Health and Safety Executive

Exposure to hexavalent chromium, nickel and cadmium compounds in the electroplating industry

Prepared by the **Health and Safety Laboratory** for the Health and Safety Executive 2013

RR963
Research Report

HSE

Health and Safety Executive

Exposure to hexavalent chromium, nickel and cadmium compounds in the electroplating industry

Chris Keen MFOH
Emma Tan
John McAlinden
Peter Woolgar
Paul Smith

Harpur Hill
Buxton
Derbyshire
SK17 9JN

This research was conducted by HSE in partnership with the Surface Engineering Association (SEA). The aim was to investigate whether repeat Biological Monitoring (BM) over a period of time could be used to help drive sustainable improvements in exposure control.

Fifty-three companies engaged in nickel, hexavalent chromium and/or cadmium electroplating were visited. An occupational hygiene assessment of relevant tasks and exposure controls was conducted at each visit. BM (post shift urine sampling) was used to quantitatively assess nickel, chromium and (where used) cadmium exposures. Other measurements, such as levels of contamination of worker's hands and workplace surfaces with nickel and/or chrome, were also made to provide further information on exposure paths.

A detailed insight is provided into nickel, hexavalent chromium and cadmium exposures in electroplating. The extensive measurement programme employed allows identification of a number of tasks and worker groups with potential for exposure and provides a clear picture of the standard of exposure control achieved. This provides an improved understanding of exposure routes and allows exposure control to be better targeted.

Sustainable statistically significant reductions in exposure were achieved at the companies with the highest initial levels of urinary nickel and/or chromium. This was as a direct result of developing a better understanding of exposure pathways and implementing repeat Biological Monitoring (BM) over the lifetime of the project to provide evidence of exposure control. Reductions were in the range 30 to 40% for nickel, and 20 to 30% for chromium.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

HSE Books

First published 2013

ACKNOWLEDGEMENTS

Thanks are given to the Surface Engineering Association (SEA) who partnered HSE in this work and to the companies who were visited as part of the project.

KEY MESSAGES

1) The significant reductions in urinary nickel and chromium levels at those sites with higher exposures at the time of the initial HSE project visit, provide clear evidence that interventions have reduced exposures to these two carcinogens. This has been accomplished by providing targeted advice to the individual companies concerned, and carrying out repeat biological monitoring (BM) to provide evidence that reduced exposures were sustained.

2) When a good standard of exposure control exists, periodic BM checks have provided evidence that it is possible to carry out nickel, chrome and (where used) cadmium electroplating with very little occupational exposure to these metals.

3) The use of repeated BM to track exposure over time improves risk awareness of individual workers and can help to drive sustainable exposure reductions. Continued application of BM within the electroplating industry could aid further exposure reductions.

4) Exposures to toxic metals in the electroplating industry occur via a combination of inhalation, dermal and ingestion routes. Analysis of wipe sampling and monitoring data revealed a consistently high proportion of results demonstrating contamination in production areas. Very few results were recorded below the limit of detection (LOD). This needs to be taken into account when conducting risk assessments and designing exposure control strategies. Improved control of dermal exposure across the industry could be achieved by wider adoption of recognised good practice and implementation of low cost control solutions. Examples include:

- provision of a recognised canteen area which is kept clean.
- food and drink to be taken only in that area.
- provision of clean overalls and a laundry service for workers.
- ensuring workers do not wear contaminated clothing outside the workplace.

5) The hierarchy of control should be applied to dermal exposure in the same way as it is to inhalation exposure. Use of PPE should be a ‘last line of defence’ and working practices which lead to direct hand immersion into treatment tanks and direct handling of heavily contaminated components should be avoided. When it is not reasonably practicable to avoid such practices, a rigorous management programme covering selection, use and maintenance of PPE, is required.

6) The BM results indicate that overall, electroplaters had the highest exposure potential in this study. However, other worker groups, specifically maintenance staff, chemists and those involved in ancillary work (e.g. jigging and unmasking of electroplated items), also received elevated exposures. This wide spread of exposure risk must be taken into account when designing exposure control strategies.

7) Although generally controlled below the Workplace Exposure Limit (WEL), nickel inhalation exposures are frequently not controlled to the standards set out in SEA/HSE guidance[1] or the requirements under the COSHH regulations. These require control of carcinogen and asthmagen exposure to a level which is as low as reasonably practicable. A common failing in this study was found to be the use of air agitation on nickel electroplating tanks without provision of local exhaust ventilation (LEV).

8) Some important aspects of exposure control within electroplating are still not completely understood. A comparative study of the effectiveness of the commonly applied engineering control approaches and PPE could improve understanding and inform revision and improvement of current SEA/HSE guidance[1-6]. It may also identify benchmarks of good practice for use by industry in managing exposure risks in workplaces carrying out electroplating.

EXECUTIVE SUMMARY

Introduction

This report describes a research project conducted by HSE in partnership with the Surface Engineering Association (SEA). The principal aim of the work was to investigate whether repeat BM over a period of time could be used to help drive sustainable improvements in exposure control.

Workers in the electroplating industry are potentially exposed to a range of toxic substances. Some of these are carcinogens, including nickel, hexavalent chromium (chrome VI) and cadmium compounds. HSE and industry agree that currently there are practical problems implementing substitution of these substances in some of the processes used and full process containment is not practicable. Consequently, there is reliance on good working practices, engineering controls and personal protective equipment (PPE) to control worker exposures.

Methodology

Fifty-three electroplating companies were visited. An occupational hygiene assessment of relevant tasks and exposure controls was conducted at each visit. BM (post shift urine sampling) was used to quantitatively assess nickel, chromium and (where used) cadmium exposures. Other measurements, such as levels of contamination of worker’s hands and workplace surfaces with nickel and/or chrome, were also made to provide further information on exposure paths. If significant issues were identified, a revisit was made to conduct a more detailed assessment of the relevant processes and controls.

Companies visited were provided with comprehensive feedback. No further site visits were made by the researchers, but further BM was conducted at the same companies 6 and 12 months after feedback The companies collected urine samples from their employees and sent them to the laboratory for analysis to assess the impact of the intervention on urinary nickel, chromium, and (where used) cadmium levels.

Findings, Conclusions and Recommendations

See table following

Ref No.	Finding	Conclusion	Recommendation
1	Significant reductions in both urinary nickel and chromium levels were observed across the lifetime of this project. The most notable reductions were found amongst the companies with the highest exposures at the beginning of the project and the reductions in exposure were shown to be sustainable.	(a) The reduced exposures to nickel and chromium VI in the electroplating industry were a direct result of the delivered interventions.	(a) The industry should maintain effective controls and carry out regular BM to help identify whether exposure control is adequate.
		(b) BM offers a useful tool for assessing exposure of workers to nickel and chromium in the electroplating industry. Post-shift urine sampling is the most suitable sampling strategy for these chemical agents. Elevated BM results help to identify that exposure control may not be adequate. For hexavalent chromium in electroplating the current biological monitoring guidance value (BMGV) of 10 μmol/mol creatinine is appropriate. For nickel in electroplating a BMGV of 24 μmol/mol creatinine is appropriate. With good exposure control, 90% of BM results for each of these individual carcinogens should be within these values.	(b) BM for chromium and nickel should be carried out using urine sampling and results compared with existing guidance values. Elevated BM results help to identify that exposure control may not be adequate and should trigger a review of existing exposure controls.
		(c) BM for cadmium is more complex due to the metabolism of this metal. Cadmium in blood is considered to be a more reliable indicator of occupational exposure than urinary levels.	(c) Measurement of urinary cadmium levels is appropriate as a screening tool. Urinary cadmium levels above 1 μmol/mol creatinine should trigger further action to seek specialist advice. Specialist expertise is required to apply BM as a tool to assess occupational cadmium exposure. This may require the skills of an occupational health professional and/or specialist BM expertise.

2	Only a limited level of occupational hygiene competence is available in the majority of electroplating companies	A suitable level of occupational hygiene competence to enable a review of existing exposure controls does not exist in the majority of electroplating companies.	Electroplating companies should ensure they have access to a suitable level of occupational hygiene competence to enable a review of existing exposure controls where BM shows elevated results.
3	There was routine reliance on PPE as the primary barrier against direct contact with electroplating solutions at several of the sites visited.	(a) Electroplating processes can be operated in such a way as to prevent direct contact with electroplating solutions, although suitable PPE would still be necessary as splash protection.	(a) Electroplating companies should adopt good working practices and not rely on PPE as the primary barrier against contact with hazardous substances.
		(b) Simple observation of individual working practices by the dutyholder may be sufficient to identify how exposures are occurring, and hence identify appropriate remedial action. However further measurements including traditional air sampling are often required to provide information on exposure routes and ensure compliance with any relevant WELs. Other measurement techniques which assess skin and surface contamination can be of added value in identifying potential exposure routes.	(b) Electroplating companies should review the potential exposures of all staff, where necessary using measurement techniques to quantify risk.
4	Significant exposures were also recorded for maintenance operators, the site chemist, and other ancillary staff.	Suitable control practices were not in place for some workers, especially for those not in a production role.	Exposure control strategies should cover all potentially exposed worker groups and the hierarchy of exposure control should be equally applied to these groups.
5	A range of measures are used to reduce airborne emissions from electroplating tanks, including LEV systems, tank lids, eductors (alternative to air agitation), surfactants and chroffles.	The different measures vary in cost, complexity, ease of use and efficacy. There is no clear guidance for the industry on the most appropriate and cost effective techniques.	A systematic evaluation of these measures should be carried out to allow the provision of evidence-based guidance aimed at reducing exposures to carcinogens and asthmagens in the electroplating industry.

