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Exposure to carcinogens in surface engineering: Supplementary report

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Exposure to carcinogens in surface engineering: Supplementary report

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This report details work undertaken following HSE research published as RR963 *Exposure to hexavalent chromium, nickel and cadmium compounds in the electroplating industry* (Keen et al, 2013). This examined the use of biological monitoring (BM) in the surface engineering (electroplating) industry.

The report examines the efficacy of gloves, the use of surfactants and local exhaust ventilation in chromium plating, and the potential for transfer of contaminants outside the workplace.

Laboratory tests and statistical analysis on gloves showed that although some glove types offer more protection than others, working practices should be arranged such that gloves are worn for splash protection only and not routinely used as a primary barrier to protect against dermal exposure to hazardous substances.

No real difference in urinary chromium levels in electroplaters can be attributed to the use of surfactants or LEV to control mist emissions from plating tanks. Either approach is capable of providing adequate exposure control provided it is properly implemented and maintained.

Published scientific literature indicates that the major route by which occupational contamination is transferred outside the workplace is on work clothing. There is clear potential for this to occur in the surface engineering industry when contaminated work wear is taken home for laundering.

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CONTENTS

EXECUTIVE SUMMARY

Objectives

This report details supplementary work undertaken following HSE research project OH36 which examined the use of biological monitoring (BM) in the surface engineering (electroplating) industry. The work was reported in HSE research report RR963 "Exposure to hexavalent chromium, nickel and cadmium compounds in the electroplating industry" (Keen et al., 2013).

As a result of this work, two separate small reactive projects were conducted to investigate the efficacy of chemical protective gloves in various electroplating scenarios. Subsequently, a number of pertinent queries have been raised by HSE field inspectors. These regarded the efficacy of gloves, the use of surfactants and local exhaust ventilation (LEV) in chromium plating, and the potential for transfer of contaminants outside the workplace.

The objectives of this supplementary work were to investigate:

- The practical efficacy of gloves in electroplating (collating the findings of HSL reports AS/2012/02 (Forder, 2013), AS/2010/13 (Simpson, 2010), and RR963 (Keen et al., 2013));
- The efficacy of surfactants vs LEV for controlling chromium exposures around plating tanks; and
- The potential for transfer of contamination outside the workplace, focussing on the result of taking contaminated work wear home for laundering.

This was a desk-based exercise. No further field or experimental work was undertaken.

Main Findings

Workers who solely wore "reusable (chemically resistant)" gloves had more than three times the hand contamination of those solely wearing "single use, splash resistant" (also known as "disposable") gloves.

“Reusable (chemically resistant)” PVC gloves do not offer the same degree of hand protection as other types of glove commonly used in the surface engineering industry.

Laboratory tests showed a negligible effect on dexterity when using “single use, splash resistant” gloves, provided they fit the wearer properly. It should be possible to conduct the fine, manual tasks required in surface engineering, such as the jigging of small components, whilst wearing these types of chemical protective gloves.

A range of chemical protective gloves resisted permeation and degradation when challenged with electroplating solutions in laboratory tests for up to four hours; however, chemical protective gloves fail in use for a variety of reasons other than permeation (HSE, 2009). As far as possible, working practices should be arranged such that gloves are worn for splash protection only. Gloves should not be routinely used as a primary barrier to protect against dermal exposure to hazardous substances.

No real difference in urinary chromium levels in electroplaters could be attributed to the use of surfactants or LEV to control mist emissions from plating tanks. Either approach was capable of providing adequate exposure control provided it was properly implemented and maintained. A laboratory investigation involving air sampling would be a better approach for demonstrating the effectiveness of these control measures.

Published scientific literature indicates that the major route by which occupational contamination is transferred outside the workplace is on work clothing. There is clear potential for this to occur when contaminated work wear is taken home for laundering. There is however, no information in the peer reviewed scientific literature on the transfer of contamination outside the workplace specifically in the surface engineering industry.

1 INTRODUCTION

Background

This report details supplementary work undertaken following HSE project OH36 which examined the use of biological monitoring (BM) in the surface engineering (electroplating) industry. This work was undertaken over a period of 3 years, and 53 companies were visited. The visits involved an occupational hygiene assessment of relevant tasks and exposure controls, BM (as post-shift urine sampling), and an assessment of the levels of contamination on workers hands and workplace surfaces at each site. In order to look for reductions in exposure as a result of the initial site visit, repeat BM was undertaken at 6 and 12 month intervals following feedback from the initial visit. On these occasions, BM kits were posted, sites were not revisited. The work was reported in HSE research report RR963 "Exposure to hexavalent chromium, nickel and cadmium compounds in the electroplating industry" (Keen et al., 2013).

As a result of the above work, two separate small reactive projects were also conducted to investigate the efficacy of chemical protective glove use in various electroplating scenarios. Simpson (2010) looked at gloves with cadmium (Cd) plating solution (HSL report AS/2010/13), and Forder (2013) looked at using gloves with chromium (Cr) and nickel (Ni) plating solutions (HSL report AS/2012/02).

Since the issue of these reports, a number of pertinent queries have been raised by HSE field inspectors. These queries regarded the efficacy of gloves, the use of surfactants and local exhaust ventilation (LEV) in chromium plating, and the potential for transfer of contaminants outside the workplace.

Aims and Objectives

This work investigated the queries raised by HSE field inspectors and looked at:

- The practical efficacy of gloves in electroplating (collating the findings of Forder, 2013, Simpson, 2010, and Keen et al., 2013);

- The efficacy of surfactants vs LEV for controlling chromium exposures around plating tanks; and
- The potential for transfer of contamination outside the workplace, focussing on the result of taking contaminated work wear home for laundering.

This was a desk-based exercise. No further field or experimental work was undertaken.

2 METHODOLOGY

The statistical analysis was complicated due to "confounding factors". These are variables that influence the dependent variable (e.g. urinary concentration), and are also associated with another independent variable. Unless controlled in the original design of the study, these may distort the association being studied between the two. Confounding factors for this work included site-specific working practices, control measures and cleanliness. Some data sets were dominated by results from a single company. In these particular cases, findings cannot be extrapolated more widely.

The BM results used for the statistical analysis were all within the normal creatinine range of 3 - 30 mmol/L. Results outside this range were not included in the statistical analysis.

Background levels of urinary chromium and nickel for non-occupationally exposed individuals are up to 3 and 10 µmol/mol creatinine respectively. Where statistical parameters (median etc.) for datasets were close to these background levels then the validity of statistical analysis is limited.

