Ann. Occup. Hyg., Vol. 54, No. 1, pp. 23–30, 2010

doi:10.1093/annhyg/mep080

Assessment of Dermal Exposure and Skin Condition of Workers Exposed to Nickel at a South African Base Metal Refinery

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Received 28 April 2009; in final form 30 October 2009; published online 30 November 2009

Objectives: The objectives of this study were to assess dermal exposure of cell workers to nickel at a South African base metal refinery and to characterize their skin condition by measuring the skin hydration and trans epidermal water loss (TEWL) indices. Methods: The skin hydration index of the index finger, palm, neck, and forehead was measured before, during and at the end of the shift. The TEWL index was measured before and at the end of the shift. Dermal exposure samples were collected with Ghostwipes™ from the index finger and palm of the dominant hand, before, during, and at the end of the shift. Neck and forehead samples were collected before and at the end of the shift. Wipe samples of various surfaces in the workplace were also collected. Wipes were analyzed for nickel according to NIOSH method 9102, using inductively coupled plasma-atomic emission spectrometry. Results: Hydration indices measured on the hands decreased significantly during the shift, but recovered to normal levels by the end of the shift. TEWL indices for the index finger and palm of the hands are indicative of a low barrier function even before commencement of the shift, which further deteriorated significantly during the shift. During the shift, substantial nickel skin loading occurred on the index finger and palm of the hand. Levels on the neck and forehead were much lower. Various workplace surfaces, which workers come into contact with, were also contaminated with nickel. Conclusions: The skin condition and high levels of nickel on the skin were most probably caused by inadequate chemical protection provided by protective gloves. Although, the permeability of nickel through intact skin is considered to be low, a decreased barrier function of dehydrated or slightly damaged skin will increase its permeability for nickel. The ethnicity of these exposed workers may contribute significantly toward the low incidence of allergic contact dermatitis observed. Several measures to lower dermal exposure to nickel are also recommended.

Keywords: dermal exposure; nickel; refinery; skin condition

INTRODUCTION

Occupationally as well as among the general population, nickel is considered to be the most common contact allergen causing type IV (delayed) hypersensitivity reactions. Sensitization occurs generally after direct and prolonged skin contact with nickel ions (Vahter *et al.*, 2007). Following dermal or systemic exposure, nickel-allergic contact dermatitis manifests in a wide range of skin eruptions (Hostynek, 2002, 2006).

Occupational hygiene has traditionally focused on inhalation exposure because it was generally considered to be the most important route of exposure. This

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meant that other exposure routes, such as ingestion and dermal absorption, were often overlooked (Sartorelli, 2002; Semple, 2004). There are three types of chemical–skin interactions. First, the chemical may become systemic after passing through the skin. Second, the chemical may act locally, thereby causing effects such as irritation, burns, or degradation of the skin barrier function. Third, the chemical may induce allergic skin reactions. However, in all three instances, diffusion of the chemical through the outer skin layers is a prerequisite (Semple, 2004).

The skin is a complex membrane and the percutaneous absorption of metals through human skin is governed by several interrelated mechanisms and influenced by numerous exogenous and endogenous factors (Hostynek, 2002). The *in vitro* permeation rate for nickel through intact skin is considered to be very low, yet *in vivo* it elicits allergic skin reactions on contact in sensitized individuals (Hostynek, 2003). Recently, Larese Filon *et al.* (2007) reported an *in vitro* permeation flux of 0.0165 $\mu g\ cm^{-2}\ h^{-1}$, a permeability coefficient (K_p) of 6.1×10^{-4} and a very long lag time of 14.56 h. Results also indicate that *in vivo*, nickel ions may permeate simultaneously by routes of diffusion such as the shunt pathway and the slower transcellular/intracellular diffusion pathway (Tanajo *et al.*, 2001).

Numerous measurement methods and strategies have been developed during the past 40 years to assess occupational dermal exposure. Most of these dermal exposure studies have focused on liquid contaminants such as pesticides. These methods include interception methods (surrogate skin methods), removal of contaminant (substance) methods, and *in situ* detection methods (fluorescent tracer methods) (Fenske, 1993; Brouwer *et al.*, 2000; Cherrie *et al.*, 2000; Soutar *et al.*, 2000; Du Plessis *et al.*, 2008). However, no dermal (skin) occupational exposure limits exist for any hazardous chemical substances.

