1	Forearms: Sample 2	Forearms: Sample 3	Average forearm
	Dermal nickel exposure (µg/cm^2)							
Nickel refinery:								
Raw materials operator	2.42	1.49	1.69	1.87	2.05	0.49	6.61	3.05
Raw materials operator	N/A	0.68	0.77	0.73	N/A	1.07	0.57	0.82
Raw materials store - loader driver	3.73	3.17	3.80	3.57	0.17	0.33	0.81	0.44
Electrolysis - Lifting/checking	1.38	0.34	0.20	0.64	0.80	0.56	0.82	0.73
Electrolysis - Lifting/checking	1.25	3.54	0.79	1.86	<0.02	0.28	0.33	0.21
Electrolysis - Unloading/cleaning	1.08	1.60	1.08	1.25	0.16	0.19	2.35	0.90
$NiCl_2$ packer	24.88	34.26	33.35	30.83	0.66	1.14	<0.02	0.61
$NiCl_2$ packer	3.49	6.28	6.57	5.44	2.99	0.55	1.22	1.59
$NiCl_2$ packer	0.45	4.45	17.20	7.37	<0.02	1.10	2.28	1.13
$NiCl_2$ packer	0.30	0.13	0.39	0.27	0.22	0.20	0.44	0.29
$NiCl_2$ packer - Supervisor	13.68	33.65	2.55	16.62	4.08	1.52	0.82	2.14
$NiCl_2$ packer - Supervisor	12.32	3.89	2.80	6.33	2.62	4.16	1.35	2.71
Powder metallurgy:								
Powder mixer op	0.72	1.84	1.84	1.47	0.07	0.91	<0.02	0.33
Setter, press shop	5.05	0.96	8.10	4.70	1.32	5.75	16.51	7.86
Setter, press shop	1.53	27.69	111.77	47.00	0.34	4.19	23.59	9.37
Setter, press shop	5.10	4.76	4.20	4.69	2.00	0.35	0.85	1.07
Grinding m/c operator	0.03	0.51	0.10	0.21	<0.02	<0.02	<0.02	<0.02
Grinding m/c operator	1.25	0.39	0.53	0.72	0.25	0.48	0.42	0.39
Grinding m/c operator	3.30	2.06	1.64	2.33	0.53	0.46	2.70	1.23
Grinding m/c operator	2.33	0.71	0.76	1.27	6.31	0.40	1.11	2.61
Stainless steel production:								
Alloy handler	N/A	N/A	0.11	0.11	N/A	N/A	0.04	0.04
Alloy handler	0.03	0.06	0.04	0.04	0.06	<0.02	0.04	0.04
Alloy handler	0.06	0.09	0.10	0.08	0.06	0.03	0.03	0.04
Alloy handler	0.12	N/A	0.13	0.13	0.05	N/A	0.06	0.05
Alloy handler	0.11	0.03	0.22	0.12	0.02	0.04	0.14	0.07
Raw materials inspector	0.11	0.16	0.07	0.11	0.09	<0.02	0.04	0.05
Raw materials inspector	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
DC Arc Technician	0.11	0.09	0.14	0.11	0.21	0.09	0.44	0.25
DC Arc Technician	0.24	0.06	0.79	0.36	0.14	0.05	0.84	0.34
DC Arc Technician	N/A	0.04	0.05	0.05	N/A	0.06	0.10	0.08
DC Arc Technician	N/A	0.07	0.06	0.06	N/A	0.23	0.11	0.17
DC Arc Technician	0.35	0.56	3.15	1.35	0.33	0.45	0.60	0.46
DC arc technician	0.06	0.88	0.44	0.46	0.05	0.56	0.24	0.28

N/A – Not available, not sampled.

5.1 ANALYSIS OF DERMAL EXPOSURE DATA BY TASK AND EASE CATEGORY

All jobs fell within a single EASE task category. This was non-dispersive use with intermittent direct contact. The predicted dermal exposure values for this category is 0.1 – 1 $mg/cm^2/day$. The justifications for including the data in the different EASE categories were previously given in the relevant subsections of Section 4. EASE is a relatively crude exposure model and cannot be used to differentiate between different tasks where there are only subtle differences in working methods and control methods. Therefore, the data are categorised in terms of the industry sector and subdivided by each department or similarly exposed group.

The summary exposure data detailed in Tables 1 – 3 were analysed for each anatomical area sampled by job title/task to determine the number of samples per category (N), the exposure range (minimum and maximum values), median and the upper 90^{th} percentile value.

Exposure results are provided for the hands (average of three separate measurements per subject), forearms (average of three separate measurements), arms and forearms combined (weighted average of hands and arms), neck, face and chest. In addition, the total number of samples, minimum, maximum, median and 90^{th} percentile values is calculated for all exposure measurements within each task category.

These are sorted by the separate job titles/tasks for each of the industries surveyed as follows: nickel refinery; raw materials handling (Table 7); electrolysis (Table 8), nickel chloride packing (Table 9); powder metallurgy (Tables 10 and 11) and stainless steel production (Tables 12 and 13).

For the purposes of this assessment, the workers involved in powder metallurgy were split into two groups (powder operator/machine setters and grinding machine operators) since the workers within each were considered to be similarly exposed. This was due to the fact that the setters and the powder operator were all directly exposed to nickel powders. The grinding machine operators were not directly exposed to nickel powders but handled the nickel containing alloys that were being produced. Similarly the workers in the stainless steel production plant were split in to two similarly exposed groups. The alloy handlers and raw materials inspectors formed one group due to their involvement or proximity to the nickel briquettes and nickel cathodes. The second group comprised the DC-arc technicians, who did not come into direct contact with the pure nickel metal, but were involved in maintenance work in the general area where the alloys and other metals were being used.

Comparisons of dermal exposure for each anatomical area are illustrated graphically for each task category in the box-plots shown in Figures 1 – 7. In these plots, the boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box furthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles. It should be noted that a minimum number of data points is required to compute each set of percentiles. At least three points are required to compute the 25th and 75th percentiles, five points to compute the 10th percentile, and six points to compute the 5th, 90th, and 95th percentiles. If SigmaPlot is unable to compute a percentile point, that set of points is not drawn.

Table 7 Summary of dermal nickel exposures by industry/task

Nickel refinery – Raw materials handling

Anatomical area	N	Min	Max	Median	90th %
	Dermal nickel exposures (μg/cm²)				
Soluble Nickel					
Average Hands	3	0.25	0.51	0.35	0.48
Average Forearms	3	0.04	0.47	0.24	0.42
Hands & Arms	3	0.17	0.48	0.24	0.44
Neck	3	0.07	0.35	0.23	0.33
Face	3	0.56	1.51	0.86	1.38
Chest	3	<0.02	0.37	0.11	0.32
All sample areas	15	<0.02	1.51	0.35	0.74
Insoluble Nickel					
Average Hands	3	0.48	3.22	1.36	2.85
Average Forearms	3	0.40	2.58	0.58	2.18
Hands & Arms	3	0.54	2.06	1.60	1.97
Neck	3	0.09	0.62	0.11	0.52
Face	3	0.50	5.44	5.40	5.43
Chest	3	0.13	1.23	0.49	1.08
All sample areas	15	0.09	5.44	0.58	4.53
Total Nickel					
Average Hands	3	0.73	3.57	1.87	3.23
Average Forearms	3	0.44	3.05	0.82	2.60
Hands & Arms	3	0.78	2.55	1.76	2.39
Neck	3	0.16	0.97	0.34	0.85
Face	3	1.06	6.91	6.29	6.78
Chest	3	0.24	1.60	0.50	1.38
All sample areas	15	0.16	6.91	0.97	5.20

Note: The tasks covered by these measurements were assigned EASE exposure criteria of non-dispersive use with intermittent direct contact. The predicted hand/arm exposure level for this task combination is 0.1 – 1.0 mg/cm^2 per day.

Table 8 Summary of dermal nickel exposures by industry/task

Nickel refinery - Electrolysis

Anatomical area	Dermal nickel exposures (µg/cm^2)				
	N	Min	Max	Median	90th %
Soluble Nickel					
Average Hands	3	0.11	1.07	0.42	0.94
Average Forearms	3	0.11	0.81	0.21	0.69
Hands & Arms	3	0.17	0.65	0.52	0.62
Neck	3	<0.02	0.13	0.12	0.13
Face	3	0.78	1.02	1.00	1.02
Chest	3	<0.02	0.12	<0.02	0.10
All sample areas	15	<0.02	1.07	0.13	1.02
Insoluble Nickel					
Average Hands	3	0.53	0.83	0.79	0.82
Average Forearms	3	0.09	0.52	0.10	0.43
Hands & Arms	3	0.39	0.52	0.40	0.50
Neck	3	<0.02	0.10	<0.02	0.08
Face	3	<0.02	3.30	0.16	2.67
Chest	3	<0.02	0.05	<0.02	0.04
All sample areas	15	<0.02	3.30	0.10	0.82
Total Nickel					
Average Hands	3	0.64	1.86	1.25	1.74
Average Forearms	3	0.21	0.90	0.73	0.87
Hands & Arms	3	0.69	1.05	0.91	1.02
Neck	3	<0.02	0.22	0.14	0.21
Face	3	0.94	4.32	1.01	3.66
Chest	3	<0.02	0.17	<0.02	0.14
All sample areas	15	<0.02	4.32	0.64	1.62

Note: The tasks covered by these measurements were assigned EASE exposure criteria of non-dispersive use with intermittent direct contact. The predicted hand/arm exposure level for this task combination is 0.1 – 1.0 mg/cm^2 per day.

Table 9 Summary of dermal nickel exposures by industry/task

Nickel refinery – Ni Cl2 packing

Anatomical area	Dermal nickel exposures (µg/cm^2)				
	N	Min	Max	Median	90th %
Soluble Nickel					
Average Hands	6	0.13	7.52	3.69	6.84
Average Forearms	6	0.16	0.84	0.47	0.81
Hands & Arms	6	0.17	3.52	1.84	3.31
Neck	6	<0.02	1.92	0.29	1.23
Face	6	0.66	2.55	1.40	2.20
Chest	6	<0.02	5.77	0.27	3.04
All sample areas	30	<0.02	7.52	0.62	5.78
Insoluble Nickel					
Average Hands	6	0.14	24.94	4.69	17.02
Average Forearms	6	0.09	1.92	0.83	1.75
Hands & Arms	6	0.11	10.84	2.90	7.80
Neck	6	<0.02	0.75	0.22	0.63
Face	6	0.16	1.03	0.65	0.99
Chest	6	<0.02	1.08	0.14	0.77
All sample areas	30	<0.02	24.94	0.51	4.57
Total Nickel					
Average Hands	6	0.27	30.83	6.85	23.73
Average Forearms	6	0.29	2.71	1.36	2.43
Hands & Arms	6	0.28	13.43	4.01	10.86
Neck	6	0.08	2.43	0.74	1.59
Face	6	0.90	3.12	2.24	3.00
Chest	6	<0.02	6.23	0.42	3.66
All sample areas	30	<0.02	30.83	1.15	6.44

Note: The tasks covered by these measurements were assigned EASE exposure criteria of non-dispersive use with intermittent direct contact. The predicted hand/arm exposure level for this task combination is 0.1 – 1.0 mg/cm^2 per day.