2.1 EFFICACY OF GLOVES

Statistical analysis for this work was conducted using the original project data (as reported in RR963 (Keen et al., 2013)). This work looked at the handwashing (hand contamination) and BM results for nickel, chromium and cadmium, along with glove types employed for individuals at each site.

Workers were classified into the following subgroups:

Chromium:

- all chromium workers (all individuals whose work had direct potential for chromium exposure);

- with a subset of chromium electroplaters (defined as those individuals who reported spending some time actually electroplating at any stage of the original project); and
- non-chromium workers.

Nickel:

- all nickel workers (all individuals whose work had direct potential for nickel exposure);
    - with a subset of nickel electroplaters (defined as those individuals who reported spending some time actually electroplating at any stage of the original project); and
- non-nickel workers.

Cadmium:

- Due to the limited nature of the dataset, only cadmium workers (including cadmium electroplaters) were considered.

Handwash data were categorised with details of the glove type worn by each operative. This was difficult to establish for a number of reasons:

- a wide variety of gloves were used at the sites visited;
- some companies left the decision of which glove to wear to individual operatives, meaning that gloves worn may be different depending on the operative's decisions during the day;
- some companies had a "managed" approach, specifying which gloves to be worn for each task; and
- some workers were noted to wear different or multiple types of gloves during their shift, dependent on the various tasks undertaken.

General information was gathered about the types of gloves used at each site for the work detailed in report RR963; however, it was outside the scope of work to collect detailed information about each type of glove worn for each individual at each site.

Appendix 1 gives the details of the different glove types and combinations observed during the site visits.

Where gloves were noted in the original work to be "disposable", as per HSE definitions used in http://www.hse.gov.uk/skin/posters/singleusegloves.pdf and http://www.hse.gov.uk/skin/posters/reusablegloves.pdf, these are now redefined as "single use, splash resistant", and where "reusable", as "reusable (chemically resistant)". Glove types were grouped together for the purposes of this work, i.e. all types of material (e.g. all "reusable (chemically resistant)" PVC gloves) were grouped together, not as individual makes or manufacturers.

The detailed methodology for the statistical analysis is presented in Appendix 2.

2.2 EFFICACY OF LEV VS SURFACTANTS

To investigate the effect on chromium exposures in chromium electroplaters, the chromium BM data were arranged with additional information on whether there was any LEV present, and if there was a surfactant (also known as a spray suppressant) added to the plating tanks.

The statistical analysis was complicated due to "confounding factors". This is discussed in section 2.1 above. The detailed methodology for the statistical analysis is presented in Appendix 2.

2.3 THE POTENTIAL FOR TRANSFER OF CONTAMINATION OUTSIDE THE WORKPLACE

A literature search was conducted by HSE's Information Services team.

The search terms used were:

- transfer of contamination on work wear;
- transfer of contamination on clothing;
- transfer of contamination on personal protective equipment (PPE);
- secondary exposure;
- exposure of family members;
- third party exposure;
- laundering/washing of work wear;
- home washing/laundering of work wear;
- contamination in cars/vehicles; and
- wearing contaminated work wear outside of the workplace.

There was no restriction placed on time coverage. The review found 112 papers with dates ranging between 1964 and 2013.

Information sources included:

- Oshrom;
- Web of Science;
- Ergonomics Abstracts;
- PQScitech (on the STN platform); and
- Chemical Safety Abstracts, Embase, Medline, Toxfile.

For the majority of papers, only the abstracts were studied, as many papers were not directly relevant to the chemicals/processes considered here.

3 RESULTS & DISCUSSION

3.1 THE PRACTICAL EFFICACY OF GLOVES

3.1.1 General

There were multiple, different types of gloves used at the companies visited for the project. These included "reusable (chemically resistant)" and "single use, splash resistant" (also known as "disposable") types.

Summary information on glove use is presented in Table 1 and further details of makes, types and combinations can be seen in Appendix 1. More workers wore "reusable (chemically resistant)" gloves than "single use, splash resistant" types (or a combination of).

Gloves materials included:

- nitrile;
- PVC;
- latex;
- vinyl;
- butyl rubber;
- neoprene; and
- non-chemical resistant types (e.g. abrasive protective gloves, cotton liner gloves, (non-chemically resistant) PVC gauntlets).

A detailed assessment of glove use was not part of the original fieldwork. Some gloves were classified as "unknown" for the purposes of additional statistical analysis, due to a lack of detailed information. These included:

- Rubber coated fabric gloves;
- Yellow "marigold" type gloves; and
- Domestic washing up gloves.

Table 1 Number of workers who took part in the handwashing exercise, by glove type

Glove type	Total number of measurements (number of workers) #	Number of chromium workers[1] #	Number of nickel workers[2] #
None	10 (10)	3	3
Single use, splash resistant only	32 (23)	23	19
Reusable (chemically resistant) only	125 (113)	94	87
Single use, splash resistant AND reusable (chemically resistant)	27 (27)	23	13
	Total	143	122

[1] Chromium workers- including chromium electroplaters (this category also included nickel workers who also undertook some chromium work).

[2] Nickel workers- including nickel electroplaters (this category also included chromium workers who also undertook some nickel work).

The total number of chromium and nickel workers does not equal the total number of measurements, as workers can be classified as either, neither or a combination of chromium / nickel workers.

3.1.2 Laboratory glove test results

HSL reports AS/2010/13 (Simpson, 2010) and AS/2012/02 (Forder, 2013) described laboratory studies on gloves used in the plating industry. AS/2010/13 looked at two types of single use, splash resistant glove used in cadmium plating, and AS/2012/02 at three types of glove (including reusable (chemically resistant) and single use, splash resistant types) used in nickel (electrolytic) and hard chromium (Cr VI) plating. The glove types tested were:

- AS/2010/13 (Simpson, 2010):
  - "Disposable" (single use, splash resistant) PVC glove; and
  - "Disposable" (single use, splash resistant) nitrile glove.

- AS/2012/02 (Forder, 2013):
  - "Disposable" (single use, splash resistant) medical examination type nitrile glove;
  - "Reusable" (reusable, chemically resistant) nitrile glove; and
  - "Reusable" (reusable, chemically resistant) latex glove.

Both studies tested permeation, degradation, and dexterity in each of the glove types using relevant BS EN standards. Test methods are detailed in Appendix 3.

Overall, all the gloves tested resisted permeation and degradation by cadmium, nickel and chromium plating solutions for up to 4 hours.