Recently, Hughson *et al.* (2009) reported dermal and inhalation exposure to nickel in nickel production and primary user industries. Based on different tasks, dermal exposure was measured by using moist wipes to recover nickel from defined areas of the skin and analysing samples for soluble and insoluble nickel species.

To our knowledge, there is no published literature reporting the actual measurement of skin condition upon exposure and the subsequent use thereof in conjunction with dermal exposure results. Two parameters that give an indication of skin condition are the hydration index and trans epidermal water loss (TEWL) index. The skin hydration index reflects the skin's surface moisture level. TEWL reflects the total amount of water vapor lost through the skin under normal sweating conditions (Rawlings, 2006). TEWL is accepted as a reliable indicator of epidermal barrier homeostasis (Fluhr *et al.*, 2008; Rawlings *et al.*, 2008).

The objectives of this study were to assess dermal exposure of cell workers to nickel at a South African base metal refinery and to characterize the worker's skin condition by measuring skin hydration and TEWL indices.

METHODS

Workplace description

A nickel sulfate solution was pumped to the tank house (electro-winning plant) where metallic nickel was recovered from the solution using an electrolytic process. The electrolytic process transpired in 122 individual cells (electrolytic tanks) where nickel deposited onto cathodes (40 cathodes per cell). Cell workers were responsible for frequent inspections of electrodes and ensuring that the electrolytic process occurs optimally. Cathodes were removed from the cells after 6–7 days where after they were transported to an adjacent area for cutting and packaging.

Operations at the tank house are divided into three shifts, morning, afternoon, and night shift. The morning shift is considered as the shift with the highest risk of dermal exposure due to the range and extent of activities performed. It is also the shift with the most workers ($n = 59$). The afternoon and night shifts are considered as maintenance shifts with a lower risk of dermal exposure.

Twenty-six African cell workers volunteered and gave informed consent to participate in this study. Samples were collected during the morning shift of four different days. This project was approved by the Ethics Committee of the North-West University (number NWU-0026-07-S6).

Measurement of skin condition

Skin condition was measured with a EDS12 Dermal Measurement System (EnviroDerm Services, Evesham, UK) equipped with a hydration and TEWL probe. The skin hydration indices of the index finger, thumb, and palm on the ventral side of the dominant hand as well as the neck and forehead were determined before the shift, just prior to any break in shift (i.e. tea and lunch break), and at the end of the shift. For the palm of the hand, neck, and forehead, the average of at least two measurements are reported. The range and interpretation of the hydration index is indicated in Table 1.

The TEWL index was measured before and at the end of the shift on the index finger (dominant hand), palm of the hand (dominant hand), and forehead. The range and interpretation of the TEWL index is indicated in Table 2.

Skin condition questionnaire

Basic worker information such as the number of years employed in the tank house was recorded. To evaluate dermatological complaints, a validated questionnaire developed by Dalgard *et al.* (2003) was used. The questionnaire was also translated into Setswana, the native language of the participating workers. The questionnaire consists of 10 simple questions concerning common skin complaints. The answers to all the questions were scored on a four-point scale (1: no; 2: yes, a little; 3: yes, quite a lot; 4: yes, very much) and the mean was calculated. According to the authors, subject scores higher than 1.3 for non-healthcare-seeking populations have an increased risk of developing skin diseases.

Skin wipe samples

Dermal exposure samples were collected by making use of a removal method. Samples were collected before washing in order to assure that they were representative of the level of skin contamination during the shift. Commercial wipes, Ghostwipes™ (individually wrapped and moistened with distilled H_2O by the manufacturer), were used to collect samples from each worker, before the shift, prior to any break in the shift (i.e. tea break and lunch break), and at the end of the shift. Samples were collected from the ventral side of the index finger and palm of the dominant hand at the above-mentioned intervals. Neck and forehead samples were collected before and at the end of the shift. Index finger wipe samples were collected from the two most distal joints of the finger. The surface area was calculated by making a trace of the finger on paper. The trace and a 4-cm^2 reference area was cut out and repeatedly weighed ($n = 5$) on a scientific Sartorius balance (Sartorius, model number BP211) to determine their average mass. The surface area was calculated as follows: surface area of finger = mass of finger trace/mass of 1 cm^2. For palm, neck, and forehead samples, 10-cm^2 (4×2.5-cm) acetate sheet templates were used. The same operator, who wore a clean pair of disposable vinyl gloves for each sample, collected all samples. Each sample consisted of a single wipe that was wiped three consecutive times across the same sampling area. All samples were placed in separate storage vials. Twelve field blank samples were also collected. Wipes were analyzed for nickel by an accredited analytical laboratory in accordance to NIOSH method 9102, using inductively coupled plasma-atomic emission spectrometry. The minimum level of detection for this method was 0.01 $\mu g\ cm^{-2}$ nickel. Skin loading was expressed as micrograms nickel per square centimeter.