Table 10 Summary of dermal nickel exposures by industry/task

Powder metallurgy – Powder operator and machine setters

Anatomical area	Dermal nickel exposures (µg/cm^2)				
	N	Min	Max	Median	90th %
Soluble Nickel					
Average Hands	4	<0.02	0.31	0.27	0.30
Average Forearms	4	0.05	0.36	0.20	0.34
Hands & Arms	4	0.03	0.32	0.24	0.31
Neck	4	<0.02	1.39	0.18	1.03
Face	4	<0.02	2.15	1.28	2.01
Chest	4	<0.02	0.67	0.22	0.57
All sample areas	24	<0.02	2.15	0.27	1.24
Insoluble Nickel					
Average Hands	4	1.46	46.74	4.40	34.05
Average Forearms	4	0.29	9.01	4.26	8.58
Hands & Arms	4	0.78	25.02	4.32	19.38
Neck	4	0.45	2.95	0.67	2.30
Face	4	0.12	31.08	7.60	25.66
Chest	4	<0.02	4.43	2.40	3.92
All sample areas	24	<0.02	46.74	2.56	21.42
Total Nickel					
Average Hands	4	1.47	47.00	4.69	34.31
Average Forearms	4	0.33	9.37	4.46	8.92
Hands & Arms	4	0.81	25.33	4.56	19.69
Neck	4	0.58	4.34	0.79	3.33
Face	4	0.13	33.23	8.89	27.67
Chest	4	<0.02	4.56	2.90	4.10
All sample areas	24	<0.02	47.00	3.05	22.15

Note: The tasks covered by these measurements were assigned EASE exposure criteria of non-dispersive use with intermittent direct contact. The predicted hand/arm exposure level for this task combination is 0.1 – 1.0 mg/cm^2 per day.

Table 11 Summary of dermal nickel exposures by industry/task

Powder metallurgy – Grinding machine operators

Anatomical area	N	Min	Max	Median	90th %
	Dermal nickel exposures (µg/cm²)				
Soluble Nickel					
Average Hands	4	<0.02	0.09	0.06	0.09
Average Forearms	4	<0.02	0.24	0.05	0.18
Hands & Arms	4	<0.02	0.18	0.05	0.14
Neck	4	<0.02	0.25	0.09	0.23
Face	4	<0.02	0.22	0.12	0.19
Chest	4	<0.02	0.19	0.06	0.15
All sample areas	24	<0.02	0.25	0.07	0.21
Insoluble Nickel					
Average Hands	4	0.20	2.29	0.91	1.95
Average Forearms	4	<0.02	2.37	0.76	2.02
Hands & Arms	4	0.09	1.86	1.06	1.80
Neck	4	<0.02	0.79	0.26	0.71
Face	4	0.09	2.80	0.40	2.14
Chest	4	<0.02	0.29	0.09	0.24
All sample areas	24	<0.02	2.80	0.39	2.16
Total Nickel					
Average Hands	4	0.21	2.33	0.99	2.01
Average Forearms	4	<0.02	2.61	0.81	2.19
Hands & Arms	4	0.10	2.04	1.11	1.94
Neck	4	<0.02	1.04	0.35	0.93
Face	4	0.22	2.81	0.57	2.22
Chest	4	0.07	0.30	0.22	0.28
All sample areas	24	<0.02	2.81	0.46	2.24

Note: The tasks covered by these measurements were assigned EASE exposure criteria of non-dispersive use with intermittent direct contact. The predicted hand/arm exposure level for this task combination is 0.1 – 1.0 mg/cm^2 per day.

Table 12 Summary of dermal nickel exposures by industry/task

Stainless Steel Production – Alloy handlers and raw material inspectors

Anatomical area	Dermal nickel exposures (µg/cm²)				
	N	Min	Max	Median	90th %
Soluble Nickel					
Average Hands	7	<0.02	0.06	<0.02	0.05
Average Forearms	7	<0.02	0.02	<0.02	<0.02
Hands & Arms	7	<0.02	0.04	<0.02	0.03
Neck	7	<0.02	0.37	<0.02	0.19
Face	7	<0.02	0.10	<0.02	0.06
Chest	7	<0.02	0.03	<0.02	0.02
All sample areas	42	<0.02	0.37	<0.02	0.04
Insoluble Nickel					
Average Hands	7	<0.02	0.11	0.07	0.10
Average Forearms	7	<0.02	0.06	0.03	0.05
Hands & Arms	7	<0.02	0.08	0.05	0.07
Neck	6	<0.02	0.16	0.02	0.12
Face	7	<0.02	0.36	0.04	0.31
Chest	7	<0.02	0.17	0.03	0.14
All sample areas	41	<0.02	0.36	0.04	0.11
Total Nickel					
Average Hands	7	<0.02	0.13	0.11	0.12
Average Forearms	7	<0.02	0.07	0.04	0.06
Hands & Arms	7	<0.02	0.09	0.07	0.08
Neck	6	<0.02	0.52	0.08	0.31
Face	7	<0.02	0.46	0.07	0.36
Chest	7	<0.02	0.20	0.04	0.15
All sample areas	41	<0.02	0.52	0.06	0.13

Note: The tasks covered by these measurements were assigned EASE exposure criteria of non-dispersive use with intermittent direct contact. The predicted hand/arm exposure level for this task combination is 0.1 – 1.0 mg/cm² per day.

Table 13 Summary of dermal nickel exposures by industry/task

Stainless Steel Production – DC-Arc Technicians

Anatomical area	Dermal nickel exposures (µg/cm²)				
	N	Min	Max	Median	90th %
Soluble Nickel					
Average Hands	6	<0.02	0.07	0.02	0.05
Average Forearms	6	<0.02	0.04	0.02	0.04
Hands & Arms	6	<0.02	0.05	0.02	0.04
Neck	6	<0.02	0.23	0.06	0.17
Face	6	<0.02	0.20	0.10	0.18
Chest	6	<0.02	0.18	0.05	0.17
All sample areas	36	<0.02	0.23	0.03	0.15
Insoluble Nickel					
Average Hands	6	0.04	1.28	0.21	0.86
Average Forearms	6	0.07	0.42	0.24	0.37
Hands & Arms	6	0.06	0.79	0.24	0.57
Neck	6	0.10	0.43	0.18	0.40
Face	6	0.04	0.64	0.28	0.49
Chest	6	0.05	1.16	0.12	0.94
All sample areas	36	0.04	1.28	0.22	0.68
Total Nickel					
Average Hands	6	0.05	1.35	0.24	0.91
Average Forearms	6	0.08	0.46	0.27	0.40
Hands & Arms	6	0.07	0.84	0.27	0.60
Neck	6	0.11	0.66	0.22	0.57
Face	6	0.05	0.84	0.35	0.66
Chest	6	0.06	1.33	0.17	1.11
All sample areas	36	0.05	1.35	0.24	0.84

Note: The tasks covered by these measurements were assigned EASE exposure criteria of non-dispersive use with intermittent direct contact. The predicted hand/arm exposure level for this task combination is 0.1 – 1.0 mg/cm^2 per day.

5.2 ANALYSIS OF DERMAL EXPOSURE BY NICKEL SPECIES

All of the exposure measurements were analysed together to determine the ratio of soluble nickel to total nickel content for each of the process areas or tasks sampled. The summary results of this analysis are shown in Table 14 and the results for each category are illustrated graphically in box plots Figures 8 – 10. The results show that there were some differences in nickel solubility between the different task categories and also considerable variability within the task categories. Using the median values for each task category, the levels of soluble nickel in comparison with total nickel were relatively low overall. The exposures with the lowest soluble nickel were the powder metallurgy workers and the raw material handlers in the nickel refinery, although for each group there were large outliers in each data set which makes it difficult to distinguish clear patterns.

The data for the exposure measurements for the nickel chloride packers show the median ratio of soluble/total nickel to be 0.53, which is relatively lower than expected, given the high solubility of this particular nickel compound. Due to the wide range in the solubility ratios it is difficult to distinguish a clear pattern with these data.

Table 14 Ratio of soluble nickel to total nickel content of dermal exposure measurements

All samples by task category

Industry	Process area	N	Min	Max	Median	90th %
Nickel refinery	Raw materials	25	<0.01	0.67	0.23	0.53
	Electrolysis	27	0.04	0.99	0.50	0.93
	$NiCl_2$ packing	54	0.01	0.97	0.53	0.86
Powder metallurgy	Powder op/setters	36	<0.01	0.97	0.07	0.30
	Grinding	36	<0.01	0.85	0.14	0.50
Stainless steel production	Alloy handling/inspectors	56	0.04	0.87	0.34	0.51
	DC Arc techs	50	0.02	0.58	0.17	0.32

5.3 RESULTS OF INHALABLE DUST MONITORING

Measurements of total inhalable dust and nickel are presented for the majority of workers included in the dermal sampling survey (28 air samples from 33 dermal measurements).

A total of 28 inhalable dust samples were collected and these were analysed gravimetrically to determine inhalable dust concentrations. The inhalable dust samples were subsequently analysed for nickel species by a third party laboratory nominated by the sponsor. The total inhalable nickel concentration for each sample was calculated and included with the corresponding inhalable dust concentration in Table 15.

There were some interesting differences in the inhalable dust and nickel concentrations between the different workplaces and for the different jobs at each site. In the case of the nickel refinery, the highest inhalable dust concentration were measured in the raw materials areas, with the loader driver in the raw materials store having the highest exposure level for both total inhalable dust (3.5 mg/m^3) and nickel (0.25 mg/m^3).