In the laboratory tests, "reusable" glove types showed a significant amount of staining, meaning that contamination was retained on their surface. As decontamination is difficult, reuse is not recommended as there is a risk that they may later contaminate the operative and other items through storage and redonning (Forder, 2013). HSE COSHH Essentials guidance S101 "Selecting protective gloves" also states, "gloves cannot be 'maintained'. They nearly always become contaminated inside the second time they are put on".

None of the single use, splash resistant ("disposable") gloves met performance level 1 (the minimum standard) of puncture resistance specified in BS EN 388 (BSI 2003b) "Protective gloves against mechanical risks" (see Appendix 3 for further details). These gloves would therefore provide little protection against mechanical hazards. This is understandable however, as the gloves are not designed for this purpose. The "reusable" gloves performed better in this test, with both nitrile and latex types providing protection to performance level 1.

During the site visits it was noted that some workers did not wear gloves for some tasks requiring a high degree of dexterity (e.g. jigging); however, tests on "disposable" (single use, splash resistant) gloves showed a negligible effect on dexterity. There was a more pronounced reduction in dexterity with "reusable" gloves. It should be noted that although single use, splash resistant gloves may be easier to use for tasks such as jigging, care must be taken as these types of gloves are more easily punctured.

AS/2012/02 (Forder, 2013) reported a notable reduction in dexterity for reusable gloves where they did not fit the wearer properly. A selection of sizes of gloves should be made available to workers to allow them to perform tasks to a satisfactory standard without the need to remove gloves, and therefore risk contamination. Guidance on the sizing of gloves is detailed by HSE (2009), "Gloves should fit the wearer. Tight gloves can make hands feel tired and lose their grip. Gloves that are too large can create folds; these can impair work and be uncomfortable".

3.1.3 A comparison between glove types and materials

Due to confounding factors, we cannot conclude that any differences found in hand contamination between groups of workers were definitely caused by wearing a particular type of glove. Differences may have been caused by on-site working practices, control measures and cleanliness (independent factors). Confounding also occurred because samples from some key groups of workers were all from one particular company (for example, for non-chromium workers who did not wear gloves). The findings below must therefore be interpreted with caution.

A summary of the handwash measurement results by glove type is seen in Table 2. No analysis was carried out to investigate the effect of glove type with cadmium due to the limited nature of the cadmium dataset.

Table 2 Summary of handwash measurements by glove type

		Handwash measurements (mg)	
		Chromium in Chromium workers	**Nickel in Nickel workers**
Single use, splash resistant only *	**Median (90th percentile)**	0.008 (0.079) n=23	0.140 (0.832) n=19
Reusable (chemically resistant) only *	**Median (90th percentile)**	0.047 (0.682) n=94	0.427 (2.404) n=87
Single use, splash resistant AND reusable (chemically resistant) *	**Median (90th percentile)**	0.060 (0.308) n=23	0.060 (1.816) n=13

* Details of the makes, types and combinations of glove included in this analysis are found in Appendix 1.

The analysis showed significant differences between "single use, splash resistant" and "reusable (chemically resistant)" glove types, in terms of hand contamination amongst chromium and nickel workers. The results showed:

- Chromium workers solely using "reusable (chemically resistant)" gloves had chromium handwash measurements that were 4.95 times (95% confidence interval (C.I.) in the range [2.02, 12.12]) higher than those wearing "single use, splash resistant" gloves.

- Nickel workers solely using “reusable (chemically resistant)” gloves had nickel handwash measurements that were 3.02 times (95% confidence interval in the range [1.11, 8.25]) higher than those wearing “single use, splash resistant” gloves.

Significantly higher results for reusable (chemically resistant) gloves than single use, splash resistant ones may have been due to:

- repeated reuse of gloves causing contamination of hands whilst donning and doffing; and
- reduced dexterity leading to glove removal for some tasks.

Table 3 shows a summary of handwash measurements by glove material. No significant difference was found in the handwash results between the majority of different types of gloves (with regards to material), except for PVC and non-chemical resistant gloves. The data for vinyl, butyl and neoprene gloves were too limited to undertake any statistical analysis.

Table 3 Summary of handwash measurements by glove material for reusable (chemically resistant) types

		Handwash measurements (mg)	
		Chromium in Chromium workers	**Nickel in Nickel workers**
Nitrile	**Median (90th percentile)**	0.022 (0.529) n=63	0.198 (1.393) n=30
PVC	**Median (90th percentile)**	0.059 (0.553) n=72	0.482 (2.676) n=55
Latex	**Median (90th percentile)**	0.021 (0.205) n=32	0.370 (3.848) n=19
Non-chemical resistant (but reusable)	**Median (90th percentile)**	0.004 (0.202) n=15	0.076 (0.428) n=10

PVC gloves were the most commonly used. These gloves were all "reusable (chemically resistant)" types (see Tables 4 and 5) and worn by 51% of chromium workers, and 57% of nickel workers. Their use was associated with significantly higher chromium and nickel hand contamination levels than all of the other glove types used.

- For chromium "electroplaters" wearing PVC gloves, chromium handwash measurements were 3.23 times higher (95% C.I. [1.49, 6.99]) than those who wore other glove types.

- For (all) chromium "workers" wearing PVC gloves, chromium handwash measurements were 2.53 times higher (95% C.I. [1.32, 4.86]) than those who wore other glove types.

- For nickel "electroplaters" wearing PVC gloves, nickel handwash measurements were 2.75 times higher (95% C.I. [1.39, 5.46]) than those who wore other glove types.

- For (all) nickel "workers" wearing PVC gloves, nickel handwash measurements were 2.41 times higher (95% C.I. [1.16, 5.01]) than those who wore other glove types.

These consistent findings show that PVC gloves did not offer as much protection as gloves made from other materials. This same finding was also detailed by Roff (2007) in work on the UV lithographic industry, which found that PVC gloves did not perform as well in testing for a range of different chemicals.

Table 4 Glove use in chromium workers by glove material

Number of chromium workers				
	Single use, splash resistant	**Reusable (chemically resistant)**	**Single use, splash resistant AND Reusable (chemically resistant)**	**Total workers (Total electroplaters)**
Nitrile	27	32	4	63 (47)
PVC	0	72	0	72 (58)
Latex	15	17	0	32 (17)
Vinyl	1	0	0	1 (0)
Butyl	0	4	0	4 (4)
Non-chemical resistant (but reusable)	0	15	0	15 (4)
Neoprene	0	6	0	6 (3)

Table 5 Glove use in nickel workers by glove material

Number of nickel workers				
	Single use, splash resistant	**Reusable (chemically resistant)**	**Single use, splash resistant AND Reusable (chemically resistant)**	**Total workers (Total electroplaters)**
Nitrile	20	25	5	50 (43)
PVC	0	63	0	63 (56)
Latex	8	14	0	22 (17)
Vinyl	0	0	0	0 (0)
Butyl	0	3	0	3 (1)
Non-chemical resistant (but reusable)	0	10	0	10 (6)
Neoprene	0	3	0	3 (0)

As so few workers (3 out of 143 chromium, and 3 out of 122 nickel) wore "no gloves" no meaningful analysis could be performed on the "no gloves" data.