Surface wipe sampling

Surfaces likely to come in contact with workers on a daily basis in the tank house tea room, smoke room, and change house were also selected for wipe sampling. For flat surfaces, a disposable cardboard template was used to demarcate a 100-cm^2 (10×10-cm) area. Each sample consisted of a single Ghostwipes™ that was used to wipe the area in an overlapping s-pattern. Each surface was wiped three times consecutively, each time the exposed side of the wipe was folded inward. For uneven surfaces, such as door handles, the surface area was also wiped three times, but without using a template. The same operator collected all samples and wore a clean pair of vinyl gloves for each sample. Samples were stored and analyzed the same way as skin wipe samples. Where applicable, results were expressed as micrograms nickel per square centimeter, otherwise only as micrograms nickel per sample.

Statistical analysis

All results were statistically analyzed using Statistica Version 8.0 (Statsoft Inc., 2009). TEWL indices, hydration indices, and wipe results were compared

Table 1. Range and interpretation of hydration index measurements

Hydration index	Skin condition
1	Extremely dry
2	Very dry
3	Dry
4	Slightly dry
5–8	Normal
9–12	Excessively hydrated

Table 2. Range and interpretation of TEWL index measurements

TEWL index	Skin barrier function	Skin condition
0–4	Excellent	Very healthy
5–9	Good	Healthy
10–12	Normal	Normal
13–16	Low	Strained
17–20	Very low	Critical

for statistical significance with paired Student's *t*-tests or repeated measures analyses of variance (ANOVAs) with a Bonferroni post-hoc test. Wipe data were not normally distributed and therefore log-transformed for statistical analysis. Interday variation of results was determined with ANOVAs. A Pearson correlation was done to correlate the nickel loading between different anatomical sites. A linear regression analysis was performed to correlate skin condition with years of employment. All results with a $P < 0.05$ were considered to be statistically significant.

RESULTS

Cell workers participating in this study ($n = 26$) worked in the tank house for an average of 7.96 ± 6.51 years (minimum: 1 year; maximum: 24 years). The workers wore a two-piece acid repellent overall and a disposable FFP2 face mask for respiratory protection. Due to the risk of cuts, up to three types of gloves were worn at one time, namely a cotton liner (toweling) glove (product code: GLKW), silver talon whizard glove (product code: 134527), and a flock lined latex glove (commarex 8'', product code: GCOM20). Not all workers preferred to wear the liner glove underneath the whizard glove. Whizard gloves were replaced when damaged, while new liner and lined latex gloves were worn at the start of each shift.

Mean hydration indices decreased significantly from normal, for the thumb (Fig. 1B) and slightly dry for the index finger (Fig. 1A) and palm (Fig. 1C), to between dry and very dry during Break 2. By the end of the shift, all the mean hydration indices recovered (increased) to levels similar to those measured before the shift. Hydration indices for the neck and forehead were normal before the shift and by the end of the shift they were even higher, indicating an improvement in the hydration levels thereof.