6	It was not unusual for companies to operate air agitated nickel electroplating baths without LEV.	Operation of air agitated nickel electroplating baths without LEV is not in accordance with SEA/HSE guidance or the requirements under the COSHH regulations to control carcinogen and asthmagen exposures to a level which is as low as reasonably practicable.	All air agitated nickel electroplating baths should be provided with suitable LEV to control the aerosols produced.
7	Statistical analysis shows a positive correlation between surface contamination, hand contamination, and urinary nickel and chromium levels.	(a) Wherever dermal exposure occurs, there is also an increased risk of inadvertent ingestion exposure. (b) Dermal exposure could be significantly reduced in many situations with minimal financial and resource investment. (c) The 90^{th} percentile values for surface and hand contamination derived from this project can be considered to be benchmarks, defining what is achievable in terms of controlling hand and surface contamination. As such, they provide useful tools for industry to assist in helping to achieve adequate exposure control.	Electroplating companies should pay greater attention to the control of exposure through the dermal route, including periodical measurement of surface and hand contamination and comparison of the results against the 90^{th} percentile values found during the research. Simple low cost solutions to reduce surface contamination leading to dermal exposure include: • provision of recognised canteen area which is kept clean. • food and drink taken only in that area. • provision of clean overalls and laundry service for workers. • ensuring contaminated clothing not worn outside the workplace.
8	Many sites are able to operate electroplating processes without the need for either manual washdown and/or blow drying freshly electroplated items using compressed air.	Manual washdown and/or compressed air drying of freshly electroplated items have a clear potential to contribute significantly to overall exposures.	Electroplating companies carrying out manual washdown and/or compressed air drying of freshly electroplated items should review the need for these activities. Where they are deemed necessary, companies should adopt good working practices, including the use of effective engineering controls to minimise potential exposures. In such situations some form of exposure monitoring (air sampling or BM) should be undertaken to demonstrate the adequacy of control.

9	Exposures to nickel, hexavalent chromium and cadmium in the electroplating industry occur via a combination of inhalation, dermal and ingestion routes.	Exposures via a combination of routes need to be taken into account when conducting risk assessments and designing exposure control strategies.	Electroplating companies should consider all exposure routes when carrying out risk assessments.
10	The wearing of contaminated work wear outside the workplace, including the home laundering of such items is not uncommon.	Contaminated work wear may be a source of exposure to persons outside the workplace, in particular the home.	Steps should be taken to prevent workers wearing or taking contaminated work wear outside the workplace, including the home laundering of such items. This practice has the potential to spread contamination and expose individuals who do not work within the electroplating industry.
11	This work has generated a much clearer understanding of potential exposure pathways in the electroplating industry.	This work has enabled the identification of areas where the current SEA/HSE guidance on exposure control is frequently not applied.	Knowledge from this work should be used in any review of existing SEA/HSE guidance on control of exposure to hazardous substances in electroplating.

CONTENTS PAGE

1. INTRODUCTION

1.1 BACKGROUND

Workers in the electroplating industry are potentially exposed to a range of toxic substances. Some of these are carcinogens, including nickel (Ni), hexavalent chromium (chrome VI, CrVI) and cadmium (Cd) compounds. Data presented to the HSE June 2007 Cancer Project Stakeholder Workshop estimated there to be approximately 3,000 workers potentially exposed to either nickel, chrome VI or cadmium in the electroplating industry.

HSE and industry agree that currently there are practical problems implementing substitution of these substances in some of the processes used and full process containment is not practicable. Consequently, there is reliance on good working practices, engineering controls and personal protective equipment (PPE) to control worker exposures. Improved risk awareness amongst workers will be an important component in achieving control of exposure.

Regular BM of workers potentially exposed to chemical carcinogens can simply and quantitatively demonstrate levels of exposure[7]. BM captures total exposure by all routes, and can provide a valuable tool for occupational exposure assessment. In previous research[8], BM has demonstrated significant variations in exposure for workers performing almost identical work in the same workplace. This indicates the pronounced effect of individual working practices. BM can provide a feedback loop for the control of exposure and demonstrate risk reduction by tracking successive results as control improves and exposure reduces. This increases risk awareness amongst individual workers and supports a culture of careful working to avoid unnecessary exposure.

Guidance on exposure control in the industry has been jointly developed by HSE and the Surface Engineering Association (SEA)[1-6] and disseminated to industry. Where relevant, the controls described in this guidance have been used as a reference against which to compare the individual companies visited.

1.2 AIMS AND OBJECTIVES

The principal aim of this work was to investigate whether repeat BM over a period of time could be used to drive sustainable improvements in exposure control.

The specific project aims were to :

i) Work with the industry trade associations to recruit member businesses to participate in this project.

ii) Visit each of the workplaces recruited to assess working practices and exposure controls for nickel, chrome VI and (where used) cadmium compounds.

iii) Make a quantitative assessment of total exposure using BM, complemented by other measurements to allow exposure routes to be understood and hence identify appropriate exposure control strategies.

iv) Conduct repeat BM at specified intervals after the initial contact to track exposures over time and assess the impact of any process or exposure control changes triggered by the initial HSE project visit.

v) Analyse the findings and compile a final report containing information to inform about trends in occupational exposure to nickel, chrome VI and cadmium in the electroplating industry.

1.2.1 Regulatory Position

Many of the nickel, hexavalent chromium and cadmium compounds used in electroplating can cause serious health effects, including cancer, asthma and dermatitis. Compounds handled include nickel sulphate, nickel chloride, chromium trioxide and cadmium oxide. Formal hazard classifications can be found at the European Chemical Information System's website[9] .

Soluble nickel, hexavalent chromium and cadmium compounds are substances hazardous to health and subject to the provisions of the COSHH Regulations [10], which require that exposure is prevented or, where this is not reasonably practicable, controlled to as low a level as is reasonably practicable (ALARP). The relevant 8 hour time weighted average (TWA) Workplace Exposure Limits (WELs) [11] are:

- Soluble nickel compounds - 0.1 mg/m^3 (as Ni)
- Hexavalent chromium compounds - 0.05 mg/m^3 (as Cr)
- Cadmium compounds - 0.025 mg/m^3 (as Cd)

Under the COSHH regulations, exposure control is defined as adequate only if : (a) the principles of good control practice are applied; (b) any WEL is not exceeded; and, (c) exposure to asthmagens, carcinogens and mutagens are reduced as low as reasonably practicable.

Hexavalent chromium compounds are also assigned a Biological Monitoring Guidance Value (BMGV) of 10 µmol/mol creatinine. BMGVs are guidance values and do not carry the same legal status as WELs.

PPE must be used where it is not possible to achieve adequate control of exposure by other control measures alone (e.g. process enclosure, LEV), and then only in addition to them [10].

1.2.2 Toxicity

Nickel compounds are asthmagens. Soluble nickel salts have recently been reclassified as carcinogens and assigned the risk phrase R49 (May cause cancer by inhalation). There are no formal BMGVs relevant to nickel compounds. Skin contact with nickel and inorganic compounds can cause skin sensitisation.

Chromium trioxide is a hexavalent chromium compound. It is assigned R45 classification (May cause cancer). It is a category 1 (proven human) carcinogen. It is also assigned a number of other risk phrases indicative of serious health effects including R42 (May cause sensitisation by inhalation), R43 (May cause sensitisation by skin contact), R46 (May cause heritable genetic damage) and R62 (Possible risk of impaired fertility).

Cadmium and its compounds are also classified as carcinogens.

2. METHODOLOGY

2.1 STAKEHOLDER ENGAGEMENT

This work has been conducted in partnership with the SEA. Regular updates have been provided to the SEA Health and Safety Committee through the lifetime of the project. A series of four stakeholder seminars were held to brief potential participants about the work. These were held at:

- Birmingham Medical Institute – November 2008
- Mercure Hotel, Rochdale – October 2009
- ITT Basingstoke – November 2009
- Bletchley Park Conference Centre – November 2009

Interim presentations on progress were made at the British Occupational Hygiene Society (BOHS) annual conference in April 2010 and the International Occupational Hygiene Association (IOHA) conference in September 2010.

The work was presented to the SEA's annual conference in October 2011. A series of further presentations were made at the BOHS annual conference in April 2012.

2.2 SITE CONTACTS

2.2.1 Initial visit

The initial visit commenced with a qualitative occupational hygiene assessment and completion of a detailed questionnaire in conjunction with the dutyholder to identify the relevant tasks and exposure controls. The visit also involved recruitment of workers for participation in the BM programme. At most sites wipe sampling (to investigate surface contamination) and hand wash sampling was conducted. Wipe sampling was conducted at 47 sites, hand wash sampling at 33 sites. At a selection of sites (n=5), where a detailed investigation of exposure routes was being conducted, some air sampling was also performed on this first visit.

The actual electroplating processes were the main area of interest for the initial visit. Other processes with exposure potential, such as preparatory work (involving chromium, nickel or cadmium), passivation, chromic anodising, maintenance activities, polishing of electroplated items and ancillary tasks were also studied.

2.2.2 Revisit

Based on the findings of the initial visit, some sites were revisited to further investigate areas of concern. Factors that triggered a revisit were:

- Significantly elevated BM results in one or more individual
- Consistently elevated BM results across the company
- The absence of exposure controls recommended in the HSE/SEA guidance

The measurement protocol on revisits included BM, hand wash, surface wipe sampling and air monitoring. Measurements were focussed on the areas of concern identified on the initial visit.

2.2.3 BM follow-on exercises

Irrespective of whether sites were revisited, further urine samples were requested approximately 6 and 12 months after feedback had been provided from the initial visit(s). The purpose of the follow-on BM exercises was to track worker exposures over time and assess the impact of any process or exposure control changes triggered by the initial HSE project visit.

The samples from the BM follow-on exercises were collected by the companies from their employees and sent to the laboratory. Post-shift urinary samples were requested on three consecutive working days from the same workers who participated in the initial exercise. Information was requested from each company on actions taken to implement recommendations from earlier visits, and on any other relevant changes to the processes on site.

2.3 VISIT PROTOCOL

2.3.1 Occupational hygiene assessment

A full assessment of relevant work tasks and associated exposure controls was conducted at each visit. This included evaluation of:

- Management controls (COSHH assessments, written procedures, operator training etc.)
- LEV systems (smoke test, airflow measurements, maintenance and testing regime)
- PPE programme
- Working practices
- Other relevant issues (e.g. use of surfactant in hexavalent chromium tanks)

To allow comprehensive and consistent collection of contextual information, a standard questionnaire was completed during the visit with the dutyholder. The completed questionnaires were submitted to HSL's Mathematical Sciences Unit for inclusion on the HSL carcinogens database.

2.3.2 Sampling methodology

A measurement programme which included BM, hand wash and wipe sampling, and air monitoring was used for this work. Detailed methodology is presented in Appendix 1.

2.3.2.1 Biological Monitoring Reference values

Quantitative assessment of worker exposures to each of the relevant metals was assessed using BM. Post-shift urine samples were requested from a selection of exposed or potentially exposed workers over a three-day period, beginning on the day of the visit. On occasions, samples were supplied the week after the visit.