Only a small number of cadmium measurements were available. Out of the fourteen cadmium workers studied, eight wore gloves and six did not. No significant difference in the cadmium handwash results were found for these workers. As the analysis was performed on a very limited dataset, again dominated by data from a single company, the findings cannot be extrapolated to all the sites investigated.

3.2 THE EFFICACY OF SURFACTANTS VS LEV

Surfactants and LEV are two control options for chromium plating which can be used to reduce chromium inhalation exposure. Surfactant is added to plating tanks in order to reduce the amount of mist generated, whilst LEV is installed to capture any mist that is generated. The HSE/Surface Engineering Association (SEA) guidance indicates that surfactants and LEV can be used in conjunction with each other or separately.

At each site, the use of LEV and surfactant tended to be the same across all workers, i.e. the majority of chromium tanks at each company had LEV or surfactants, or a combination of the two. None of the sites visited undertook chrome plating using hexavalent chromium where neither LEV nor surfactant were used; however, this situation was found at sites where trivalent chromium (chromium III) plating processes were undertaken. Although trivalent chromium mist can be inhaled, the risk to health is lower than for hexavalent chromium as it is not classified as a carcinogen or an asthmagen.

A total of 1197 urinary chromium measurements were available from 180 different workers, of which 802 and 659 measurements were associated with the use of LEV and surfactant respectively.

Table 6 and Figure 1 present a summary of the data for urinary chromium measurements in chromium VI electroplaters. All companies who had individuals who may have undertaken work using both chromium VI and chromium III, or just chromium III, were eliminated from the dataset.

Table 6 Summary of urinary chromium measurements in chromium VI platers

	Median (µmol/mol creatinine)	90^{th} percentile (µmol/mol creatinine)
LEV use (N=750) (includes LEV & surfactants, and LEV only)	3.71	13.47
No LEV use (N=268) (i.e. surfactant use only)	2.91	15.63
Surfactant use (N=518) (includes LEV & surfactants, and surfactants only)	3.85	13.40
No surfactant use (N=500) (i.e. LEV use only)	3.07	13.05
LEV and surfactant (N=279)	4.32	13.46

Note- the background level of chromium for non-occupationally exposed people is 3 µmol/mol creatinine.

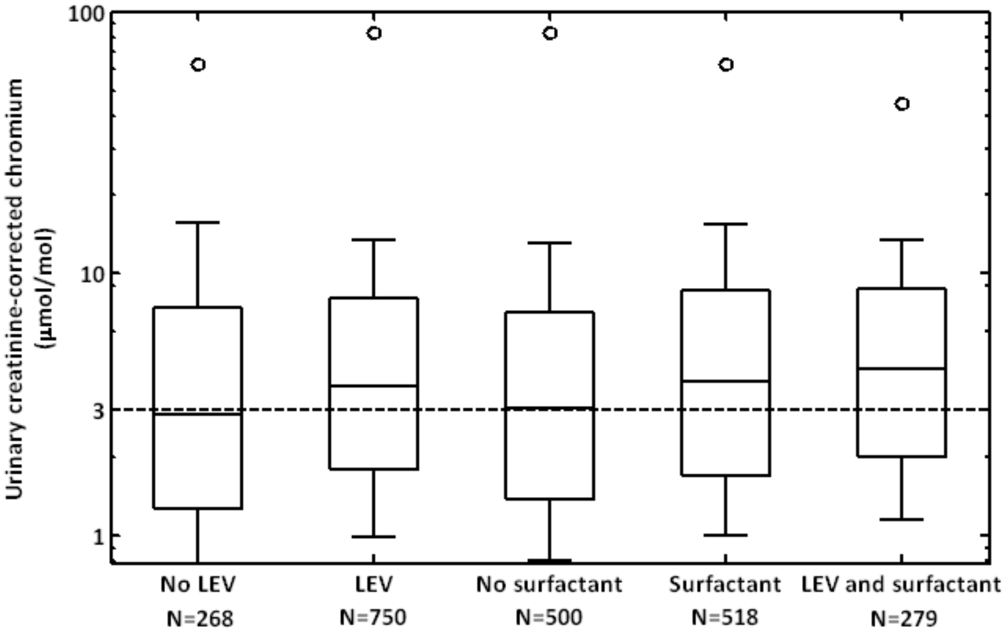

Figure 1 Boxplot* of urinary creatinine-corrected chromium levels in chromium VI platers, by surfactant use.

* The boxes represent the 25th, 50th and 75th percentiles, whilst the bars extend to the 10th and 90th percentiles. The maximum value is represented by the individual points. The dashed line indicates the background level of chromium for non-occupationally exposed people (3 µmol/mol creatinine).

Statistical analysis of the BM data suggests some slight effects linked to the use of LEV and surfactants; however, the data analysis was complicated due to confounding factors. The decision to install one, or both, of these exposure controls at any particular company will have been influenced by a number of factors, not all of which are accounted for in the statistical analysis. Furthermore, a significant proportion of the BM data falls within the background range for non-occupationally exposed individuals. Taking these factors into account, it was not possible to quantify the relative efficacy of the LEV and surfactants in controlling chromium exposures around plating tanks using the BM data. It would be necessary to deploy a different methodology to investigate emissions from plating baths. This would be better achieved by deploying static air samplers over plating baths, ideally in a controlled environment where the parameters under test can be varied in a controlled manner, with the influence of any other factors minimised.

3.3 THE POTENTIAL FOR TRANSFER OF CONTAMINATION OUTSIDE THE WORKPLACE

There was extensive literature available regarding the potential for transfer of contaminants outside the workplace; however, no papers were found that specifically looked at chromium, nickel and/or the surface engineering industry.

A significant paper was published by NIOSH, who in 1992 enacted the "Workers Family Protection Act" in order to "protect the health of workers and their families from hazardous chemicals and substances, including infectious agents, transported from the workplace to the home" (NIOSH, 2012). This study was undertaken following the implementation of this act to discover the types of contaminants and transfer routes involved. A large range of contaminants was listed in the paper, including cadmium; although it is unknown what the working practice was which involved this substance.