The inhalable dust and nickel concentrations for the electrolysis workers were low, which is unsurprising given the relatively high level of control of the process emissions in this particular area. The levels of inhalable dust were in the range 0.6 – 1.4 mg/m^3 and the inhalable nickel concentrations were 0.01 – 0.02, which is low in comparison with the UK workplace exposure limit of 0.1 mg/m^3 for soluble nickel compounds (HSE, 2005).

It is interesting to note that the inhalable dust and nickel concentrations for the nickel chloride packers were relatively low. This is in comparison to the high dermal nickel exposures measured for some of the workers. The inhalable dust and nickel concentrations and corresponding dermal exposure data are compared in Table 16. Referring to Table 16, it can be seen that the workers with the two highest dermal hand exposures, (30.83 and 16.62 µg/cm^2) had comparatively low inhalable dust concentrations at 1.10 and 0.43 mg/m^3 respectively. The corresponding inhalable nickel concentrations were 0.03 and 0.01 mg/m^3 respectively, which are relatively low in comparison with the UK workplace exposure limit of 0.1 mg/m^3 for soluble nickel compounds. The high dermal exposures for these two workers can be explained by the fact that they both did not wear gloves, or only wore them for some of the time. The highest airborne dust and nickel exposures for the nickel packers were 1.3 and 0.9 mg/m^3 respectively, although in this case the worker had a relatively low dermal exposure of 7.37 µg/cm^2.

In the powder metallurgy company, the total inhalable dust concentrations were generally low, within the range 0.4 – 1.3 mg/m^3. The inhalable nickel concentrations for the press shop setters were highest and were within the range 0.12 – 0.36 mg/m^3. Presumably this is due to the high nickel content of the powders being used in this particular work area.

The inhalable dust and nickel exposures for the powder operator were low at 0.4 mg/m^3 and 0.02 mg/m^3 respectively, which is explained by the relatively high level of dust control provided by the powder handling booth.

The inhalable dust and nickel concentrations measured for the grinding machine operators were relatively low, which is to be expected given that this is a wet process and that only very small quantities of material is removed from the alloy during the grinding process. For these workers, the measured inhalable dust concentrations were in the range 0.6 – 2.6 mg/m^3 and the inhalable nickel levels were 0.01 – 0.03 mg/m^3, which is low.

For the powder metallurgy operation the UK workplace exposure limit value of 0.5 mg/m^3 for water insoluble nickel would apply. All of the measured airborne nickel exposures were below this limit value.

There are again some interesting differences between dermal and inhalable dust exposures. One of the setters was sampled twice, on consecutive days. On the first day the dermal exposure for the hands was relatively low at 4.7 µg/cm^2 but the airborne nickel exposure was relatively high at 0.36 mg/m^3. On the second day the dermal exposure was high at 47 µg/cm^2 and the airborne nickel exposure was low at 0.12 mg/m^3.

In the stainless steel production plant the inhalable dust concentrations for the alloy handlers were high in comparison with the other industries monitored, with measurements in the range 1.2 – 5.7 mg/m^3. However, the airborne nickel concentrations were low, with levels from 0.1

– 0.04 mg/m^3. This shows that the process area was generally dusty, but that the nickel content in this particular area was low. This is further illustrated by the DC-Arc technicians, two of whom had high inhalable dust concentrations of 7.8 and 11.6 mg/m^3, but the nickel content was relatively low at 0.04 and 0.12 mg/m^3. It should be noted that the dust and nickel exposures for these workers was a consequence of maintenance and operation of a flue dust recycling plant and was not attributed to direct work with nickel products such as nickel briquettes or nickel cathode plate. Again, the workplace exposure limit of 0.5 mg/m^3 would apply to this work and the measured levels were all below the limit value.

Table 15 Results of air monitoring at in nickel user and nickel production industries

Sample No.	Job title	Time on	Time off	Volume (l)	Airborne concentration (mg/m^3) Total inhalable dust	Total inhalable nickel
Nickel refinery:						
QF-0025	Raw materials operator	14:50	20:05	609	1.3	0.19
QF-0034	Raw materials operator	10:01	12:25	288	1.0	0.05
QF-0030	Raw materials – loader driver	08:05	16:07	964	3.5	0.25
QF-0027	Electrolysis – Unloading/cleaning	15:15	20:08	576	0.8	0.01
QF-0032	Electrolysis – Lifting/checking	07:40	12:07	516	0.6	0.02
QF-0029	Electrolysis – Lifting/checking	08:15	12:00	450	1.4	0.01
QF-0028	$NiCl_2$ crystals packer	07:45	11:40	462	<0.3	0.01
QF-0026	$NiCl_2$ crystals packer	15:00	20:00	580	1.1	0.03
QF-0033	$NiCl_2$ crystals packer	07:45	11:56	502	1.3	0.09
QF-0031	$NiCl_2$ crystals – Supervisor	08:00	15:46	932	0.4	0.01
Powder metallurgy:						
QF-0019	Powder mixer op	08:30	17:42	1104	0.4	0.02
QF-0018	Setter, press shop	08:18	13:40	644	1.3	0.36
QF-0022	Setter, press shop	08:15	14:21	732	0.8	0.12
QF-0023	Setter, press shop	11:12	17:57	810	0.9	0.22
QF-0017	Grinding m/c operator	08:25	13:15	580	0.6	0.02
QF-0014	Grinding m/c operator	08:22	12:40	516	1.1	0.01
QF-0020	Grinding m/c operator	12:40	18:02	644	2.6	0.03
QF-0021	Grinding m/c operator	08:10	15:22	864	1.7	0.02
Stainless steel production:						
QF-0004	Alloy handler	16:37	19:50	386	1.2	0.03
QF-0007	Alloy handler	07:45	12:43	596	5.7	0.04
QF-0008	Alloy handler	08:11	13:05	588	5.1	0.02
QF-0012	Alloy handler	14:28	19:48	640	5.6	0.02
QF-0009	Raw materials inspector	08:40	16:12	904	2.4	0.01
QF-0011	Raw materials inspector	08:53	16:50	954	1.2	<0.01
QF-0001	DC arc technician	07:50	12:33	566	7.8	0.04
QF-0002	DC arc technician	09:12	12:33	402	11.6	0.12
QF-0003	DC arc technician	16:22	20:20	476	4.3	0.05
QF-0006	DC arc technician	16:47	19:05	276	3.5	0.06

5.4 CORRELATION OF EXPOSURE DATA BY ANATOMICAL AREA

The dermal exposure measurements for each anatomical area (hands, arms, neck, face and chest) were compared with each other to identify any associations. In addition, the dermal exposure measurements were compared with the inhalable dust and nickel concentration measurements in order to identify any association between these measurements.

The exposure data used for this comparison is detailed in Table 16 and the Pearson correlation coefficients are detailed in Table 17.

The average of all the sample results for each subject is provided as a general indication of nickel skin surface loading for each worker. This average value is calculated using all three sets of samples from the hands and forearms and one of each from the neck, face and chest and is not weighted for any particular skin surface area.

The results of the Pearson correlation tests (Table 17) show high correlation between the average dermal nickel levels of the hands and forearms (r=0.838), the hands and face (r=0.757), forearms and face (r=0.695) and forearms and neck (r=0.670).

A selection of the comparisons between dermal nickel levels for different anatomical areas are presented as scatter plots, as shown in Figures 11 – 15.

Generally, the dermal nickel exposures were not correlated well with the total inhalable dust concentrations or the inhalable nickel concentrations. While there were no statistically significant associations between dermal exposures and inhalable dust exposures, the results of the comparison suggest a negative correlation. Conversely, the corresponding comparison between dermal exposures and inhalable nickel exposures showed an indication of a positive correlation. These data are likely to be heavily influence by the results from the stainless steel production plant, where only a small proportion of the airborne dust that was sampled comprised nickel. The relation between the inhalable dust and dermal hand exposures is illustrated in Figure 15. Also, there was no significant correlation between the total inhalable dust and inhalable nickel concentrations. These correlations are illustrated in Figure 16.

However, the inhalable nickel concentrations were correlated with the dermal nickel levels for the chest (r=0.731). The correlations for inhalable nickel and the face and chest are illustrated in Figures 17 and 18 respectively.

Table 16 Comparison of dermal nickel exposures with inhalable dust and nickel concentrations

Job	Dermal (total) nickel exposures (µg/cm²)						Airborne dust (mg/m³)	
	Average hands	Average forearms	Neck	Face	Chest	Average[1] all areas	Total inhalable dust	Total inhalable nickel
Nickel Refinery:								
Raw materials operator	0.73	0.82	0.34	1.06	0.24	0.68	1.01	0.05
Raw materials operator	1.87	3.05	0.97	6.29	0.50	2.50	1.31	0.19
Raw materials - loader driver	3.57	0.44	0.16	6.91	1.60	2.30	3.52	0.25
Electrolysis - Lifting/checking	1.86	0.21	0.02	1.01	0.02	0.81	0.62	0.02
Electrolysis - Lifting/checking	0.64	0.73	0.14	4.32	0.02	0.95	1.38	0.01
Electrolysis - unloading/cleaning	1.25	0.90	0.22	0.94	0.17	0.87	0.78	0.01
NiCl2 packer	5.44	1.59	0.73	2.03	0.29	2.68	<0.3	0.01
NiCl2 packer	0.27	0.29	0.75	1.16	0.43	0.45	N/A	N/A
NiCl2 packer	7.37	1.13	0.17	0.90	6.23	3.65	1.25	0.09
NiCl2 packer	30.83	0.61	0.08	2.44	1.09	10.88	1.10	0.03
NiCl2 packer - Supervisor	16.62	2.14	0.76	2.89	0.02	6.66	0.43	0.01
NiCl2 packer - Supervisor	6.33	2.71	2.43	3.12	0.41	3.68	N/A	N/A
Powder metallurgy:								
Powder mixer op	1.47	0.33	0.58	0.13	0.02	0.68	0.37	0.02
Setter, press shop	4.70	7.86	0.62	3.06	3.04	4.93	1.29	0.36
Setter, press shop	47.00	9.37	4.34	33.23	4.56	23.47	0.78	0.12
Setter, press shop	4.69	1.07	0.96	14.71	2.76	3.97	0.91	0.22
Grinding m/c operator	0.21	0.02	0.02	2.81	0.18	0.41	0.62	0.02
Grinding m/c operator	0.72	0.39	0.68	0.31	0.25	0.51	1.09	0.01
Grinding m/c operator	2.33	1.23	0.02	0.22	0.30	1.25	2.61	0.03
Grinding m/c operator	1.27	2.61	1.04	0.83	0.07	1.51	1.75	0.02
Stainless steel production:								
Alloy handler	0.04	0.04	0.02	0.07	0.04	0.04	1.17	0.03
Alloy handler	0.08	0.04	N/A	0.05	0.06	0.06	5.70	0.04
Alloy handler	0.13	0.05	0.09	0.11	0.12	0.10	5.09	0.02
Alloy handler	0.11	0.04	0.08	0.46	0.20	0.18	N/A	N/A
Alloy handler	0.12	0.07	0.52	0.28	0.02	0.15	5.59	0.02
Raw materials inspector	0.02	0.02	0.02	0.02	0.02	0.02	1.22	<0.01
Raw materials inspector	0.11	0.05	0.08	0.02	0.02	0.07	2.38	0.01
DC Arc Technician	0.36	0.34	0.47	0.84	1.33	0.53	11.57	0.12
DC Arc Technician	0.06	0.17	0.66	0.22	0.88	0.32	N/A	N/A
DC Arc Technician	0.05	0.08	0.21	0.31	0.21	0.14	N/A	N/A
DC Arc Technician	1.35	0.46	0.17	0.47	0.13	0.69	4.29	0.05
DC Arc Technician	0.11	0.25	0.11	0.05	0.13	0.15	7.84	0.04
DC Arc Technician	0.46	0.28	0.23	0.40	0.06	0.32	3.48	0.06