Written information on the aims of the BM programme was provided to all participating workers, and informed consent was obtained in accordance with HSE guidance[7]. Where possible, samples from the day of the visit were transported back to HSL's Buxton laboratory by the visiting HSL scientist. Other samples were sent by post to the laboratory for analysis.

There is no UK BMGV for nickel. At the outset of this project the HSL BM database contained approximately 2000 results for urinary nickel. These covered workers in a wide range of industries including electroplating. The 90th percentile of urinary nickel data in the HSL BM database was approximately 24 µmol/mol creatinine, and this was adopted as a guidance value for the purposes of this study. It is not indicative of a dose response threshold and is therefore not a health-based value. There are background environmental and dietary sources of nickel. Typically, urinary nickel levels in individuals with no occupational exposure will not exceed 10 µmol/mol creatinine. Published data[12] indicates that an 8-hour inhalation exposure to soluble nickel at 0.1 mg/m^3 (the current WEL), with no additional exposure by other routes, would result in a urinary nickel level of around 100 µmol/mol creatinine.

There is a UK BMGV for chromium of 10 µmol/mol creatinine[11] . This was set based on the 90^{th} percentile of urinary chrome data from a range of industries with the potential for hexavalent chromium exposure, including electroplating. It is not indicative of a dose response threshold and is therefore not a health-based value. There are a number of background environmental and dietary sources of chromium. Typically, urinary chromium levels in individuals with no occupational exposure will not exceed 3 µmol/mol creatinine. Published data[13] indicates that an 8-hour inhalation exposure to hexavalent chromium at 0.05 mg/m^3 (the current WEL), with no additional exposure by other routes, would result in a urinary chromium level of around 40 µmol/mol creatinine.

There is no UK BMGV for cadmium. The 90th percentile of urinary cadmium data in the HSL BM database from workers potentially exposed to cadmium have concentrations below 1 µmol/mol creatinine. This was adopted as a guidance value for the purposes of this study. As an individual's urinary cadmium value can vary a little from day to day and the adopted guidance value is close to levels seen in people not occupationally exposed (usually less than 0.7 µmol/mol creatinine), a single result greater than 1 µmol/mol creatinine should be followed by a repeat sample. Therefore, specialist expertise will be required to allow the application of BM as a tool to assess occupational cadmium exposure. This may require the skills of an occupational health professional and/or specialist BM expertise.

In the United States of America, there is an exposure-based Biological Exposure Index (BEI) value of approximately 4 µmol/mol creatinine. In Germany, a recent review has seen the withdrawal of the previous guidance value of approximately 5 µmol/mol creatinine and the introduction of a revised value of approximately 0.7 µmol/mol creatinine. The measurement of cadmium in blood may provide a better indication of recent occupational exposure than urine sampling. The BM urinary method however fits with worker's natural preference for a non-invasive sampling technique.

2.3.3 Feedback

A full occupational hygiene report was produced for each visit and issued to the respective site. Reports described the relevant work processes and exposure controls, presented all measurement results, and contained a discussion, conclusions and recommendations.

For each site, a contact was established to deal with feedback of BM results. This was usually the site safety officer, but some companies nominated different staff to take on this responsibility. This individual was briefed verbally, and in writing, regarding the medical confidentiality issues relevant to BM data.

For BM follow-on exercises conducted remotely (i.e. no site visit), a summary report was produced. This presented the BM results and contained a discussion, conclusions and recommendations based on the results, prior knowledge of the site from the initial visit(s) and other information provided by the company.

2.4 DATA ANALYSIS

Statistical analysis of the collective measurement data was conducted by HSL's Mathematical Sciences Unit. The data analysis studied the BM data for different sites and worker groups and investigated time trends in exposure. The analysis also investigated the correlation between inhalation exposure and each BM result, hand contamination and each BM result and surface contamination and hand contamination. This assisted with gaining an understanding of exposure routes. Where correlation is discussed in the following sections of this report, the following categorisation system has been used:

0.0 to 0.2 - very weak to negligible correlation

0.2 to 0.4 - weak, low correlation

0.4 to 0.7 - moderate correlation

0.7 to 0.9 - strong, high correlation

0.9 to 1.0 - very strong correlation

It should be noted that correlation can be positive or negative. A mixed effects analysis was also performed on the data. Details on the methodology are presented in Appendix 2.

3. RESULTS

3.1 OVERVIEW OF DUTYHOLDER CONTACTS

53 companies were visited as part of this project.

50 of these were SEA members.

49 companies submitted BM samples

30 companies submitted a full set of BM samples (i.e. initial visit and 2 follow up exercises)

16 companies were revisited to further investigate matters of concern

18 companies conducted decorative chromium electroplating

43 companies conducted some form of nickel electroplating

36 companies conducted electrolytic nickel electroplating

24 companies conducted electroless nickel electroplating

34 companies conducted some form of chromium electroplating

23 companies conducted hard chromium electroplating

6 companies conducted cadmium electroplating

3.2 BM DATA

Summary statistics for the urinary nickel, chromium and cadmium data are presented in Tables 1, 2 and 3 respectively. For the purposes of statistical analysis individuals were classified as either nickel, chromium and/or cadmium workers or non-nickel, chromium and/or cadmium workers. Nickel, chromium and/or cadmium workers included anyone whose work had direct potential for nickel, chromium and/or cadmium exposure. A subset of this group, nickel, chromium and/or cadmium electroplaters, was also defined. Individuals who reported spending some time actually electroplating at any stage of the project, were placed in this category.

3.2.1 Nickel

Of the 3107 urinary nickel results obtained over the lifetime of the project, 269 were discarded from the statistical analysis as the creatinine content of each of the individual samples was outside the ‘normal’ range, indicating an unreliable BM result.

Table 1 : Summary of nickel BM results

Summary	**All nickel workers**	**Nickel electroplaters**	**Non-nickel workers**	**All workers**
Workers (n)	282	191	237	519
Measurements (n)	1619	1142	1219	2838
Geometric mean (μmol/mol creatinine)	9.16	10.56	5.43	7.61
Median (μmol/mol creatinine)	8.18	9.4	5.17	6.75
90th percentile (μmol/mol creatinine)	28.5	31.6	12.4	21.2

3.2.2 Chromium

Summary statistics for the urinary chromium data are presented in Table 2. Of the 3057 urinary chromium results obtained over the lifetime of the project, 272 were discarded from the statistical analysis as the creatinine content of each of the individual samples was outside the 'normal' range, indicating an unreliable BM result.

Table 2 : Summary of chromium BM results

Summary	**All chromium workers**	**Chromium electroplaters**	**Non-chromium workers**	**All workers**
Workers (n)	354	180	152	506
Measurements (n)	2079	1197	706	2785
Geometric mean (μmol/mol creatinine)	2.67	3.4	1.32	2.23
Median (μmol/mol creatinine)	2.4	3.18	1.26	1.97
90^{th} percentile (μmol/mol creatinine)	10.56	12.95	3.36	9.1

3.2.3 Cadmium

Cadmium electroplating is far less common than chromium and nickel electroplating. Cadmium electroplating was encountered at six of the sites visited so urinary cadmium was only determined in samples collected from these sites.

Summary statistics for the urinary cadmium data are presented in Table 3. Of the 598 urinary cadmium results obtained over the lifetime of the project, 57 were discarded from the statistical analysis as the creatinine content of each of the individual samples was outside the 'normal' range, indicating an unreliable BM result.

Table 3 : Summary of cadmium BM results

Summary	All cadmium workers	Cadmium electroplaters	Non-cadmium workers	All workers
Workers (n)	51	19	41	92
Measurements (n)	320	139	221	541
Geometric mean (µmol/mol creatinine)	0.94	0.65	0.34	0.69
Median (µmol/mol creatinine)	0.6	0.5	0.3	0.48
90^{th} percentile (µmol/mol creatinine)	11.3	2.74	0.77	4.98

3.2.4 Time trends for nickel

When the BM data from all 49 companies were considered, no significant reduction in nickel exposure was seen. This is a result of the data from the companies where there were no initial problems, and hence no significant control improvements made, thereby 'diluting' the analysis. A subset of companies was taken where the median urinary nickel concentration at the first visit was above the accepted background level, 10µmol/mol creatinine. There were 15 companies in this group, for these :

- There was a reduction of 33% (95% CI 13 to 48%) in urinary nickel for nickel electroplaters ;

- There was a reduction of 38% (95% CI 17 to 54 %) in urinary nickel for nickel workers.

Due to the nature of this statistical analysis, there are uncertainties associated with the findings. The confidence intervals (CI) are necessary to quantify these, and these findings should be considered in this context.

This analysis clearly shows that urinary nickel levels were reduced over the lifetime of the project at the companies with the highest nickel exposures at the outset. This demonstrates a positive impact of the project. This is perhaps unsurprising given that more effort was directed at reducing the potential nickel exposures at these sites than in the general sampled population.

3.2.5 Time trends for chromium

As with nickel, when the BM data from all 49 companies was analysed, no significant reduction in urinary chromium was seen. A subset of companies was taken where the median urinary chromium concentration at the first visit was above the accepted background level, 3µmol/mol creatinine. There were 13 companies in this group, for these :

- There was a reduction of 23% (95% CI 6 to 37%) in urinary chromium for chromium electroplaters;

- There was a reduction of 27% (95% CI 8 to 43%) in urinary chromium for chromium workers* at the 13 companies recording the highest exposures.

*BM samples were obtained for non electroplaters amongst chromium workers at only 10 of the 13 companies considered for this analysis.

This analysis clearly shows that urinary chromium levels were reduced over the lifetime of the project at the companies with the highest chromium exposures at the outset. This demonstrates a positive impact of the project. This is perhaps unsurprising given that more effort was directed at reducing the potential chromium exposures at these sites than in the general sampled population.

3.2.6 Time trends for cadmium

Although 541 results were obtained across the six sites visited, complete data sets (i.e. initial visit and 2 follow-up exercises) were only obtained from four of the six sites. Additionally the data were heavily biased towards a single site where a detailed investigation of exposure routes entailed extensive monitoring, resulting in the taking of 189 samples from 22 different workers. For these reasons, there was insufficient data to allow a meaningful analysis of time trends for urinary cadmium.