Studies showed that showering, and changing clothes and shoes before leaving work reduces the possibility of transferral of contaminants outside the workplace (Venables and Newman-Taylor, 1989); however, it was also found that where clothes are only changed, and a shower is not taken, the problem is not completely solved (Morton et al. 1982).

Studies show that where workers arrive home in their work clothes, contamination is greatest at the homes where workers do not change within two hours of getting there (McCauley et al, 2003) (Strong et al, 2009 - within one hour of getting home). As well as contamination of the family car (Piacitelli et al., 1997; Piacitelli and Whelan., 1995; CDC and NLM., 2009), the home is also contaminated. Piacitelli et al., 1997 found contamination on the family room sofa, exterior entry floor, and laundry room floor.

There is extensive literature available regarding workers taking home asbestos fibres on their clothing; and also for lead, with high blood lead concentrations being found in children due to their parents taking the contaminant home from work. A few examples of this include Sider et al., 1987, Krousel et al., 1986, and Epler et al., 1980 (asbestos fibres); Khan, 2010; Gerson et al., 1996; CDC and NLM, 2001; Chan, 2000; Chiaradia et al, 1997; Armour, 2000; Piacitelli and Whelan, 1995; Dolcourt el al., 1978; and Baker et al., 1977 (lead).

Various studies looked at the laundering of work wear at home, and the potential contamination of other clothing. Contamination can occur through various mechanisms including:

- Clothing being in the same wash as the contaminated clothing (Laughlin et al., 1981); and
- in loads following the contaminated load (leading to a contaminated washing machine) (Snyder, 2007).

There was no literature found that specifically looked at the home laundering of clothing contaminated with chromium or nickel.

The literature reports that contaminants can be transferred to the home along various routes, either intentionally and / or accidentally. These routes include:

- on work clothing (NIOSH, 2012);
- on tools and equipment (NIOSH, 2012);
- taking items home from work (i.e. bags, rags, scrap materials etc.) (NIOSH, 2012);
- on the workers body (NIOSH, 2012) or hair (Agnew et al., 2002);
- in the family car (Whelan et al. 1997, Piacitelli et al., 1997, Piacitelli and Whelan, 1995, CDC and NLM., 2009); and
- through family members visiting the workplace (Agnew et al, 2002).

Safe practices to help reduce the issue of contaminant transferral include (NIOSH, 2012, Safety and Health, 2006):

- changing clothes at work;
- leaving the contaminated clothes at work;
- storing non-contaminated clothes away from work clothes;
- showering before leaving work;
- not taking tools, packaging or other items home;
- laundering work clothes separately; and
- preventing family members from visiting the work area.

Many studies show that after intervention (information, instruction and training as well as the provision of resources for washing, cleaning and changing clothes, and a laundry facility in the workplace) the levels of contamination transferred outside the workplace can be reduced (CDC and NLM, 2012; Lozier et al., 2012; Salvatore et al., 2009; Strong et al., 2009). Regular refresher training and maintenance should be undertaken, to ensure that workers continue with new practices.

The taking home of work clothing dominates the literature as the most common method of contamination transferral outside the workplace. Eighty four out of 112 papers (75%) discussed this topic. Only four out of 112 (<4%) papers had findings which showed insufficient evidence or no connection for the specific contaminants measured.

Further details on this work can be found in Appendix 4 of this report.

4 CONCLUSIONS

Workers who solely wore "reusable (chemically resistant)" gloves had more than three times the hand contamination of those solely wearing "single use, splash resistant" (also known as "disposable") gloves. "Reusable (chemically resistant)" PVC gloves do not offer the same degree of hand protection as other types of glove commonly used in the surface engineering industry.

Laboratory tests showed a negligible effect on dexterity when using "single use, splash resistant" gloves, provided they fit the wearer properly. It should be possible to conduct the fine, manual tasks required in surface engineering, such as the jigging of small components, whilst wearing these types of chemical protective gloves.

A range of chemical protective gloves resisted permeation and degradation when challenged with electroplating solutions in laboratory tests for up to four hours; however, chemical protective gloves fail in use for a variety of reasons other than permeation (HSE, 2009). As far as possible, working practices should be arranged such that gloves are worn for splash protection only. Gloves should not be routinely used as a primary barrier to protect against dermal exposure to hazardous substances.

No real difference in urinary chromium levels in electroplaters can be attributed to the use of surfactants or LEV to control mist emissions from plating tanks. Either approach is capable of providing adequate exposure control provided it is properly implemented and maintained. A laboratory investigation involving air sampling would be a better approach for demonstrating the effectiveness of these control measures.

Published scientific literature indicates that the major route by which occupational contamination is transferred outside the workplace is on work clothing. There is a clear potential for this to occur when contaminated work wear is taken home for laundering. No information exists however, in the peer reviewed scientific literature, on the transfer of contamination outside the workplace specifically in the surface engineering industry.

5 APPENDICES

Appendix 1: Types of gloves used by workers in the project (as noted in site visit reports and questionnaires)

1. **"Single use, splash resistant" (also known as "disposable"):**
   a) Latex;
   b) Nitrile; and
   c) Vinyl.

2. **"Reusable (chemically resistant)":**
   a) PVC:
      i. *Vychem actifresh gauntlets;*
      ii. *Polychem P43/E10 PVC gauntlets;*
      iii. *Red PVC reusable (chemically resistant) gauntlets;*
      iv. *PVC fabric backed gauntlets;*
      v. *Rednek plus actifresh PVC gauntlets;*
      vi. *Polychem P43/E10 PVC gauntlets;*
      vii. *Arco PVC gauntlets;*
      viii. *"PVC gauntlet";*
      ix. *"PVC gauntlet (with cotton liner)";*
      x. *Reusable (chemically resistant) Strongoflex Super 690 double dipped; and*
      xi. *PVC fabric backed gloves.*

   b) Nitrile:
      i. *Solvex Ansell Nitrile;*
      ii. *Ansell Solvex nitrile reusable with a Ansell Hyflex Ultralite liner;*
      iii. *Nitrile Marigold industrial gloves;*
      iv. *Marigold green nitrile gauntlets;*
      v. *Showa nitrile gauntlets;*
      vi. *"Green nitrile gloves";*

vii. *Ansell Edmont Solvex 37-675 nitrile;*

viii. *Ansell Edmont Solvex Premium Nitrile;*

ix. *Marigold industrial blue nitrile; and*

x. *Ansell alphatec*

c) Natural rubber latex:

i. *Marigold Tripletech G44R glove;*

ii. *Black Polyco Chemprotec natural rubber gauntlets;*

iii. *"Natural rubber latex gauntlet";*

iv. *Marigold Industrial Suregrip G4Y natural rubber latex gloves;*

v. *Arco Chemgripz latex glove;*

vi. *Ansell cotton flocked natural rubber latex Econohands plus; and*

vii. *Black Marigold Industrial Emperor ME105.*

d) Neoprene:

i. *Ansell Marigold black neoprene 87950 with a Ansell Hyflex Ultralite liner;*

ii. *Ansell Marigold black neoprene 87950 with "disposable" nitrile beneath; and*

iii. *Neoprene gloves with cotton liners and cuffs.*

e) Butyl rubber:

i. *Butyl rubber long cuffed gauntlets; and*

ii. *Marigold industrial butyl rubber.*

f) Other (non-chemically resistant, but reusable):

i. *Abrasive protective gloves;*

ii. *Cotton liner gloves; and*

iii. *("Non-chemically resistant") PVC gauntlets.*

3. Glove types worn in multiples:

a) Ansell Solvex nitrile “reusable” with a Ansell Hyflex Ultralite liner;

b) Ansell Marigold black neoprene 87950 with a Ansell Hyflex Ultralite liner;

c) Ansell Marigold black neoprene 87950 with a “disposable” nitrile beneath;

d) PVC gauntlet (with cotton liner);

e) “Disposable” (“single use, splash resistant”) vinyl gloves over a cotton-lining glove; and

f) “Disposable” (“single use, splash resistant”) nitrile gloves over a cotton-lining glove.

Appendix 2: Statistical Analysis Methodology

For consistency with the analyses undertaken for the original work (RR963), samples that were outside the normal creatinine range of 3 – 30 mmol/L, were discarded from the analyses for this work.

BM and handwash data were assumed to follow a lognormal distribution. No statistical models were fitted for cadmium in handwash samples due to the low number of samples.

The BM dataset consisted of chromium levels in urine samples collected on several workers from each company at various time points over the lifetime of the project. A mixed effects analysis (where statistical models containing both fixed and random effects are fitted) is usually considered appropriate for this sort of data, where the company-specific random effects represent differences between the average company measurements, and the average measurement across all companies. A company's random effect may represent differences due to that company's exposure controls, amongst other factors, and is 'random' because the company has been randomly selected from a larger population of companies.

A mixed effects analysis was carried out for the previous work (HSE report RR963, Keen et al., 2013) where trends in BM data over time were investigated. Carrying out a similar mixed effects analysis for investigating the effects of LEV and surfactant use is more problematic due to the nature of the dataset and the issue of possible confounding variables (e.g. LEV use may be correlated with urinary measurements, but it may also be correlated with company-specific exposure control levels). Although confounding between company-specific exposure control and the effects due to LEV/surfactants cannot be quantified nor eradicated, simple linear models (with just fixed effects) were nevertheless fitted to the dataset to determine whether, ignoring any correlations between measurements, any relationships exist between BM data and LEV/surfactant use. A similar linear model was also fitted for investigating the efficacy of glove use on levels of nickel and chromium in handwash samples.

The linear models were specified on the log scale and took the following forms:

$$\log(Y_i) = Mean + \beta_1 LEV\_always_i + \beta_2 LEV\_sometimes_i + \varepsilon_i$$

$$\log(Y_i) = \mu + \beta_1 Surfactant_i + \varepsilon_i$$

$$\log(Y_i) = \mu + \beta_1 LEV\_always_i + \beta_2 LEV\_sometimes_i + \beta_3 Surfactant_i + \beta_4 LEV\_always_i * Surfactant_i + \beta_5 LEV_{sometimes_i} * Surfactant_i + \varepsilon_i$$

$$\varepsilon_i \sim N(0, \sigma^2)$$

where Y_i represents the ith urinary chromium measurement, LEV_always_i and $LEV\_sometimes_i$ are independent variables representing LEV use (always and sometimes), β_1, β_2 etc. are parameters that measure consistent differences to the overall mean due to LEV use/surfactant use etc. on the log scale, and the residual errors ε_i are assumed to be normally distributed with mean zero. μ represents the *mean*.

The first two equations investigated the relationship between LEV use and surfactant use on BM data respectively. The third investigated the relationship and interaction between these variables.

For the handwash data, linear models were also specified on the log scale and took forms similar to the above:

$$\log(Y_i) = Mean + \beta_1 GloveType_i + \varepsilon_i$$

where Y_i represents the ith handwash measurement, $GloveType_i$ are independent variables representing glove type (e.g. single use, splash resistant, reusable (chemically resistant) (chemically resistant), neoprene, latex), β_1 is a parameter that measures consistent differences to the overall mean due to glove type, and the residual errors ε_i are assumed to be normally distributed with mean zero.

The statistical models were fitted in the software R version 2.15.1 (The R Foundation for Statistical Computing, 2012).

Appendix 3: Glove testing methods

Permeation Test

Glove samples (76 mm diameter discs) were taken from the gloves' palms and conditioned for 24 hours at a temperature of 23 ± 2°C and relative humidity (RH) of 50 ± 5 % RH, after which the weight and thickness of the samples were measured. The thickness was taken as the median of five measurements.

The chemical permeation tests were performed in triplicate following method BS EN 374-3 (BSI 2003a) ("Protective gloves against chemicals and micro-organisms. Determination of resistance to permeation by chemicals") except that the tests with the nickel plating solutions were performed at a temperature of 60°C rather than the standard 23°C in order to replicate typical conditions when used in industry.

The samples were loaded into proprietary permeation test cells. One surface of the glove was exposed to the challenge solution (50 ml) whilst the other was exposed to the deionised water collection medium (80 ml). The water in the closed system was agitated via a stirring rod, allowing representative sampling and minimizing boundary layer resistance to the transfer of any permeant. Samples (5 ml) of the collection fluid were taken after 30, 60, 90, 120, 180 and 240 minutes, with fresh collection fluid replacing that removed. For the nickel and chromium solutions, a sample was also taken at 0 minutes, prior to the addition of the challenge solution.

The aliquots taken during the test were analysed for nickel, chromium or cadmium depending on the challenge solution by inductively coupled plasma – atomic emission spectroscopy (ICP-AES).

Degradation Test

After the permeation test the glove samples were rinsed with deionised water and excess water removed with paper towel. The samples were then reconditioned at 23 ± 2 °C and 50 ± 5 % RH overnight and then reweighed and puncture tested.