The mean TEWL index (Table 3) for the forehead before the shift is considered to be normal. The mean TEWL indices for both the index finger and the palm of the hand had a low barrier function, indicating a strained skin condition, even before the shift commenced. At the end of the shift the mean forehead TEWL index drastically deteriorated to a low barrier

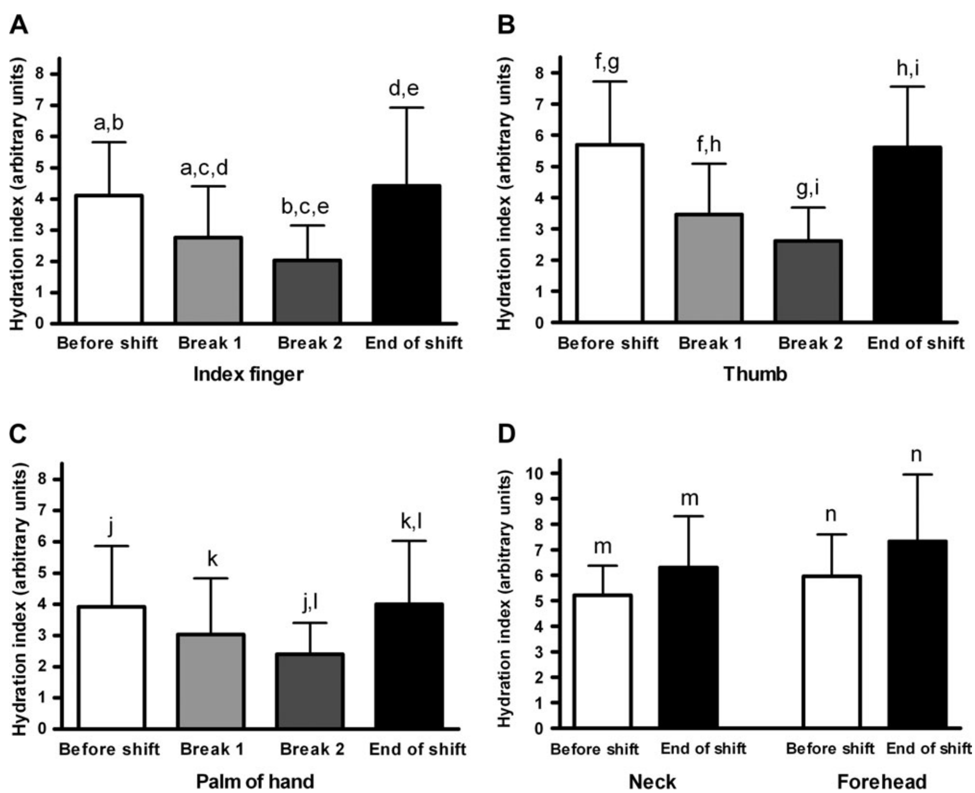

Fig. 1. Hydration index for the (A) index finger, (B) thumb, (C) palm of the hand, and (D) neck and forehead ($n = 26$). a–n indicates statistical significance ($P < 0.05$) between means. Statistical significance was determined by repeated measures ANOVA with a Bonferroni post-hoc test for (A), (B), and (C), while a dependent Student's *t*-test was used for (D).

function (indicative of a strained skin condition), while the TEWL indices for the index finger and palm of the hand deteriorated even further to very low barrier function which is indicative of critical skin condition. For all three anatomical sites, the increase of the mean TEWL index between the start of the shift and end of the shift was highly statistically significant (index finger: $P = 0.003$; palm of hand: $P = 0.01$; forehead: $P < 0.001$).

A total of 11 workers reported one or more of the following skin conditions: itchy skin (23.08% or six workers); dry/sore rash and scaly skin (both, 11.54% or three workers); pimples and warts (7.69% each or two workers); and itchy rash on hands, other rashes on the face, and troublesome sweating (3.85% each or one worker). Of those workers who reported a skin condition, six indicated that these conditions started >6 months ago. The average Dalgard skin score for all the workers was 1.112 ± 0.197 and in total, only three workers had a Dalgard score >1.3 which is indicative of being at risk of developing skin diseases. There is also no correlation between skin condition of workers and the number of years of employment in the tank house ($P = 0.825$, $r = 0.045$, $r^2 = 0.002$).

Dermal exposure data are presented in Table 4. It is evident that workers had detectible levels of nickel on their index finger, palm of the hand, neck, and forehead, even before commencement of the shift. Hand exposures were highly variable, ranging from 0.236 to 177.772 μg cm^{-2} and from 0.045 to 229.860 μg cm^{-2} measured for the index finger and palm of the hand, respectively. The geometric means of dermal exposure measured throughout the shift, for both the index finger and the palm of the hands, were relatively constant and did not differ significantly from each other. During the shift, there was also loading of nickel on the skin of the neck and forehead. However, only the amount of nickel deposited on the neck differed statistically between the start and the end of the shift. A Pearson correlation was done to determine the correlation between the amount of skin loading on the index finger, palm of the hand, forehead, and neck. The only significant correlation that existed was between the index finger and palm of the hand ($r = 0.9$, $P < 0.001$). Statistical analysis with ANOVAs proved that there was no statistical significant interday variability between skin wipe results (results not shown).