3.3 HAND WASH DATA

Typically, hands receive the highest level of dermal contamination. Hands are of most importance in terms of transfer of contamination to mouth. For these reasons, dermal exposure assessment for the project was limited to the determination of hand contamination.

Various methodologies exist to assess dermal exposure, including the use of tracer chemicals, wipe sampling (of the hands), the use of sampling gloves and hand washing. There are limitations on all of these methodologies[14,15], and hence the results should be viewed as semi-quantitative only. Nevertheless, measurement of skin contamination is a useful tool in identifying potential exposure routes.

Hand wash sampling using deionised water as the collection medium was selected for this work. Summary data from the hand wash sampling are presented in Table 4.

Table 4 : Summary of hand wash data

	Nickel**	**Chromium**	**Cadmium**
Companies	35	36	4
Workers (n)	153	155	32
Measurements (n)	173	164	32
Median – Electroplaters* (samples)	0.352 (104)	0.052 (93)	0.170 (9)
Median - Ni/Cr/Cd workers* (samples)	0.320 (120)	0.040 (131)	0.142 (19)
Median - Non-Ni/Cr/Cd workers* (samples)	0.006 (53)	0.008 (33)	0.008 (13)
90th percentile- Electroplaters *	2.50	0.73	1.37
90th percentile- Ni/Cr/Cd workers*	2.07	0.50	1.37
90th percentile- Non-Ni/Cr/Cd workers*	0.39	0.50	0.16
*Median and 90th percentile values are expressed in milligrams of contamination – this is the total contamination on both hands **This is total nickel (both soluble and insoluble)			

The median is a summary statistic that is not influenced by a small number of non-detects. It should be noted that only a small amount of hand wash data was obtained for cadmium. Hence, the statistical parameters presented in table 4 for cadmium will be subject to a greater degree of uncertainty than those for nickel and chromium.

3.3.1 Correlation between hand wash and BM data

The correlation between nickel hand contamination and urinary nickel levels was;

- moderate (correlation co-efficient 0.43) for nickel electroplaters;

- moderate (correlation co-efficient 0.45) for nickel workers;
- weak (correlation co-efficient 0.34) for non-nickel workers.

The correlation between chromium hand contamination and urinary chromium levels was;

- strong (correlation co-efficient 0.71) for chromium electroplaters;
- moderate (correlation co-efficient 0.63) for chromium workers;
- low (correlation co-efficient 0.13) for non-chromium workers.

The correlation between cadmium hand contamination and urinary cadmium levels was;

- moderate (correlation co-efficient 0.66) for cadmium electroplaters;
- moderate (correlation co-efficient 0.59) for cadmium workers;
- weak (correlation co-efficient 0.43) for non-cadmium workers;

The correlations for cadmium electroplaters and workers were based on a very small sample size of three and five respectively.

The general trend is for a moderate positive correlation between hand contamination and the BM results. This provides some evidence that dermal exposure is significant in terms of the contribution to the overall systemic dose. Where dermal exposure occurs it is accompanied by the potential for inadvertent ingestion exposure through direct hand to mouth transfer or via contaminated food, drink or cigarettes. It is not clear in this instance whether dermal absorption or ingestion is the most significant exposure route, although dermal absorption rates for the relevant metal salts studied in this project are reportedly low[16,17]. By controlling dermal exposure through good working practices, supported by appropriate and correctly used PPE, the potential for inadvertent ingestion should also be mitigated.

3.4 SURFACE WIPE DATA

Surface wipes were collected at 49 companies in areas that were classified as either ‘Production’ or ‘Clean’, as described in Appendix 1. All but two of these companies had associated BM data.

Table 5 shows a summary of the data. Between 5% and 9% of individual measurements of nickel, soluble nickel, chromium and cadmium in ‘production’ areas were below the limit of detection (LOD). In ‘clean’ areas however, between 19% and 63% of individual measurements of nickel, soluble nickel, chromium and cadmium were below the LOD. The median is a summary statistic that is not influenced by a small number of non-detects (as is the case for the majority of the surface wipes sample groups in this data set), however, a median has not been calculated for the cadmium measurements for ‘clean’ samples due to the high proportion of non-detects.

Table 5 : Summary of surface wipe data

	Production				Clean			
	Ni	**Sol Ni**	**Cr**	**Cd**	**Ni**	**Sol Ni**	**Cr**	**Cd**
Companies (n)	34	15	36	4	43	17	44	4
Measurements (n)	219	91	215	32	448	176	456	40
<LOD (n)	12	6	12	3	85	50	144	25
<LOD (% of measurements)	5	7	6	9	19	28	32	63
Median (µg/cm^2)	1.50	1.33	0.58	0.97	0.13	0.05	0.04	<LOD
90th percentile (µg/cm^2)	22	10.8	19.1	7.2	1.4	0.48	0.28	0.09

As would be expected, surface contamination was significantly higher in production areas than in the 'clean' areas.

Although not a direct measure of exposure, surface wipe sampling nevertheless provides an indication of the potential for dermal exposure. Clearly it is unrealistic to expect no measurable surface contamination in production areas. However, these results illustrate the need for good working practices in such areas to minimise spillage and splashing. The wipe sampling results are, however, perhaps more pertinent in 'clean' areas, such as canteens. The detection of significant levels of contamination in such areas at some sites is an indication of a failure to:

- adequately prevent the spread of contamination from work areas;
- provide an effective cleaning regime.

3.4.1 Correlation between surface wipe and handwash data

If surface wipe sampling provides some indication of the potential for actual dermal exposure, then some correlation might be expected between the surface wipe results and the corresponding handwash results from the same site taken on the same day. The statistical analysis revealed :

- 'Production' areas - there was moderate positive correlation between surface wipe concentrations and handwash measurements for nickel (correlation co-efficient 0.55), and cadmium (correlation co-efficient 0.53). There was a weak, low positive correlation for chromium (correlation co-efficient 0.29)

- 'Clean' areas - there was strong positive correlation between surface wipe concentrations and handwash measurements for nickel (correlation co-efficient 0.7) and weak, low positive correlation for chromium (correlation co-efficient 0.38). There was insufficient data to form conclusions for cadmium.

The general trend is for a moderate positive correlation between surface wipe samples and handwash measurements. This appears to be more marked for nickel than for chromium, although more data would be required to add confidence to this finding.

3.5 AIR SAMPLING DATA

Personal air sampling to estimate inhalation exposures was only conducted at a subset of the sites visited. In general, it was performed on revisits where the initial visit had yielded elevated BM results. It is reasonable to assume that exposure controls at such sites were of a lower standard than at other sites visited. The results are summarised in Table 6.

Table 6 : Summary of air sampling results

	WEL	Range	Number of			
	(mg/m³)		Sites	Workers	Results > WEL	Results < LOD
Soluble nickel	0.1	<0.01 – 0.077	7	26	0	6
Total nickel	0.5	<0.01 – 0.58	8	30	1*	15
Hexavalent chromium	0.05	<0.0001 – 0. 011	14	41	0	10
Total chromium	0.5	<0.01 – 1.89	7	20	1**	12
Cadmium	8 data points obtained from a single site, all exposures <0.006 mg/m³					

*This result was for a polisher, exposure would have been to metallic nickel.

**This worker performed a mixture of chrome electroplating and polishing on the day of sampling

It is clear from these results that inhalation exposure levels for all three metals were mostly substantially below the relevant WELs. This is true even in situations where exposure controls were not in accordance with SEA/HSE guidance, such as in the case of nickel electroplating baths operated without LEV.

3.5.1 Correlation between air sampling and BM data

Statistical analysis revealed a moderate positive correlation between inhalation exposure and BM results for nickel and chromium (total and hexavalent), but a weak positive correlation for soluble nickel. This provides some evidence that a proportion of exposure is occurring via the inhalation route. There was insufficient data to perform this analysis for cadmium. A significant amount of air monitoring results were <LOD. These were included in the statistical analysis. The results of this analysis are presented in table 7.

Table 7 : Correlation between air sampling and BM data

	Nickel	**Soluble nickel**	**Chromium VI**	**Total chromium**
Correlation† between air and BM concentration	0.56 25 samples	0.08 20 samples	0.62 37 samples	0.52 (0.42††, 0.56†††) 17samples

† Correlations calculated on the log-transformed data
†† Non-detects substituted by LOD
††† Non-detects substituted by ¼ LOD

Based on data from published scientific literature[12, 13], the urinary nickel and chromium results seen throughout this work cannot be fully accounted for by the measured inhalation exposures. For nickel, there is some dependence on the solubility of the specific nickel salts to which an individual is exposed. An inhalation exposure of 0.1 mg/m^3, with no additional exposure by other routes, would result in a urinary nickel level of around 100 µmol/mol creatinine. An 8-hour inhalation exposure to hexavalent chromium at 0.05 mg//m^3, with no additional exposure by the dermal or ingestion routes, would result in a urinary chromium level of around 40 µmol/mol creatinine.

Although we have recorded a number of BM results around these levels in this project, the small amount of data collected on inhalation exposures indicates that these do not even approach the relevant WELs. If exposure occurred via inhalation alone then the BM results would have been much lower. This, supported by the conclusions of other researchers[18], indicates that a significant proportion of exposure occurs via other routes, either via ingestion and/or dermal absorption.

4. ACTIVITIES WITH EXPOSURE POTENTIAL

Overall, the BM results indicated that workers directly involved with the electroplating activity (electroplaters) receive the highest exposures although there was significant inter-worker and inter-site variation. Elevated BM results were however, also recorded in other worker groups. These are discussed in the following sections.

4.1.1 Jigging and other preparatory work

At a number of sites elevated BM results were observed for workers involved in jigging/dejigging and/or masking/unmasking of components. There were differences in the way work was organised at the different sites visited. At some sites this work was conducted by the electroplaters, at others dedicated operatives conducted the work. These activities frequently require significant direct handling of components before and after electroplating. Gloves were not worn for this task at all sites visited. When questioned, a number of sites indicated that they did not feel that it was possible to do the fine manual work involved in this task whilst wearing gloves.

4.1.2 Site chemist

At a number of sites, the highest BM results were obtained for the site chemist. Tasks performed by the site chemist include sampling and analysis of tank contents. This task was typically done frequently and, at sites with large numbers of electroplating tanks, the chemist can spend a significant amount of time on this activity. Some of the highest BM results were obtained at sites where this was done by manually dipping a container into the tank to obtain a sample. High surface contamination was measured in the on-site laboratories at some sites.