Glove puncture resistance testing was performed using a Testometric CX materials testing machine following a method based upon BS EN 388 (BSI 2003b) ("Protective gloves against mechanical risks"), but with testing being carried out shortly after removal of excess test chemical. For comparison, six samples of each glove type were puncture tested without having undergone chemical exposure.

The minimum value for the puncture resistance is used to assess the glove material and assign it to one of the performance levels described in the standard; level 1 (20 N), level 2 (60 N), level 3 (100 N) and level 4 (150 N).

Dexterity Test

The ability of the gloves to allow wearers to perform tasks that require a high degree of dexterity and touch was tested using a Purdue Pegboard. The test involves a subject placing as many metal pegs as possible into holes in the wooden board in 30 seconds. The pegs were ~2.8 mm diameter and the holes in the board were ~3.2 mm. Once the test had been practiced sufficiently, the exercise was performed three times with the left hand, then three times with the right hand, gloveless and then whilst wearing both types of glove. The test was repeated and the glove results combined. One person only performed the tests.

The standard test described in BS EN 420 (BSI 2003c) ("Protective gloves. General requirements and test methods") was not used to test the gloves because it was considered too coarse for the type of gloves being assessed. It was expected that this test would not show a difference between any of the gloves. This test requires the wearer to handle metal pins with diameters of between 5 and 11 mm.

Appendix 4: Main findings of the literature review

There are numerous published studies on many different hazardous substances that may be transferred to the home environment from the workplace. Many of these studies are from the US. None of the papers found were specific to chromium, nickel or cadmium in the surface engineering industry.

A summary of contaminants discussed in the literature are:

- asbestos fibres;
- lead;
- respiratory crystalline silica (RCS);
- mercury;
- atrazine;
- flour dust;
- tritium;
- polychlorinated biphenols (PCBs);
- animal laboratory dusts;
- halogenated platinum slats;
- polycyclic aromatic hydrocarbons (PAHs);
- chlorinated hydrocarbons;
- beryllium;
- arsenic;
- cadmium;
- pesticides;
- caustic farm products;
- fibrous glass;
- cyclothriethylenetriamine (RDX);
- “infectious agents”;
- “estrogenic substances”;
- “asthmagens”; and
- “allergens”.

NIOSH, 2012 states that:

> "*The Workers' Family Protection Act (29 U.S.C. 671a) was enacted on October 26, 1992, as section 209 of Public Law 102-522, the "Fire Administration Authorization Act of 1992." The purpose of the Act is to protect the health of workers and their families from hazardous chemicals and substances, including infectious agents, transported from the workplace to the home.*
>
> *Under the Act, NIOSH was mandated to conduct a study to evaluate the problem of contamination of workers' homes by hazardous chemicals and substances transported from the workplace. Therefore, NIOSH requested information on the contamination of workers' home by hazardous chemicals and substances transported from the workplace on equipment, clothing, or the worker's person."*

The NIOSH study following this Act was published in 1995. The study found many contaminants that had caused various health effects among the workers families. These included beryllium, asbestos, lead, mercury, arsenic, cadmium, pesticides, caustic farm products, chlorinated hydrocarbons, estrogenic substances, asthmagens and allergens, fibrous glass, cyclothriethylenetriamine (RDX), and infectious agents. It was found that there are various transferral routes to the home, including on work clothing, tools and equipment, taking items home from work (i.e. bags, rags, scrap materials etc.), and on the worker's body. There were also cases where work was done at home property (i.e. cottage industries and farming), as well as family visits into the workplace.

A summary of the NIOSH study found in Safety and Health, 2006 gives safe practices to reduce exposure including changing clothes at work, leaving soiled clothes at work, storing non-soiled clothes away from work clothes, showering before leaving work, not taking tools, packaging or other items home, laundering work clothes separately, and preventing family members from visiting the work area. There are also safe practices listed for people who work at home. These are; keeping work and living areas separate, keeping family members out of the work area, storing hazardous materials properly, disposing of all dangerous materials properly, and washing work clothes separately. A summary of the NIOSH work is found in the online document "Protect your family. Reduce Contamination at Home" (NIOSH, 1997).

There are also many other studies, which focus mainly on lead (mostly in children), asbestos (many law suits (mainly in US)), beryllium, and pesticides (various types). There are a few others, including RCS, mercury, atrazine, flour dust, tritium, PCBs, animal laboratory dusts, halogenated platinum slats, and PAHs.

All the studies included in this literature search, show evidence of workers transferring contamination to the home. Transferral methods included intentional ones as well as accidental/ unintended. These included on "*workers clothing or external body surfaces (skin/ hair), visitors or family members at the workplace, improper storage of hazardous agents, or cottage industry production*" (Agnew et al, 2002), on tools (Piacitelli and Whelan, 1996), wearing of work clothing home, laundering of work clothes at home, driving the family car to and from the work place (Whelan et al. 1997), and on personal objects (Knishkowy and Baker, 1986).

Studies showed contaminated vehicles especially in the driver's foot well and on armrest(s) - both the driver's and passenger's (Piacitelli et al., 1997), contaminated steering wheels (Piacitelli and Whelan, 1995) and child car seats (CDC and NLM, 2009).

Some studies showed that contamination was greatest in the home where workers do not change work clothes within two hours of getting home (McCauley et al, 2003) (Strong et al, 2009 - one hour of getting home). Piacitelli et al. (1997), found evidence of contamination on the family room sofa, exterior entry floor, and laundry room floor.

It has been found that just changing clothing and shoes before leaving work does not completely solve the problem of contamination transferral to the home; however, it is reduced (Morton et al. 1982). The transferral does reduce further, when workers shower before leaving work in addition to changing clothes (Venables and Newman-Taylor, 1989). Analysis of blood lead data in children of construction workers (Piacitelli et al., 1997) showed significant differences between workers who did not shower before leaving work, and those who did. Piacitelli and Whelan (1995) conclude, "*the failure to shower and change clothes and shoes led to significantly increased levels of lead in workers vehicles*". A paper by Khan (2011) states however, that some workers (in the oil field) may not be provided with facilities to shower and change.

There are many studies which conclude that with intervention and improvements in behaviour, the contamination spread to the home is reduced (these include, CDC and NLM, 2012; Lozier et al., 2012; Salvatore et al., 2009; Strong et al., 2009).

Laundering of clothing

Various studies looked at the laundering of clothing at home, and the potential contamination of other clothing. This can take place via clothing either in the same wash as the contaminated clothing, or in loads following the contaminated load (washing machine contaminated). Work clothing taken home for cleaning, appears to be the most common method of contamination transferral outside the workplace, especially in the case of asbestos.