N/A – Not sampled, not available

[1]Average is calculated using all measurements from each subject, i.e. three individual hand samples, three different forearm samples, neck, and one each from the neck, face and chest.

Table 17 Correlations between dermal exposures between different anatomical areas and airborne dust and nickel concentrations

Total nickel or total dust (log-transformed data)

Anatomical area / correlation test		Hands	Fore-arms	Neck	Face	Chest	Inhalable dust
Forearms	Pearson correlation (r)	0.838					
	Sig (2-tailed) (p)	<0.001					
	N	33					
Neck	Pearson correlation (r)	0.451	0.670				
	Sig (2-tailed) (p)	0.010	<0.001				
	N	32	32				
Face	Pearson correlation (r)	0.757	0.695	0.514			
	Sig (2-tailed) (p)	<0.001	<0.001	0.003			
	N	33	33	32			
Chest	Pearson correlation (r)	0.476	0.499	0.385	0.569		
	Sig (2-tailed) (p)	0.005	0.003	0.029	0.001		
	N	33	33	32	33		
Airborne dust	Pearson correlation (r)	-0.454	-0.312	-0.145	-0.368	0.009	
	Sig (2-tailed) (p)	0.015	0.107	0.469	0.054	0.963	
	N	28	28	27	28	28	
Inhalable nickel	Pearson correlation (r)	0.276	0.368	0.274	0.434	0.731	0.290
	Sig (2-tailed) (p)	0.164	0.059	0.175	0.024	<0.001	0.143
	N	27	27	26	27	27	27

6 DISCUSSION

The sampling method used for this study was a removal method using moist wipes to remove surface contamination from the exposed skin, or skin areas beneath protective clothing. As such, the results obtained may be considered to be measurements of the average nickel skin surface loading over the working shift. These average exposures were calculated using the results of separate measurements for the hands and forearms obtained at three sampling intervals over the working shift. Additional measurements were obtained from the face, neck and chest, once at the end of the shift. The procedure for measuring the dermal nickel exposures in this second phase of the study was identical to that of the first phase, previously reported (Hughson, 2005). The data sets are therefore directly comparable and may be considered as relevant exposure data for risk assessment purposes. The differentiation between soluble and insoluble nickel in the sample analysis also enables comparison with known threshold levels for elicitation or induction of nickel sensitisation, since it is the soluble nickel content and nickel ions released from insoluble nickel compounds in contact with the skin that are biologically relevant in this regard.

While it is recognised that there are certain limitations to this method, including concerns about removal efficiency (Brouwer *et al.*, 2000), this method was validated for nickel compounds and the sampling protocol was designed to be comparable with previous work carried out for zinc compounds (Hughson and Cherrie, 2005), the data from which has been used for regulatory risk assessments for zinc metal (ECB 2004), zinc oxide and other zinc compounds.

One concern about removal methods in dermal exposure assessment is due to the possibility of skin absorption of the skin contaminant before samples are collected, thereby resulting in an underestimate of actual dermal exposure. This is not normally a problem for metallic dusts since the rate of skin absorption is generally believed to be low. Independent tests on dermal permeation of nickel have confirmed this, with absorption of soluble nickel and metallic nickel shown to be low, at 2% and 0.2% respectively (Hostynek *et al.*, 2001, Tanojo *et al.*, 2001). It is therefore unlikely that a significant amount of nickel was absorbed between sampling times.

We therefore consider that this method is suitable and appropriate for assessing dermal occupational exposure levels to nickel and nickel compounds. A full explanation and discussion of the method validation is given in our Phase 1 report (Hughson, 2005).

It is clear from the results that nickel skin surface loadings in the majority of cases within the industry sectors included in this survey were very low for most jobs. The jobs with the highest measured levels of dermal exposure were for the nickel chloride packers and the powder metallurgy workers (machine setters). However, in both cases there was a high contribution of insoluble nickel species. This is understandable for the powder metallurgy process since the nickel powder being used had a low level of solubility. However, it is not clear why the nickel chloride hexahydrate packers had relatively high levels of insoluble nickel detected since nickel chloride hexahydrate is considered to be highly soluble. There was no indication of other sources of nickel in these particular cases and the observed levels of visible contamination were broadly consistent with the measured dermal total nickel exposures, so it is possible that this is an artefact of the soluble nickel sample recovery that has yet to be identified. It is possible that the higher exposure samples had so much soluble nickel present that the desorption solutions became saturated with nickel ions and the soluble nickel not taken up into solution was recovered in the insoluble fraction. However, we consider this to be unlikely since the method was validated using much higher spike levels of nickel salts than were detected in the field samples. Further research may be needed to identify sources of possible error in the sample preparation and analytical methodology.

Again, the results from this survey has shown that it is not just the hands and forearms which become exposed to nickel and nickel compounds, but there is potential for similar levels in other exposed skin areas such as the face and neck. Significant exposures to the face and neck were identified for the nickel chloride packers and the press shop setters in powder metallurgy. This is likely to be due to the deposition from the air onto the skin or touching of the neck and face areas by contaminated hands.

The airborne dust and nickel exposures for the three different workplaces were all less than the relevant UK workplace exposure limits, indicating that the processes were generally well controlled. One or two elevated air concentrations for inhalable dust and nickel indicated that the survey included some examples of control lapses due to unusually high work rates or poor working practices. This provides a degree of reassurance that the results of the survey as a whole are representative of a wide range of working conditions.

Examining all the dermal exposure data together, there were some interesting associations between the nickel levels on different anatomical areas. As might be expected, the dermal nickel levels for the hands and forearms were strongly correlated, but the fact that the levels for all the other body parts were strongly correlated is encouraging since it may be possible to use these data to construct an empirical exposure model useful for predicting exposures for other similar workplaces or for different substances with similar physical properties to nickel. Further work would be required to investigate this in more detail.

Previous studies have indicated the possibility of some association between airborne levels of workplace contaminants and dermal exposure levels, e.g. Vermeulen, 2000. However, it is interesting to find no clear association in this study. The relationships between dermal exposure and other routes of exposure including inhalable dust are clearly complex. Many of the exposure determinants are not fully described, although clearly the variable use of protective clothing has a major influence.

The pattern of dermal nickel deposition combined with observed working practices shows that there is potential for inadvertent ingestion of nickel and nickel compounds, either through hand to mouth contact or from deposition into or around the perioral region. The significance of this route of exposure needs to be investigated in more detail.

The dermal nickel exposures for the stainless steel production were all very low, which is consistent with the observed working practices, which minimised the potential for incidental or prolonged contact with the nickel products being used. In fact, there were so few opportunities for direct contact with nickel products that it is possible that the measured dermal nickel exposures were mainly due to background contamination from secondary emissions from the foundry processes or from the use of high nickel alloys or stainless steel scrap.

There was some variability in dermal exposure levels within each of the task categories. This is probably due to the pattern of glove use. Certainly, the higher dermal exposures observed for the nickel chloride workers and press shop setters were observed in workers who had not worn work gloves before the samples were collected. This illustrates that simple occupational hygiene measures such as the use of gloves for critical tasks can have a highly protective effect, provided of course that they are maintained in a clean and efficient state.

The various tasks identified in this study can be grouped into one exposure category as defined by the EASE model. These would be categorised as either non-dispersive use with intermittent direct handling. When the measurements are compared with the EASE prediction for this category (0.1 – 1 mg/cm^2), it is clear that the prediction is very much higher than the measured levels, by a factor of about 100. However, the predicted exposure levels produced by EASE are intended to be estimates of the level of contamination on the outer clothing layer. Nevertheless, one might not expect gloves or other standard work wear to provide such a high level of protection (Brouwer *et al.,* 2001). The results of this study indicate that EASE tends to over-estimate exposure for these workplace scenarios, which is in line with previous evaluations of the EASE model (Creely *et al.,* 2005; Hughson and Cherrie, 2005). However, it should be noted that the observed jobs are not easily categorised according to the EASE criteria and other users may select different options for the same workplace and thereby produce different estimates. This highlights other weakness in the EASE model, i.e., that it is not always possible to consistently categorise real-world tasks according to the EASE criteria.

The dermal exposure results for Phase 1 of this study can be directly compared to those of Phase 2 since the same sampling and analytical methods were used. The highest dermal nickel exposure measurements in Phase 1 were observed for nickel powder packing workers, where the combined hand and arm total nickel exposures were within the range 3.10 – 17.49 µg/cm^2 with a median of 8.40 µg/cm^2 (soluble nickel range was 1.12 – 4.72 µg/cm^2 with a median of 2.61 µg/cm^2). This level of exposure is very similar to the powder handling workers in the powder metallurgy process included in Phase 2, where the hand/arm exposures were in the range 0.81 – 25.33 µg/cm^2 with a median of 4.56 µg/cm^2 (soluble nickel range was 0.03 – 0.32 µg/cm^2 with a median of 0.24 µg/cm^2). Both groups of workers also had significant exposures to the face and neck regions, and relatively high airborne dust exposures. This pattern of exposure is understandable, given the mobile nature of the powder products being used and its tendency to become airborne. The amount of soluble nickel exposure is most important to consider since this represents the nickel ions available for causing nickel sensitization reactions. Since nickel powder from both sites had low solubility this needs to be taken into account when assessing the risks to health.