4.1.3 Maintenance work

Elevated BM results for some maintenance workers indicate the potential for significant exposure associated with some maintenance tasks, especially when working directly on electroplating tanks and associated equipment. It is often the case that the engineering controls used during routine production do not control the exposure of these workers. For maintenance, it is generally necessary to place greater reliance on safe systems of work and PPE. In such cases, individual worker behaviour can greatly influence exposure. The wide range of maintenance tasks conducted in the surface engineering industry mean that the daily activity of maintenance workers will be varied, and hence the exposure potential will also vary from day to day.

In general, sites employed dedicated maintenance workers, however, at a small number of companies, workers were multi tasking and were involved in both production activities and maintenance. High levels of contamination were measured on equipment (tools etc.) used by maintenance workers, indicating inadequate decontamination of these items after use.

4.1.4 Polishing

Polishing (of electroplated items) was done using either hand held or floor/bench mounted power tools. Various grades of abrasives and soft buffing wheels were used depending on the final finish required. This has the potential to generate airborne dust. Any metals contained within this dust would be in the metallic (elemental) form at this stage. For chromium and nickel, the toxicity of the metallic form is much lower than for the salts used in the actual electroplating process. Cadmium metal is classified as a carcinogen.

In general, LEV was applied to polishing operations, in the form of captor hoods. At some sites, where large items were being polished, movable, flexible arm systems were used. These were not always positioned as close to the exposure source as they possibly could be. This would substantially reduce their capture efficiency. Respiratory Protective Equipment (RPE) was usually, but not always, worn for polishing, with positive pressure powered equipment in use at some sites.

4.1.5 Manual washdown

After electroplating is complete it is necessary to remove excess electroplating solution from the electroplated items. This task is carried out by the electroplaters and is often achieved by immersing the electroplated items in one or more rinse tanks. At some sites however, this was done by washing the excess solution from the electroplated items with a hosepipe or similar, a task typically referred to as manual washdown. Where this is done using high pressure hoses, or where it is done at head height or above, there is the potential for mist generation and hence, inhalation exposure. Conversely, manual washdown was observed at some sites using low pressure hoses, working carefully at the minimum practical height above the tank. In such situations the exposure potential is significantly reduced and, where manual washdown is deemed necessary, such good practice should assist provision of adequate exposure control.

4.1.6 Compressed air drying

The use of compressed air to blow electroplated items dry was observed at several sites. Although workpieces had been rinsed or washed down at this stage, there will still be some low level of electroplating solution present on the surface, and compressed air blowing will create aerosols and the potential for inhalation exposure. Where compressed air drying was carried out it was either done by the electroplaters or by ancillary workers, occasionally the jiggers.

4.1.7 Bulk additions

In order to maintain the correct balance of chemicals within the electroplating tanks it is necessary to make bulk additions to the tanks periodically. Substances added included nickel sulphate, nickel chloride and chromium trioxide. Although these materials were occasionally purchased and handled in aqueous solution, it was more usual to add them in the solid form. Most companies appeared to add solid chemicals in 'full bag' quantities, removing the need for weighing and splitting packs. There is some potential for generating airborne dust when making bulk additions, although the materials are generally fairly coarse crystalline products, and hence not particularly dusty. At some sites the additions were made by the site chemist, at others by electroplaters or maintenance staff. Metallic nickel and cadmium in the form of spherical 'shot' are also added to electroplating baths. There is no significant exposure potential associated with making additions in this way.

5. EXPOSURE CONTROL

5.1 ENGINEERING CONTROLS - NICKEL

The SEA/HSE guidance[1-6] states that LEV is almost always needed on air agitated nickel electroplating tanks. Twenty four sites visited carried out electrolytic nickel electroplating with air agitation but only sixteen provided LEV on the nickel tanks.

Whilst the BM results from some of these sites indicated that nickel exposures were generally well controlled, it should be noted that 10 of the 15 sites with the highest urinary nickel concentrations were operating nickel electroplating tanks without LEV. However, a mixed effects analysis of the BM data for nickel workers at all companies indicated that the presence (or absence) of LEV on electroplating tanks had no statistically significant effect on urinary nickel levels.

The emission of nickel aerosols from nickel electroplating operations is dependent upon the complex interaction of a number of factors. These include current density, electroplating time, degree of solution agitation, surface area of tank, workload and freeboard. Operator inhalation exposure is further complicated by the extent of their interaction with the process, with lower exposure potential being associated with semi-automated electroplating tanks.

The use of covers on nickel electroplating tanks was not common at the sites visited for this work. In general, the short electroplating times observed at many of the sites visited would have made the use of covers impractical.

Several sites used eductors to generate movement of the electroplating solution, however they were far less common than air agitation. Mixed opinions were provided on the effectiveness of eductors. Some companies had installed eductors but found they did not work whilst others were using them successfully.

Cathode rod movement was not in common use at the sites visited. The SEA indicate that, although cathode rod movement is applicable where similar items are being electroplated regularly, it is more difficult to apply for ‘jobbing’ companies, who are required to process a wide range of items.

Chroffles are used within the industry to form a thermally insulating layer at the liquid surface in electroplating tanks, reducing the energy required to maintain elevated tank temperatures. The SEA/HSE guidance indicates that they are not considered to act as an exposure control. However, they do form a physical barrier at the liquid surface within an electroplating tank, and in doing so might be expected to reduce airborne emissions. A situation was encountered at a single site where some nickel electroplating tanks were fully covered with chroffles and others were not, with other tank operating conditions being similar. Airborne nickel concentrations above the tanks with full chroffle coverage were significantly lower than above tanks with only partial coverage. There are insufficient data on which to draw conclusions, but this suggests that a more detailed examination into the potential for chroffles to reduce airborne tank emissions would be worthwhile.

5.2 ENGINEERING CONTROLS - CHROMIUM

All of the hexavalent chromium electroplating baths observed during this project were either fitted with LEV or contained a surfactant to reduce mist formation. Perfluorooctane sulphonate (PFOS) was the most commonly encountered surfactant. Some electroplating baths had both control measures installed.

Several sites using surfactant as the primary exposure control did not properly manage its use. Some companies relied on the results of the fortnightly static monitoring above the baths to inform the need for additions of surfactant. The SEA/HSE guidance[3] states that *'Surface tension should not be allowed to rise above the level specified by the surfactant supplier and must be monitored using a tensiometer at regular intervals. Initially this should be every 4 hours of use. When the characteristics of the process are understood the frequency of testing can be adjusted as appropriate but should not exceed 40 hours of tank operation. A logbook should be kept showing surfactant additions together with a graph of surface tension.'*

Analysis of the BM data for chromium workers at all companies does not indicate whether surfactant is more effective than LEV in reducing chromium exposures. A more detailed analysis of the data and/or additional research would be required to study this.

The use of covers on chromium electroplating tanks was not common at the sites visited for this work. Similarly, chroffles were rarely observed in chromium electroplating tanks. The short electroplating times (typically several minutes) used in decorative electroplating necessitate frequent tank loading and unloading. It is probable that the use of tank covers and/or chroffles would not be practical in this situation. It is probable that the use of tank covers and/or chroffles is more practical in hard chrome electroplating where longer electroplating times (typically several hours) mean that frequent tank loading and unloading is unnecessary.

5.3 ENGINEERING CONTROLS – CADMIUM

None of the six companies visited carrying out cadmium electroplating had LEV fitted to the electroplating tanks. The SEA advise that due to the high efficiency of the cadmium electroplating process, very little hydrogen is generated. The potential for mist generation is low and hence LEV is considered unnecessary.

5.4 SUBSTITUTION

Where it can be achieved, substitution of a toxic compound with a less toxic alternative is preferable to the application of engineering controls. It is possible to conduct some forms of chrome electroplating using trivalent chromium solutions rather than hexavalent chromium. This control approach removes the potential for exposure to hexavalent chromium. Trivalent chromium compounds do not have the potential to cause the same serious health effects associated with hexavalent chromium.

It is generally accepted within the industry that decorative chromium electroplating can be achieved using trivalent rather than hexavalent chromium compounds. However, this is more complex, requiring much closer control of process operating parameters. Of the 18 sites visited that carried out decorative chromium electroplating, only six had the facilities on site to use trivalent chromium compounds. Three of these sites used trivalent chromium exclusively for decorative chromium electroplating. The other three had the option of using either trivalent chromium or hexavalent chromium. The choice was dictated by customer requirements. The other 12 sites that carried out decorative chromium electroplating used hexavalent chromium exclusively for this purpose.

5.5 PERSONAL PROTECTIVE EQUIPMENT (PPE)

PPE use varied greatly across the sites visited, and within individual sites depending on the specific tasks being performed.

Chemical protective gloves were worn at all sites for tank side work with the potential for direct hand contact with electroplating solution. There was inconsistency in types of gloves used, and the management of their use. Glove selection procedures varied widely from site to site, and it was commonly found that the company had not specifically researched the compatibility of their chosen gloves with the materials in use on site. Glove changing frequency also varied from site to site, and was often left to individual worker's discretion.

RPE was not used as a control measure for electroplating at any site visited. Nor was RPE worn for any other routine tank side work. RPE was worn, however, at some sites when making bulk additions of solid chemicals to electroplating tanks and for certain maintenance activities where it was perceived that there was the potential for inhalation exposure.

At some sites RPE was worn for ancillary tasks such as polishing. At others, it was not. RPE used for this activity ranged from disposable, negative pressure orinasal masks to full face, positive pressure equipment.

Situations were encountered at several sites where the siting of PPE lockers resulted in the spread of contamination into notionally clean areas such as canteens.

6. DISCUSSION

This project has provided a detailed insight into nickel, hexavalent chromium and cadmium exposures in the electroplating industry. The number of sites visited, coupled with the extensive measurement programme, has allowed the identification of a number of tasks and worker groups with the potential for exposure and provided a clear picture of the standard of exposure control achieved. The work has provided quantitative information on exposure, and has allowed a better understanding of exposure routes, which allows exposure control to be better targeted.

Statistically significant reductions in exposure were achieved at the companies with the highest initial levels of urinary nickel and/or chromium. Reductions for nickel were in the range 30 to 40%, and for chromium in the range 20 to 30%. Many of these companies were revisited on at least one occasion to address the identified issues. Others were provided with clear information on the need to improve exposure controls. The follow-on BM exercises provide evidence that these specific interventions reduced the relevant carcinogen exposures.