There are many papers which deal with lawsuit cases with regards to asbestos contamination. Most of these cases are due to workers families developing mesothelioma, when they have never worked with asbestos, through the washing of contaminated clothing (a few examples of this include Sider et al., 1987, Krousel et al., 1986, and Epler et al., 1980).

Other findings concerning laundry are:

- Snyder, 2007 in a PAH study found that there is unlikely to be contamination of the washing machine following the washing of soiled items, and that there is unlikely potential for the contamination of subsequent loads; however, there is a likely potential of contamination of other clothes in the washer at the same time as the soiled clothing.

- Verson and Bunn, 1989 in a RCS study found that there is no difference between airborne levels of RCS in the home laundry area to outside ambient air during washing.

- Braun et al., 1989 found that Pyrazophos (a fungicide) was not completely removed from the fabric after three different types of wash.

- Laughlin et al., 1981 found that a small percentage of pesticides (Methyl-parathion) can be transferred from denim fabrics on to other cotton fabrics during laundering.

- Finley et al., 1964 found that home laundering did reduce "*insecticide residues, but that contaminated clothing should not be washed with non-contaminated clothing*".

Lead

The majority of lead papers concentrated on lead found in blood samples taken from children. Multiple papers (mainly from the United States) detail lead overexposure in children via indirect methods such as parents. These include Khan, 2010 (via clothes and contaminated environment at home); Gerson et al., 1996 (via clothing); CDC and NLM, 2001 (via clothing and shoes); Chan, 2000 (via clothes, and inadequate use of protective equipment, and poor hygiene practices); Chiaradia et al, 1997 (via clothes, shoes, hair, skin, and motor vehicles); Armour, 2000 (via clothes, body and hair); Piacitelli and Whelan, 1995 (via clothing, shoes, skin); Dolcourt el al., 1978 (via clothing); Baker et al., 1977 (via clothing). One paper (Czachur et al., 1995) however, finds that there were "*little differences in the blood lead levels of the children regardless of whether their parents showered at work, drove while wearing work clothes, or spent time at home in work clothes*".

Piacitelli et al., 1997 reports "*lead contamination on hands and interior surfaces of homes and automobiles*". This study found that "*armrests (in automobiles driven home by the lead-exposed workers) were 10 times more contaminated for the exposed group*" and that surface lead concentrations were also significantly higher for exposed homes compared with control homes where clothing was changed. This study also details that "*requirements intended to prevent "take-home" lead exposures were reported by workers in this study to be infrequently followed by employers*".

A recent study by Boraiko et al., 2013 found that floorboards of vehicles of paint remediation workers were contaminated with lead dust.

Another study by CDC and NLM, 2012, found that 85% of vehicle dust samples, and 49% of home dust samples collected exceeded the US Environmental Protection Agency (EPA) level of concern for lead. Levels of blood lead were measured in children for this study, and it was found that the blood lead levels decreased once shower facilities, shoe washes and clean changing areas were installed, and education, environmental follow-up and case management was undertaken.

Pesticides

There are multiple studies concerning the "take home" of various pesticides. The majority of these studies also discuss the taking home of work clothing and shoes (Blewett and Nicol, 2011, Harnly et al., 2009, Curwin et al., 2002), so contaminating the home. An atrazine study by Lozier et al., 2012 found that removing shoes outside the home resulted in lower atrazine contamination, and changing work clothes in the master bedroom resulted in a significantly higher atrazine contamination. Strong et al., 2009 found that changes in pesticide levels were significantly greater (after intervention) when work shoes were removed before entering the home, and changing out of work clothing within 1 hour of arriving home.

Other transfer methods include inhalation of drift, proximity of the home to the spraying, residue in carpets, vehicles, laundry (Blewett and Nicol, 2011), storing pesticide products in the home (diazinon), having a home less clean, having air conditioning (Harnly et al., 2009). It was also found however, that many employers do not provide resources for handwashing (Thompson et al., 2003). Once workers received warm water and soap for hand washing, as well as gloves, coveralls and education, some behaviours improved significantly, such as washing before break time and home time (Salvatore et al., 2009), and so reducing the risk of home contamination.

Flour

Tagiyeva et al., 2012, found positive correlations of wheat flour allergens on baker's foreheads and cars, foreheads and houses, shoes and houses, and of fungal a-amylase on shoes and houses, and cars and houses. Also compared to non-bakers, bakers had higher median levels of wheat flour allergens and fungal a-amylase in house vacuum samples.

Nursing Uniforms

Higginson, 2011 finds a risk of transferral of contamination from nursing uniforms which are washed in the home, which can cause a considerable health risk from cross-infection.

Mercury

Two papers discuss mercury transferral to the home. The first was from a school, where a family member was exposed and then three family members subsequently became ill (Tezer et al., 2011). The second (Zirschky and Witherell, 1987), where mercury was carried to the home on work clothing.

Beryllium

Beryllium is another substance discussed in multiple papers which has been found to be transferred to the home environment. One example is Sanderson et al. 1999, where workers did not change out of their work clothes and shoes at the end of a shift. Wipe samples collected from workers' hands and in vehicles, show this to be the case, with the greatest levels found on the driver's floor of the vehicle. Another study by Sanderson, 2002, found that although workers change clothing and shoes at the end of a shift, few actually showered before leaving work showing that additional interventions are required.

Lieben and Williams (1969) found that the wives of beryllium workers had become ill after washing contaminated clothing.

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Exposure to carcinogens in surface engineering: Supplementary report

This report details work undertaken following HSE research published as RR963 *Exposure to hexavalent chromium, nickel and cadmium compounds in the electroplating industry* (Keen et al, 2013). This examined the use of biological monitoring (BM) in the surface engineering (electroplating) industry.

The report examines the efficacy of gloves, the use of surfactants and local exhaust ventilation in chromium plating, and the potential for transfer of contaminants outside the workplace.

Laboratory tests and statistical analysis on gloves showed that although some glove types offer more protection than others, working practices should be arranged such that gloves are worn for splash protection only and not routinely used as a primary barrier to protect against dermal exposure to hazardous substances.

No real difference in urinary chromium levels in electroplaters can be attributed to the use of surfactants or LEV to control mist emissions from plating tanks. Either approach is capable of providing adequate exposure control provided it is properly implemented and maintained.

Published scientific literature indicates that the major route by which occupational contamination is transferred outside the workplace is on work clothing. There is clear potential for this to occur in the surface engineering industry when contaminated work wear is taken home for laundering.

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