The Phase 1 study also included exposure measurements obtained from workers involved in packing of nickel compounds, including nickel sulphate hexahydrate and nickel hydroxycarbonate. While these products may have similar physical properties to the nickel chloride hexahydrate that was included in Phase 2, the dermal exposures were very different. For packing nickel compounds in Phase 1, the total dermal nickel exposures for the hands and arms combined were very low at 0.11 – 1.34 µg/cm^2, with a median of 0.59 µg/cm^2 (soluble nickel: 0.08 – 0.90 µg/cm^2 and median of 0.39 µg/cm^2). The corresponding results for nickel chloride packing were in the range 0.28 – 13.43 µg/cm^2 with a median of 4.01 µg/cm^2 (soluble nickel: 0.17 – 3.52 µg/cm^2 and median of 1.84). This difference can be attributed to the different levels of control technology applied to the two processes. The process for packing nickel compounds in Phase 1 involved fully automatic and enclosed packing machines together with sophisticated robotic material handling equipment. Although the equipment used for the nickel chloride packing in Phase 2 was automatic, it did not have the same level of containment and additionally, there was some manual involvement when the sacks were being stacked onto pallets or boxes. The fraction of soluble nickel in the exposure measurements obtained in Phase 1 was generally higher than that obtained in Phase 2, but this cannot be explained by differences in the relative solubility of the different compounds exposure since the nickel chloride in Phase 2 would be expected to have a similar solubility. This discrepancy has yet to be resolved. Nevertheless, it is important that soluble nickel salts are handled with care since there is greater potential for nickel sensitisation reactions if skin exposure to soluble nickel ions from these compounds is sufficient.

The electro-winning process included in Phase 1 was quite different to that included in Phase 2. Both processes involved electrolytic recovery of nickel metal onto metal cathodes, but the Phase 2 workplace process evolved chlorine gas so a high level of containment and ventilation control was applied to the electrolysis tanks. The tank emissions from the Phase 1 workplace process were less noxious and, while the general area was kept well ventilated, there was no effective control of emissions from the electrolysis tanks themselves. While the airborne dust and nickel exposures were quite different, the difference between the dermal exposures was less noticeable. For comparison, the dermal exposures for the hands/arms in Phase 1 electro-winning were in the range 0.16 – 3.19 $\mu g/cm^2$ with a median of 0.30 $\mu g/cm^2$ (soluble nickel: 0.12 – 1.78, with median of 0.25 $\mu g/cm^2$), whereas the corresponding measurements for Phase 2 were 0.69 – 1.05 $\mu g/cm^2$ and 0.91$\mu g/cm^2$ respectively (soluble nickel: 0.17 – 0.65 $\mu g/cm^2$, and median of 0.52 $\mu g/cm^2$). Again, most of the nickel exposure was to soluble nickel compounds. This was due to the electrolytes used in the process. The relatively low level exposures measured for the workers in these areas is most likely due to the consistent use of protective clothing, including gloves and face protection in both workplaces.

There are interesting differences between the dermal exposures in the workers involved in the production of nickel briquettes and nickel cathodes in Phase 1 and the workers involved in using these materials in the stainless steel plant in the Phase 2 study. In the nickel refinery the dermal exposures for the nickel briquette packers were relatively high, in the range 0.74 – 9.12 $\mu g/cm^2$ with a median of 1.10 $\mu g/cm^2$ (soluble nickel: 0.10 – 0.94 $\mu g/cm^2$, with a median of 0.24 $\mu g/cm^2$). These measurements may have been influenced by contact with nickel powder which was present in the same work area. For the nickel cathode cutting workers in Phase 1, there was no potential for contact with nickel powder and the combined hand/arm exposures were lower, in the range 0.62 – 0.94 $\mu g/cm^2$, with a median of 0.65 $\mu g/cm^2$ (soluble nickel: 0.25 – 0.32 $\mu g/cm^2$, median: 0.26 $\mu g/cm^2$). The workers at the stainless steel production plant that were likely to have potential for contact with nickel briquettes and nickel cathodes had very low dermal exposures in comparison. In this case, the dermal nickel levels were in the range <0.02 – 0.09 $\mu g/cm^2$ with a median of 0.07 $\mu g/cm^2$ (soluble nickel: <0.02 – 0.04 $\mu g/cm^2$, median: <0.02 $\mu g/cm^2$). The low exposures for the stainless steel workers are almost certainly due to the mechanical handling methods used in the process. All of the workers in these groups had relatively low levels of soluble nickel exposures, which is to be expected since there was only potential for contact with metallic nickel or nickel alloys in these particular cases.

7 CONCLUSIONS

A monitoring programme to assess dermal nickel exposures was carried out for one nickel refinery and two primary users of nickel products. A total of 28 sets of dermal exposure measurements were collected from 24 different workers. In all cases, the production and activity levels within each workplace were considered to be typical of normal production, so the measured exposures can be considered representative of normal production conditions. In doing this, we have achieved the main aim of this study, which was to expand the existing scientific knowledge of dermal nickel exposure in these industry sectors.

The survey programme used a removal method for dermal sampling, with proven reliability. Although it is not possible to state with confidence how much nickel was bound to or was absorbed through the skin prior to sampling, this is not considered to be significant since the rates of dermal absorption of soluble nickel and metallic nickel have been shown to be low, at 2% and 0.2%, respectively (Hostynek *et al.,* 2001, Tanojo *et al.,* 2001).

Overall, the dermal exposures were low, and certainly very much less than predicted values generated by the EASE model. In addition, the dermal nickel levels were much lower than levels of exposure to zinc and zinc compounds previously obtained from the zinc industry. It is concluded that this is largely due to the much higher levels of engineering controls applied to the nickel production processes generally, combined with specific hygiene measures such as the consistent use of personal protective equipment.

Nevertheless there were measurable nickel deposits on the majority of hands, arms, face, neck and chest areas of all workers monitored and there was a high degree of correlation between the dermal exposure levels for the hands and forearms, neck, face and chest.

The inhalable dust and nickel exposures for each of the three sites were generally well controlled and all were less than the relevant UK workplace exposure limit for nickel and nickel compounds. A small number of inhalable dust and nickel samples could be considered to be significant, but these were associated with maintenance work or other particularly dusty operations. There were no clear associations between airborne dust and nickel concentrations and dermal exposure levels, which indicates that the main exposure determinants for each of different routes of exposure are different, at least for the workplaces visited in this study.

8 STATEMENT OF QUALITY

IOM recognise and adopt accepted UK guidelines for good survey practice.

This project was carried out under the IOM project management system, which includes preparation of a written protocol for the research and periodic auditing of the work by experienced senior scientists not actively involved in the study.

IOM has UKAS accreditation for several measurement techniques. While the laboratory analysis of all samples collected under this study is covered by the UKAS accreditation, the sampling protocol is a non-standard research procedure and cannot easily be accredited. However, the sampling procedures followed the general quality procedures required by the overall quality management system. Sampling and analytical quality assurance included appropriate calibration checks, replicate analyses and blank samples

Data processing and reporting was subject to the internal data processing control procedures. Raw data is stored for five years and can be audited by the sponsor.