Overall, the BM results indicate that electroplaters received the highest exposures, although there was much variation between sites. Significant exposures were also recorded in other worker groups, notably maintenance operatives, site chemists and workers engaged in jigging and other preparatory work.

A common failing at many sites was a tendency for workers to immerse gloved hands into electroplating tanks. Wherever reasonably practicable such direct contact with electroplating solutions should be avoided. For example, when taking samples of tank solutions, workers could use long handled tools to provide a safe working distance between the operator and the electroplating solution[19,20].

The application of hand wash and surface wipe sampling has provided a much clearer understanding of exposure pathways in the electroplating industry. The measurement results, supported by observations made during the visits, indicate that exposures occurred via a combination of inhalation, dermal and ingestion routes. At the early stages of the project, there were no reference values available against which to interpret the results of the hand wash and surface wipe measurements. As the work progressed, reference values were derived using the 90th percentile values for each data set. These were reviewed periodically over the lifetime of the project. The final 90th percentile values for hand wash and surface wipe sampling from the project are presented in Tables 4 and 5 of this report. These can be considered to be benchmarks, defining what is achievable in terms of controlling hand and surface contamination. As such, they provide useful tools to assist industry to assist achieve adequate exposure control.

The variability in work activity and exposure control strategies across the sites visited meant that it was not possible to accurately attribute the relative contributions made by inhalation, dermal and ingestion exposures. It is clear, however, that all three routes can be significant. The scientific literature suggests that dermal penetration of nickel and hexavalent chromium compounds is low. It must, however, be borne in mind that dermal deposition of these materials is accompanied by the potential for ingestion as a result of hand to mouth transfer, including nail biting[21]. There is further potential for ingestion if food is subsequently consumed without thorough hand washing.

The measured inhalation exposures for the metals studied were usually substantially below the WEL, with only two from 126 results being above the relevant WEL. The measured inhalation exposures were not sufficient to account for the BM results which supports the assertion above, that exposures occurred via a combination of routes. Given the health effects associated with these metals the legal requirement is to control exposure to ALARP. Simply being below the WEL is not sufficient. Although engineering controls (surfactant and/or LEV) were applied on hexavalent chromium tanks at all sites, air agitated nickel electroplating tanks without LEV were commonly encountered.

Throughout this project BM has proved to be effective as a screening tool for exposure assessment for nickel and chromium. Low BM results have provided clear evidence of adequate control and allowed dutyholder and HSE resources to be clearly targeted in areas where control improvements are required. Elevated BM results should generate immediate action to review exposure controls and reduce exposures. Given the mechanisms by which nickel and chromium compounds are metabolised and eliminated from the human body, a significant reduction in exposure should become apparent in the form of reduced BM results within four weeks.

The results suggest that for nickel electroplating the guidance value of 24 µmol/mol creatinine (90^{th} percentile from HSL BM database), adopted at the beginning of the project, appears to be appropriate. The results also suggest that the current BMGV of 10 µmol/mol creatinine for chromium is appropriate for the electroplating industry. With good exposure control it is possible to control urinary nickel and/or chromium levels to within these values for the majority of workers engaged in electroplating and associated activities.

This project has underlined the complexity of using BM to assess cadmium exposure. Although urinary cadmium appears to be a useful screening method, elevated results should be treated with caution. The guidance value of 1 µmol/mol creatinine, used in this project, is close to the 'background' level of cadmium in non-occupationally exposed individuals, and is an appropriate value to trigger further action. In addition to cadmium, it is also possible to measure retinol binding protein in urine, as this is a measure of renal dysfunction which may be due to cadmium exposure. Biological effect monitoring (BEM) such as this is of limited value as an occupational hygiene technique, where the aim is to identify exposure at an early stage, and hence prevent ill health. However, in this instance BEM is a useful health surveillance technique to detect early signs of physiological changes in the early stages of ill health. Cadmium in blood is considered a more reliable measure of recent occupational exposure than urinary cadmium. This, however, requires an invasive sampling technique and it was not considered appropriate to use this routinely to assess cadmium exposures in this study.

A number of exceptionally high BM results were obtained during this study. On many occasions, it is strongly suspected that these resulted from sample contamination at the point of sampling. Samples were taken on three consecutive working days to assist identify such exceptionally high results although expert interpretation is required to make this judgement.

It is recognised that financial constraints may make it impractical for dutyholders to submit multiple BM samples from each worker every time they conduct BM measurements. Nevertheless, this underlines the need for workers to thoroughly wash their hands before providing a sample. As with any exposure assessment programme, it is not possible to draw firm conclusions based on a single result. It is more useful to consider results in terms of groups of workers conducting similar activities, by looking at trends in individual workers over time, or by using a combination of both of these.

The addition of covers to electroplating baths has the potential to reduce airborne emissions into the workroom. Covers were rarely used at the sites visited for this work. It is recognised that covers restrict tank access, and where regular tank access is required they may be impractical. Where electroplating times of several hours are in operation, as is often the case in hard chromium electroplating, covers offer a low cost solution to reduce airborne emissions from electroplating tanks into the workroom atmosphere. If covers are to be employed, then they must be of the correct design. Makeshift covers, made from flexible plastic sheeting were commonly observed during the project, and these were generally in direct contact with the surface of the electroplating solution during use. In such situations, the covers themselves become heavily contaminated and increase the potential for dermal exposure. In order to control the explosion risk due to the build up of hydrogen gas, it is necessary to extract the headspace within the covered tank enclosure. Slot extraction LEV would perform this function. Tank covers allow LEV air flow rates to be reduced significantly whilst maintaining effective capture of airborne tank emissions. This would reduce the running costs of LEV systems.

Many of the sites visited provided personal lockers for storing 'in-use' workwear (e.g. PPE, overalls) between work shifts. However, examples were seen where these lockers were located within notionally clean areas, such as canteens, rather than at the clean/production area interface. This provides a route for the transfer of contamination into clean areas, and should be viewed as poor practice.

A significant proportion of the sites visited had no formal system in place for laundering workwear, resulting in workers taking contaminated items home for laundering. This has the potential to spread contamination outside the workplace, into workers vehicles and homes, and hence lead to indirect exposure of others. This is poor practice for any class of chemical, but especially so for substances associated with serious health effects. Appendix 1 to the COSHH Regulations 2002 (as amended) ACOP[10] deals with the control of carcinogenic and mutagenic substances. This contains clear information on the need to control the spread of contamination when working with carcinogens.

The manual jigging and de-jigging of small components requires a lot of direct handling of components. Gloves are often not worn due to the level of manual dexterity required. When de-jigging freshly electroplated components there is the potential for dermal exposure. This can be minimised by thorough rinsing prior to dejigging, and this was done in all cases where dejigging was performed. Wherever this task can be avoided by working in a different way, e.g. barrel electroplating instead of jigging individual components, then this should be considered.

The use of compressed air to dry electroplated components has the potential to generate an aerosol, and lead to inhalation exposure. This will lead to further spread of contamination onto surfaces, also increasing the potential for dermal exposure. Wherever this was observed at the sites visited during the project, the components had been rinsed prior to blow drying. However, they still carried a low level of contamination. This was evident from a build-up of contamination on surfaces immediately adjacent. If compressed air drying can be avoided then it should be. This is clearly expressed in the SEA/HSE guidance sheet 'prevention of exposure and control of chromic acid mist'. If individual companies consider the continued use of compressed air drying is justified, then engineering controls should be employed to capture and contain the aerosol generated, and some form of exposure monitoring (air sampling or BM) undertaken to verify the adequacy of control.

The manual wash down of electroplated components using water hoses is another activity that has the potential to generate aerosols, leading to inhalation exposure. Although this can be reduced by careful working with low pressure hoses, it is preferable wherever possible to remove the electroplating solution by immersion in rinse tanks, than by manual wash down.

The use of trivalent chromium chemistry for decorative chromium electroplating was not widely employed at the sites visited. Six of the 18 sites carrying out decorative chromium electroplating had the facilities to use trivalent chromium for this purpose. Three of these used trivalent chromium exclusively, the other three used a combination of trivalent and hexavalent chromium, depending on customer requirements. The other twelve sites carrying out decorative chromium electroplating used hexavalent chromium exclusively for this purpose.

Similarly, although it is possible to use trivalent chromium for passivation, this was not common. Hexavalent chromium compounds were generally used for this activity also.

There was no common policy used across the sites visited for the selection of chemical protective gloves. It was uncommon for companies to use glove performance data to select appropriate gloves. At some sites a variety of glove types were made available, with selection and changing frequency being left to individual worker's discretion. This can, and often does, lead to a single pair of gloves being used for excessively long periods, and being re-used on numerous occasions. A number of dutyholders expressed an opinion that skin checks, conducted as part of their health surveillance programme, would identify inadequacies in their glove programme. While this may be true where gross skin contamination is occurring, resulting in observable changes to the skin, lower level dermal exposure, which could add to the systemic dose, would not necessarily be detected by this method.

Further research is planned to study the efficacy of exposure control solutions for the surface engineering industry. This includes investigating the permeability of commonly used chemical protective gloves with typical chromium and nickel electroplating solutions, and a systematic laboratory evaluation to quantify the efficacy of engineering controls. The proposed work would cover LEV (effect of air flow rates, freeboard and tank lids), the use of eductors as an alternative to air agitation in nickel electroplating, and the extent to which chroffles might reduce airborne tank emissions.

7. CONCLUSIONS

BM offers a useful tool for assessing total exposure to nickel and chromium in the electroplating industry. Post shift urine sampling is the most suitable sampling strategy for these agents. For nickel electroplating the adopted guidance value of 24 µmol/mol creatinine was found to be appropriate based on this study. For hexavalent chromium electroplating the current BMGV of 10 µmol/mol creatinine was found to be appropriate based upon this study. With good exposure control, 90% of BM results should be within these values.

BM for cadmium is more complex due to the metabolism of this metal. Cadmium in blood is considered to be a more reliable indicator of occupational exposure than urinary levels. However, measurement of urinary cadmium levels is appropriate as a screening tool. Urinary cadmium levels above 1 µmol/mol creatinine should trigger further action. Specialist expertise is required to apply BM as a tool to assess occupational cadmium exposure. This may require the skills of an occupational health professional and/or specialist BM expertise.