Nickel was detected on surfaces that workers are likely to come in contact with on a daily basis. On uneven surfaces, such as door handles and taps, the amount of nickel varied between 3.879 and 794.739 μg, with an average of 270.535 μg cm^{-2} ($n = 5$) and 25.733 μg cm^{-2} ($n = 7$) for each, respectively. On table surfaces ($n = 3$), the average amount was 0.308 ± 0.196 μg Ni cm^{-2}. The amount of nickel collected from the change house overall collection counter averaged 1.021 ± 0.414 μg cm^{-2} ($n = 4$), while on benches used by workers to undress and dress, the average was 0.211 ± 0.062 μg cm^{-2} ($n = 3$).

Table 3. TEWL index for the index finger, palm of the hand, and forehead ($n = 26$)

		TEWL index (arbitrary units)		
		Mean	SD	Range
Index finger	Before shift	15.538[a]	4.510	5–20
	End of shift	17.769[a]	2.717	11–20
Palm of hand	Before shift	15.115[b]	5.080	2–20
	End of shift	17.500[b]	4.022	3–20
Forehead	Before shift	10.269[c]	5.265	4–20
	End of shift	15.077[c]	5.528	5–20

SD, standard deviation.
a, b, and c indicates statistical significant differences between the means as indicated by dependent Student's *t*-tests.

DISCUSSION

Hydration indices of the index finger and palm of the hand indicated a slightly dry skin at the start and at the end of the shift, while that of the thumb was normal. Furthermore, TEWL indices indicated decreased barrier function of the skin, which was also highlighted by the occurrence of the maximum value for the index (20 arbitrary units) for each anatomical site even before the start of the shift.

Although workers wore up to three different types of gloves while performing their tasks, the decrease in the hydration index of the hands (index finger, thumb, and palm) during the shift is probably due to direct contact with the nickel–electrolyte solution (containing sulfuric acid, pH = 3.5) due to the lack of chemical protection provided by the gloves (Pavlides, 2008). The presence of sulfuric acid mist in the tank house may also contribute to this. The recovery of the hydration indices between Break 2 and the end of shift may be attributed to a very short duration of this part of the shift (<90 min), lower task activity, and some workers removing their protective gloves upon completion of all tasks. From observation, it was quite clear that the initial part of the shift (start of shift to Break 2) was far more labor intensive, where workers loaded new nickel starter sheets and inspected or removed existing sheets once they have been extracted from the cells.

Contrary to physical measurement results of the skin, the Dalgard score, based on the questionnaire,

Table 4. Nickel deposited on the skin as shown by wipe sampling and analysis by inductively coupled plasma-atomic emission spectrometry

		μg Ni cm^{-2}			
		GM	GSD	Minimum	Maximum
Index finger	Before shift	0.782[a,b,c]	2.344	0.239	2.612
	Break 1	3.709[a]	170.159	0.236	177.772
	Break 2	3.931[b]	25.349	0.301	42.339
	End of shift	2.888[c]	7.470	0.813	11.3688
Palm of hand	Before shift	0.407[d,e,f]	1.138	0.078	6.963
	Break 1	2.749[d]	94.737	0.045	229.860
	Break 2	2.936[e]	28.419	0.064	56.709
	End of shift	3.389[f]	9.699	0.517	19.439
Neck	Before shift	0.189[g]	1.039	0.034	1.169
	End of shift	1.047[g]	4.009	0.174	16.969
Forehead	Before shift	0.372[h]	1.259	0.087	8.599
	End of shift	0.893[h]	2.679	0.056	3.151

a–f indicates statistical significant differences of log-transformed data as determined by repeated measures ANOVA with a Bonferroni post-hoc test. g and h indicates statistical significance as determined by dependent Student's *t*-test. GM = geometric mean, GSD = geometric standard deviation.

indicated a normal skin condition for 88.5% of the workers. This implies that workers are of the opinion that their skin condition is healthy or pose no risk. Skin condition is also not related to the number of years employed in the tank house. The low incidence of skin conditions, such as contact dermatitis, in these African workers may be due to ethnic differences in skin structure and function, where stratum corneum function is reported to be stronger in subjects with darker skin upon chemical or mechanical challenge (Rawlings, 2006). Although reports on the incidence of allergic contact dermatitis in blacks are conflicting (Berardesca and Maibach, 2003), Dogliotti (1970) reported lower incidences in black South Africans.