9 ACKNOWLEDGEMENTS

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11 FIGURES

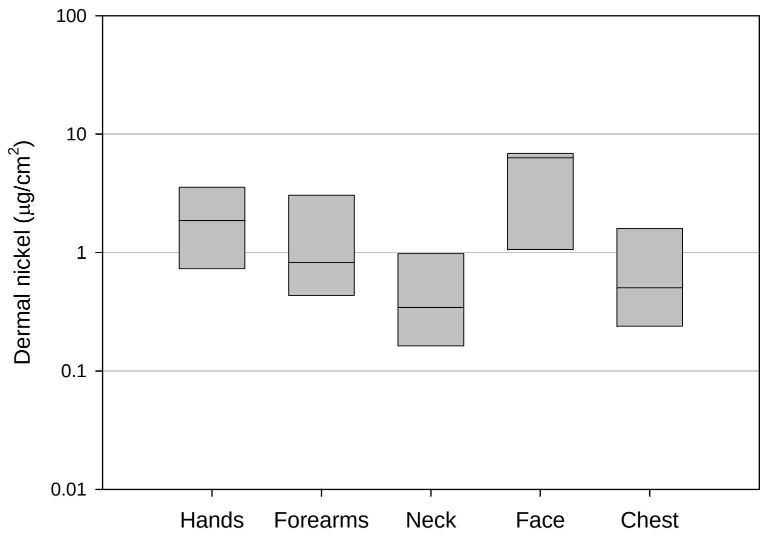

Figure 1 Dermal nickel exposures
Nickel refinery - Raw materials operators

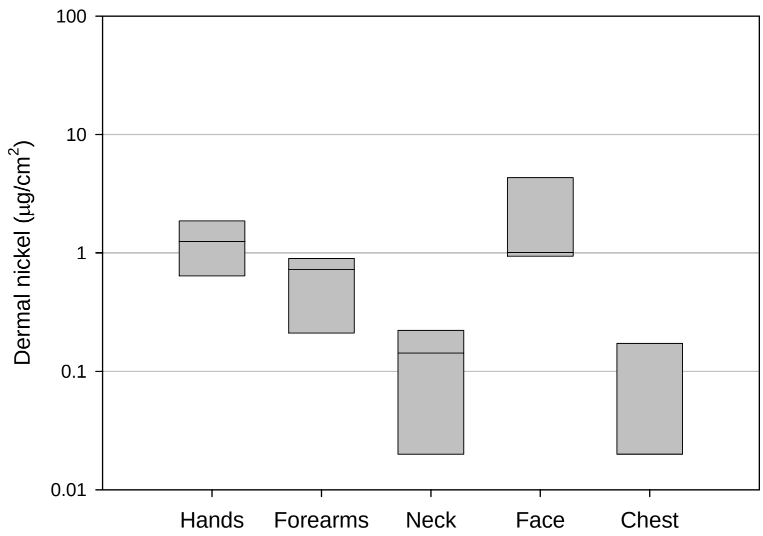

Figure 2 Dermal nickel exposures
Nickel refinery - Electrolysis operators

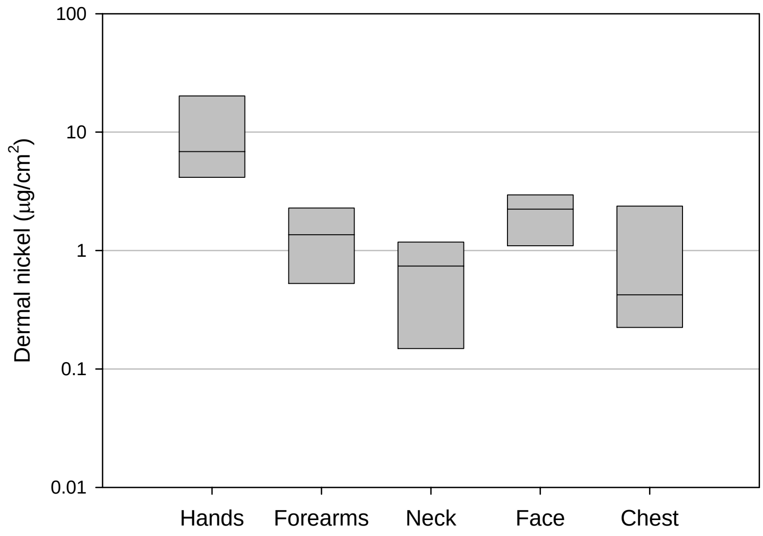

Figure 3 Dermal nickel exposures
Nickel refinery - Nickel chloride packers

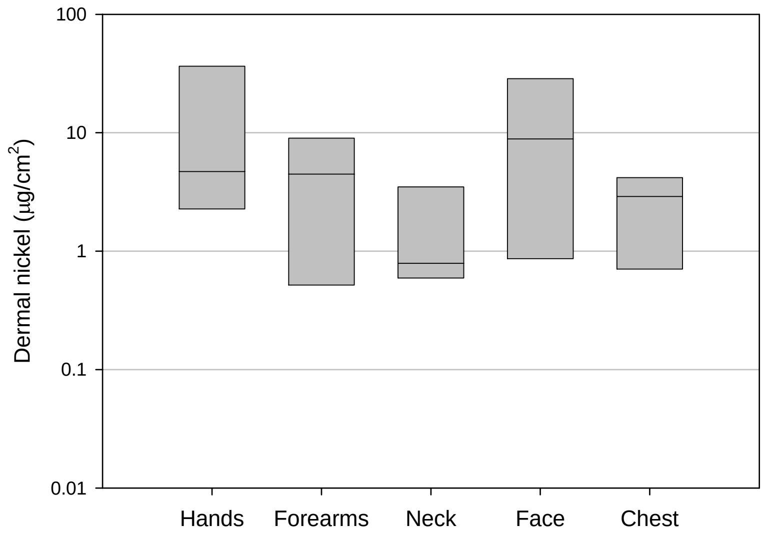

Figure 4 Dermal nickel exposures
Powder metallurgy - Powder operator and press machine setters

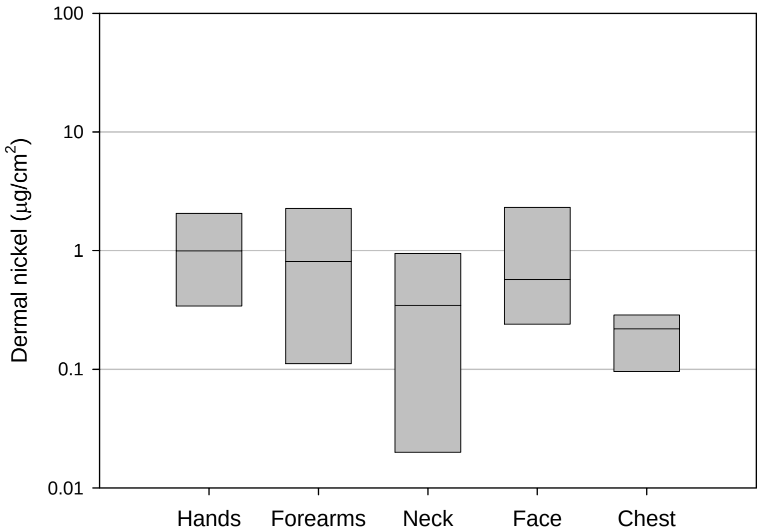

Figure 5 Dermal nickel exposures
Powder metallurgy - Grinding machine operators

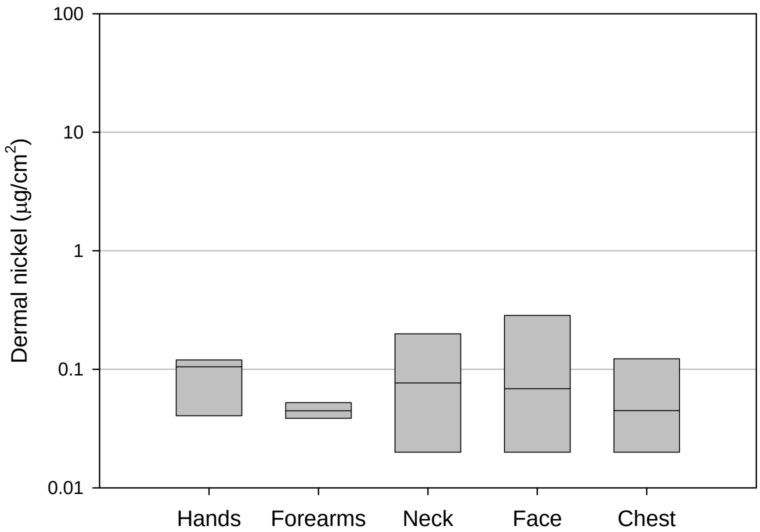

Figure 6 Dermal nickel exposures
Stainless steel production plant - Alloy handlers and raw materials inspectors

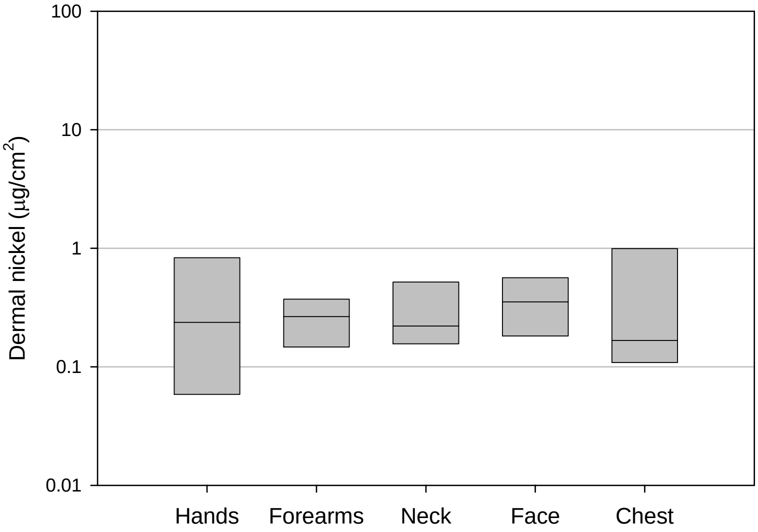

Figure 7 Dermal nickel exposures
Stainless steel production plant – DC-Arc technicians

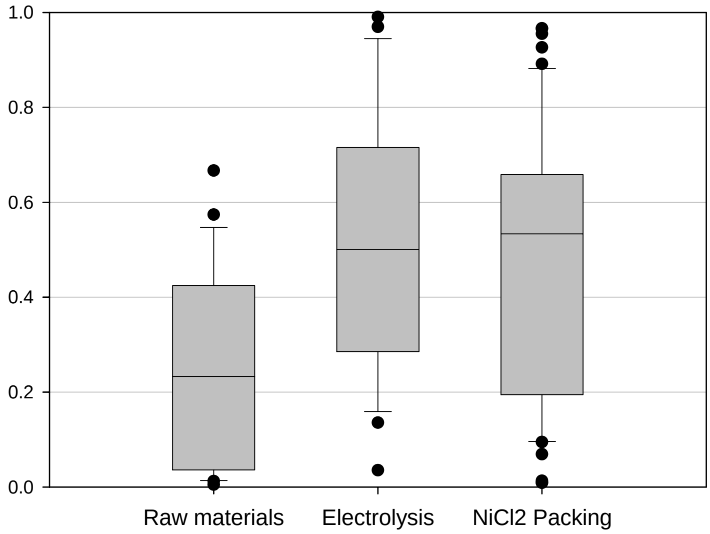

Figure 8 Ratio of soluble nickel to total nickel content of all dermal exposure measurements - Nickel refinery

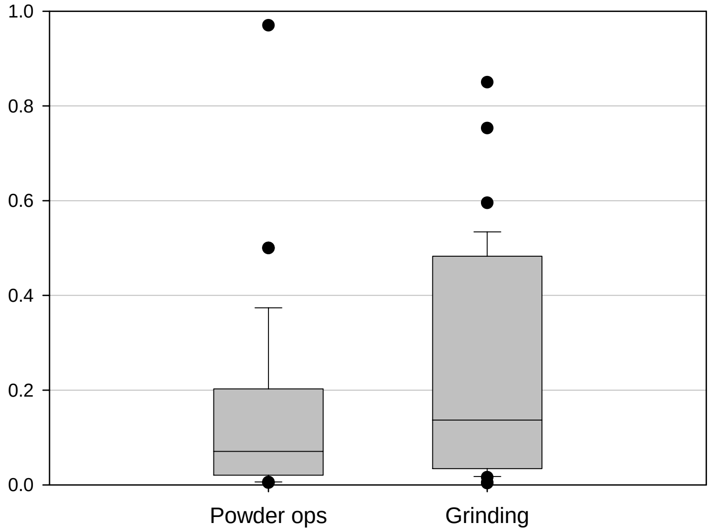

Figure 9 Ratio of soluble nickel to total nickel content of all dermal exposure measurements – Powder metallurgy