The significant reductions in urinary nickel and chromium observed across the lifetime of the project provide clear evidence that the interventions have reduced exposures to carcinogens in the surface engineering industry. The most notable reductions were found amongst the companies with the highest exposures at the beginning of the project, and the reductions in exposure were shown to be sustainable.

Elevated BM results identify that exposure control may not be adequate and should trigger a review of exposure controls. This will require a degree of occupational hygiene competence which may not exist in many surface engineering companies. Observation of individual working practices may be sufficient to identify how exposures are occurring and hence identify appropriate remedial action. In many cases, however, further measurement including traditional air sampling is often required to provide information on exposure routes and ensure compliance with relevant WELs. Other measurement techniques which assess skin and surface contamination can be of further value in identifying exposure routes.

Exposures to nickel, hexavalent chromium and cadmium in the electroplating industry occur via a combination of inhalation, dermal and ingestion routes. This needs to be taken into account when conducting risk assessments and designing exposure control strategies.

Generally, exposures to hexavalent chromium by inhalation were controlled below the WEL in accordance with SEA/HSE guidance, although some deficiencies in the maintenance of controls were noted. Similarily, exposures to nickel by inhalation were controlled below the WEL, but it was not unusual for companies to operate air agitated nickel electroplating baths with no provision of LEV. This is not in accordance with SEA/HSE guidance or the requirements under the COSHH regulations to control carcinogen and asthmagen exposures to a level which is ALARP.

Pulling together several strands of the statistical analysis, the work has demonstrated an overall positive correlation between surface contamination, hand contamination, and urinary chromium and nickel. Many situations were seen throughout the project where dermal exposure could be significantly reduced with minimal financial and resource investment. Wherever dermal exposure occurs, there is an increased risk of inadvertent ingestion exposure also. The 90^{th} percentile values for surface and hand contamination derived from this project can be considered to be benchmarks, defining what is achievable in terms of controlling hand and surface contamination. As such, they provide useful tools for industry to assist in achieving adequate exposure control.

It is possible to operate electroplating processes in such a way as to prevent routine direct contact with electroplating solutions, although PPE would still be necessary for splash protection. There was routine reliance on PPE as a primary barrier against direct contact with electroplating solutions at several of the sites visited. This creates unnecessary exposure potential and is not good practice.

Significant exposures were recorded in maintenance operators, site chemist and other ancillary staff as well as workers actually operating the electroplating process. It is important that exposure control strategies cover all potentially exposed worker groups and that the hierarchy of exposure control is applied to these groups.

Certain tasks have clear potential to contribute significantly to overall exposures, most notably manual washdown and/or compressed air drying of freshly electroplated items. Many sites are able to operate electroplating processes without the need for either of these activities. Where these activities are deemed necessary it is especially important to adopt good working practices, including the use of effective engineering controls to minimise exposures. In such situations some form of exposure monitoring (air sampling or BM) should be undertaken to verify the adequacy of control.

The wearing of contaminated work wear outside the workplace, including the home laundering of such items, is not uncommon and steps should be taken to prevent this. This practice has the potential to spread contamination and cause exposure to individuals who do not work within the surface engineering industry.

This study has generated a much clearer understanding of exposure pathways in the surface engineering industry, and has identified areas where the current SEA/HSE guidance on exposure control is frequently not applied. This knowledge could be used to further improve use of this guidance.

A range of measures exist which may reduce airborne emissions from electroplating tanks, including LEV systems, tank lids, eductors (alternative to air agitation), surfactants and chroffles. These vary in cost, complexity, ease of use and efficacy. A systematic evaluation of these factors would allow the provision of evidence-based guidance aimed at reducing exposures to carcinogens and asthmagens in the surface engineering industry.

8. REFERENCES AND RELEVANT PUBLICATIONS

References

[1] SEA/HSE Guidance Sheet – Nickel and nickel alloy electroplating operations : Controlling the risk of inhaling mist containing nickel http://www.hse.gov.uk/surfaceengineering/nickelinhalation.pdf

[2] SEA/HSE Guidance sheet - Prevention and control of exposure to chromic acid http://www.hse.gov.uk/surfaceengineering/chromicacid.pdf

[3] SEA/HSE Guidance sheet - Prevention of exposure and control of chromic acid mist http://www.hse.gov.uk/surfaceengineering/chromicacidmist.pdf

[4] SEA/HSE Guidance sheet – Health surveillance for hexavalent chromium processes http://www.hse.gov.uk/surfaceengineering/eh2.pdf

[5] SEA/HSE Guidance Sheet – Monitoring for electrolytic hexavalent chromium processes http://www.hse.gov.uk/surfaceengineering/hexavalentchromium.pdf

[6] SEA/HSE Guidance Sheet – Nickel and nickel alloy electroplating operations: Controlling the risk of skin exposure http://www.hse.gov.uk/surfaceengineering/nickelexposure.pdf

[7] HSE, 1997. Health and Safety Guidance, HS(G) 167. Biological monitoring in the workplace. A practical guide to its application to chemical exposure. Biological monitoring in the workplace: A guide to its practical application to chemical exposure - HSG167

[8] HSE 2010. HSE Research report RR 828 'Occupational exposure to MbOCA (4,4'-methylene-bis-ortho-chloroaniline) and isocyanates in polyurethane manufacture'. RR828 - Occupational exposure to MbOCA (4,4'-methylene-bis-ortho-chloroaniline)...

[9] ESIS (European Chemical Substances Information System) ahttp://esis.jrc.ec.europa.eu/index.php?PGM=cla

[10] HSE, 2005 (2). Control of substances hazardous to health regulations 2002 (as amended), Approved code of practice and guidance. HSE publication L5. Control of substances hazardous to health (Fifth edition) - L5

[11] HSE, 2012. EH40/2005 Workplace exposure limits EH40/2005 Workplace exposure limits

[12] DFG 2011. Deutsche Forschungsgemeinschaft List of MAK and BAT Values 2011.

[13] BEI 2004. Chromium (VI), Water-Soluble Fume: BEI® 7th Edition Documentation ACGIH Publication #7DOC-671.

[14] Fenske RA. Dermal Exposure Assessment techniques. Annals of Occupational Hygiene, 1993, Vol 37, number 6, pp 687-706.

[15] Brouwer DH Boeniger MF and Van Hemmen J. Hand wash and manual skin wipes, Annals of Occupational Hygiene, 2000, Vol 44, number 7, pp 501-510.

[16] IPCS 1988 (1). International Programme On Chemical Safety, Environmental Health Criteria 61, Chromium. Available from http://www.inchem.org/documents/ehc/ehc/ehc61.htm (Accessed 1st February 2012)

[17] IPCS 1988 (2). International Programme On Chemical Safety, Environmental Health Criteria 108, Nickel. Available from http://www.inchem.org/documents/ehc/ehc/ehc108.htm (accessed 1st February 2012)

[18] Killunen et al 1997. Occupational exposure to nickel salts in electrolytic electroplating. Killunen M, Aitio A and Tossavainen A. Annals of Occupational Hygiene, 1997, Vol 41, number 2, pp 189 - 200.

[19] Sithamparanadarajah 2008. 'Controlling skin exposure to chemicals and wet work. A practical book'.

[20] HSE 2009. 'HSE Guidance document HSG 262, Managing skin exposure risks at work'. http://www.hse.gov.uk/pubns/priced/hsg262.pdf

[21] Cherrie JW, Semple S, Christopher Y, Saleem A, Hughson G and Phillips A. 'How important is Inadvertent ingestions of Hazardous Substances at Work'. Annals of Occupational Hygiene 2006, Vol 50, number 7, pp 693 – 704.

Other relevant publications

HSE, 2004. Health and Safety Guidance HSG 97. A Step by Step Guide to COSHH Assessment. http://www.hse.gov.uk/pubns/books/hsg97.htm

HSE, 2005. Health and Safety Executive Guidance HSG53. Respiratory protective equipment at work. A practical guide. http://www.hse.gov.uk/pubns/books/hsg53.htm

HSE 2008 INDG 408. Clearing the air. A simple guide to buying and using local exhaust ventilation. http://www.hse.gov.uk/pubns/indg408.pdf

HSE 2011. Health and Safety Executive Guidance HSG 258. Controlling airborne contaminants at work. A guide to local exhaust ventilation. Controlling airborne contaminants at work: A guide to local exhaust ventilation (LEV) - HSG258

IARC, 1992. http://monographs.iarc.fr/ENG/Monographs/vol54/volume54.pdf

HSE 2008. Guidance note HSG 258. Controlling airborne contaminants at work. A guide to local exhaust ventilation (LEV). http://www.hse.gov.uk/pubns/books/hsg258.htm

HSE 1997. Safe work in confined spaces. Confined Spaces Regulations 1997. Approved Code of Practice, Regulations and guidance L101. http://www.hse.gov.uk/pubns/books/l101.htm

9. GLOSSARY

Biological monitoring guidance value (BMGV). These are guidance values for the concentration of a substance (or a marker substance) in urine. They are based on what is achievable by industry with good exposure control, they are not health-based limits.

Workplace Exposure Limit (WEL). These relate to inhalation exposure, and are set over an 8 hour reference period. Some substances are also assigned a short term exposure limit (STEL) which is a maximum value averaged over a 15 minute reference period.

Local exhaust ventilation (LEV). May be defined as the use of extraction to remove contaminated air at or near to it's source.

Personal protective equipment (PPE). May be defined as any device or appliance designed to be worn or held by an individual for protection against one or more health and safety hazards

Respiratory protective equipment (RPE). May be defined as a particular type of PPE that is designed to protect the wearer against inhalation of substances in the air"

Passivation. May be defined as the treating of a metal / metal coating in order to reduce the chemical reactivity of the surface. This has often been achieved by the use of chromate coatings, although a number of alternatives now exist.

Limit of detection (LOD). When no analyte can be detected by the chemical analysis, results are quoted as <LOD. LOD depends on a number of parameters, including the size of the sample and the analytical method used.

Hierarchy of control. Some exposure control solutions are more robust and reliable than others, however these are not always practicably applicable. There is a preferred order in which exposure control solutions should be implemented. This is summarised in regulation 7 of the COSHH regulations thus :

(a) the design and use of appropriate work processes, systems and engineering controls and the provision and use of suitable work equipment and materials;

(b) the control of exposure at source, including adequate ventilation systems and appropriate organisational measures; and

(c) where adequate control of exposure cannot be achieved by other means, the provision of suitable personal protective equipment in addition to the measures required by sub-paragraphs (a) and (b).