The efficiency of Ghostwipes™ as sampling media in removing metals from surfaces was previously reported in the Occupational Safety and Health Administration's Method ID-125G (OSHA, 2002). The analytical recovery of nickel by means of liquid spiking was reported as 101.4%, while the removal efficiency of nickel from glass surfaces was >90%. The method's reproducibility between different persons collecting samples also provided recovery efficiencies ranging between 92.6 and 93.3%. The difference between sampling from human skin and a glass surface is acknowledged by the authors of this paper, but the same is also true for any other surrogate skin surface (i.e. cured leather or silicone rubber membranes) used in validation studies by other authors. This remains a limitation in all dermal exposure studies lacking *in vivo* validation of the method and results should be interpreted accordingly.

Recently, Hughson *et al.* (2009) reported background levels of nickel on the skin of non-occupationally exposed individuals with a geometric mean of 0.02 μg Ni cm^{-2} for the hands (ventral and dorsal sides combined). The presence of much higher levels of nickel on the skin of workers before the start of the shift in this study may have been due to the following reasons: (i) From surface sampling results, it is evident that surfaces in the change house itself (i.e. benches and overall collection counter) were contaminated. (ii) On arrival at the base metal refinery, workers dressed in their overalls in the change house, where after they proceeded to the tea room of the tank house for a briefing session before commencement of their daily tasks. In order to access the tea room, workers had to walk through the tank house itself and opened the tea room door manually. Surface wipe results indicated that this door handles and other surfaces in the tea room were contaminated. Both these reasons may explain the presence of nickel on the finger and palm of the hand, but it does not explain the detectible levels of nickel on the neck and forehead. The 'clean' (washed) overalls may also have been a possible source of contamination and handling it may significantly contribute to contamination. The interior harness of worker's hard hats that keeps the hard hat in place on the head may also have been a potential source of contamination as these are not decontaminated after completion of a shift. The possibility of significant 'take-home' contamination from previous days' exposure cannot be ruled out and future sampling before entering the change house at the beginning of the shift and after washing up at the end of the shift will most likely clarify this matter.

Results of this study cannot be compared directly with the results of Hughson *et al.* (2009) as there are differences in the sampling protocol and anatomical sites from which samples were collected. Hughson *et al.* (2009) used a commercial wet wipe (Jeyes 'Sticky Fingers' Wet Ones) and each sample consisted of three individual wipes, each used to wipe the demarcated skin surface three times. Hand sample results reported by Hughson *et al.* (2009) represent both the dorsal and the ventral surfaces of the hands, and face samples refer to those collected from perioral (in the vicinity of the mouth) areas. Hand and forearm dermal exposure reported by Hughson *et al.* (2009) had a geometric mean of 0.56 $\mu g\ cm^{-2}$ (total nickel) and a range of 0.16–3.19 $\mu g\ cm^{-2}$. The geometric mean total nickel dermal exposure was 0.25 $\mu g\ cm^{-2}$ ($<$0.02 to 2.21 $\mu g\ cm^{-2}$) and 0.58 $\mu g\ cm^{-2}$ ($<$0.02 to 4.32 $\mu g\ cm^{-2}$) for the neck and face (perioral), respectively. Results of our study also indicated that dermal exposure between workers was highly variable. Samples of this study were only collected from the ventral surfaces of the index finger and palm of the hand. Hypothetically, if it is assumed that exposure of the ventral surface of the index finger and back of the hand was zero, the geometric mean exposure during the shift of this study, irrespective of the difference in the sampling protocol, still proved to be 5.40–6.27 times higher than those reported by Hughson *et al.* (2009). The high levels of nickel on the hands of cell workers in this study was most probably due to inadequate chemical protection provided by the gloves used. When neck wipe results are compared, the result of our study is 4.19 times higher than those reported by Hughson *et al.* (2009).