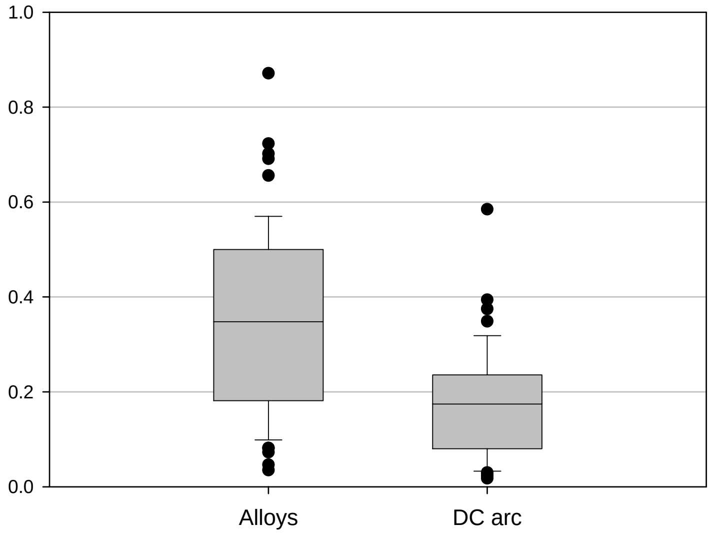

Figure 10 Ratio of soluble nickel to total nickel content of all dermal exposure measurements - Stainless steel production

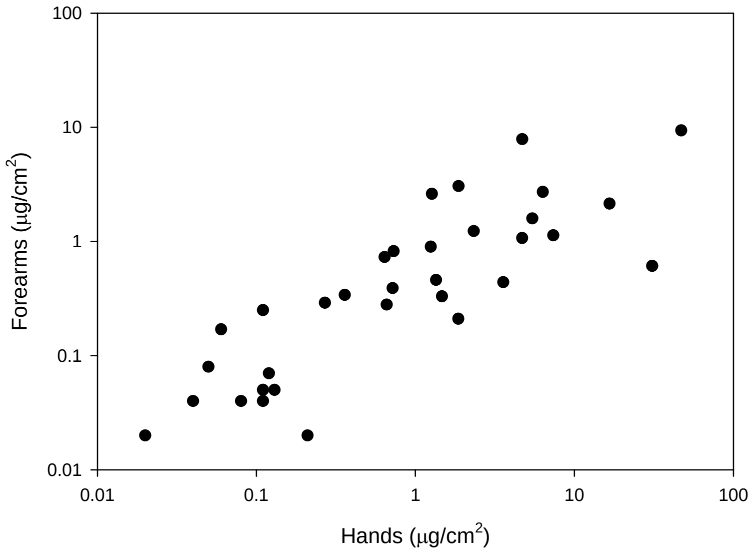

Figure 11 Scatter plot of dermal hand and forearm exposures for all workers

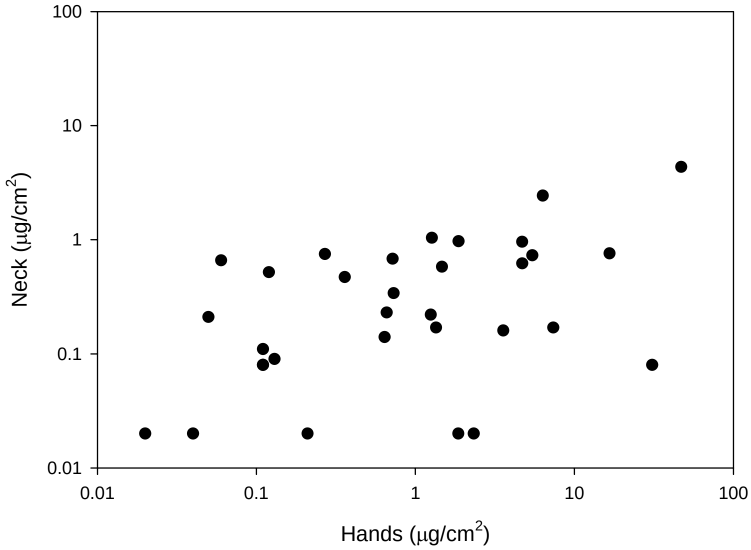

Figure 12 Scatter plot of dermal hand and neck exposures for all workers

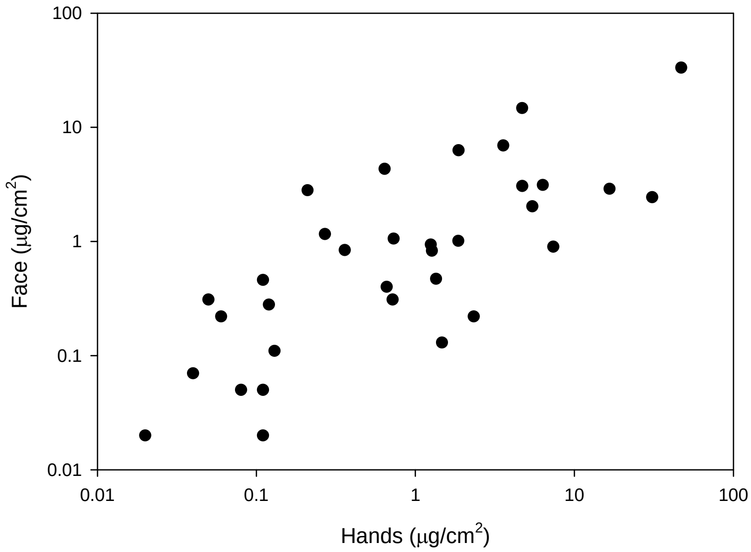

Figure 13 Scatter plot of dermal hand and face exposures for all workers

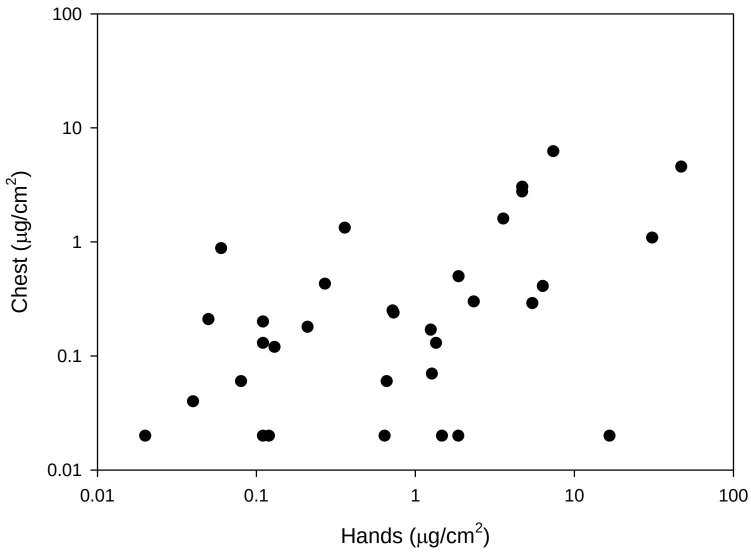

Figure 14 Scatter plot of dermal hand and chest exposures for all workers

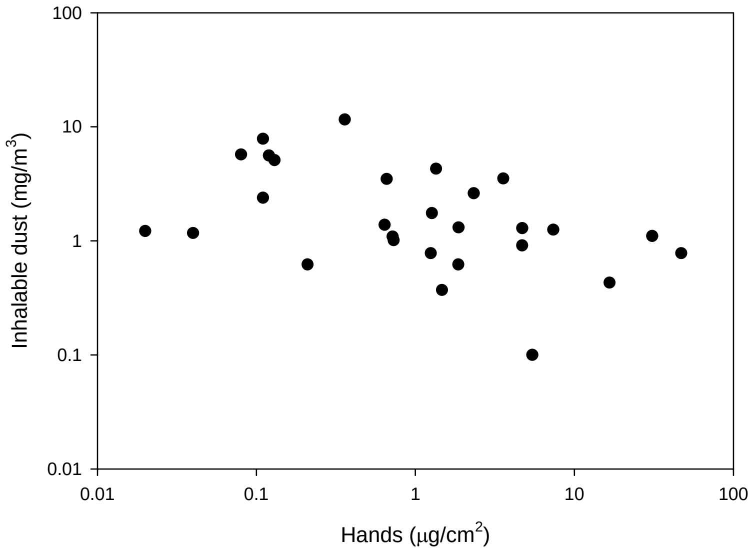

Figure 15 Scatter plot of dermal hand and inhalable dust exposures for all workers

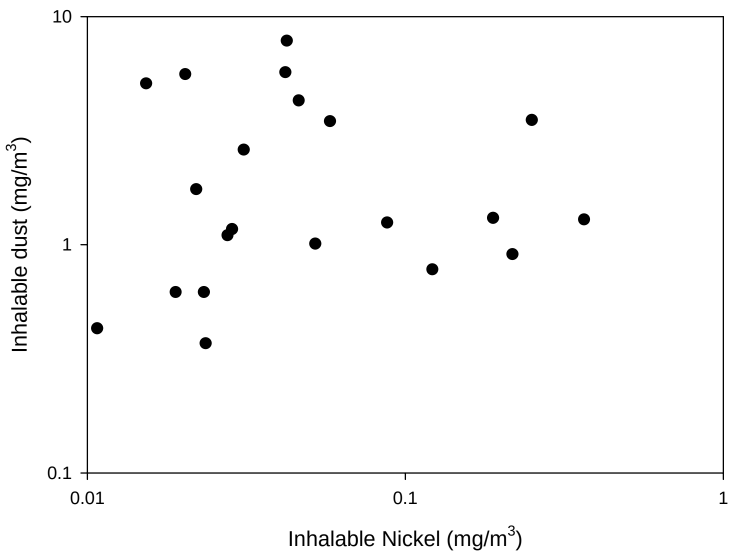

Figure 16 Scatter plot of inhalable nickel and total dust exposures for all workers

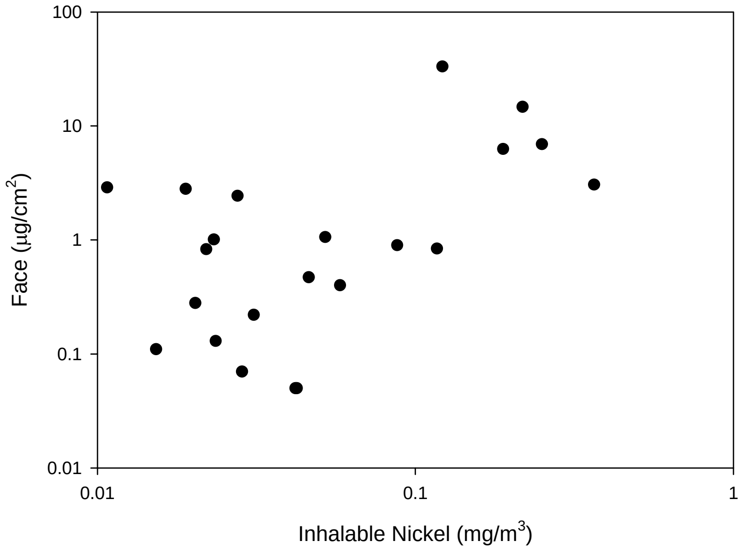

Figure 17 Scatter plot of inhalable nickel and dermal face exposures for all workers