Principles of good hygiene control - see Schedule 2a of COSHH ACOP[10]

Requirements for carcinogens - see Appendix I of COSHH ACOP[10]

10. APPENDICES

10.1 APPENDIX 1 – MEASUREMENT METHODOLOGY

Biological Monitoring

Post-shift urine samples were requested from a selection of exposed or potentially exposed workers over a three-day period, beginning on the day of the visit.

Written information on the aims of the BM programme was provided to all participating workers, and informed consent was obtained in accordance with HSE guidance, HSG 167, (HSE, 1997(1)). Where possible samples from the day of the visit were transported back to HSL's Buxton laboratory by the visiting HSL scientist. Other samples were sent by post to the laboratory.

Urine samples were analysed in accordance with the UKAS accredited HSL standard operating method BM OP01. Urine samples were typically diluted twenty-fold with an acidic diluent (consisting of 1% nitric acid (Romil grade), 10 µg/L of each internal standard and 0.1% m/v EDTA). ICP-MS standards were used for calibration of the instrument, a single ICP-MS standard for chromium (from 1000 mg/L stock, BDH, Poole UK) and a multi-element standard for nickel and cadmium (Primar, from 100 mg/L stock, Fisher Chemicals Loughborough). Urinary chromium was determined in a separate analysis to urinary nickel and urinary cadmium. Calibration standards were made in the range 0-4 µg/L for chromium and 0-5µg/L for cadmium and nickel. The limits of detection for the methods (defined as three time the concentration for the blank concentration) were 0.08 µg/L for chromium, 0.12 µg/L for nickel and 0.009 µg/L for cadmium.

Urine samples were analysed by inductively coupled plasma mass spectrometry (ICP-MS) using an X7 Series 2 ICP-MS (Thermo-Fisher Scientific, Hemel Hempstead, UK). For nickel and cadmium analysis the X7 Series 2 ICP-MS instrument (Thermo-Fisher Scientific, Hemel Hempstead, UK) used direct nebulisation in normal mode with optimised conditions. For chromium analysis the X7 Series 2 ICP-MS instrument (Thermo-Fisher Scientific, Hemel Hempstead, UK) used collision cell mode to determine urinary chromium introducing the cell gas of 7% hydrogen in helium (approximately 3.5mL min-1). The ICP-MS conditions were optimised daily using a 10 µg/L tuning solution containing As, Co, In and U.

Dwell times were 50 ms for 52Cr, 60Ni, 111Cd and 10ms for the internal standards 72Ge, 89Y, 103Rh. Fifty sweeps were carried out per replicate and three replicates per sample.

Urine samples were brought to room temperature and mixed on sample rollers for a minimum of 20 minutes. All urine samples and quality control (QC) samples were diluted 1 in 20. External QC samples used consisted of a mix of Lyphochek Urine Metals Control levels 1 and 2 ClinChek Levels 1 and 2 (Bio-Rad Laboratories Ltd, Hemel Hempstead, UK), and a low and high level were analysed at the start, end and after every 20 samples throughout each analysis. Each analysis also had a calibration standard analysed every ten samples as a check for drift throughout the analysis.

Urinary Creatinine was determined by an automated alkaline picrate method (Cocker et al. 2011), using either a COBAS FARA spectrophotometer (Roche Diagnostic Systems, Basel, Switzerland), a COBAS MIRA spectrophotometer (Roche Diagnostic Systems, Basel, Switzerland) or an ABX Pentra 400 spectrophotometer (HORIBA ABX UK, Northampton, UK).

Surface wipe sampling

An assessment of surface contamination was made in various locations around each site visited. Ghost wipes™ were used together with, where possible, a 100 mm x 100 mm template so that a known area could be wiped. For areas where the template could not be used then the area wiped was estimated.

The locations where wipe sampling was conducted were divided into notionally 'clean' areas (canteens, offices, welfare facilities etc.) and production areas. In general, wipe sampling was conducted where there was the potential for transfer of contamination onto workers skin.

Examples of locations which were commonly wipe sampled include :

Production areas

- Handrails
- Control panels
- Workbenches
- Tool handles

Clean areas

- Canteen table surfaces
- Canteen equipment - microwave controls, tap handles, kettles, interior of food fridges, drinking cups
- Washroom taps
- Clean lockers

At some companies wipe samples were taken at further locations if they were suspected of being exposure sources. A more detailed and focussed programme of wipe sampling was conducted on some re-visits if dermal exposure was suspected as being significant, or if concerns existed regarding particular areas of the site.

At the outset of the project no reference data were available for surface contamination. As the project progressed guidance values were adopted based on the emerging data. These were used to inform the conclusions at later site visits.

The wipes were hotblock digested in nitric acid and the resulting solution analysed for nickel, chromium and cadmium content by ICP-AES.

Handwash sampling

Handwash sampling was used as a means of measuring the amount of contamination on workers' hands. For each sample, the worker's hand was placed in a polythene bag containing 200 ml of demineralised water and the water agitated around the hand and wrist area for approximately 30 seconds. Approximately 20 ml of the resulting solution was decanted into a sample bottle. Left and right hands were sampled separately. Where possible, samples were taken after a sustained period of work, typically before the main meal break or immediately prior to the end of the work shift. Workers were asked not to wash their own hands before the hand wash sampling was performed. These samples were analysed for chromium, nickel and cadmium content using ICP-AES.

Air sampling

As it was being used to assess the potential for inhalation exposure, air sampling focussed on personal monitoring with samplers mounted in the workers breathing zone. Typically sampling was conducted to ascertain full shift exposures, and sampling durations reflected this, typically being in excess of half the working shift. Conversions to 8-hour TWA exposures were made based on knowledge of activities outside the sampled period and the shift length. For all three metals, sampling was conducted in accordance with MDHS 14/3 "General methods for the sampling and gravimetric analysis of respirable and inhalable dust". Samples were taken onto filters mounted in stainless steel cassettes in IOM heads. Sample flow rate was two litres/minute. Specific details for all three metals are presented in Table 8.

Table 8 : specific measurement methodologies for air sampling

Analyte	Filter type	Analytical methodology
Nickel	GLA 5000	X-ray fluorescence or Microwave digestion into nitric acid followed by Inductively Coupled Plasma – Atomic Emission Spectrometry
Nickel (soluble)	GLA 5000	Filters leached into ammonium citrate solution followed by Inductively Coupled Plasma – Atomic Emission Spectrometry.
Chromium	GLA 5000	X-ray fluorescence or Microwave digestion into nitric acid followed by Inductively Coupled Plasma – Atomic Emission Spectrometry
Chromium (hexavalent)	Hydroxide treated PVDF	Filters leached into sodium hydroxide/sodium carbonate solution followed by ion chromatography
Cadmium	GN4	Microwave digestion into nitric acid followed by Inductively Coupled Plasma – Atomic Emission Spectrometry

.

10.2 APPENDIX 2 – STATISTICAL ANALYSIS – MIXED EFFECTS MODEL

Compound concentrations were assumed to follow a lognormal distribution. As several urine samples were collected on workers at various time points over the lifetime of the project, spanning several years in some cases, a mixed effects analysis (where statistical models containing both fixed and random effects are fitted) was considered appropriate for the data.

Mixed effect models include random effect terms and are appropriate for representing dependent data arising when observations are taken on related individuals, or over time on the same individual. In the case of the BM survey, correlations occur between measurements on individuals within the same company; these correlations were modelled by introducing company effects that were assumed to be random (these random company effects are also referred to as random intercepts at the company level). Correlations also occur between measurements made over time on a worker; these correlations have been modelled by introducing worker effects that were assumed to be random.

The mixed effect model was specified on the log scale and was of the form:

$$\log(Y_{ijk}) = \mu + \sum_{m=1}^{p} \beta_m x_{ijkm} + c_i + w_{ij} + \varepsilon_{ijk}$$

$c_i \sim N(0,\sigma_c^2)$
$w_{ij} \sim N(0,\sigma_w^2)$
$\varepsilon_{ijk} \sim N(0,\sigma^2)$

where Y_{ijk} is the k^{th} observation for the j^{th} worker in the i^{th} company, μ is the mean term, x_{ijkm} are the independent variables with associated parameter β_m, c_i is the random effect for company i, w_{ij} is the random effect for the j^{th} worker in the i^{th} company, and ε_{ijk} are the normally distributed residual errors. The β_m terms are corrections to the mean μ and measure consistent differences in variables such as visit type. In the models for the BM data, the independent variable has been taken to be the visit type treated as a factor with six levels, associated with each of the six visit codes. By doing so, any significant differences in urinary concentration at subsequent visits can be identified and quantified.

In addition to the random effect for company as specified above, a temporal random effect associated with the BM follow-on exercises for each company has been considered in some of the models.

HSE

Health and Safety Executive

Exposure to hexavalent chromium, nickel and cadmium compounds in the electroplating industry

This research was conducted by HSE in partnership with the Surface Engineering Association (SEA). The aim was to investigate whether repeat Biological Monitoring (BM) over a period of time could be used to help drive sustainable improvements in exposure control.

Fifty-three companies engaged in nickel, hexavalent chromium and/or cadmium electroplating were visited. An occupational hygiene assessment of relevant tasks and exposure controls was conducted at each visit. BM (post shift urine sampling) was used to quantitatively assess nickel, chromium and (where used) cadmium exposures. Other measurements, such as levels of contamination of worker's hands and workplace surfaces with nickel and/or chrome, were also made to provide further information on exposure paths.

A detailed insight is provided into nickel, hexavalent chromium and cadmium exposures in electroplating. The extensive measurement programme employed allows identification of a number of tasks and worker groups with potential for exposure and provides a clear picture of the standard of exposure control achieved. This provides an improved understanding of exposure routes and allows exposure control to be better targeted.

Sustainable statistically significant reductions in exposure were achieved at the companies with the highest initial levels of urinary nickel and/or chromium. This was as a direct result of developing a better understanding of exposure pathways and implementing repeat Biological Monitoring (BM) over the lifetime of the project to provide evidence of exposure control. Reductions were in the range 30 to 40% for nickel, and 20 to 30% for chromium.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

RR963

www.hse.gov.uk