From skin wipe results of this study, it was indicated that nickel exposure and dermal loading of the index finger and palm of the hand did not differ statistically from each other. This indicates that either the index finger or the palm of the hand may be chosen to represent the hand as anatomical sites for future dermal sampling in this occupational setting.

The amount of nickel on surfaces in the tea room, which is supposed to be a clean area, suitable for consuming food and drink, is alarming. Nickel on door handles, taps, and table surfaces therefore may potentially come into contact with unprotected skin and contribute toward the total skin loading of the shift or even be ingested.

The high levels of nickel collected from the overall collection counter of the change house is expected as this counter is right beside the bin in which workers place their contaminated overalls after completion of a shift. However, workers only hand in their contaminated overalls after taking a shower and getting dressed in civilian clothes. By handling the contaminated overall, worker's hands become contaminated with nickel and they thus leave the refinery contaminated with nickel.

Sensitization to nickel and the subsequent development to allergic contact dermatitis require direct and prolonged contact with nickel ions (Vahter *et al.*, 2007). Semple (2004) indicated that the presence of another chemical on the skin, which irritates the skin, greatly enhances permeation of the other chemical. Turkall *et al.* (2003) also found that the potential health risk from dermal exposure to nickel is enhanced if another chemical is present. Nielsen *et al.* (2007) demonstrated that limited damage to the skin significantly increases the permeability coefficient (K_p) as well as the total percutaneous penetration of chemicals, in particular those with low penetration rates through intact skin. *In vitro* experiments conducted by Larese Filon *et al.* (2009) showed an 84.87-fold increase in nickel powder's skin permeation through damaged skin when compared to healthy skin. Furthermore, Semple (2004) found that occlusion of the skin (by i.e. protective gloves) may facilitate permeation of a chemical already present on the skin, by as much as 5-fold (Semple, 2004).

From a pure economic perspective (i.e. monthly income) it seems plausible that skin care is not a very high priority for this group of workers, especially when they are of the opinion that their skin condition is healthy. This can in part explain the low hydration levels and poor barrier function observed in this study. However, they are exposed daily to an electrolyte solution with a very low pH that irritate the skin and degrade the barrier function even further (as indicated by the hydration and TEWL results) due to the inadequate chemical protection provided by the types of protective gloves used. They are also exposed to various surfaces in the workplace contaminated with nickel. Although, the permeability of nickel through intact skin is considered to be low, the decreased barrier function of dehydrated or slightly damaged skin will increase its permeability for nickel, thereby increasing the internal dose. From literature, it is also clear that occlusion provided by protective gloves may also enhance permeation. The presence of such high levels on the skin of the hands also increases the risk of oral ingestion of nickel through a hand-to-mouth shunt. However, the ethnicity of these exposed cell workers may be a significant contributor toward the low incidence of allergic contact dermatitis observed.

CONCLUSIONS

The skin on the hands of cell workers in the tank house was dehydrated and has a low barrier function probably due to frequent contact with an acidic electrolyte solution. High levels of nickel were detected on the index finger and palm of the hands. The skin condition and high levels of nickel on the skin are most probably caused by inadequate chemical protection provided by protective gloves (types selected for mechanical protection). Nickel was also detected on surfaces in the tea room and change house. Although, the permeability of nickel through intact skin is considered to be low, the decreased barrier function of dehydrated or slightly damaged skin will increase its permeability for nickel. The ethnicity of the exposed workers in this study may have contributed significantly toward the low incidence of allergic contact dermatitis. Recommended measures to lower dermal exposure were as follows: (i) selection of a combination of protective gloves that will provide mechanical and chemical protection, (ii) improvement of hand wash facilities in the tank house, (iii) changes in operating procedures for cleaning of areas and surfaces, (iv) the use of a colorimetric test (dimethylglyoxime and ammonium hydroxide) to be used as spot-checks on cleaned surfaces, (v) the use of emollient skin moisturizing cream after completion of the shift in order to improve skin condition, and (vi) more frequent information and training sessions focusing on personal hygiene.

Acknowledgements—The authors are grateful to management and in particular the workers from the base metal refinery who participated in this study and Zoé Selenati-Dreyer for her assistance during skin condition measurements.

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