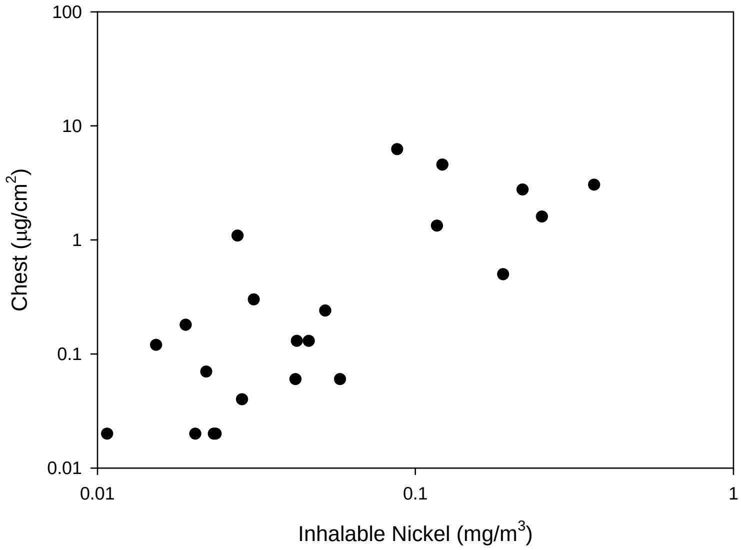

Figure 18 Scatter plot of inhalable nickel and dermal chest exposures for all workers

APPENDIX A: JOB ACTIVITY RECORDS RELATING TO DERMAL EXPOSURE SURVEY

Table A1 – Job activity record - Refinery (a)

Subject code	Job/task description	Sample interval	Observations and work activities before sampling interval
864-66	Raw materials operator	1	Clean hands - sampling Ni & Co solutions
		2	Clean hands - routine sampling and inspections in process area
		3	Clean hands - visual checks in ‘attack’ area.
864-56	Raw materials operator	1	PVC gloves worn, hands clean - sampling Ni & Co solutions
		2	Clean hands – routine sampling and inspection
		3	Clean hands – routine sampling and inspection
864-61	Raw materials operator	1	Dirty hands – driving mechanical loader in materials store
		2	Dirty hands – sampling raw materials
		3	Very dirty hands – changing sulphur (by product from process)
864-63	Electrolysis	1	Clean hands - unloading Ni cathodes from tanks and loading to conveyor
		2	Clean hands - routine loading/unloading tasks
		3	Clean hands - plant shut-down, worked in control room
864-60	Electrolysis	1	Clean hands - unloading Ni cathodes from tanks and loading to conveyor
		2	Clean hands - routine loading/unloading tasks
		3	Clean hands - routine loading/unloading tasks

Table A2 – Job activity record - Refinery (b)

Subject code	Job/task description	Sample interval	Observations and work activities before sampling interval
864-59	$NiCl_2$ packer	1	Clean hands – 200 bags packed
		2	Clean hands – 130 bags packed
		3	Clean hands – No details recorded
864-65	$NiCl_2$ packer	1	Clean hands – 160 sacks packed
		2	Clean hands – 80 sacks packed
		3	No details
864-64	$NiCl_2$ packer	1	Clean hands - 250 sacks packed
		2	Clean hands - 80 sacks packed
		3	Packing – not involved with maintenance work carried out in area
864-57	$NiCl_2$ packer	1	Visible green tinge to hands - 190 bags packed
		2	Slight green colour to hands - 130 bags packed
		3	130 bags packed.
864-62	$NiCl_2$ packer	1	Clean hands - packed 330 sacks
		2	Clean hands - carried out maintenance on machine – no packing
		3	Green colour to hands - maintenance work carried out
864-67	$NiCl_2$ packer	1	Clean hands - packed $NiCl_2$ no quantities noted
		2	Clean hands - packed $NiCl_2$ no quantities noted
		3	Clean hands - packed $NiCl_2$ no quantities noted

Table A3 – Job activity record - Powder metallurgy (a)

Subject code	Job/task description	Sample interval	Observations and work activities before sampling interval
864-51	Powder mixer operator	1	Cotton gloves – Preparing raw materials and containers in area
		2	Cotton gloves – 2 x 150kg batches prepared (21kg Ni each batch)
		3	Cotton gloves - Transferred AlNiCo load from mixer to store
864-48	Press-shop setter	1	Gloves not worn
		2	Disposable gloves worn during setting procedures
		3	Disposable gloves worn during setting procedures
864-53	Press-shop setter	1	Disposable gloves worn. Stripping parts, setting up m/c. Supervising 2nd m/c.
		2	Gloves not worn. Setting press
		3	Gloves not worn. Added powders to intake using scoop
864-55	Press-shop setter	1	Gloves not worn – running 2 press m/cs
		2	Gloves not worn – Manual scooping of powder to feed hopper
		3	Gloves not worn – running 2 presses as before

Table A4 – Job activity record - Powder metallurgy (b)

Subject code	Job/task description	Sample interval	Observations and work activities before sampling interval
864-49	Grinding machine operator	1	Disposable latex gloves worn – continuous supervision of m/c
		2	Gloves worn
		3	Gloves worn – Total 23,000 parts produced in shift
864-50	Grinding machine operator	1	Gloves not worn - continuous supervision of m/c
		2	Gloves not worn
		3	Gloves not worn – Total 36,000 parts produced in shift
864-52	Grinding machine operator	1	Gloves not worn - Continuous supervision of 2 machines
		2	Gloves not worn
		3	Gloves not worm – 18,000 + 33,000 parts produced.
864-54	Grinding machine operator	1	Gloves not worn - Continuous supervision of machines
		2	Gloves not worn
		3	Gloves not worn.

Table A5 – Job activity record - Stainless steel production (a)

Subject code	Job/task description	Sample interval	Observations and work activities before sampling interval
864-41	Alloy handler	1	Mainly control room duties
		2	Mainly control room duties
		3	Mainly control room duties
864-43	Alloy handler	1	Loading alloys with fork truck and loader
		2	Loading but work interrupted due to breakdown
		3	Alloy handling and furnace duties
864-44	Alloy handler	1	Loading alloys with loader and fork truck
		2	Missed sample – washed hands
		3	2 big bags nickel briquettes and general cleaning up
864-37	Alloy handler	1	Missed sample
		2	Missed sample
		3	Loaded 7 x 2 tonne bags of Ni briquettes using fork truck.
864-47	Alloy handler	1	Transferred alloys to exotic compounds driving mechanical shovel
		2	Loading alloys to hopper system
		3	Loading Mo
864-46	Raw material inspector	1	Checked stock in alloy shop and scrap metal areas
		2	Tipped 20-30 wagons of scrap metal. General cleaning in alloy shop.
		3	Unloaded and stacked 24 big bags of Ni briquettes from truck
864-45	Raw material inspector	1	Checked stock in alloy shop and scrap metal areas
		2	Unloaded 10 x 2 tonne Ni briquettes in big bags and 2 x 20 tonne loads from tipper trucks
		3	Moving Mo drums to alloy shop, tipping scrap, tipping 60 tonne Ni briquettes

Table A6 – Job activity record - Stainless steel production (b)

Subject code	Job/task description	Sample interval	Observations and work activities before sampling interval
864-36	DC-Arc Technician	1	Hands very dirty – Cleaning up in area
		2	Hands not so dirty – wore latex gloves under leather gloves. Cleaning up.
		3	Maintenance in area. Changed a valve.
864-39	DC-Arc Technician	1	Missed sample
		2	Repairs on outdoor plant
		3	Repairs on outdoor plant
864-38	DC-Arc Technician	1	Missed sample
		2	Repairs on outdoor plant
		3	Repairs on outdoor plant – Dirty neck and chest
864-40	DC-Arc Technician	1	Changing motors in DC-arc plant
		2	Changing motors in DC-arc plant
		3	Changing motors in DC-arc plant – Hands very dirty
864-35	DC-Arc Technician	1	Furnace maintenance shovelling rubble– Gloves worn but dirty wrists
		2	Furnace maintenance
		3	Maintenance in dust plant. Changed a valve.
864-42	DC-Arc Technician	1	Changed motors in DC-arc plant
		2	Stripping pneumatic cylinder – Hands very dirty
		3	Other mechanical maintenance – Hands very dirty

Institute of Occupational Medicine

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Applying science for a better working environment

The Institute of Occupational Medicine

The IOM is a major independent centre of scientific excellence in the fields of occupational and environmental health, hygiene and safety. We aim to provide quality research, consultancy and training to help to ensure that people's health is not damaged by conditions at work or in the environment. Our principal research disciplines are exposure assessment, epidemiology, toxicology, ergonomics and behavioural and social sciences, with a strong focus on multi-disciplinary approaches to problem solving.

Our beginnings

Our first major research programme began in the 1950s, on respiratory health problems in the coal mining industry. Major themes were quantification of airborne dust concentrations in different jobs, characterisation of types and constituents of the dusts, measurement of health effects, relationships between exposure and disease, and proposals for prevention. This research became an international benchmark for epidemiological studies of occupational health, and was the primary influence on dust standards in mines in the UK, US and other countries.

Current themes

Our current work spans many other industries including asbestos, MMMF, pesticides, chemicals, energy, telecoms, metals, textiles, construction, agriculture as well as the environment. While diseases of the respiratory tract remain a major interest, our scope now extends to many other health outcomes such as mortality, cardiovascular effects, cancer, back pain, upper-limb disorders, hearing loss, skin diseases, thermal stress and psychological stress. Related work includes the development and application of measurement and control systems, mathematical models and survey methods.

Who we work for

Our work in these areas is conducted for a wide range of organisations in the UK, the EU, and the US, including Government departments, international agencies, industry associations, local authorities, charitable organisations, and industrial and commercial companies. The IOM is a World Heath Organisation (WHO) collaborating centre and is an approved institute of the Universities of Edinburgh and Aberdeen, enjoying collaborative research links with NIOSH, IARC, and many other institutes throughout the world.

Publication

We believe that our research findings should be publicly available and subject to the scrutiny of the international scientific community. We publish our findings in the peer reviewed scientific literature and through our own series of Research Reports.

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